UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL & CONSTRUCTION ENGINEERING

PERFORMANCE EVALUATION OF PEDESTRIAN FACILITIES AT DONHOLM INTERCHANGE ALONG OUTER RING ROAD NAIROBI.

Thesis Submitted to the School of Engineering of the University of Nairobi in Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil Engineering

(Transportation Engineering)

By

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DECLARATION OF ORIGINALITY

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DEDICATION

Special dedication to my dear wife Victoria, our children Bryan and Gift Mueni for their caring love and understanding.

ACKNOWLEDGEMENT

I would like to first and foremost thank the Almighty and living God for His sufficient grace which has propelled me to these great education heights.

Secondly, I thank my supervisors Prof. S. K Mwea and Dr. S. N Osano for their tireless effort, guidance and professional advice which has enabled me to successfully defend and complete my thesis.

Third, I thank my lecturers Prof. F. J Gichanga, Prof. S.K Mwea and Prof. O.O Mbeche for their great knowledge in Transportation Engineering. As a result of their lectures I have learned a lot as far as flexible and rigid pavements, highway and transportation engineering is concerned.

Fourthly my classmates Kenneth, Caroline Indakwa, Cyprian, Zackary, Nyamu and Kinyanjui It was nice meeting you guys as Engineers and colleagues in the Masters class of transportation engineering 2017.

I also thank the entire Engineering department headed by the Dean - school of engineering, Chairman Civil Engineering Department for the support during the entire study period.

Lastly, my research assistants especially during the data collection period David, and your team feel appreciated.

ABSTRACT

Under Vision 2030, the Kenyan government recognized transportation infrastructure as enabling fast economic growth. The development of transport infrastructure is fundamental to socio-economic transformation. In order to make Nairobi a center of development, an integrated and cohesive socio-economic infrastructure is crucial for further development. Critical to solving Nairobi's congestion and the problem of pedestrian transport service is investing in new road equipment and traffic management measures. Because the pedestrian environment is multi-dimensional, there are several aspects that influence the pedestrian's perception of comfort, security and convenience on the sidewalk setting. The physical infrastructure comprises of sidewalks, parking lanes, landscaped buffers, sidewalk width among others. The operational feature includes the traffic volume, speed limits and travel patterns. Thus, the analysis of Level of Service (LOS) is paramount in evaluating the real potential towards more sustainable lives. The project was in line with the objectives of the Performance assessment of pedestrian facilities at Donholm interchange along Outer Ring Road Nairobi. Specifically, the study sought to find out the pedestrian space provided at the sideways and sidewalks of the overpass, establish the pedestrian travel speed and find out the Level of Service. The study adopted the Highway Capacity Manual (HCM)-based LOS Method and the Pedestrian Level Of Service (PLOS) Model. The study considered literature from foreign and local manuals, previous studies, journals, articles, government policies and regulations, and other related documents. The study earmarked a section of Outer Ring Road, this being the Manyanja and Donholm overpasses for its field data collection process. This study adopted direct observation (manual count) to collect data on pedestrian traffic on the sidewalks of the study areas. Observation took place from a fixed elevated position to get a general view of the area of study. Site survey and visual inspections involved visually inspecting the sidewalks and measuring the provided walking spaces in terms of width and length. The study found out that the overpass serves on average 14,000-16,000 pedestrian in a whole day both directions combined. From the study 14,012 pedestrians used the overpass on Monday which was the lowest tally while 16,431 pedestrians were counted on Thursday which was the highest tally. The average time taken to cross the overpass of 60 m long was one-minute meaning that the walking speed 1m/sec which is slightly lower than the normal walking speeds of pedestrians in walkways. The spaces provided per pedestrian was found to be 0.04m2 which according to **Hcm Model 2010** is described as **LOS F** and whose score is less than 25. This score represents the worst pedestrian facility at peak hours. The interaction between pedestrians and the vehicles is at the shoulders which also serve as the sidewalks with no designated busstops. This study therefore recommends construction of two-foot bridges of minimum 2 meters width parallel to the overpasses on both directions which was serious design omission. The foot bridges will improve the performance of the overpasses to the desirable peak period pedestrian flow of **LOS C** or above (TRB,2003; Orlando et al.,2003) and to a greater extend improve pedestrian safety at the interchange. Further recommendations include provision of lighting and signage at the overpasses.

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LIST OF ABBREVIATIONS

FCFS	First Come First Served
GDP	Gross Domestic Product
HCM	Highway Capacity Manual
JICA	Japan International Cooperation Agency
LOS	Level of Service
PLOS	Pedestrian Level of Service

CHAPTER 1: INTRODUCTION

1.1 Background

In Kenya, urban transport has recently been molded by rapid economic transformation. The transport infrastructure in Nairobi hardly meets the current requirement as shown in the Nairobi Metropolitan Area Master Plan for Urban Transport (2006 – 2015). Transport infrastructure is identified as a facilitator of rapid economic growth and its expansion and growth is thus central to socio-economic change. To accommodate growth, Nairobi City requires an integrated socio-economic transport infrastructure. It is essential to invest in modern road equipment and traffic management in Nairobi to mitigate traffic congestion and transport service problems (African Development Bank, 2013). The environment for the pedestrian is multi-dimensional and the road side environment subjects the pedestrian to a set of factors that significantly affect the perception of comfort, safety and convenience (Wimbardana, Tarigan & Sagala, 2018).

Measurement of these factors is essential in understanding how pedestrian travel is accommodated by a road. The Level of service (LOS) of pedestrians is affected by many dynamics and can be grouped into two broad categories. These include the operational and physical infrastructure features. Features of the physical infrastructure encompass landscape buffers, sidewalks, street widths, parking lanes and so on. Operational features are traffic volume, travel patterns and speed limits (Chandana, Ibrahim & Kumar, 2016). Thus, analysis of pedestrian LOS is important in evaluating the potential towards more sustainable lives. This study is aligned to the objectives of the performance assessment of pedestrian amenities from the perspective of pedestrians and vehicle users at Donholm interchange along Outer Ring Road Nairobi.

1.2 Study Area

1.2.1 Eastern Nairobi

Nairobi is Kenya's capital city. It covers 684 square kilometers and has 3.3 million inhabitants according to the 2009 census. Nairobi has the biggest and well established commercial sector in East and Central Africa due to the strategic geographic location of Kenya in Eastern Africa (Omwenga, 2010). This enables Nairobi to contribute above 50% of Kenya's GDP and 50% of the country's employment (JICA, 2014). Eastern Nairobi is to the South East of Nairobi City. The region has over 15 estates with almost three quarters of the total population in Nairobi Eastlands area because of the low rent and proximity to the CBD. Contrary to the belief that the area is prone to insecurity and poor living conditions, in Eastlands there is high security levels and a high happiness index. Few estates like Kariobangi and Dandora experience some of insecurity but most estates are very good to live in (Venasnews, 2015).

1.2.3 The Nairobi Outer Ring Road

Formerly an arterial road, Nairobi's Outer Ring Road has been improved to an urban dual carriageway highway, with the objective of easing congestion. Outer Ring road is 13 kilometers long, two way dual carriage roadway of bituminous surface (Figure 1.1). The road navigates Nairobi North and Nairobi East thus benefitting approximately 2.2 million inhabitants which is close to 70 percent of the City's population. Users of arterial roads in Eastern Nairobi connecting Nairobi - Thika superhighway, the Eastern bypass and Mombasa road are other beneficiaries of Outer Ring road. Improved accessibility to Nairobi's Eastland area, reduced time travel, better quality of air to travelers and those residing close to the road, improved value of property and improved business environments arising from better sanitation and new market facilities are some key outcomes of the upgrading of the road.

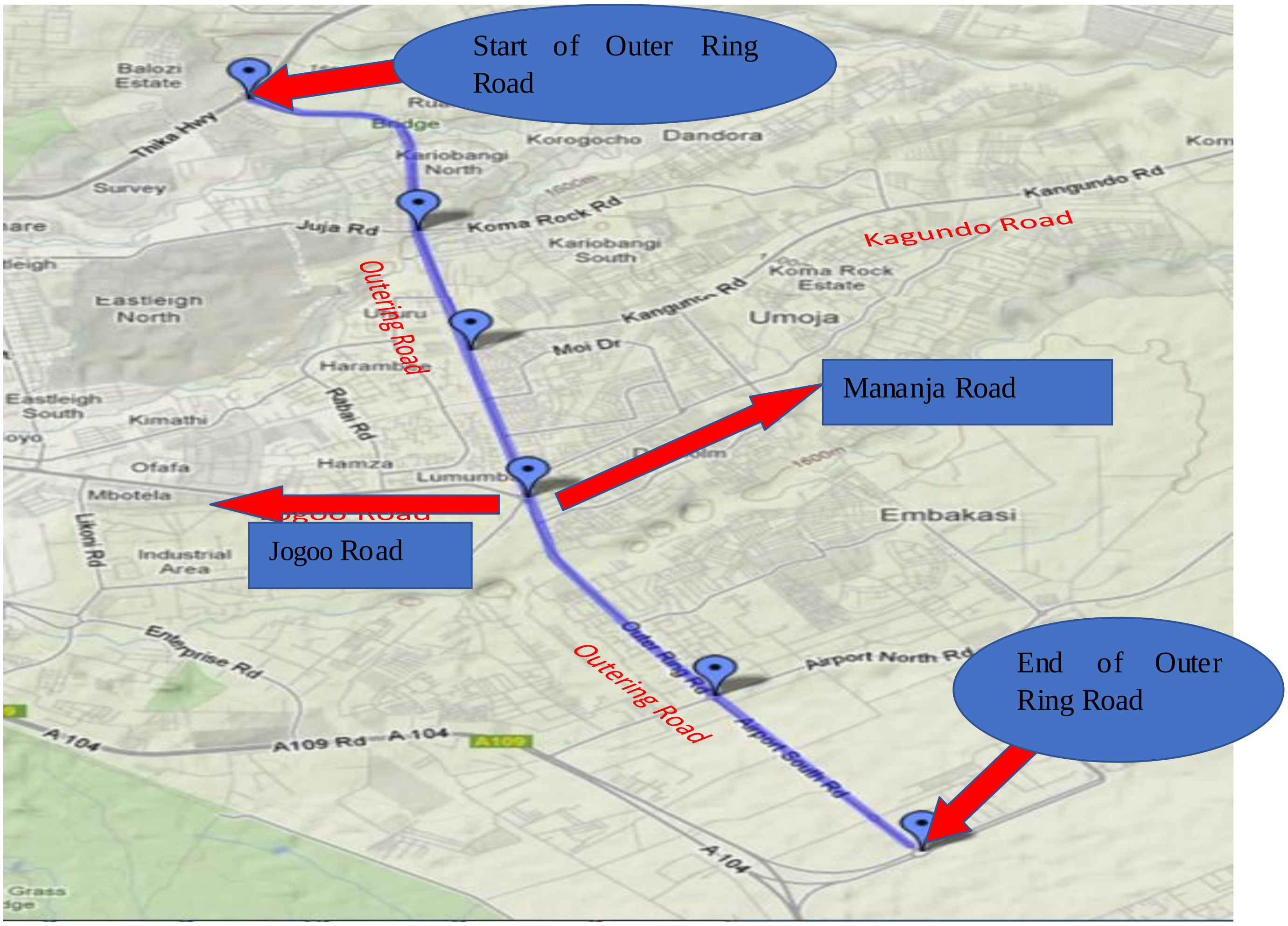

Figure 1.1: Outer Ring Road (Source, Study 2018)

1.3 Problem Statement

Fast urbanization greatly contributed to a decline in the safety levels of pedestrians. In the endeavor for provision of better transport amenities, traffic engineers often fail to either offer pedestrian facilities on the road side or compromise safety (Rankavat & Tiwari, 2016). Pedestrians should be provided with a safe environment without interference with other transport modes. Many pedestrians cross the road before traffic police officers report for duty, the near misses are a nightmare for both pedestrians and motorists. Even with the traffic police, the absence of bus stops in the newly constructed Outer Ring Road interrupts smooth traffic flow on the new Road.

Nairobi Outer Ring Road has received negative feedback from residents of Eastern Nairobi in that it has not lived up to expectations especially on its service to pedestrians. The newly constructed Outer Ring road lacks sufficient sidewalks (Plate 1.1), and busstops at the overpass (Plate 1.2) and even one lane near Kariobangi South has illegally been converted into a bus stop (Musambi, 2018).

Plate 1. 1: Outer Ring Road has no designated bus stops

Plate 1. 2: Pedestrian walking space is very small

Lack of footbridges and emergency service lanes are among the challenges facing road users along the newly upgraded Outer Ring road. Pedestrians, especially women have expressed concerns about crossing the road (Otieno, 2018). In the absence of footbridges along Outer ring road, pedestrians have been spotted on the stretch between Donholm and Taj Mall risking their lives to cross the very busy road. Some jumped over the guardrails while carrying children as others crawled underneath them (Ochieng, 2018). Plate 1.3 and 1.4 show the pedestrians struggle while using the road.

Plate 1. 1: Pedestrians jumping over the guardrails while carrying children; Source (Michira, 2018).

Plate 1. 2: Pedestrians crawling under the guardrails (Michira, 2018)

Previous studies on sidewalk performance have been carried out with quantifiable parameters like space occupied by a pedestrian, sidewalk width and pedestrian and/or vehicle traffic (for example Huang *et al.*, 2008; Landis *et al.*, 2001; TRB, 2000) and neglected qualitative parameters such as the LOS. The studies that have included qualitative parameters were biased due to the survey personnel giving limited importance of pedestrian perception of safety and comfort. However, in Kenya, there is lack of efficient evaluation tools for assessing the service quality of sidewalks that rely on the needs of users of sidewalks.

1.4 Research Questions

i. What pedestrian facilities are available at the Donholm interchange?

ii. How many pedestrians are using the Donholm interchange in a day?

iii. How do the pedestrians and vehicles interact at Donholm interchange?

1.5 Objectives

1.5.1 Overall Objective

The main aim of the study was performance assessment of pedestrian facilities from the perspective of pedestrians and vehicle users at Donholm interchange along Outer Ring Road.

1.5.2 Specific Objectives

The study specifically sought:

i. To find out the pedestrian space provided at the sideways and sidewalks and establish the pedestrian travel speed at the Donholm interchange along Outer Ring Road Nairobi.

ii. To assess the level of service of the pedestrian facilities at the Donholm interchange along Outer Ring Road Nairobi.

iii. To make recommendations on how to improve the performance of the overpass in terms of its service to pedestrians.

1.6 Scope of Work

In the assessment of the performance of Outer Ring road from a pedestrian and vehicular user perspectives, this study aimed at finding out the pedestrian space provided at the sideways and sidewalks, the pedestrian travel speed and the LOS and its score of the Donholm interchange along Outer Ring Road Nairobi. The study concentrated on current pedestrian amenities and their use by pedestrians. The study was conducted between December 2018 to August 2019.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents data on the advancement and current state of theory, practice and research of the prevailing phenomenon. This section begins with an introduction on sidewalks and characteristics associated with pedestrian flow. This is followed by the theoretical review where the theories anchoring the study objectives are presented. The empirical review and the summary are also presented.

2.1.1 Sidewalks and Walkways

A sidewalk is the space devoted to pedestrian travel within the right-of-way. Walkway is a term used synonymously with sidewalk. Sidewalks refer to the surfaces, usually paved, alongside a road and are elevated from the road level and divided by a curve while walkways encompass a broader variety of either raised or grade improved paths for use exclusively by pedestrians (Langegger, 2016). Sidewalks and walkways are important constituents of streets and roadways where pedestrians should experience efficient mobility, comfort, safety and accessibility. When vehicles and pedestrians are separated by sidewalks and walkways, safety increase where vertically, the curb is raised and horizontally if there is available space (Pinna & Murrau, 2017).

Studies show that where there are many pedestrian facilities, there is more pedestrian travel and even higher numbers in areas with complete and continuous sidewalks, walkways, crossings, and other pedestrian amenities (Mc Millen, 2013). Sidewalks and walkways greatly contribute to the safety of pedestrians. Nationally, pedestrians account for 10 to 15 percent of annual crashes of accidents where most crashes happen on high speed roads that are not designed well for pedestrians. Given the State initiatives to encourage and increase pedestrian travel, there exists a need to offer more pedestrian facilities and improve the current ones.

2.1.2 Pedestrian Flow Characteristics

Pedestrian flows are similar in many ways to those used for vehicular flow. This is because of the conversant variables such as volume, density, speed and the rate of flow. The only difference is that the flow of pedestrians is either to one direction (unidirectional), to two directions (bidirectional) or to many different directions (multidirectional). Usually, pedestrians never move in clear lanes, but tend to move under heavy flow (Mathew, 2014).

2.1.2.1 Pedestrian Speed – Pedestrian Density Relationship

The fundamental relationship between density, volume and speed in pedestrian flow is comparability with vehicle flow (Mohammed & Mashros, 2015). As pedestrian volume and pedestrian density rise, pedestrian speed decreases. When the pedestrian density increases and the space occupied by each pedestrian decrease, the degree of mobility for each pedestrian and the mean speed of the pedestrian flow decreases (Mathew, 2014).

2.1.2.2 Pedestrian Flow – Pedestrian Density Relationship

The association of speed, density and flow for pedestrians is related to that for the flow of vehicles and is shown in Equation 2.1 below.

$$Q_{ped} = S_{ped} \; x \; D_{ped} \quad \ldots\ldots.. \text{ (Eq 2.1)}$$

Where:

Q_{ped} is the unit flow rate (p/min/m)

S_{ped} is the speed of the pedestrian(m/sec)

D_{ped} is the density of the pedestrian (p/m^2)

Pedestrian density as a variable has fractional values in a square meter of pedestrian and is the opposite of pedestrian Unit Flow Rate and articulated in terms of space module (M). Pedestrian facilities are analysed more practically using the inverse of density.

Equation 2.2 illustrates the basic relationship between flow and space. The conditions show the capacity of the sidewalk facility during the maximum flow.

$$Q_{ped} = \frac{S_{ped}}{M} \qquad \text{Eq (2.2)}$$

Where; M is (m^2/ped).

Figure 2.1 graphically shows the relationship between pedestrian space and flow

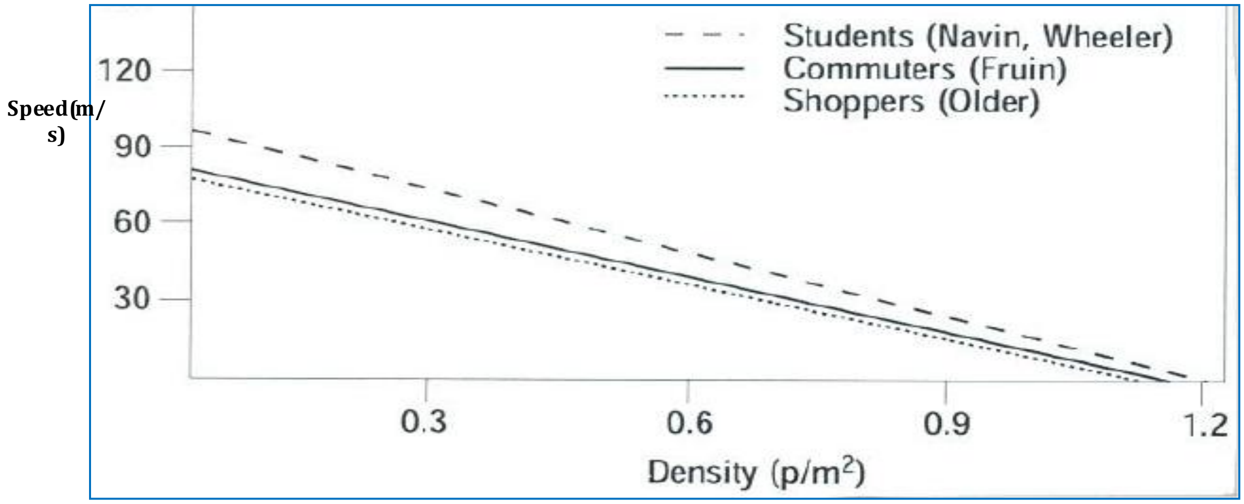

Figure 2.1:Relation of pedestrian s pace and flow (Source: HCM, 2010)

From the graph the mean speed of each pedestrian fluctuating between spaces of 0.4 and 0.9 m^2/p. As the density increases walking speeds reduce. The highest speed is realized when the facility has enough space to allow free pedestrian movement. When the density increases towards 1.2p/m^2 the pedestrian speed reduces considerably because the space available cannot allow for free movement of the pedestrians.

2.1.2.3 Relation of pedestrian speed and flow

Figure 2.2 illustrates the association of pedestrian speed and flow. The curves reveal that when the pedestrians are few on a sidewalk, more space is available translating to walking speeds that are high. When pedestrians increase, high flow rate, the walking speed reduces because there is close interaction between pedestrians. When there is crowding on the sidewalk, movement is restricted leading to decrease in speed and flow. This is clearly demonstrated in the figure 2.2 below the pedestrian speeds below 1.0 m/s is due to increase in Pedestrian Flow Rates. As the Pedestrian Flow rate increases so does the speeds.

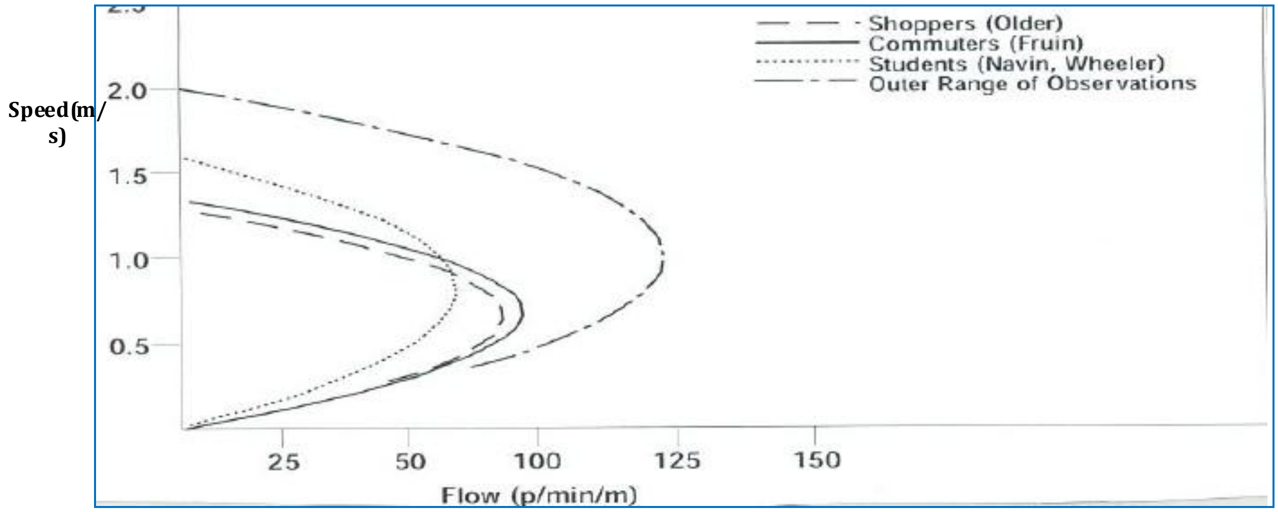

Figure 2.2: Association of pedestrian speed and flow (Source: HCM, 2010

Figure 2.3 confirms the connection between pedestrian speed and the space available and this indicates some separation points for coming up with the conditions for the level of service. The observations that are out of range show that with a mean space of below 1.5m^2/p, even a slow pedestrian cannot attain the speed that they desire to walk. Pedestrians walking faster at 1.8m/s cannot attain that speed except the mean pedestrian space is 4.0m^2/p or higher.

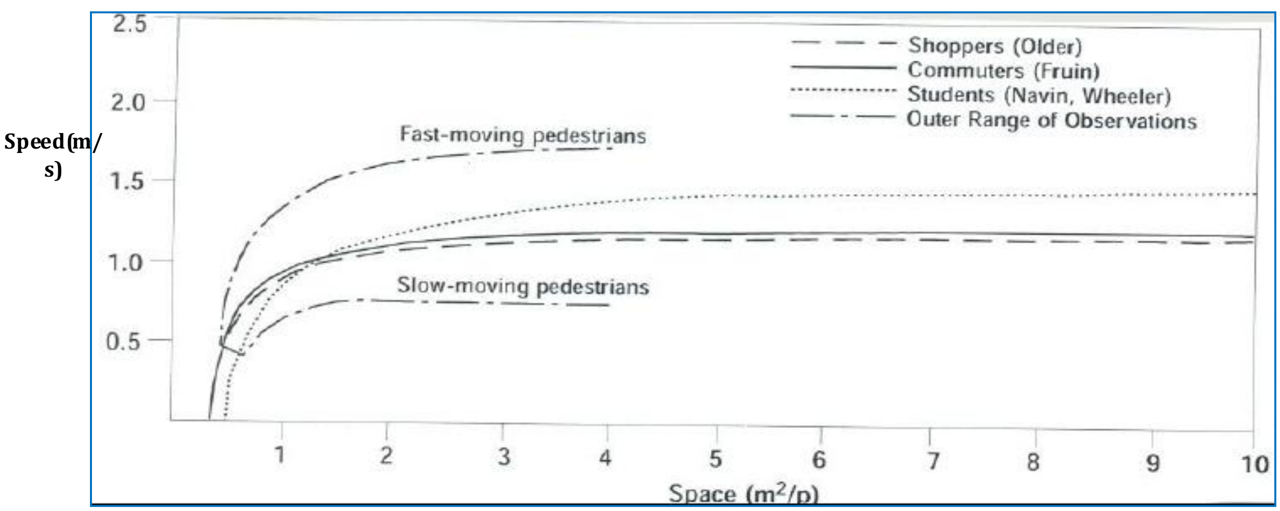

Figure 2.3: Connection between pedestrian speed and available space (Source: HCM, 2010)

2.1.2.4 Pedestrian Walking Speed

According to HCM 2010 Walking speed depends on the percentage of older pedestrians in the flow. If up to 20 percent are elders, the mean pedestrian speed will be 1.2 meters per second on sidewalks. If the elders are more than 20 percent, the mean pedestrian speed declines to 1.0

meters per second. The pedestrian flow speed on sidewalks is roughly 1.5 meters per second. The presence of children in the pedestrian flow could also decrease the mean pedestrian speed .

2.2 Theoretical Review

2.2.1 A Queuing Based Analytical Model

The general rate of service can be projected by the time taken to travel subjected by the current level of service. This indicates that the model developed can be employed in assessing the LOS for a particular rate (Rahman *et al.,* 2013). Furthermore, Figure 2.1 can be employed in the queueing model in a combined plan setting for a pedestrian facility. The particulars for the preparation and computing process are shown in Figure 2.4.

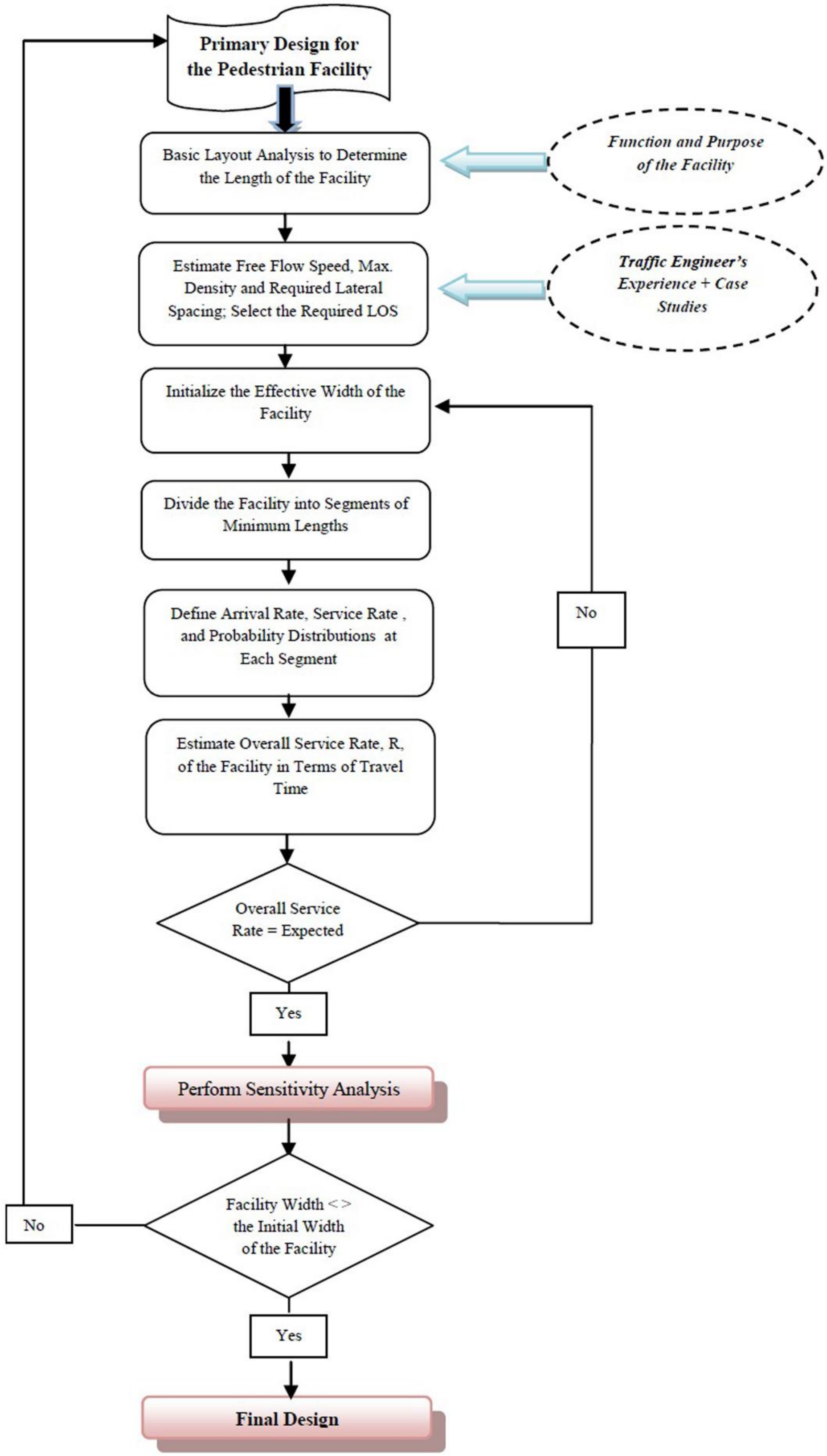

Figure 2.4: Process for computing of overall service rate (Rahman et al., 2013)

Queueing theory is a division of stochastic processes and has been highly used analytically in operation studies (Medhi, 1994). This theory is founded on the notion that a queue forms when customers, or in this case – pedestrians, are provided with less services than they require when they arrive at a service point. This theory examines these queues using mathematical simulations or models. The elementary entities that describe a queueing model include the rate of arrival, mechanism service, the discipline for queueing such as first come first served, and the designated service points or nodes. The theory of a lane for pedestrians is employed to perfect the time taken by pedestrians to travel and also how the pedestrian facility performs grounded on the theory of queueing which is like modelling a lane in a highway.

2.2.2 Bureau of Public Roads Model

This model was commonly used by road traffic policy makers and researchers to approximate the time it took for road travel (Rahman *et al.,* 2013). In approximating the time taken for pedestrians to travel on diverse walking amenities, the Bureau of Public Roads model takes the following form (Equation 2.3).

$$t(k) = t_0 + A.\ \left(K/k_j\right)^s \qquad \text{Equation 2.3}$$

Where:

$t(k)$ is the time taken to travel (in seconds) at density k or flow level,

t_0 is the time taken to travel in free flow in seconds,

k is the flow of pedestrians (pedestrians/meter/second) or the pedestrian flow rate (peds/m/s)

$A.$ are the constants estimated in the model fit procedure

$K.$is the pedestrian density of the pedestrian facility

k_j is the pedestrian amenity capacity (pedestrians/meter/square or pedestrian density peds/m^2)

K/k_j is the ratio of demand by pedestrians to pedestrian facility/amenity capacity.

The applied measure of travel time reflects the time taken to queue and also the required time to travel along the sidewalk by a pedestrian (Daly *et al.,* 1991). Equation 2.3 is only appropriate if the *kj* value exceeds the *k* value.

The pedestrian assignment model in Equation 2.3 was employed in estimating the travel time by pedestrians in the crowded London Underground (LU) system. Various authors (Cheung & Lam, 1998; Lam *et al.,* 2002; Lam & Cheung, 2000) employed the equation in predicting pedestrian travel times and in establishing the association between pedestrian speed and flow. However, Al-Masaeid et al. (1993) used pedestrian demand ratio and pedestrian capacity to examine the number of pedestrians on a sidewalk. Additionally, adjusting the vehicle test technique, Virkler (1998) came up with a new technique that uses test pedestrian to forecast and quantity the queueing and walking times on pedestrian routes.

While the delay on a pedestrian facility is reflected empirically in studies that employed Equation 2.3, it is nonetheless not openly reflected in preparation of travel time model. The measurements and models also do not clearly consider the dimensions of the resident pedestrian's body (such as adjacent space for movement) and capacity for walking (free flow speed). Additionally, the models are limited in ability in the provision of a policy for analyzing sensitivity. While it is representation of reality, the queueing theory model mitigates these challenges and can articulate in a complete manner the complex and stochastic movement of pedestrians and travel times. The model is specifically designed for sidewalks and is also adopted in assessing the effect of pertinent determinants and efficient factors.

The model that has been developed assumes a state of steady equilibrium situations where similar probabilities are created by repeat observations of a similar pattern of flow. This kind of assumption is essential for endorsing proper or suitable policy and design. The model is appropriate in studies on sidewalks joined by overpasses and pedestrian flow is not interrupted. Moreover, with a few adjustments, the model can be adopted in designing and analyzing a highway with multiple lanes. Therefore, the developed model can be employed in assessing multi-modal Level of Service for pedestrian, bicycle and transit modes (Phillips *et al.,* 2001).

2.2.3 Highway Capacity Manual (HCM) Based LOS Method

The HCM is the standard guide in analyzing level of service (LOS) in the planning industry and traffic engineering (Akmaz & Celik, 2016). It provides a uniform technique for collection of data and for measuring congestion found in a pedestrian amenity (Martinez & Olmeda, 2013). From the time of publication of the HCM Pedestrian Level Of Service technique, studies on how to measure PLOS better focus on: the environment of the sidewalk, characteristics of pedestrians and characteristics of flow (Rahman *et al.*, 2013). The association between the three categories has been explained in pedestrian literature where the sidewalk environment which constitutes characteristics of pedestrians and the flow, nearness to transport and land use. These studies also explain the way, characteristics of pedestrians form the density and speed characteristics of flow (Van Eggermond & Erath, 2015). The Highway Capacity Manual adopts the space occupied by pedestrians as the primary indicator of effectiveness. The average flow rate and speed are used as secondary indicators. Providing ample space for queueing and moving flow of pedestrians is essential in ensuring a good LOS. The Level of Service is considered as the comfort of pedestrians, the perception of security and safety and convenience (Mathew, 2014) see Table 2.1

Table 2.1:PLOS score and the level of improvement needed (Source: HCM, 2010)

PLOS Score	PLOS Rating	Condition	Description	Level of Improvement
>125	A	Excellent	Highest quality sidewalk facilities	No improvement needed
≥100 - <125	B	Very Good	High quality of sidewalk facilities and light issues of pedestrian comfort	Very limited improvement needed
≥75 - <100	C	Good	Basic quality of sidewalk facilities with considerable issues of pedestrian comfort	Limited improvement needed
≥49 - <75	D	Average	Average quality facilities for pedestrian with slight issues of safety and comfort	Some improvement needed
≥25 - <49	E	Poor	Low quality facilities for pedestrian with severe issues of safety and comfort	Many improvements are needed
<25	F	Worst	Worst pedestrian facilities where factors influencing PLOS are below acceptable standards	Very many improvements are needed

The level of service according to the HCM model 2010 can also be described according to the pedestrian spaces provided at the sidewalks and the pedestrian density (flow – p/min/m) as shown in Table 2.2.

Table 2.2:Level of Service for foot paths

LOS	Pedestrian Space (m^2/ped)	Unit width Flow(p/min/m)	Description
A	> 49.24	<1.64	Without conflict with other pedestrians, walking speeds are freely chosen
B	>8.36– 9.24	> 1.64-9.84	The speeds of walking are selected freely, pedestrians are aware of others and respond to their presence.
C	>3.72– 8.36	> 9.84-19.68	In unidirectional streams, walking speeds are freely chosen, minor disputes occur for reverse or crossing motions.
D	> 2.14-3.72	> 19.68-36.09	There is restricted freedom to select necessary walking speeds and pass others, high probability of reverse or crossing conflicts over movement.
E	> 1.02-2.14	> 36.09-59.06	For all pedestrians, walking speeds and ability to pass are limited; forward motion is only possible by snuffing; reverse or cross motion is achieved with extreme problems; traffic volume approach limits walking capacity.
F	< 1.02	> 59.06	Walking speeds are highly restricted; frequent, involuntary contact with others; inverse or cross movements are almost impossible.

(Source HCM, 2010)

2.2.4 Pedestrian Level of Service Model

Importance of sidewalk characteristics and their conditions for operation based on the perspective of the pedestrian is employed in the current study. PLOS is adopted founded on a point system to grade the overpasses for the quality of service. PLOS can be mathematically defined as in Equation 2.4:

$$PLOS = \sum_{i-1}^{10} A_i \ x \ B_i \qquad \text{Equation (2.4)}$$

Where:

$\boldsymbol{A_i}$ – Relative importance weight for physical and user characteristics,

$\boldsymbol{B_i}$ – quality satisfaction score for physical and user characteristics,

$\boldsymbol{i}$ – Number of parameters.

***10** – Scale factor from 1-10*

The relative importance weight of each sidewalk characteristics (A) give the effect of each sidewalk factor for the PLOS. The relative weight of each sidewalk is given by equation 2.5:

$$A_i = \frac{\sum_{j-1}^{j-5} I_j \ x \ n_j}{N} \qquad \text{Equation (2.5)}$$

Here,

$\boldsymbol{A}$ is relative mass of a sidewalk factor,

$\boldsymbol{i}$ is number of parameters,

$\boldsymbol{I}$ is importance rating,

$\boldsymbol{j}$ is the rating from 1 - 5

$\boldsymbol{n}$ represents the pedestrians choosing *'j'* rating,

$\boldsymbol{N}$ represents the sum of all pedestrians.

PLOS score is obtained when the satisfaction rating of existing conditions of sidewalk characteristics is calculated. Satisfaction score is also calculated by multiplying the coresponding five point scale rating to the number of pedestrians who has been given that rating (Rahman et al., 2013). In this study, excellent rating gets five points, very good gets four points, good gets three points, satisfactory gets two points while poor gets one point. The satisfaction assessment score for each factor is given using equation 2.6:

$$B_i = \frac{\sum_{j-1}^{j-5} S_j \ x \ n_j}{N} \qquad \text{Equation (2.6)}$$

Where:

B is the satisfaction score obtained for each sidewalk,

i is the number of parameters,

S is the satisfaction score,

J is the rating from 1 – 5,

n is the number of the pedestrians choosing 'j' rating, and

N is the total number of pedestrians

PLOS score classifications involves rating from A to F. PLOS 'A' indicates that excellent street facilities and sidewalks are in excellent condition, 'B' indicates that street facilities and sidewalks are in very good condition, PLOS 'C' indicates that street facilities and sidewalks are in good condition, PLOS 'D' indicates that street facilities and sidewalks are of average quality, PLOS 'E' indicates that street facilities and sidewalks are in poor condition with severe issues on safety and comfort. PLOS 'F' indicates that street facilities and sidewalks are at worst condition and not at all appropriate for walking.

2.3 Empirical Review

2.3.1 Pedestrian Space Provided at the Sideways and Sidewalks of the Overpass

Sidewalks are essential in the social and physical environment of a city (Lindner, 2015). They meet pedestrian infrastructural demand where they allow circulation space drawn from vehicles and other modes of transport (Deacon, 2013). Extra attention should be accorded to sidewalks so as to shift the belief that sidewalks are only for pedestrian movement but for several purposes (Liebman, 2015). The principle focus of regulating and planning sidewalks is pedestrian circulation and flow (Muraleetharan *et al.,* 2004). Studies that have been done on sidewalks have often focused on LOS and rates of pedestrian flows. These engineering terms have been used to determine the capability of sidewalk facilities to hold diverse pedestrian levels to comprehend pedestrian density and suitable volumes of space. For example, in the United States, a study that reviewed the national criteria for the levels of sidewalk service and evaluating them in contrast to New York City standards was carried out by the Department of City Planning in 2006. The study developed a comprehensive way of evaluating sidewalks.

Whereas regulations, specifically for liability and safety concerns, should be put in place for controlling sidewalks, it is essential to look into how these rules or regulations influence the perception of pedestrians as they are the key users of the sidewalks (Bahari *et al.,* 2013). Additionally, more researchers have focused on precise aspects of sidewalks. In South Korea, Wang et al. (2012) explored the elements of pedestrian satisfaction with the environments of the sidewalks in South Korea and observed that the spatial perception of pedestrians affects the satisfaction of sidewalk space more than beautification factors. While street scaping efforts add to pedestrian satisfaction, they are not the main focus of sidewalks. When a pedestrian amenity is being designed, special attention should be accorded to width and length by engineers. The length of the facility is determined by the purpose and function of the pedestrian facility. After the length is determined, it is of essence to define the width of the pedestrian facility. The sidewalk width remains constant so as to deliver convenient and comfortable movement to pedestrians (Pinna & Murrau, 2017).

In a high-density flow, pedestrians are obligated to move in a methodical pattern more often in somewhat straight lines like that of automobiles in a highway (Duives *et al.,* 2016). Accordingly, the lane model like that of the highway can be adopted in the flow of pedestrians to approximate the number of pedestrians that can walk simultaneously on a pedestrian facility with uniform width. To avoid interference, when two pedestrians walking in same directions on a sidewalk, the necessary horizontal spacing or width is 0.75 to 0.80 meters (figure 2.5) for every pedestrian on the sidewalk (Council, 2000; Navin & Wheeler, 1969). However, if the pedestrians are acquaintances, the horizontal spacing is 0.65 to 0.70 meters (Figure 2.6). When analyzing the pedestrian amenity, the space that is unused on the sides of the sidewalk because of the walls and the curb, should be deducted from the existing width. Navin & Wheeler (1969) asserted that 1.07 meters ought to be deducted from the existing sidewalk width. Therefore, the theoretic capability of a sidewalk will be larger than the real capacity value.

Some studies have identified sidewalk width, presence and buffering/amenities as forecasters of perceived pedestrian safety, quality and travel of the environment of the facility (Marshall & Garrick, 2010; Landis et al., 2005). In a guide for the significance of pedestrians using wheelchairs and width of the sidewalk, the condition of the pavement and the material it is made of were observed to be key variables for accessing the sidewalk (Ferreira & Da Penha Sanches, 2008). Additionally, other variables for quantifying walkability comprised width of the sidewalk, slope and existence of a buffer (Meghelal & Capp, 2012).

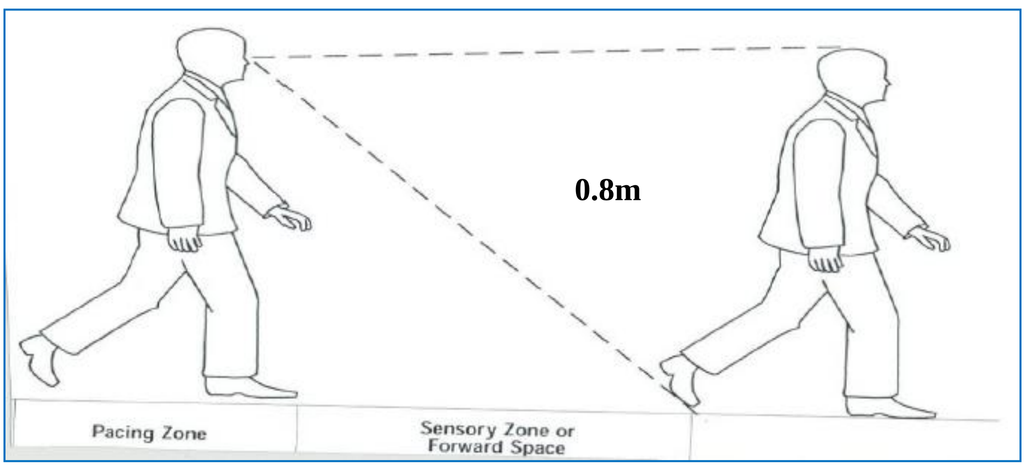

Figure 2.5:Pedestrian walking space requirement (Source: HCM, 2010)

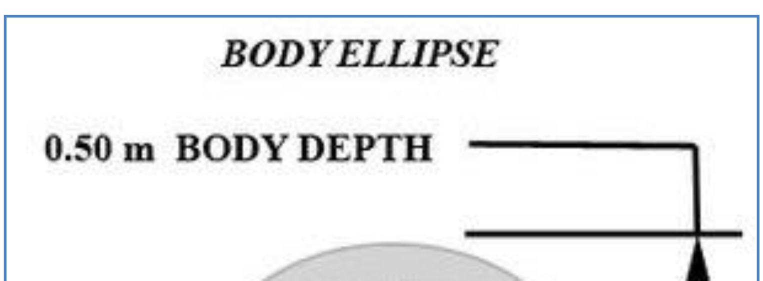

Figure 2.6:Pedestrian body ellipse (Source: HCM, 2010)

2.3.2 Pedestrian Travel Speed

When a pedestrian is not obstructed by other pedestrians, the speed with which he/she wishes to walk is referred to as the free flow speed ***(Vf)*** (Daamen & Hoogendoorn, 2006). This measure is important in developing relevant models in designing and improving pedestrian amenities and timetables. Additionally, determining these speeds is essential in evaluating the limits on movements of pedestrians that ensue at different traffic concentration levels (Fruin, 1970). This speed is determined by pedestrian characteristics such as age, gender and the capacity of a pedestrian to carry baggage, nature of the sidewalk facility for example, the grade, outdoor or indoor walking facility, and ambience factors like the weather or walkability. This free flow speed varies with pedestrians in different nations (Rahman *et al.,* 2012). Therefore, the rate of free flow speed of the native pedestrian ought to be integrated in the model, the time it takes for the pedestrian to travel and the facilities design. Including this speed partly includes the stochastic form of movements by pedestrians.

This modelling of movements by pedestrians and capability of predicting pedestrian travel time are handy in the evaluation of how a pedestrian facility performs (Wilkie, 2015). Nevertheless, there is scarce literature that integrate the pedestrian facility design, dimensions of the pedestrian body, the pedestrian waiting time/delay and pedestrian movement LOS. As a utility for applicable factors, Rahman et al. (2013) developed an analytical model of queueing to forecast time taken for pedestrians to travel on walking facilities and observed that movements by pedestrians are outcomes of various stochastic aspects. This model can be employed in assessing the general service rate of a pedestrian amenity layout and compare it to provision of the best LOS to pedestrians. The model is also able to deliver an indistinct plan on the design and size of pedestrian amenities. When empirically authenticated, the model is a strong tool in understanding how well a specific pedestrian facility creates convenience and comfortable movements by pedestrians. Analysis on sensitivity is also carried out to observe the effect of vital factors of the model on pedestrian amenities' performance.

In Bangladesh, Hossain (1991) examined the effectiveness of pedestrian overpasses in Dhaka metropolitan at Farmgate and Zia International airport. The study employed pedestrian volume counts, site surveys and interviews to pedestrians and found that 50% of the pedestrians use the overpass, 37% use designated crossing points such as zebra crossings and 13% cross illegally. At Zia International airport, 53% use the overpass and 47% cross illegally. Reasons for not using the overpass included difficulty in ascending (23%), overpass being too high (22%), and the overpass being far from pedestrian travel routes (17%). Data was analyzed to find out the pedestrian distribution for pedestrian preference, age and occupation.

In past research, mean speeds fluctuate in sidewalks from 1.23 m/s to 1.50 m/s. In Asian countries, variation is between 1.23m/s – 1.39m/s (Lam & Cheung, 2000; Kotkar *et al.,* 2010), in European countries mean speeds fluctuate from 1.31m/s to 1.50m/s (Oeding, 1963; Older, 1968), and 1.31m/s to 1.37m/s in the United States (Fruin, 1971; Navin & Wheeler, 1969). In Asian countries, the average mean speed is lower than in European countries. This shows the cultural effect on speed. Some studies that have calculated critical speed at maximum flow (capacity) and observed that it ranges between 0.61m/s to 0.82m/s on sidewalks (Sarkar & Janardhan, 1997; Lam *et al.,* 2003).

2.3.3 Level of Service (LOS)

PLOS measures how pedestrian facilities perform. PLOS does not consider the special requirements for a sidewalk only, but the experience of the pedestrians too (Singh & Jain, 2011).

The LOS concept is a construct of the quality of the current phenomenon during the time of the study and location. LOS techniques are different in diverse areas but the Level of Service is mainly denoted by ‘A’ to ‘F’ points or levels as shown in Table 2.1. Although LOS ‘A’ is deemed most favourable, system managers who focus on utilizing the pedestrian capacity best with satisfactory negative outcomes for pedestrians do not take it to be the best case like in the case of LOS ‘C’.

Diverse flows of traffic (bicycle, pedestrian, vehicular and transit) require diverse descriptions of Level of Service grounded on the factors and characteristics affecting these flows. Additionally, for modes such as vehicular, LOS can be described founded on diverse parameters such as fluid flow, capacity usage, delay and so on. Different constructions of PLOS on crosswalks and sidewalks are provided by HCM (2010). HCM has many debatable constraints for pedestrian facilities (Singh & Jain, 2011), meaning that there are many diverse methods and perspectives for PLOS to consider. There are many studies for describing better classified and accepted method. Some of these studies improve current methods with contrast and comparison and some attempt to come up with new methods (Singh & Jain, 2011). HCM based PLOS is the most ostensible but extremely criticized method (Lovas *et al.*, 2015).

The general rate of service has an association with the LOS which assesses how a pedestrian facility performs. This is due to the fact that in pedestrian densities, an interaction exists between the pedestrian speed or travel time and LOS (Day *et al.*, 2016). This relation can be used to assess the facility size required in provision of a predetermined LOS (Yuhaski & Smith, 1989). Thus, pedestrian speed is deliberated in formulating the general rate of service. This is given by equation 2.7:

$$R = s.\ \frac{1}{t\ (k)} = s.\ \frac{1}{t^{out} -\ t^{in}}$$ Equation 2.7

Where:

R=the general rate of service of the pedestrian facility;

s=Pedestrians that the pedestrian facility can accommodate in the minimum length;

t^{in}=time (seconds) when the pedestrian entered the facility;

t^{out}=time (seconds) when the pedestrian exited the facility

$t(k) = t^{out} - t^{in}$ = pedestrian travel time (seconds) at k density

The performance or general rate of service in regard to pedestrian travel time is dependent on capability of the pedestrian to walk – free flow speed, the current density – Level of Service in the flow, horizontal space requisite for a pedestrian, maximum allowable density on the pedestrian facility, and the lingering time or requisite delay. Research regarding the advancement of LOS principles have been conducted in many countries. Polus et al. (1983) examined the features and characteristics of the flow of pedestrians in Israel where information was collected using a clock-linked video recorder to help specify walking speeds. LOS was examined by the relationship between density and speed using linear models. The findings showed an inversely proportional relationship between density and speed.

Using conjoint method, Muraleetharan *et al.,* (2003) analyzed PLOS by examining the role of sidewalk features such as width of the sidewalk, pedestrian flow rate, presence of obstacles and facilities available for crossing. The study revealed that the most important aspect to influence PLOS was the rate of flow of pedestrians and the sidewalk width. However, presence of obstacles was insignificant in influencing PLOS. Petritsch *et al.,* (2008) evaluated the service quality on a user centered technique in place of a provider centered technique. The effect of the width of the sidewalk, walkway and traffic separation, width of the buffer, speed and volume of traffic, volume of pedestrians and parking on-street was examined for PLOS on walkway facilities.

Using a pedestrian survey, Tan et al. (2007) examined PLOS by assessing the bond between perceptions of pedestrians and operation of traffic flow. The study determined PLOS for the region as ‘C’. Landis et al. (2001) assessed the perception of pedestrian comfort and safety on the sidewalk to provide an indicator of PLOS. Asadi Shekari *et al.* (2014) examined the PLOS for streets in Malaysian campuses for evaluation and improvement. Design indicators for pedestrians were founded on different guidelines. The researchers came up with a formulation based on Twenty Seven measures determining PLOS for campus streets. Karatas (2015) assessed PLOS for sidewalks and revealed that presence of sidewalks on both sides, protection from the weather and infrastructure had a significant influence on walking.

2.3.4 Satisfaction with the Pedestrian Facilities

Walking is among all methods, the most fundamental, active and healthy to pedestrians . Apart from financial benefits such as savings in the price of vehicles or public transport, time savings and reduced transportation (Litman, 2003), it also improves the possibilities of private mobility. It also encourages fair access to transport alternatives, particularly for socially vulnerable persons such as females, children and the elderly (Borst *et al.*, 2009). In the present transport planning and policy development, however, walking has continued to be undervalued (Shoup, 2010).

Despite the reality that pedestrians make up about 40–60 percent of modal shares (Leather *et al.*, 2011), pedestrians and the needs of pedestrians remained the least concern of the government and private industries, especially in the context of developing countries. This blatant disregard for non-motorized transport customers is also reflected in the insufficient provision of excellent quality pedestrian services, the restricted financing allocation for pedestrian infrastructure, and transport planning and policies that essentially target drivers of private vehicles (Newman & Kenworthy, 1999). Pedestrian input can be used from the view of the highway user to determine appropriate service satisfaction rates. Most previous studies of sidewalk performance were conducted with quantitative factors such as pedestrian room, pedestrian and/or car traffic and sidewalk width (e.g., Huang et al., 2007, Landis et al., 2001, TRB, 2000). In this study, pedestrian satisfaction with sidewalk facilities will be measured by the pavement condition, presence of a buffer**,** pedestrian space, sidewalk width and sidewalk slope.

Pedestrian satisfaction studies were carried out widely using different techniques (Papadimitriou, 2013; Asadi, Moeinaddini & Zaly, 2013) and are not limited to the capacity based model (Stradling, Anable & Carreno, 2007), but also to the model based on the roadway characteristic. Furthermore, studies on pedestrian facilities are not restricted to quantitative methods (Landis *et al.*, 2001) but also qualitative approach. These early studies have become reference points in current studies on pedestrian level of services.

Sisiopiku (2010) assessed the engineering methods for designing safe pedestrian facilities in the United States and found that the traditional engineering treatments for pedestrian safety and satisfaction require pedestrian accommodations at intersections. The important intersection issues for consideration are: improved pedestrian conspicuity, pedestrian action and movement predictability, distance and time that pedestrians have to cross the road, and ease of movement from walkway to street level and vice versa.

Yadav, Jaiswal and Nateriya (2015) sought to find out factors affecting the level of service for pedestrians at signalized intersection crosswalks and suggested a technique for determining pedestrian service level at signalized intersections by influencing and analyzing the perceived general level of satisfaction experienced by pedestrians. The study found that pedestrian level of service measurements can provide an understanding of the situation of the crosswalk. These measures would assist to assess and prioritize pedestrian requirements at existing intersections. The study also found that Pedestrian LOS can be used to create a minimum LOS standard that could prescribe a minimally acceptable LOS for satisfactory pedestrian accommodation. However, this study focused on crosswalks of signalized intersection while the current study is more inclined on assessment of pedestrian amenities from the perspective of pedestrian and vehicle users.

This study adopted the HCM 2010 model because of the following reasons;

- It is widely used and acceptable model in evaluation of pedestrian facilities
- It's simple, easy to collect data and compute LOS

2.4 Summary of Literature Review

Table 2.3: Summary of literature review

Author	Title	Strengths	Remarks
Hossain (1991)	Effectiveness of pedestrian overpasses in metropolitan Dhaka, Bangladesh by investigating the pedestrian overpasses at Farmgate and at Zia-International Airport.	This study included both the field investigations - site surveys, pedestrian volume counts, pedestrian interviews at each of the overpasses and data analyses.	The study was conducted in Bangladesh while the current study seeks a Kenyan perspective
Rahman et al. (2013)	An analytical queueing model to forecast time taken for pedestrians to travel on walking facilities	This model can be employed in assessing the general service rate of a pedestrian amenity layout and compare it to provision of the best LOS to pedestrians The model can also deliver an indistinct plan on the design and size of pedestrian amenities	Based on pedestrian movements, the study adopted an analytical queueing model to forecast time taken for pedestrians to travel on walking facilities while the current study is based on different theories.
Muraleetharan *et al.*, (2003)	The role of sidewalk features such as the pedestrian flow rate, sidewalk width, facilities available for crossing and presence of obstacles	The most important aspect to influence PLOS was the flow rate of pedestrians and the sidewalk width	The presence of obstacles was insignificant in influencing PLOS
Petritsch *et al.*, (2008)	Evaluation of the service quality on a user centered technique in place of a provider centered technique	The effect of the width of the sidewalk, walkway and traffic separation, width of the buffer, speed of the volume of traffic, volume of pedestrians and the parking on-street was examined for PLOS on walkway facilities	In evaluating the quality of service, the study employed a pedestrian user-based method in place of a provider-based method.

Author	Title	Strengths	Remarks
Tan *et al.*, (2007)	Assessment of the PLOS by examining the association among the perception of pedestrians, quality of road facilities, and also the traffic flow operation.	The study is an educational source of reference that highlights the reason as to why transport infrastructures are inefficient in current societies, and offers solutions for improving pedestrian systems.	The study focused on quality of road facilities perceptions of pedestrians and also the traffic flow operation while the current study seeks to establish the pedestrian travel speed at the sideways and sidewalks of the overpass.
Asadi Shekari *et al.* (2014)	Pedestrian LOS streets in campus to improvement and evaluation	In this study, measures of pedestrian design were founded on Twenty diverse guidelines.	The study focused on evaluating and improving pedestrian LOS for the streets in campus while the current study focuses on public facilities where the characteristics of pedestrian flow are different from a campus setting
Karataş (2015)	PLOS for sidewalks in Turkey	Presence of sidewalks on the roadsides, infrastructure, sidewalks being protected from the weather etc. had a significant influence on increase in pedestrian walking.	The study was conducted in Ankara, Turkey while the current one seeks a Kenyan perspective.

CHAPTER 3: METHODOLOGY

3.1 Desk Review

The research considered literature from foreign and local manuals, previous studies, journals articles, government policies and regulations, and other related documents. The study reviewed data on the use and design of pedestrian walking facilities and the parameters which influence the comfort and safety of pedestrians.

3.2 Study Site

The research earmarked a section of Outer Ring Road, this being the Manyanja and Donholm overpasses for its field data collection process. The site faces the constraints of pedestrian walking due to Mini buses queueing for passengers in places not designated as bus stops.

The selected sections of Outer Ring Road usually experience pedestrian movement in a stream, which is a requirement for determining footpath width, travel speed, pedestrian LOS and pedestrian satisfaction with the available pedestrian facilities.

3.3 Data Required for the Study

To satisfy the objectives of the study, quantitative research was conducted. The data required for the study is summarized Table 3.1.

Table 3.1:Data required for the study

Objective	Required Data
Pedestrian space provided at the sideways and sidewalks	Number of pedestrians, width of the sidewalk, presence of a buffer and the sidewalk slope
Pedestrian travel speed	Traffic concentration levels (density), pedestrian characteristics (gender, ability to carry gender, age, ambient factors like walkability, weather)
Level of Service and its score	Horizontal space necessary for a pedestrian, the highest allowable density/congestion on the sidewalk

3.4 Data Collection

The possible approaches of finding the standard of pedestrian amenities, included manual counts and video recording.

3.4.1 Manual counts

This is where pedestrians were counted manually along the sidewalks using a tally marking sheet. Manual counting of pedestrians was done at 15-minute interval between morning(6am) and in the evening (6pm). The peak hours were 6am -9am and 4pm-6pm while the off-peak hours were between 10 am -3pm. The exercise was done for six days starting from Monday (8th April 2019) and ended on Saturday (13th April 2019). The observation site was judiciously chosen so as to make sure that the prevailing demand was witnessed. The merits of this approach is that it is flexible and simple to carry out (see Plate 3.1)

Plate 3. 1: An enumerator at post 2 during a pedestrian manual count

3.4.2 Video Survey

Video cameras were put in place at a vantage point at the survey site and pedestrians were recorded for the duration of observation. This approach yielded a lasting record of how pedestrians moved and how they interacted with automobiles. In this approach, the behavioral pattern was also recorded. This survey method also helped a lot in determining the pedestrian speed. The process involved recording the time taken by a pedestrian to cross the overpass as shown in Plate 3.2.

Plate 3. 2: Video recording

Site Survey and Visual Inspections

This involved visually inspecting the sidewalks and measuring the provided walking spaces in terms of width and length.

Plate 3. 3: Measurement of sidewalk width and length

3.5 Data Processing

From the recordings of the manual count, one second interval was employed to measure the speed of walking, pedestrian flow and density. The speed with which pedestrians travel was gathered by recording the time that a pedestrian took to move past the marked area. Density or pedestrian congestion was acquired by manually counting pedestrians that are in the boundaries of the observation area when the pedestrian was in the middle.

Pedestrian rate of flow was acquired by totaling the pedestrians passing through the middle of the selected site inside the one second interlude or interval. The information gathered was consolidated, in the assumption that the study areas had similar physical characteristics. The association between density, speed and flow was determined and LOS criteria was recommended for sidewalk facilities.

CHAPTER 4: DATA ANALYSIS AND DISCUSSION

4.0 Introduction

The current study sought to assess the performance of pedestrian amenities from pedestrian and vehicular user perspectives at Donholm interchange along Outer ring road in Nairobi, Kenya. The information for this study was gathered using two sources namely primary and secondary sources. Primary data collection methods included pedestrian surveys, pedestrian infrastructure survey. The pedestrian volume study was performed using the manual traffic counter on each path during a particular date and moment. The secondary sources included use of the literature from previous studies like the HCM model. The data collected was analyzed and presented using tables and graphs.

4.1 Pedestrian Volume analysis and discussions

Plate 4.1 shows the aerial photo of the area of study (Donholm interchange). The enumerators were placed along each route at Four points, all situated in the pedestrian generation areas.

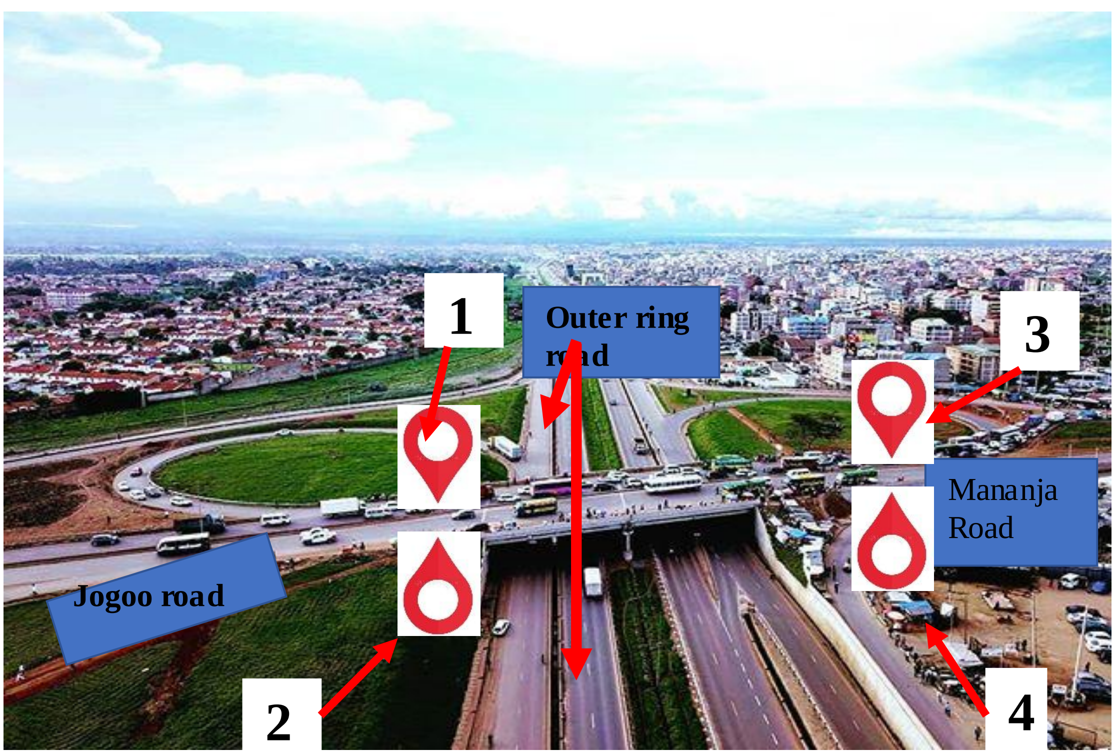

Plate 4.1 : Donholm interchange overpass

d times see ... Table 4.1

Table 4.1: Details of pedestrian volume count (Posts 1, 2, 3 & 4)

Route	Date	Time
Post 1: Manyanja road to Jogoo road (West bound)	8th April 2019 – 13th April 2019	0600 – 0900hrs 1200 – 1400hrs 1600 – 1800hrs
Post 2: Manyanja road to Jogoo road (East bound)	8th April 2019 – 13th April 2019	0600 – 0900hrs 1200 – 1400hrs 1600 – 1800hrs
Post 3: Jogoo road to Manyanja road (West bound)	8th April 2019 – 13th April 2019	0600 – 0900hrs 1200 – 1400hrs 1600 – 1800hrs
Post 4: Jogoo road to Manyanja road (East bound)	8th April 2019 – 13th April 2019	0600 – 0900hrs 1200 – 1400hrs 1600 – 1800hrs

The Month of April was chosen because it fell within the academic calendar.

From manual counts the number of pedestrians using the overpass sidewalks daily was recorded and analyzed on table 4.2

V15 means the number of pedestrians counted within the Fifteen minutes interval counts

V60 means the number of pedestrians counted within an hour

Table 4.2:Pedestrian Volume Analysis combined for both directions

Time interval	Monday (8/4/19)		Tuesday (9/4/19)		Wednesday (10/4/19)		Thursday (11/4/19)		Friday (12/4/19)		Saturday (13/4/19)	
	V15	V60	V15	V60	V15	V60	V15	V60	V15	V60	V15	V60
6:00am - 6:15am	427		480		447		941		568		505	
6:15am - 6:30am	505		519		465		1,031		653		618	
6:30am - 6:45am	524		520		472		794		669		624	
6:45am - 7:00am	575	2,031	543	2,062	480	1,864	957	3,723	758	2,648	715	2,462
7:00am - 7:15am	581		587		570		991		840		631	
7:15am - 7:30am	583		713		680		1,105		809		695	
7:30am - 7:45am	610		649		582		1,285		873		872	
7:45am - 8:00am	573	2,347	602	2,551	802	2,634	1,137	4,518	925	3,447	799	2,997

Time interval	Monday (8/4/19)		Tuesday (9/4/19)		Wednesday (10/4/19)		Thursday (11/4/19)		Friday (12/4/19)		Saturday (13/4/19)	
8:00am - 8:15am	549		593		871		957		891		762	
8:15am - 8:30am	561		654		888		897		970		814	
8:30am - 8:45am	550		592		778		761		852		851	
8:45am - 9:00am	485	2,145	679	2,518	874	3,411	653	3,268	884	3597	1052	3,479
12:00 - 12:15pm	340		330		269		267		297		218	
12:15pm - 12:30pm	332		355		256		245		354		261	
12:30pm - 12:45pm	320		312		251		313		364		269	
12:45pm - 1:00pm	240	1,232	274	1,271	252	1,028	389	1,214	237	1,252	334	1,082
1:00pm - 1:15pm	209		239		227		404		254		602	
1:15pm - 1:30pm	178		229		275		339		209		550	
1:30pm - 1:45pm	199		235		256		227		245		605	
1:45pm - 2:00pm	214	800	281	984	310	1,068	211	1,181	269	977	553	2,310
4.00pm- 4.15pm	340		314		369		453		379		223	
4:15pm - 4:30pm	442		462		573		653		504		209	
4:30pm - 4:45pm	544		599		576		826		645		326	
4:45pm - 5:00pm	721	2,047	836	2,211	693	2,211	857	2,789	844	2,372	375	1,133
5:00pm - 5:15pm	727		824		916		985		886		404	
5:15pm - 5:30pm	770		928		978		1078		968		427	
5:30pm - 5:45pm	901		909		1038		1246		1042		340	
5:45pm - 6:00pm	1012	3,410	963	3,624	1,083	4,015	1190	4,499	1197	4,093	638	1,809

The study also analyzed the Maximum, Average and Minimum 15-minute pedestrian counts as seen on **table 4.3** and **table 4.4** for both sides.

Table 4.3:Average, maximum and minimum 15 minute pedestrian volume (Manyanja road to Jogoo Road)

Parameter	Day and Date					
	Monday (8/4/19)	**Tuesday (9/4/19)**	**Wednesday (10/4/19)**	**Thursday (11/4/19)**	**Friday (12/4/19)**	**Saturday (13/4/19)**
Average V15	344	380	429	587	510	402
Minimum V15	93	87	137	125	119	65
Maximum V15	725	731	820	905	894	919

Table 4.4:Average, maximum and minimum 15 minute pedestrian volume (Jogoo road to Manyanja Road)

Parameter	Day and Date					
	Monday (8/4/19)	**Tuesday (9/4/19)**	**Wednesday (10/4/19)**	**Thursday (11/4/19)**	**Friday (12/4/19)**	**Saturday (13/4/19)**
Average V15	158	163	152	171	148	144
Minimum V15	83	95	88	76	90	85
Maximum V15	310	302	307	357	303	287

From the study the overpass is serving almost 14000 – 16000 pedestrians daily,

Monday (8/4/2019) had the least number of pedestrians counted 14012 whereas Thursday (8/4/2019) recorded the highest number of pedestrians 16431.

The 15 minute counts showed that Thursday (11/4/2019) had the highest peak of 357 pedestrians and Saturday (13/4/2019) had the least peak of 287 pedestrians.

4.1.2 Pedestrian Volume analysis using Graphs

Graphs were used to analyse and compare the 15-minute pedestrian volumes daily as shown in Figure 4.1.

From the graph below Thursday had the highest number of pedestrians (1,300) during the morning peak hours between 7.45am and 8.00am, During the off-peak Saturday recorded the highest number of pedestrians (600), the evening hours peaks the highest number of pedestrians were recorded on Thursday (1,250).

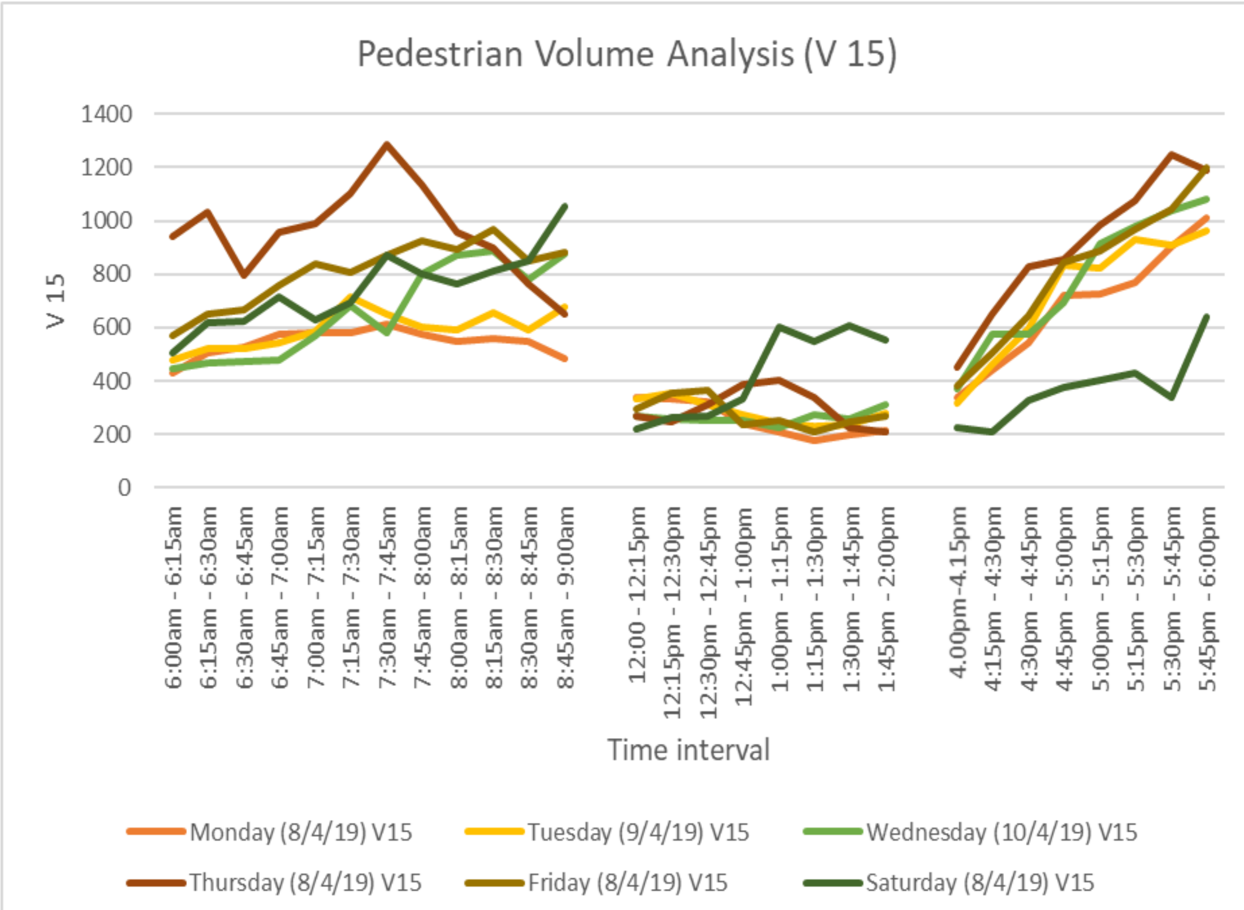

Figure 4.1:Pedestrian Volume Analysis (V 15)

The hourly variations within the week recorded the peak hours having the highest number of pedestrians and a significant drop of the same during the midday off peak hours followed by a rise in numbers during the evening peak hours.

4.2 Pedestrian speed analysis

Figure 4.2 below compares the time recorded when pedestrians were crossing the overpass at different time interval and dates.

On average most pedestrians took 65 secs to cross the overpass which is approximately 60 meters long.

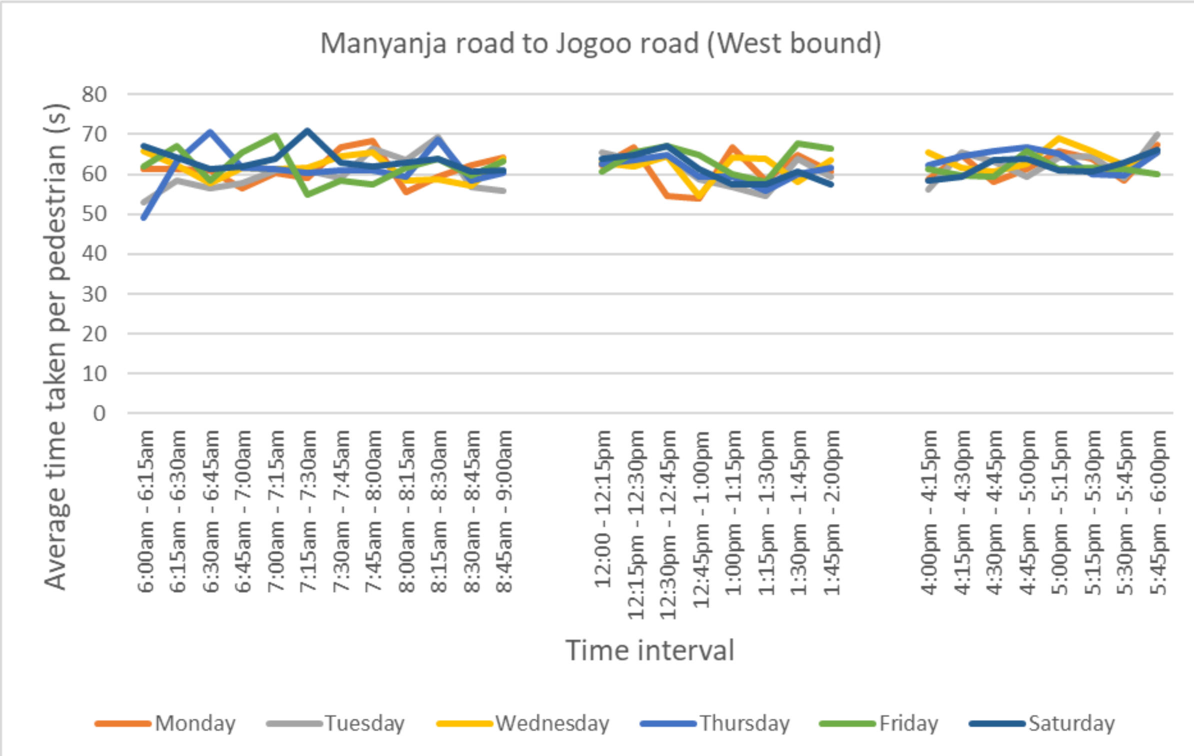

Figure 4.2:Comparison of the Average Time Taken per Pedestrian

A video camera was employed in retrieving data, the technique is beneficial over direct observation as it can readily be watched over and over again, thus acquiring more precise information.

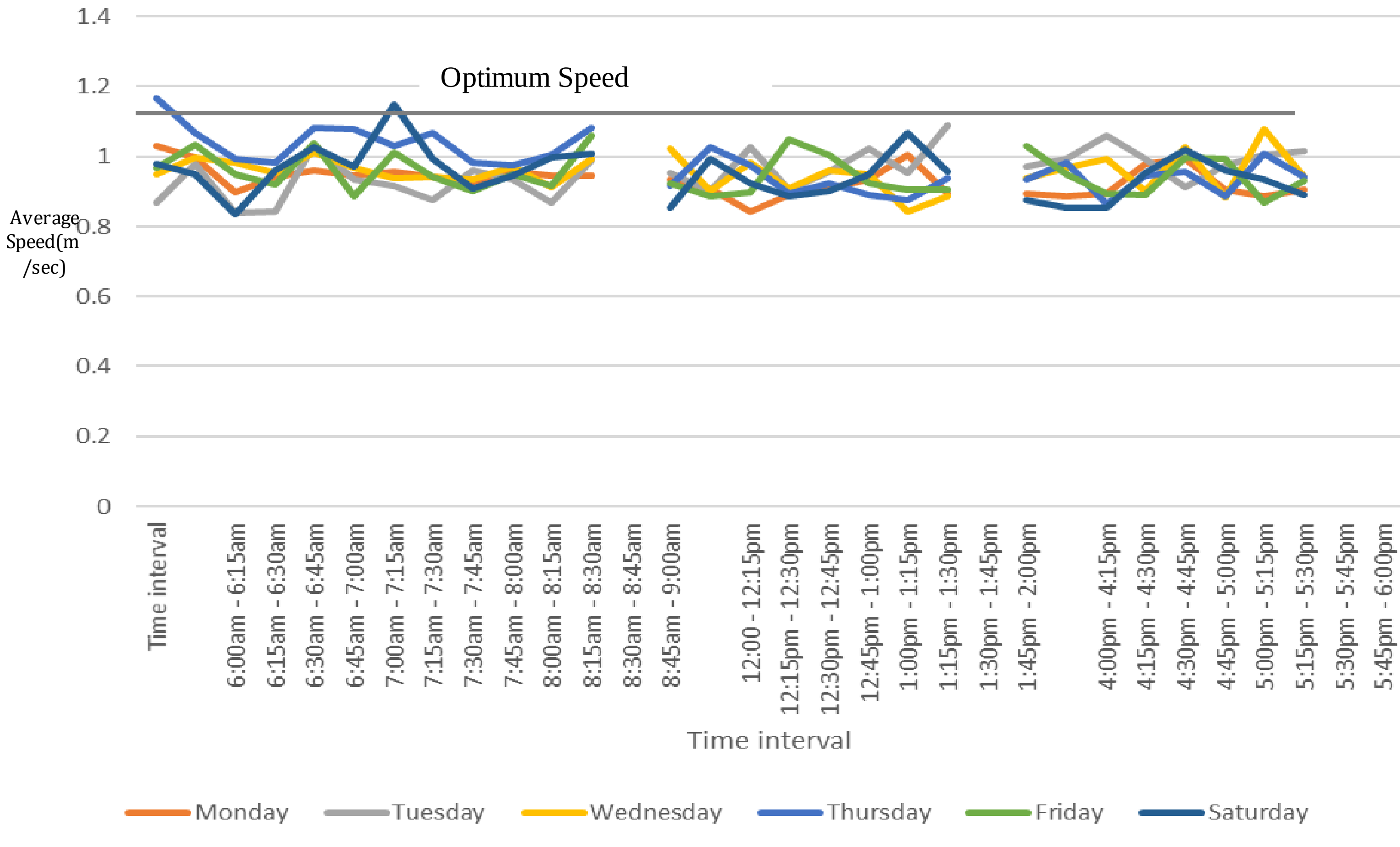

Figure 4.3: Comparison of pedestrian speed (of the different days) in crossing the 60m overpass for Manyanja Road to Jogoo Road

More analysis of the pedestrian speed is attached as Appendix 3

4.3. Determination of Pedestrian density and Level of Service

4.3.1 Peak Hour Flow and Maximum Flow Rate

According to Miranda & Carvasco (2011), a peak hour factor (PHF) describes the mathematical relationship between peak hour volume and peak hour flow rate as follows.

$$PHF = {}^{Vp}/_{P \ x \ Vmn} \qquad \text{Equation 4.1}$$

Where;

Vp is the Peak Hour Volume

Vmn is the maximum volume for a n minute

P is the number of period within the hour

Manyanja Road to Jogoo Road PHF is computed as follows:

$\text{PHF} = {}^{3680}/_{4\ x\ 919} = 1.00$ ....Refer to Appendix 1 and table 4.3

This means that the pedestrian flow within the hour is uniform and evenly distributed

Jogoo Road to Manyanja Road PHF is computed as follows:

$\text{PHF} = {}^{1165}/_{4\ x\ 357} = 0.82$ ....Refer to Appendix 2 and table 4.4

This means that the pedestrian flow within the hour is almost uniform and evenly distributed.

The maximum rate of flow is then computed as follows:

Manyanja Road to Jogoo Road

$$\text{Maximum Design Flow Rate} = \frac{\text{Pedestrian Hourly Volume (Vp)}}{\text{Pedestrian Hourly Flow (PHF)}}$$ .... Equation 4.2

$$\text{Maximum Design Flow Rate} = \frac{3680}{1.0} = 3680\ \text{ped/hour}$$

Jogoo Road to Manyanja Road

$$\text{Maximum Design Flow Rate} = \frac{1165}{0.81} = 1439\ \text{ped/hour}$$

4.3.1: Pedestrian Density

According to Orland et al. (2003), the average area occupied by the pedestrian can be calculated by dividing the area of the efficient walkway width with the maximum pedestrian volume.

$$\text{Average pedestrian Area} = \frac{\text{Area of effective walkway width}}{\text{Peak Hour Pedestrian Volume}}$$

The other steps of determining the pedestrian density are in table 4.5 below

Table 4.5:Determining Pedestrian Density and level of service

Parameter	**Formula**	**Calculations**	**Results**
Effective width of the walkway	$W_E = W_1 - W_2$	$2.4 - 0.2m$	2.2m
Total Length of the overpass walkway			60m
Area of Effective walkway width	$Area = W_E * L$	$60m * 2.2$	132m^2
Pedestrian peak volume, Vp			3680 Ped/Hour
Average pedestrian space	$APA = \frac{Area}{V_p}$	$\frac{132_{m^2}}{3680}$	0.04m2/ped
Level of service			F

(Source: Author, 2019)

The average pedestrian space provided at the sidewalks from the study is 0.04m2/ped at peak hours.

This area according to Table 2.1 and 2.2 is described as ‘F’ and the corresponding score is Less than 25.

Due to the absence of the appropriate Non-Motorized facilities and designated Bus stops pedestrians are dropped and picked at the sidewalks of the overpass.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study concludes the following

- The overpass at Donholm interchange serves between 14,000 – 16000 pedestrians per day. During the period of study Thursday (11/4/2019) recorded the highest number of pedestrians at 16431 and Monday (8/4/2019) recorded the least number of pedestrians at 14012.

- The length of the overpass is 60m long and on average most of the pedestrians took a minute to cross.

  The study concludes that the walking speeds are 1.02metres pers second which comparatively is lower than the 1.5metres per second speed recommended by the HCM model 2010.

- At peak hours the pedestrian spaces are very small and this leads to a congestion at the overpass. The effective width of the sidewalks was found to be 2.2 m.

- The study found out that the average space provide is 0.04m2 /ped and this represents the worst pedestrian facility at peak hour. According to the HCM model 2010 the appropriate space provided per pedestrian at peak hours should be 3.72-8.36m2/ped with a corresponding unit flow of 9.84-19.68ped/min/m.

- The overpass operates at Level of service 'F' at peak hours and the corresponding score is 25. Referring to Table 2.1 and 2.2). The desirable peak period pedestrian flow should operate at LOS C or above (TRB,2003;Orlando et al.,2003).

5.2 Recommendations

5.2.1 Recommendations resulting from the study

5.2.1.1 Construction of two-foot bridges

- This study recommends construction of Two Footbridges parallel to the overpass.

Figure 5.1 proposed two footbridge locations

5.2.1.2 Provision of road signs

- This study recommends provision of these Road signs at the overpass sidewalks.

.5.2.1.3 Provision of lighting

- This study recommends improved lighting at the overpass especially at Night.

5.2.1.4 Satisfaction

- Improve Connectivity on the sidewalks and construct ramps to enable the Persons with disability to use the sidewalks comfortably.

5.2.2 Recommendations for further study

- Further studies should be done to see if the walking patterns change on the remaining months of the year and also all the days of the month.

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APPENDIX 1: PEDESTRIAN MANUAL COUNTS (Manyanja Road to Jogoo Road)

Pedestrian Volume Analysis (Manyanja Road to Jogoo Road)

Time interval	Monday (8/4/19)		Tuesday (9/4/19)		Wednesday (10/4/19)		Thursday (8/4/19)		Friday (8/4/19)		Saturday (8/4/19)	
	V15	V60	V15	V60	V15	V60	V15	V60	V15	V60	V15	V60
6:00am - 6:15am	330		385		341		822		446		405	
6:15am - 6:30am	388		399		355		909		526		522	
6:30am - 6:45am	390		391		346		655		542		539	
6:45am - 7:00am	410	1518	397	1572	338	1380	793	3179	631	2145	630	2096
7:00am - 7:15am	402		414		403		814		682		538	
7:15am - 7:30am	381		519		463		920		656		595	
7:30am - 7:45am	375		423		426		1065		698		737	
7:45am - 8:00am	403	1561	422	1778	688	1980	881	3680	755	2791	661	2531
8:00am - 8:15am	426		458		725		782		715		621	
8:15am - 8:30am	453		511		767		743		795		677	
8:30am - 8:45am	452		455		656		602		680		678	
8:45am - 9:00am	401	1732	513	1937	753	2901	495	2622	748	2938	919	2895
12:00 - 12:15pm	188		190		156		154		160		118	
12:15pm - 12:30pm	209		224		147		138		231		174	
12:30pm - 12:45pm	199		190		153		219		260		172	
12:45pm - 1:00pm	132	728	144	748	137	593	290	801	123	774	172	636
1:00pm - 1:15pm	126		114		139		328		163		442	
1:15pm - 1:30pm	93		87		161		238		119		411	
1:30pm - 1:45pm	97		119		149		146		153		460	
1:45pm - 2:00pm	103	419	146	466	209	658	125	837	173	608	416	1729
4.00pm-4.15pm	222		190		279		314		278		95	

Time interval	Monday (8/4/19)		Tuesday (9/4/19)		Wednesday (10/4/19)		Thursday (8/4/19)		Friday (8/4/19)		Saturday (8/4/19)	
4:15pm - 4:30pm	271		320		405		431		367		65	
4:30pm - 4:45pm	372		417		425		578		516		165	
4:45pm - 5:00pm	471	1336	596	1523	477	1586	655	1978	605	1766	178	503
5:00pm - 5:15pm	508		645		634		760		698		195	
5:15pm - 5:30pm	494		651		671		780		782		178	
5:30pm - 5:45pm	591		607		763		889		861		147	
5:45pm - 6:00pm	725	2318	731	2634	820	2888	905	3334	894	3235	351	871

APPENDIX 2: MANUAL COUNTS (Jogoo Road to Manyanja Road)

Pedestrian Volume Analysis (Jogoo Road to Manyanja Road)

Time interval	Monday (8/4/19)		Tuesday (9/4/19)		Wednesday (10/4/19)		Thursday (11/4/19)		Friday (12/4/19)		Saturday (13/4/19)	
	V15	V60	V15	V60	V15	V60	V15	V60	V15	V60	V15	V60
6:00am - 6:15am	97		95		106		119		122		100	
6:15am - 6:30am	117		120		110		122		127		96	
6:30am - 6:45am	134		129		126		139		127		85	
6:45am - 7:00am	165	513	146	490	142	484	164	544	127	503	85	366
7:00am - 7:15am	179		173		167			177	158		93	
7:15am - 7:30am	202		194		217			185	153		100	
7:30am - 7:45am	235		226		156		220		175		135	
7:45am - 8:00am	170	786	180	773	114	654	256	838	170	656	138	466
8:00am - 8:15am	123		135		146		175		176		141	
8:15am - 8:30am	108		143		121		154		175		137	
8:30am - 8:45am	98		137		122		159		172		173	
8:45am - 9:00am	84	413	166	581	121	510	158	646	136	659	133	584
12:00 - 12:15pm	152		140		113		113		137		100	
12:15pm - 12:30pm	123		131		109		107		123		87	
12:30pm - 12:45pm	121		122		98		94		104		97	
12:45pm - 1:00pm	108	504	130	523	115	435	99	413	114	478	162	446
1:00pm - 1:15pm	83		125		88		76		91		160	
1:15pm - 1:30pm	107		142		114		101		90		139	
1:30pm - 1:45pm	102		116		107		81		92		145	
1:45pm - 2:00pm	111	381	135	518	101	410	86	344	96	369	137	581
4.00pm-4.15pm	118		124		90		139		101		128	
4:15pm - 4:30pm	171		142		168		222		137		144	
4:30pm - 4:45pm	172		182		151		248		129		161	
4:45pm - 5:00pm	250	711	240	688	216	625	202	811	239	606	197	630
5:00pm - 5:15pm	219		179		282		225		188		209	
5:15pm - 5:30pm	276		277		307		298		186		249	
5:30pm - 5:45pm	310		302		275		357		181		193	
5:45pm - 6:00pm	287	1092	232	990	263	1127	285	1165	303	858	287	938

APPENDIX 3: Speed analysis

Time interval	Monday 8/4/2019		Tuesday 9/4/2019		Wednesday 10/4/2019		Thursday 11/4/2019		Friday 12/4/2019		Saturday 13/4/2019	
	Average time taken by pedestrians to cross the 60m	Speed in m/sec	Average time taken by pedestrians to cross the 60m overpass	Speed in m/sec	Average time taken by pedestrians to cross the 60m overpass	Speed in m/sec	Average time taken by pedestrians to cross the 60m overpass	Speed in m/sec	Average time taken by pedestrians to cross the 60m overpass	Speed in m/sec	Average time taken by pedestrians to cross the 60m overpass	Speed in m/sec
6:00am - 6:15am	58.2	1.03	69.1	0.87	63.3	0.95	51.5	1.17	62	0.97	61.4	0.98
6:15am - 6:30am	60.2	1.00	61.3	0.98	60.1	1.00	56.3	1.07	58.1	1.03	63.2	0.95
6:30am - 6:45am	66.9	0.90	71.7	0.84	61.1	0.98	60.3	1.00	63.1	0.95	72	0.83
6:45am - 7:00am	63.7	0.94	71.3	0.84	63	0.95	61	0.98	65.2	0.92	62.4	0.96
7:00am - 7:15am	62.4	0.96	58.1	1.03	59.4	1.01	55.5	1.08	57.8	1.04	58.55	1.02
7:15am - 7:30am	63.4	0.95	64.3	0.93	62.1	0.97	55.6	1.08	67.6	0.89	61.7	0.97
7:30am - 7:45am	62.7	0.96	65.5	0.92	63.9	0.94	58.3	1.03	59.4	1.01	52.2	1.15
7:45am - 8:00am	63.8	0.94	68.4	0.88	63.8	0.94	56.3	1.07	63.6	0.94	60.5	0.99
8:00am - 8:15am	64.8	0.93	62.6	0.96	64.3	0.93	61.1	0.98	66.7	0.90	66	0.91
8:15am - 8:30am	62.8	0.96	64.2	0.93	61.8	0.97	61.6	0.97	63.3	0.95	63.5	0.94
8:30am - 8:45am	63.5	0.94	69.1	0.87	65.9	0.91	59.8	1.00	65.6	0.91	60.2	1.00
8:45am - 9:00am	63.5	0.94	60.6	0.99	60.3	1.00	55.5	1.08	56.7	1.06	59.5	1.01
12:00 - 12:15pm	64.1	0.94	62.9	0.95	58.7	1.02	65.6	0.91	65	0.92	70.3	0.85

Time interval	Monday 8/4/2019		Tuesday 9/4/2019		Wednesday 10/4/2019		Thursday 11/4/2019		Friday 12/4/2019		Saturday 13/4/2019	
12:15pm - 12:30pm	66	0.91	66.5	0.90	66.6	0.90	58.5	1.03	67.8	0.88	60.5	0.99
12:30pm - 12:45pm	71.3	0.84	58.4	1.03	61.1	0.98	61.6	0.97	66.9	0.90	64.9	0.92
12:45pm - 1:00pm	67.5	0.89	66.3	0.90	66	0.91	67	0.90	57.2	1.05	67.7	0.89
1:00pm - 1:15pm	66	0.91	62.7	0.96	62.5	0.96	64.9	0.92	59.8	1.00	66.6	0.90
1:15pm - 1:30pm	64.2	0.93	58.6	1.02	63.2	0.95	67.3	0.89	65.1	0.92	63.2	0.95
1:30pm - 1:45pm	59.7	1.01	62.9	0.95	71.3	0.84	68.6	0.87	66.2	0.91	56.3	1.07
1:45pm - 2:00pm	67.2	0.89	55	1.09	67.8	0.88	64	0.94	66.4	0.90	62.7	0.96
4:00pm - 4:15pm	67.1	0.89	61.7	0.97	63.9	0.94	64.3	0.93	58.3	1.03	68.5	0.88
4:15pm - 4:30pm	67.6	0.89	60.3	1.00	62	0.97	61.1	0.98	63.3	0.95	70.3	0.85
4:30pm - 4:45pm	67.1	0.89	56.7	1.06	60.5	0.99	69.5	0.86	67	0.90	70.3	0.85
4:45pm - 5:00pm	61.3	0.98	60.3	1.00	66.6	0.90	63.5	0.94	67.4	0.89	62.9	0.95
5:00pm - 5:15pm	60.5	0.99	65.8	0.91	58.5	1.03	62.7	0.96	60.1	1.00	58.9	1.02
5:15pm - 5:30pm	66.3	0.90	61.5	0.98	68	0.88	67.8	0.88	60.3	1.00	62.5	0.96
5:30pm - 5:45pm	67.7	0.89	59.8	1.00	55.7	1.08	59.6	1.01	69	0.87	64.3	0.93
5:45pm - 6:00pm	66.2	0.91	59	1.02	63.8	0.94	63.6	0.94	64.5	0.93	67.4	0.89