UNIVERSITY OF NAIROBI
School of Engineering

ASSESSMENT OF THE UNIVERSITY OF NAIROBI PEDESTRIAN TUNNEL ACROSS UHURU HIGHWAY

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Declaration of Originality

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Approval

This research thesis has been submitted for examination with our approval as the University Supervisors.

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Dedication

To my beloved wife Lilian for your love and support,

my dear mother Nyakisumo for your toil and strength,

and my cherished princesses

Melissa, Melinda and Mahalia

Acknowledgement

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OGINGA, Reinhard O. Wilfred

Abstract

ASSESSMENTOF THE UNIVERSITY OF NAIROBI
PEDESTRIAN TUNNEL ACROSS UHURU HIGHWAY

Pedestrian facility assessment has to do with the evaluation of the quality of service provided to the user by the facility based on the physical and operational requirements.

Physical assessment is based on safety and security; connectivity; convenience; and visual appeal and amenity. The Environmental Level of Service (E-LOS) of a facility based on the above factors form the basis of physical evaluation of a pedestrian facility.

The walkway width, and in particular the space available for pedestrians is the most important factor in determining the level of comfort while walking. Pedestrian comfort is classified on the basis of the magnitude of crowding pedestrians experience on the facility. Pedestrian crowding, or pedestrian flow rate is measured in pedestrians per meter of clear facility width per minute. Pedestrian comfort, or P-LOS is a factor of the flow rate. The operational comfort of a pedestrian facility is measured on the basis of Pedestrian Level of Service (P-LOS), or simply Level of Service (LOS), which is a measure of the facility's ability to accommodate the demand.

The primary objective of this study was to assess the University of Nairobi Pedestrian Tunnel across Uhuru Highway on the basis of the E-LOS and P-LOS.

The study revealed that the facility operates at P-LOS F most of the time, while the E-LOS characterization established that the tunnel is currently operating at E-LOS C for connectivity, F for Security, F for Visual Appeal and Amenity, and E for Convenience.

In the recommendation, a concept design for a new GSPC has been formulated based on Year 2030 projected pedestrian volume. Other consideration incorporated in the design of the GSPC include two directional flows, a provision for an exclusive one-way roadway to cater for bus shuttle system, cyclists as well as emergency traffic.

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Acronyms

AADT	Average Annual Daily Traffic
ADA	American Disabilities Act
ADD	Architecture, Design and Development
ADT	Average Daily Traffic
CAE	College of Architecture and Engineering
CBD	Central Business District
CCN	City Council of Nairobi
CCTV	Closed – Circuit Television
CHSS	College of Humanities and Social Sciences
DN	Daily Nation
DOT	Department of Transport
E – LOS	Environmental Level of Service
FHWA	Federal Highway Administration
GSPC	Grade Separated Pedestrian Crossing
HCM	Highway Capacity Manual
INTP	Integrated National Transport Policy
ITE	Institute of Transportation Engineers
KeNHA	Kenya National Highways Authority
KeRRA	Kenya Rural Roads Authority
KURA	Kenya Urban Roads Authority
KWS	Kenya Wildlife Service
LOS	Level of Service
MoNMED	Ministry of Nairobi Metropolitan Development
MoR	Ministry of Roads
MRWA	Main Roads Western Australia
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
NMIMT	Non-Motorized and Intermediate Means of Transport
NMT	Non-Motorized Transport
P – LOS	Pedestrian Level of Service
PHF	Peak Hour Factor
PHV	Peak Hour Volume
PWC	Price WaterHouse Coopers

PWD	Persons with Disabilities
SSD	Stopping Sight Distance
SWA	Students Welfare Authority
TCQSM	Transit Capacity & Quality of Service Manual
TMP	Traffic Management Plan
TRB	Transportation Research Board
TRUMM	Traffic and Road Use Management Manual
UK	United Kingdom
UON	University of Nairobi
USA	United States of America
V/C	Volume to Capacity Ratio
YWCA	Young Women’s Christian Association

1 INTRODUCTION

1.1 General

In the past transport planning has tended to concentrate on providing for the needs of vehicular movement, to the detriment of pedestrians and cyclists, especially the disabled people. This has resulted in an imbalance in the provision of quality transport, an imbalance which is particularly serious in view of the importance of walking and the increased interest in cycling (O'flaherty, 1997). In the 1990s, state departments of transportation began to reverse this trend by integrating pedestrians back into their planning processes and stressing their importance (Hallenbeck & Davis, 2008).

In Kenya, transportation planning and investment has been focused on road construction and maintenance, with the sole objective of moving vehicles. Policies in support of Non-Motorized Transport (NMT) have not been put in place and NMT facilities are disproportionately few compared to the overall quantity and cost of transport projects. Further, design for NMT facilities often result in functionally or aesthetically poor products due to lack of guidelines for planning, design and construction of pedestrian facilities, including crossing treatments.

The existing pedestrian crossing facilities such as footbridges and crossing aids such as traffic signals are installed without due consideration for operational efficiency and design suitability. Examples abound of pedestrian footbridges that are not being used, pedestrians preferring level crossing on busy urban multilane arterials, especially along Uhuru Highway and the entire Northern Corridor in spite of reports of fatalities. However, a shift towards planning and implementation of more comprehensive and integrated transport policies has started to take place, as evidenced with the formulation of the Integrated National Transport Policy (INTP) of 2009.

Creating direct, safe, secure, and attractive NMT network is the basic necessity for increased walking trips. Physical and even perceptional barriers such as highways and major roads, railway lines and rivers are cause reduction in walking trips. However, the extent of walking is more likely to be impeded by the ‘barrier effect’ created by vehicular traffic, and the consequent delays and reduced access (Price WaterHouse Coopers, 2011). One of the most common causes of the barrier effect for pedestrian movement in Nairobi is the high speed arterial roads, among them Uhuru Highway.

1.2 Study Area

1.2.1 The Physical Context

The tunnel is located across Uhuru Highway (A104) between University Way Roundabout and Museum Hill Interchange.

Uhuru Highway is the main access road to the Central Business District (CBD) of Nairobi from the west, and also links the Central Business District (CBD) to the city’s Industrial Area. The highway is a 3 – lane dual carriageway, with a 6 metre wide central median. Each lane measures 3 meters wide. The highway has an at-grade rotary intersection at the University Way, and a grade separated interchange at the Museum Hill intersection. The rotary junction at University Way is signalized (Mbeche & Otieno, 2001).

The road section traverses through Main Campus of the University of Nairobi, which is a public university in Kenya. The campus has hostels, dining facilities, health center, sports facilities, Graduation Square, and the adjoining Chiromo Campus on the Western side of Road A104 (Uhuru Highway), and tuition facilities, administrative offices and library on the Eastern side. The land use adjacent to the study area is predominantly institutional, with minor residential and commercial activities also taking place.

Currently, pedestrian circulation across the study section is accomplished through the at-grade signalized crossing at the University Way Roundabout (St. Paul’s Church), and through a pedestrian tunnel. The tunnel measures 2.2 meter wide by 2.3 meter high, and stretches through a length of 40.6 meters across Uhuru Highway. Occasional jaywalking has been observed from preliminary site appreciation visits.

The location map of the study area is presented in *Figure 1-1* on page 3.

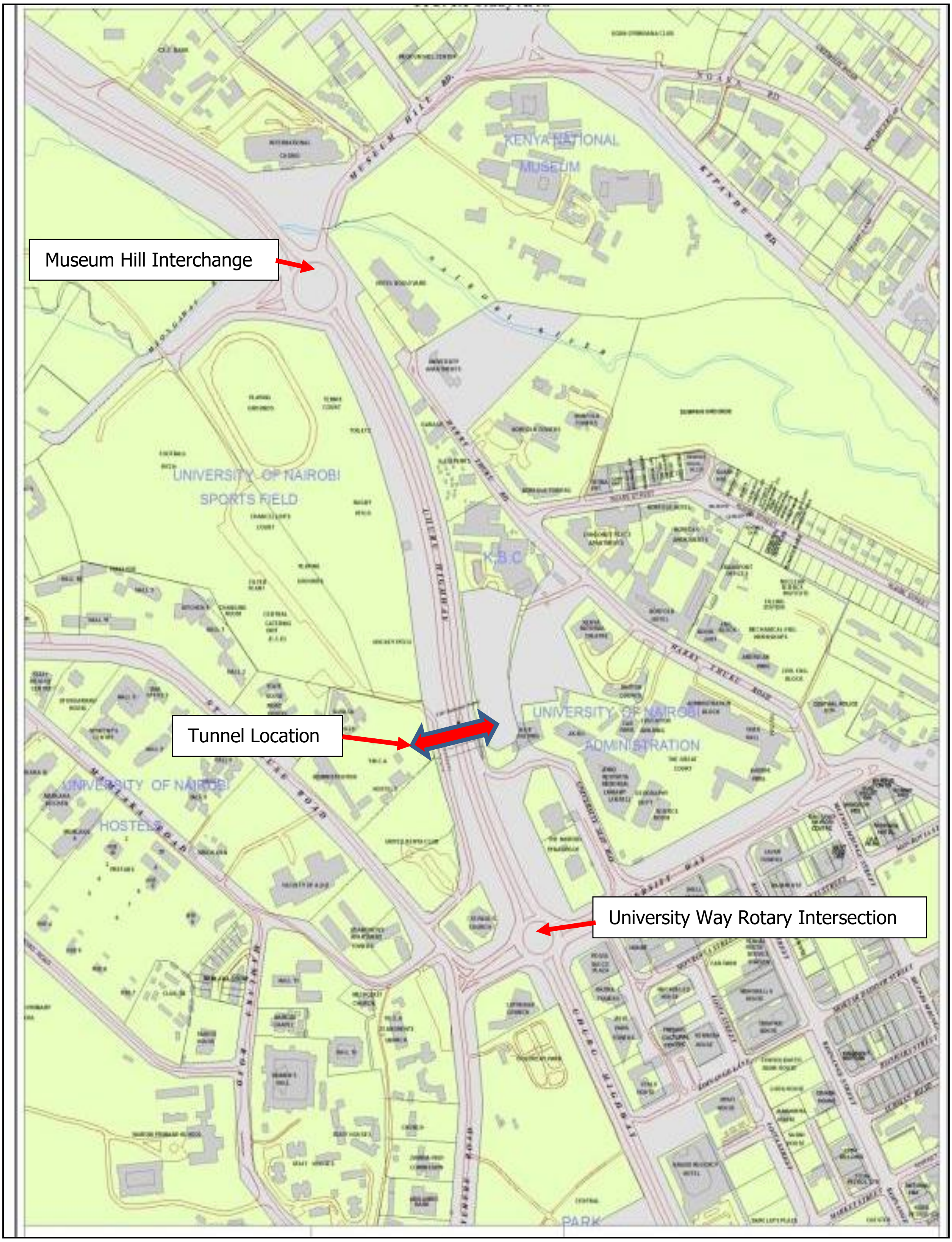


Figure 1-1: Location Sketch of the Study Area (Author, 2016)

1.2.2 The Historical Context

The University of Nairobi started in 1956 as the Royal Technical College, when it admitted its first lot of A-level graduates. On 25th June 1961, the Royal Technical College was transformed into the University College of East Africa, and named Royal College Nairobi. On 20th May 1964, the Royal College Nairobi was converted to a constituent college of the Federal University of East Africa, and renamed University College Nairobi. In 1970, the University College Nairobi transformed into the University of Nairobi, and became the first national university in Kenya (University of Nairobi, 2016).

The Royal Technical College of East Africa enrolled 215 students when it opened its doors to students for the first time on 23rd April 1956. The University College Nairobi had a population of about 1,000 students between 1963 and 1970. Upon becoming a fully-fledged university in 1970, student enrolment was gradually increased to 8,900 in 1984 (www.che.or.ke/history.html*)*.

Currently, the University is home to approximately 98,713 students, 2,052 academic staff and 5,525 administrative and technical staff. The Main Campus that domiciles the College of Architecture and Engineering (CAE), and the College of Humanities and Social Sciences (CHSS) had a total enrolment of approximately 29,536 students (University of Nairobi, 2016).

1.2.2 The Tunnel History

On 11th February, 1963, students protested at what they called “the City Council’s failure to provide a safe road crossing or bridge for use by students going to college” in reaction to a fatal accident involving a student pedestrian crossing Princess Elizabeth Highway (Today Uhuru Highway). They obstructed the traffic on Princess Elizabeth Highway at St. Andrews Church roundabout (Daily Nation Vol 734, 1963).

As a result of the protests, the College Council gave a directive on the construction of pedestrian tunnel to link the Western and Eastern sides of the campus across Princess Elizabeth Highway (City Council of Nairobi, 1965). The City Council of Nairobi was invited to design and supervise the construction of a pedestrian subway on behalf of the college.

The tunnel was estimated to cost £ 9,500. The project was funded by Gandhi Smarak Nidhi Trustees (£5,000), Dalgety East Africa Limited (£ 25), Twiga Chemical Industries (£ 25), and Kenya Shell Limited (300 gallons of 80/100 penetration grade bitumen) (City Council of Nairobi, 1965). The contract for the construction of the tunnel was awarded to M/s Crescent Construction Co. Ltd. The commencement date of the project was 8th December 1965, while the completion date was set for 19th July 1966 (project period of 32 weeks). The tunnel was adopted by the City Council of Nairobi in 1967 as a public tunnel.

1.3 Problem statement

The pedestrian experience on the tunnel is uncomfortable and unattractive due to poor environmental and operational levels of service due to capacity constraints, design deficiencies and lack of maintenance. The problems are presented below.

1.3.1 Pedestrian Congestion

The existing capacity of the tunnel has been outstripped by the demand due to the general population growth and rural – urban migration within the country, as well as university expansion hence growth in the population of students and staff. The net result of the increasing pedestrian volume for the same space is the diminishing ability of the tunnel to accommodate pedestrian flows.

The jostling for space observed in the pedestrian streams through the tunnel is an indication of inadequate capacity. The phenomenon is illustrated by *Plate 1-1* and *Plate 1-2* shown below.

Plate 1-1: Capacity Constraint, exhibited by Congestion at the Tunnel Entrance (Author, 2016)

Plate 1-2: Congestion along the Ramp, also exhibiting Static Activity (Hawking) (Author, 2016)

1.3.2 Faulty Design and Design Omissions

The tunnel has glaring design errors and omissions that contribute to the general discomfort to the pedestrians including the following:

1.3.2.1 Poor/Absence of Lighting

The tunnel is characterized by darkness even during daylight due to inadequate skylight, coupled by the absence of artificial light. This situation causes anxieties of insecurity for pedestrians. *Plate 1-3* illustrates the lighting problem;

1.3.2.2 Faulty Elevation and Poor Drainage System

The tunnel is sunken or depressed below the existing ground level. The result is that all storm water from the surrounding collects within the tunnel during rainy seasons. When this water is not drained efficiently because the outfall drains are clogged, a pool is formed right inside the tunnel, a situation that renders the tunnel completely unusable. The tunnel also has no provision for dry weather flow channels as to ensure that the walking platform remains dry all seasons. *Plate 1-4* illustrates the elevation, and the subsequent drainage problem;

1.3.2.3 Absence of Street Furniture and Channelization Barriers

The tunnel does not have any form of signage for information, direction or warning, rendering the tunnel unfriendly and unsafe for use. There also exist no rails along the outer edge of the road to protect pedestrians and enforce the usage of the tunnel *Plate 1-5* illustrates the absence of signage as well as barriers.

1.3.2.4 Lack of Consideration for Persons with Disabilities (PWD)

The tunnel is not accessible to pedestrians with special needs such as PWD. The approach ramp slopes are steep and have no handrails, the width is not adequate for wheelchair passing and turning, and the drainage sump at the entrance does not permit access by a wheelchair. School children and visually impaired persons would find difficulty using the tunnel due to poor visibility and absence of direction and information signs. *Plate 1-6* illustrates the point;

1.3.2.5 Steep Ramp Slopes

The ramp slopes are high, rendering the tunnel difficult to use. The effectiveness of GSPC depends on their perceived ease of use. Pedestrians therefore prefer long and gentle slopes.

1.3.2.6 Absence of Activity Points or Active Uses

There exists no activity within the vicinity of the tunnel, whether social or economic, hence nothing to attract pedestrians to the place. The situation also creates a feeling of loneliness and insecurity among pedestrians, thus scaring them away.

1.3.2.7 Absence of Rest Areas / Benches

The tunnel accesses and linkages generally have no rest areas fitted with seating facilities. The few existing seats are characterized by lack of maintenance, dereliction and filthiness that scares away pedestrians.

Plate 1-3: Lighting Condition inside the Tunnel during Daylight (Author, 2016)

Plate 1-4: State of Drainage at the Eastern Portal when it rains (Author, 2016)

Plate 1-5: Absence of Pedestrian Channelization Barriers along the median encourages Jaywalking and Vehicle – Pedestrian Conflicts (Author, 2016)

Plate 1-6: Open Drainage Sumps at the Entrances do not permit Universal Access and also poses safety threat to children, persons with disabilities and elderly pedestrians (Author, 2016)

1.3.3 Lack of Maintenance

The existing atmosphere of dereliction and neglect at the tunnel evokes negative feelings of insecurity and crime, hence pedestrian safety. Poor maintenance also symbolizes a lack of personal touch that generates undesired consequences such as vandalism and graffiti, which are signs of a crime area. The following situations make the tunnel undesirable and uncomfortable to pedestrians:

- The tunnel environment is characterized by filth, debris, graffiti and overgrown bushes at the gateways, demonstrating lack of maintenance. The situation is understandably unfriendly to the pedestrian. The situation is illustrated in *Plate 1-7* and *Plate 1-8*;
- Cracks on the top slab and lateral displacements of the retaining wall panels evoke anxieties of risk among pedestrians, and lead to avoidance. The situation is illustrated in *Plate 1-9*;
- The graffiti on the tunnel walls evoke feelings of crime and insecurity, thereby scaring away potential users. The situation is illustrated in *Plate 1-10.*

Plate 1-7: Overgrown Vegetation at the Tunnel Entrance (Author, 2015)

Plate 1-8: Open Filthy Drainage Sump at the Entrance (Author, 2015)

Plate 1-9: Cracks on the Structure evoke feelings of Personal Risk (Author, 2015)

Plate 1-10: Graffiti on the tunnel walls evoke feelings of Crime and Insecurity (Author, 2015)

1.3.4 General Unattractiveness

The tunnel structure is more of a structural element than a decorative one. The finishes on the structure do not enhance beauty and character. The tunnel is characterized by sidewalls of concrete covered with cracks and peeling paint. The tunnel does not have any features such as public art including mosaics, murals, carvings and photo paintings that enhance the beauty and character of the tunnel.

1.4 Research Questions

This study seeks to provide a response to the following questions:

a) Does the existing policy, legal and regulatory framework in the Country support walking as a mode of transport?
b) Is the existing technical framework for NMT sufficient?
c) Is the existing maintenance framework efficient to address NMT issues?
d) Does the Environmental Level of Service (E – LOS) of the tunnel influence usage by pedestrians?
e) Does the Operational Level of Service (P – LOS) of the tunnel influence usage by pedestrians?

1.5 Study Objectives

The overarching objective of this study is to establish the environmental and operational level of service of the Pedestrian Tunnel, and recommend policy, planning, design and maintenance as well as environmental solutions.

Specific objectives include:

a) To assess the existing policy, legal, institutional and regulatory framework for NMT in the country, make an opinion as their adequacy;
b) To assess the existing technical standards and guidelines, and determine their adequacy for planning, design and construction of NMT facilities;
c) To assess the existing maintenance framework for NMT facilities;
d) To assess the physical condition of the pedestrian tunnel, and characterize the Tunnel’s Environmental Level of Service (E – LOS);

e) To assess the operational performance of the tunnel in terms of Pedestrian Level of Service (P – LOS);

1.6 Scope and Limitations of the Study

This study establishes the physical and design conditions as well as capacity analysis of the existing Pedestrian Tunnel and the quality of service it offers to the users. This involves the determination of existing E-LOS and P-LOS. Finally, the study analyses a suitable tunnel capacity that meets both current and future pedestrian demand.

Safety at pedestrian crossings, whether real, that is supported by crash data, or imagined, as determined from models are not covered in this study.

2 LITERATURE REVIEW

2.1 Road Classification and Pedestrian Crossing

2.1.1 General

Roadway crossings can be barriers to pedestrian travel. The provision of specific crossing assistance for pedestrians at a particular location, especially in urban areas, is essential to pedestrian mobility. Pedestrian crosswalks and other crossing facilities should meet the basic NMT user requirements namely safety, security, coherence and attractiveness.

Road classification defines the function of the public road based on function, shape and use. According to (de Langen & Tembele, 2001), the function of a road is either transit or access while the shape refers to the actual geometric configuration. The use of a road is defined by the actual traffic composition, volume, speed, and other characteristics of the traffic stream.

Depending on a road category or class, a certain crossing type is chosen. It has been shown that GSPC is required when it is critical, whether on the basis of safety, land use type, or consideration, to physically separate the crossing of a high volume of pedestrians from a highway or major road with high vehicular traffic volumes, typically on urban arterials. GSPCs are considered the safest type of pedestrian crossing facility with zero delay to both vehicular and pedestrian traffic.

2.1.2 Warrants for Grade Separated Pedestrian Crossing (GSPC) Facilities

Past studies have recommended grade separated pedestrian crossings (GSPC) for urban highways, with full elimination of all forms of at-grade crossing treatments.

However, according to Zageer & Zageer (1988), GSPC facilities are considered to be minimally beneficial or even harmful in the following environments:

a) Places which are prone to high rates of crime such as underpasses;
b) Poorly designed facilitates or those that are inconvenient for the elderly and disabled;
c) Locations with no physical barriers constructed to control at-grade crossing; and
d) Locations where more pedestrians are unlikely to use the GSPC.

2.1.2.1 American Guidelines

According to Zegeer & Zegeer (1988), GSPC are most beneficial under the following conditions:

a) Locations with moderate to high pedestrian demand to cross a highway;
b) Locations with large number of young children who frequently cross a road with high vehicular speed or volume;
c) Along streets with high vehicle volumes and high pedestrian crossing volumes;
d) Locations posing extreme hazard for pedestrians, for example across wide streets with high-speed traffic and poor sight distance), and
e) Locations with a well-defined pedestrian origin and destination, for example, a residential neighborhood across a busy street from an affiliated university.

The warrant for GSPC by Zageer & Zageer (1998) takes account of important factors such as demand for crossing opportunities which is a factor of pedestrian demand including vehicular and pedestrian traffic characteristics (volume and speed) and road geometry and land use factors. The warrant however does not consider other factors including safety (accident history at a crossing location) and integration of a wider traffic management plan (proximity to adjacent signals, signal timings and traffic arrival patterns). Also, the warrant does not comprehensively consider the special provisions due to demographic characteristics of the pedestrian stream. Other than consideration for children, the warrant does not consider the proportions of the elderly and the physically disabled.

Florida State Department of Transport (State of Florida, 1999) gives the following conditions for use of GSPC:

a) Locations with high vehicular and pedestrian volume;
b) Needed a cross roads with high speeds and many lanes with limited gaps;
c) Schools where highway separates athletics field or a second campus from main campus.

The warrant for GSPC by Florida State DOT (1999) takes account of the demand for crossing opportunities and land use factors. The warrant however does not consider safety, integration of a wider traffic management plan, as well as special provisions due to demographic characteristics of the pedestrian stream such as proportions of children, the disabled and the elderly.

According to Axler (1984), the following conditions warrant consideration for GSPC:

a) Continuous pedestrian hourly flow rate of 300 persons per hour for the highest four hour periods coupled with vehicle speed exceeding 64 km/h within urban setups;
b) Vehicular volume exceeding 10,000 in the same four-hour period used for the pedestrian volume, or ADT volume exceeding 35,000 for vehicular speed exceeding 64 km/within urban setups. If these two conditions are not met, the vehicular volume exceed 7,500 in the four hours or have an ADT exceeding 25,000;
c) The proposed location should be within 180 meters from the nearest alternative safe crossing;
d) Locations with specific need for GSPC based on the existing or proposed land use(s).

Axler specifies the following conditions for ensuring the success of GSPC:

a) A physical barrier to prohibit at-grade crossing;
b) Artificial lighting to reduce potential crime;
c) Suitable topography at the proposed location to minimize changes in elevation for users, and to prohibit excessive construction costs;
d) Availability of funding for construction.

The warrant for GSPC by Axler (1984) takes account of the demand for crossing opportunities, integration of a wider traffic management plan and land use factors. The warrant however does not consider safety, as well as special provisions due to demographic characteristics of the pedestrian stream such as proportions of children, the disabled and the elderly.

According to ITE committee (1972), the following criteria warrant provision of GSPC across highways with no access control:

e) The existence of a strong desire for GSPC advocated through citizen's action;
f) Lack of a practical alternative route or mode for pedestrians who want to cross;
g) Lack of traffic control or GSPC within 201 meters of the proposed location;
h) A potential to prohibit at-grade crossing;
i) Feasibility of GSPC within existing physical conditions; and
j) Vehicular and pedestrian volumes exceeding those that would warrant the provision of traffic signal as indicated in the MUTCD.

The ITE warrant considers citizen’s action, integration, and demand, but does not take into account other important aspects such as safety, land use factors as well as special provisions due to proportions of children, the elderly and the disabled.

2.1.2.2 Australian Guidelines

The New Zealand standards (New Zealand Transport Agency, 2009), West Australian State Standards, (Main Roads Western Australia, 2011), Queensland State Standards (Queensland Government , 2007) all recommend grade separation along major urban arterials.

While all these warrants propose GSPC along major urban arterials, their decisions are made solely on the basis of demand for crossing opportunities, without giving due consideration to other important factors such as safety, integration with wide area traffic management plans, land use factors as well as special provisions due to proportions of children, the elderly and the disabled.

2.1.2.3 South African Guidelines

According to Ribbens (1985) GSPCs are warranted when the cycle length of the signalized crossing has to exceed 110 seconds (corresponding pedestrian delay of 50 sec) to accommodate the vehicular traffic flow. The criteria are shown in *Table 2-1*below.

Table 2-1: Warrants for GSPC on Urban Arterials (Ribbens, H, 1985)

Road Configuration	Cycle Length (s)	Vehicle volume per hour	Pedestrian Volume per Hour
Four-lane two-way	60	3 675	2125
	75	4 175	2500
	90	4 500	2 800
Four-lane one-way	60	4 450	2 125
	75	5 000	2 500
	90	5 350	2 800
Three-lane one-way	60	3 330	2 125
	75	3 750	2 500
	90	4 050	2 800

The warrant by Ribbens (1985) does not consider safety, land use factors as well as special provisions due to proportions of children, the elderly and the disabled.

2.1.2.4 Kenya and the East Africa Regional Guidelines

Sub Saharan Africa Standards (de Langen & Tembele, 2001) recommends the use of grade separation as solutions to crossing large urban corridors or urban highways; on condition that they are properly designed to make them user friendly and the intervals are fairly far apart due to cost considerations.

The warrant by de Langen & Tembele (2001) only alludes to demand for crossing opportunity due to road geometry, but does not consider safety, integration with a wider traffic management plan, land use factors as well as special provisions due to proportions of children, the elderly and the disabled, and special events such as sports stadia.

2.1.3 Gaps in the Literature on Warrants for GSPC

Table 2-2 below contains a summary of the literature on warrants for GSPC reviewed, and the gaps found.

Table 2-2: Gaps in the Literature on Warrants for GSPC (Author, 2016)

Author	**Crossing Opportunities** *(vehicular volumes and speed, pedestrian demand including suppressed demand, road geometry)*	**Safety** *(Real safety problem based on accident history, or perceived safety problem based on models, stopping sight distance)*	**Integration with Wider Traffic Management Plan** *(proximity to adjacent traffic signals, signal timing, traffic arrival patterns)*	**Land Use Factors** *(concentration of pedestrians at a location due to special land use, e.g. schools)*	**Special Provision** *(Proportion of children, the disabled, the elderly, or locations of special events such as sports stadia)*
Zageer & Zageer (1988)	√	x	X	√	x
Florida State DOT (1999)	√	x	X	√	x
Axler (1984)	√	x	√	√	x
ITE (1972)	√	x	√	x	x
New Zealand Transport Agency (2009)	√	x	X	x	x
Main Roads Western Australia (2011)	√	x	X	x	x
Queensland Government (2007)	√	x	X	x	x
Ribbens (1985)	√	x	√	x	x
de Langen & Tembele (2001)	√	x	X	x	x

Key:

√ - Area covered in the literature

X – Area not covered in the literature

2.2 Environmental Factors for Pedestrians

2.2.1 Safety and Security

Pedestrian crossing assistance must ensure low risk of traffic accidents and low level of vehicle – pedestrian conflicts. Another aspect of safety at crossing facilities is the personal security from crime such as robbery and harassment. Important factors that increase security risk include darkness and poor visibility.

For crossing facilities that are structural in nature such as footbridges and underpasses, the physical form must not exhibit any perception of structural risk.

2.2.2 Comfort

Pedestrian crossing facilities must offer comfortable movement to the users. This means minimal hindrance by other users. To achieve this, the capacity of the facilities ought to be optimum for the pedestrian volume to avoid congestion. Other aspects of comfort for crossing facilities and crosswalks include smooth and hard pavements with no surprises and gentle gradients.

2.2.3 Connectivity

Pedestrian crosswalks and other crossing facilities ought to be located as much as possible along the desire line linking the origins and destinations, and must form seamless connections for pedestrians between their origins and destinations, and must be as short as possible.

2.2.4 Visual Appeal and Amenity

The crossing environment including the approaches and the crosswalk / facility should be conducive to walking. Important aspects of an attractive facility include clean facilities, shops that are not encroaching on the crossing width, rest areas, and zero or minimal exposure to motorized traffic noise and air pollution.

The aim is to provide a clear and tidy appearance to the underpass structure, coupled with adequate lighting, the use of appealing materials and color schemes on walls and ceilings.

Factors of attractiveness include:

2.2.4.1 Vitality

These include active uses and activity points such as small shops, restaurants, art galleries and souvenir shops along the GSPC route.

2.2.4.2 Greenery

These will include GSPC streetscapes with natural trees, shrubs, and grass lawns.

2.2.4.3 Beauty

These include artistic elements such as public art, murals and mosaics that depict identity and character of the place.

2.3 Pedestrian Flow Concepts

2.3.1 Terminologies

The following pedestrian flow terminologies have been used in the study:

a) Pedestrian speed, denoted S: This is the average walking speed expressed meters per second (m/s) or meters per minute (m/min);
b) Pedestrian flow rate per unit of width, denoted V: This is the number of pedestrians passing a unit effective width of facility within a unit of time, mostly expressed as pedestrians per minute per meter (p/min/m);
c) Pedestrian density, denoted D: This is the number of pedestrians per unit of area, expressed as pedestrians per square meter (p/m^2);
d) Pedestrian space, denoted M: This is the area occupied by each pedestrian, or the inverse of density, expressed as square meters per pedestrian;

2.3.2 Pedestrian Space Requirements

The space requirement for a walking pedestrian is dependent upon the body ellipse with a buffer zone, and a forward space composed of pacing zone and sensory zone as shown in *Figure 2-1* and *Figure 2-2* below.

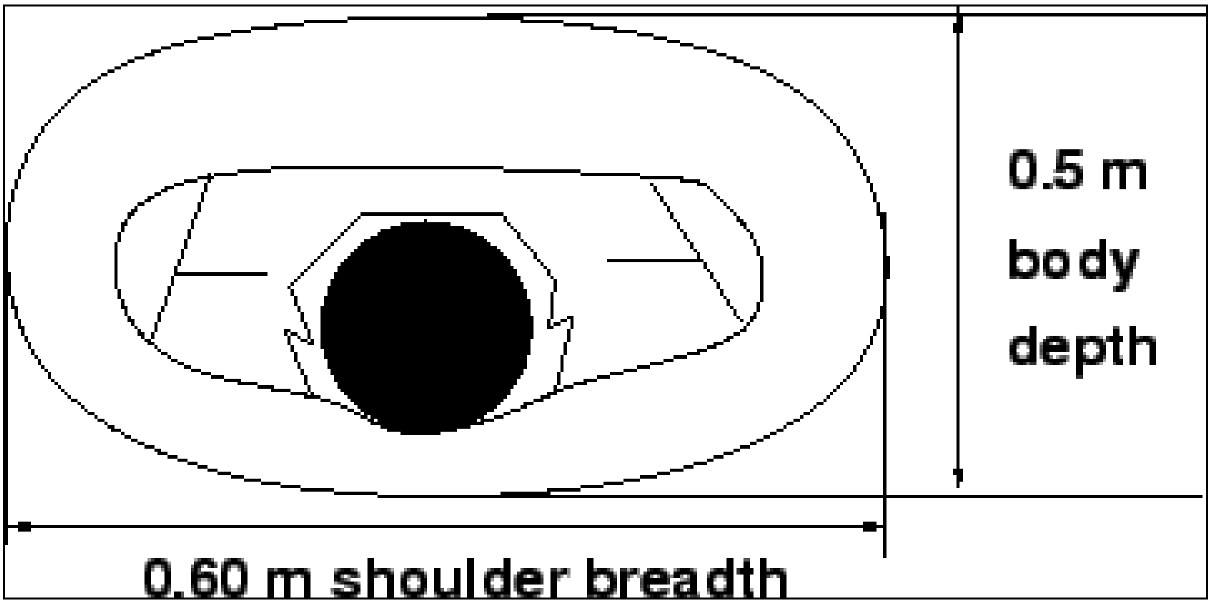


Figure 2-1: Pedestrian Body Ellipse (TRB, 2010)

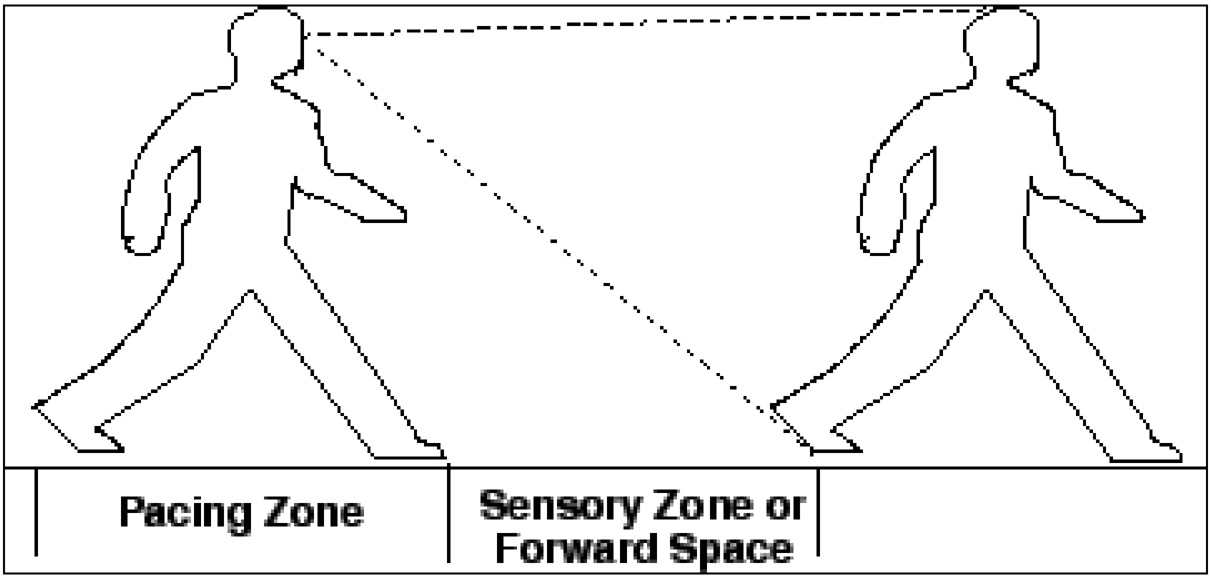


Figure 2-2: Pedestrian Walking Space Requirement (TRB, 2010)

2.3.3 Pedestrian Flow, Density and Speed

For a pedestrian stream, the relationship between flow, speed and density represented by the following equation (TRB, 2010):

$v = S \times D$ Equation 2-1 (TRB, 2010)

where:

v *Flow per unit width (p/m/min);*

S *Speed (m/min); and*

D *Density (p/m^2)*

2.3.3.1 Speed – Density Relationship

The relationship between pedestrian speed and density is illustrated graphically in *Figure 2-3* below.

It shows that speed and density within a pedestrian traffic stream exhibit an inverse linear proportionality, whereby the increase in density results in linear decrease in speed due to decreased mobility.

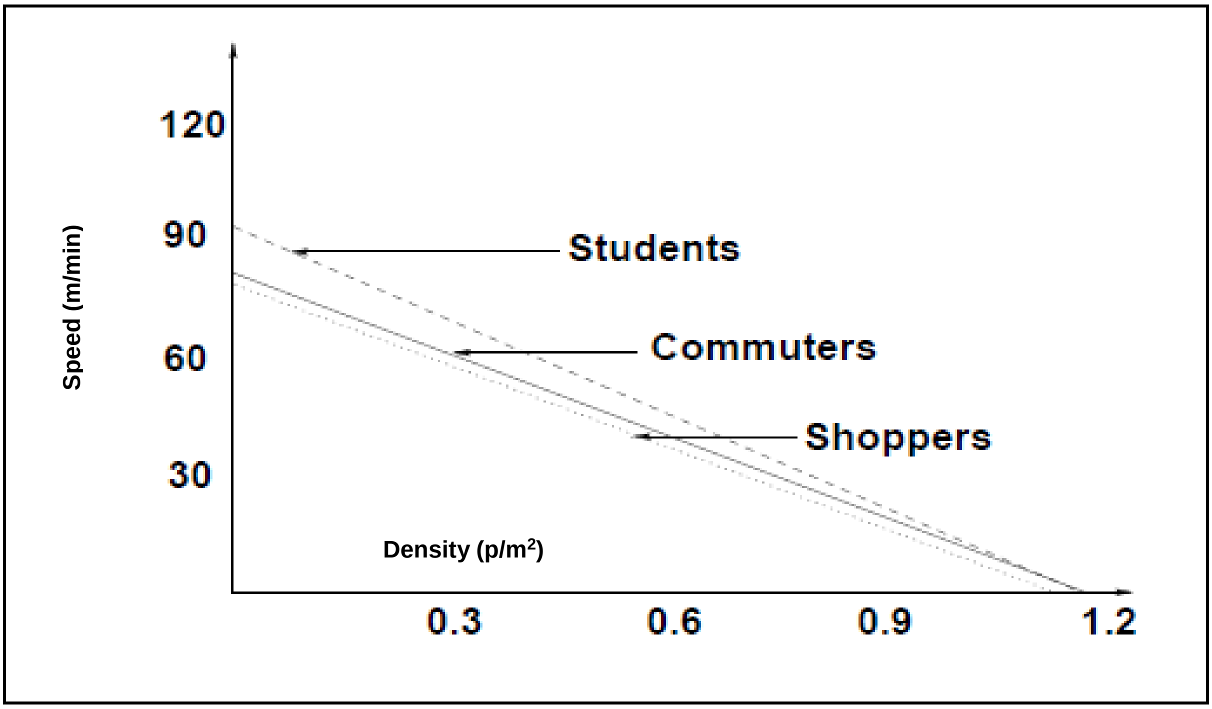


Figure 2-3: Pedestrian Speed – Density Relationship - Adapted from HCM 2010 (TRB, 2010)

2.3.3.2 Flow – Space Relationship

Pedestrian density is an impractical variable since it yields fractional values for pedestrians per square meter. Space, the inverse of density is therefore adopted for analysis since fractional values for space occupied is more sensible. The relationship between pedestrian flow, speed and space is shown the equation below:

$$v = \frac{S}{M}$$ **Equation 2-2 (TRB, 2010)**

Where:

v *Flow per unit width (p/m/min);*

S *Speed (m/min); and*

M *Space (m^2/p), adjusted for pedestrian characteristics.*

The relationship is illustrated graphically in *Figure 2-4* below.

It is shown that maximum flow (capacity of the facility) is achieved at an average pedestrian space of 0.46 – 0.84 m^2 per person. Space below 0.46m^2/p reduces the flow drastically, until all movement stops at approximately 0.23 – 0.46m^2 /p (minimum space).

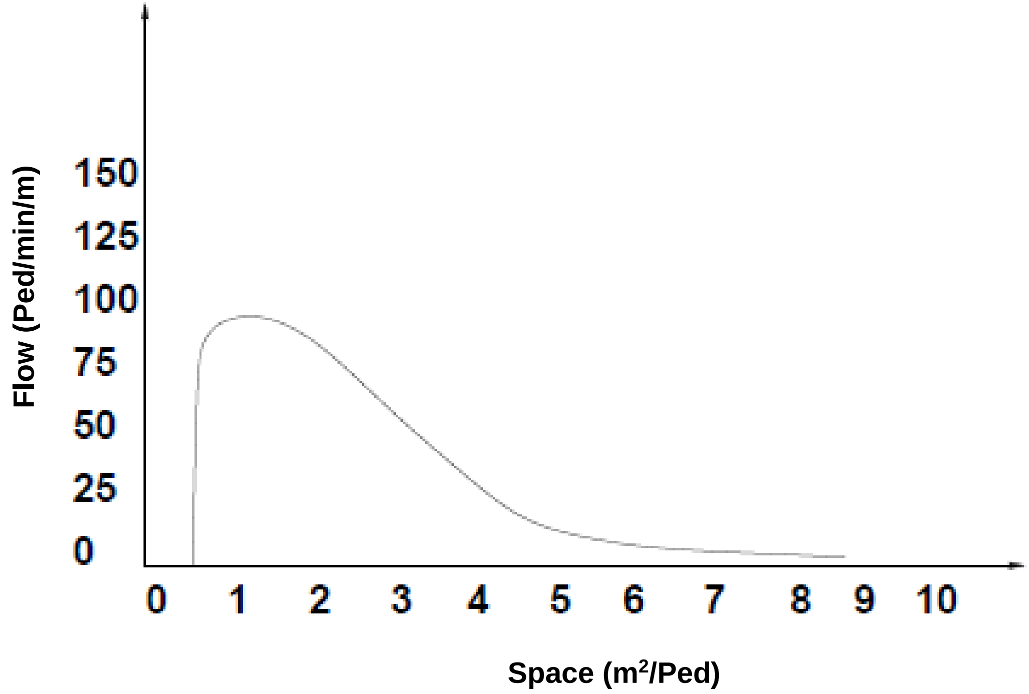


Figure 2-4: Pedestrian Flow - Space Relationship – Adapted From HCM 2010 (TRB, 2010)

2.3.3.3 Speed – Space Relationship

Figure 2-5 below shows that for a space allocation of less than 1.4m^2/p, then pedestrian speeds are constrained by the traffic stream factors. Pedestrian movement stops at space allocation of 0.46m^2/p.

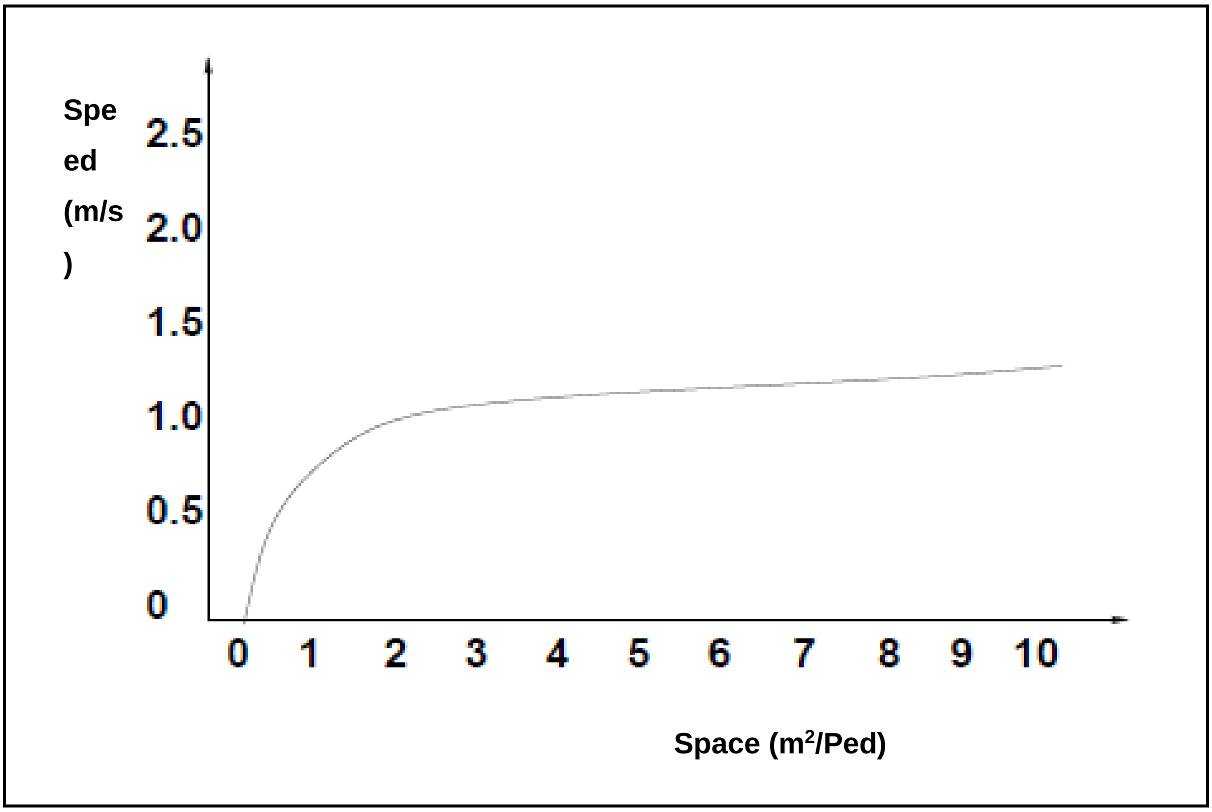


Figure 2-5: Pedestrian Speed - Space Relationship – Adapted from HCM 2010 (TRB, 2010)

2.3.3.4 Speed – Flow Relationship

Figure 2-6 below illustrates the speed – flow relationship for pedestrians.

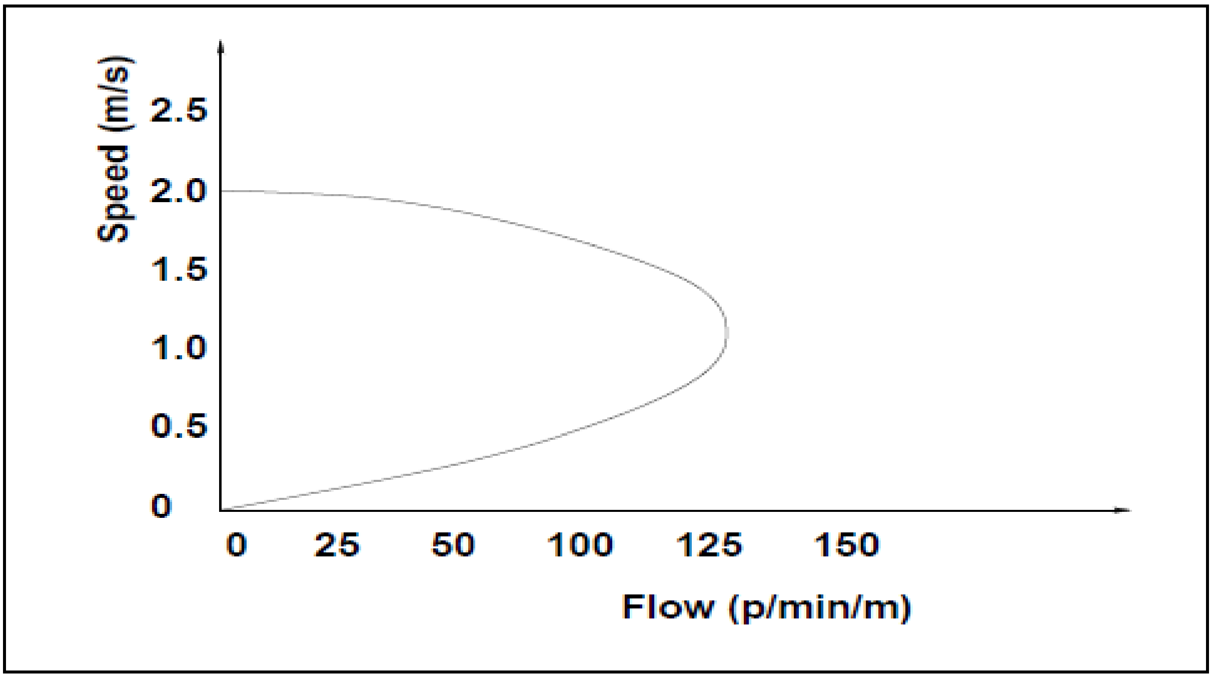


Figure 2-6: Relationship between Pedestrian Speed and Flow - Adapted from HCM 2010

The curve shows that at low flow rates (fewer pedestrians), pedestrians have ample space to adopt higher walking speeds. As flow rate increases, pedestrian speeds decline due to closer interactions within the traffic stream. When a critical level of crowding is reached, movement becomes extremely constrained, and both flow and speed decline.

2.3.4 Effective Walkway Width

The principal measure of operational performance for pedestrian facilities is space. The ultimate factor that determines the capacity of walkways and sidewalks is the effective width. Several studies have shown that pedestrians keep approximately 0.5 meter separation width from adjacent walls, and other obstructions. The HCM (2010) recommends a buffer of 0.5 meter for walls, and 0.3 meter for other obstructions.

According to HCM (2010), the effective walkway width is calculated using the equation below:

$W_E = W_T - W_O$ **Equation 2-3 (TRB 2010)**

Where

W_E *effective walkway width (m),*

W_T *total walkway width (m), and*

W_O *sum of widths and shy distances from obstructions on the walkway (m)*

Figure 2-7 below illustrates the pre-emption distances for various obstacles.

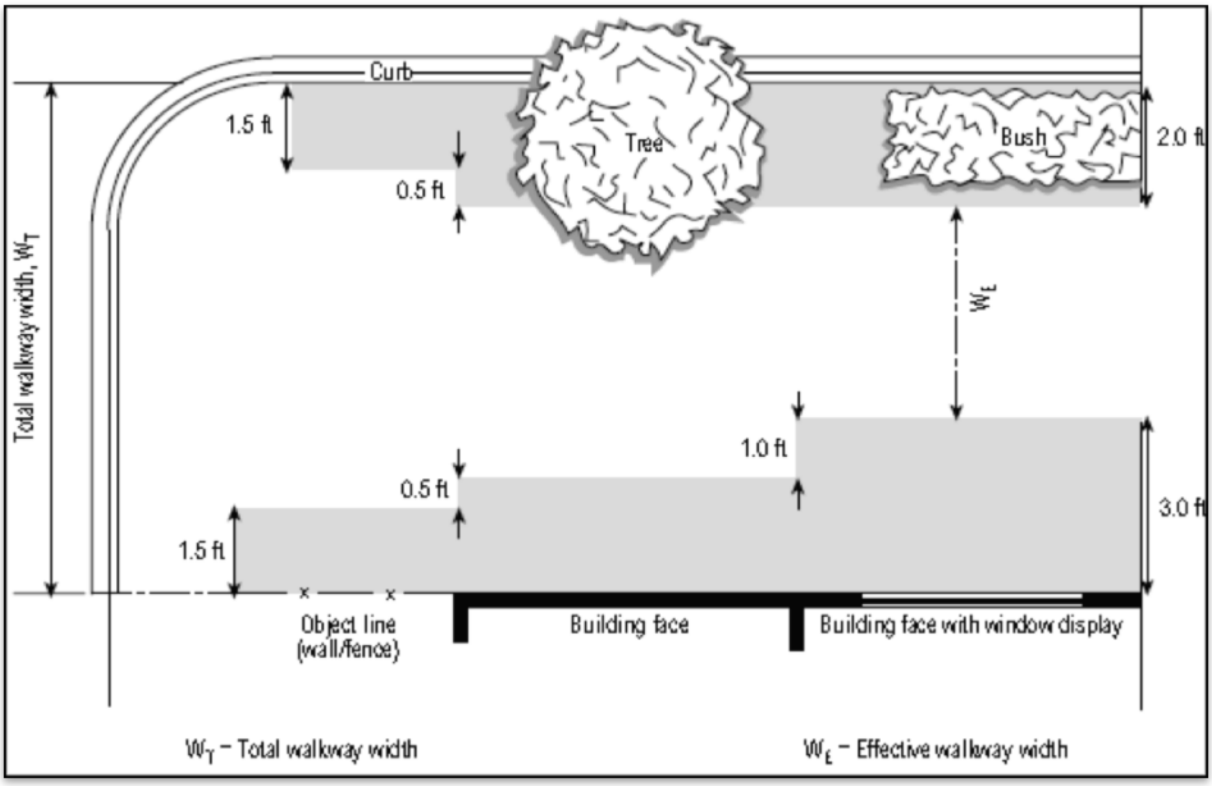


Figure 2-7: Width Adjustment for Various Fixed Obstacles (TRB, 2010)

The methods of determination of the Effective Walkway Width in the Highway Capacity Manual (HCM) and the Transit Capacity and Quality of Service Manual (TCQSM) are different. The method in the HCM (2010) is applicable for sidewalks, while the method in the TCQSM is applicable for transit facilities. In the TCQSM, 0.5m is given as the pre-emption width for all obstacles considering that the actual shy distance would be less than that of the congested condition. The HCM 2010 specifies different buffer distances for various obstacles.

2.4 Pedestrian Capacity and Level of Service (P-LOS) for Walkways

2.4.1 Overview

According to HCM (2010), the main objective of capacity analysis is to estimate the maximum number of persons or vehicles that a facility can accommodate within a specified time period. The conditions at maximum flow represent the capacity of a facility.

Capacity of a facility is defined as the maximum number of pedestrians who can pass through a point, expressed as persons per unit time or persons per unit area (TRB, 2010).

Operational criteria is defined by the Level of Service (LOS), a quantitative measure that characterizes operational conditions using service measures such as travel time which is a factor of pedestrian speed, pedestrian space which is a factor of freedom to maneuver, and pedestrian flow which is a factor of comfort and convenience. Pedestrian level of service (P-LOS) is therefore useful in evaluating the capacity and comfort of a pedestrian facility, hence the availability of pedestrian crossing opportunities under the existing conditions. (TRB, 2010). The need for specific crossing assistance to pedestrians to improve comfort is determined by the LOS offered to pedestrians under the existing conditions.

The concept of operational level of service for pedestrians is illustrated in *Figure 2-8* below.

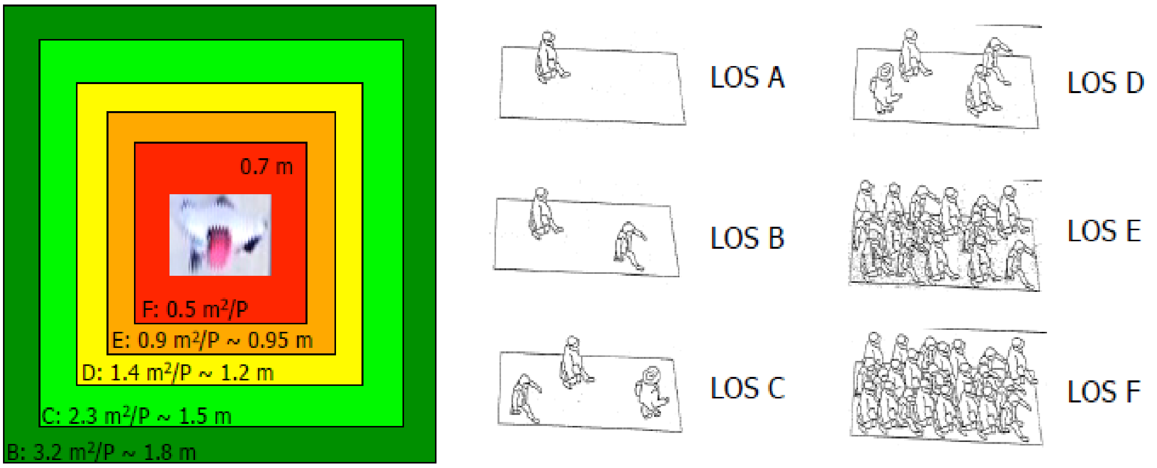


Figure 2-8: Illustration of Pedestrian Level of Service (P-LOS) (Hoogendoorn, 2012)

Several P-LOS thresholds have been developed in different countries, including United States, Continental Europe, and parts of Asia. P-LOS thresholds have not been developed in African countries.

2.4.2 American Thresholds for Pedestrian Level of Service (P-LOS) for Walkways

2.4.2.1 Highway Capacity Manual (2010) Methodology

HCM 2010 calculates the pedestrian unit flow rate from the relationship shown below. Volume to capacity (v/c) ratio is then computed assuming 75p/min/m for capacity.

$$v_P = \frac{V_{15}}{15 * W_E}$$

Where: **Equation 2-4**

v_P – *Pedestrian unit flow rate (p/min/m.)*

V_{15} – *Peak 15min flow rate (p/15min)*

WE – *Effective walkway width (m)*

The criteria for pedestrian level of service for walkways are shown *Table 2-3* below. These thresholds account for average flow.

Table 2-3: Pedestrian LOS Criteria for Walkways and Sidewalks (TRB, 2010)

LOS	Space (m^2/p)	Flow Rate (p/min/m.)	Speed (m/s)	v/c Ratio
A	> 5.6	> 16	> 1.3	≤ 0.21
B	3.7 – 5.6	16 – 23	1.27 – 1.3	0.21 – 0.31
C	2.2 – 3.7	23 – 33	1.22 – 1.27	0.31 – 0.44
D	1.4 – 2.2	33 – 49	1.14 – 1.22	0.44 – 0.65
E	0.7 – 1.4	49 – 75	0.76 – 1.14	0.65 – 1.0
F	≤ 0.7	Variable	≤ 0.76	Variable

When platooning occurs in the pedestrian traffic stream, then the adjusted LOS threshold criteria shown in *Table 2-4* below is applicable.

Table 2-4: Platoon Adjusted LOS Criteria for Walkways and Sidewalks (TRB, 2010)

LOS	Space (m^2/p)	Flow Rate (p/min/m)
A	> 49.24	≤ 0.15
B	> 8.36 – 49.24	> 0.15 – 0.91
C	> 3.71 – 8.36	> 0.91 – 1.83
D	> 2.14 – 3.71	> 1.83 – 3.35
E	> 1.02 – 2.14	> 3.35 – 5.49
F	≤ 1.02	> 5.49

The advantage of the HCM methodology is simplicity since it is easy to collect data and compute the LOS, with the necessary data being 15-min pedestrian count, the effective width of the walkway, and the observation whether platooning occurs.

However, the HCM methodology has limitations that include the following:

a) The flow rate calculation assumes a uniform flow, hence does not account for pedestrian stream characteristics such as cross-flows and standing pedestrians. Therefore, friction introduced by the opposing pedestrian flow is not accounted for. In case of high pedestrian volumes cross-flows will disrupt the speed – flow relationships, resulting in lower pedestrian speeds at equivalent flow rates. Stationary pedestrians represent obstacles on the walkway and reduce flow by causing a turbulent movement around them;
b) The makeup of the study population or the flow composition is generalized without consideration for individual pedestrian characteristics. For example, pedestrians' gender, age, and trip purpose could have significant impact on their speed and comfort level;
c) The methodology does not account for the effects of the walkway infrastructure, including grades beyond 3%, pavement surface quality, inclination (uphill or downhill movement and separation from moving traffic);
d) Trip purpose is recognized as a factor that affects pedestrian flow, but no disaggregation is made for various trip purposes in the thresholds.

2.4.2.2 Transit Capacity and Quality of Service Manual (TCQSM) Methodology

The Transit Capacity and Quality of service Manual (Transportation Research Board, 2003) thresholds for P-LOS for walkways in transit facilities are shown in *Table 2-5* below. Capacity is taken to be 82p/m/min corresponding to LOS E.

Table 2-5: P- LOS on Walkways for Transit Facilities (Transportation Research Board, 2003)

LOS	Space (m^2/p)	Average Speed (m/min)	Flow per Unit Width (p/m/min)	v/c Ratio
A	> 3.3	79	0 – 23	0.0 – 0.3
B	2.3 – 3.3	76	23 - 33	0.3 – 0.4
C	1.4 – 2.3	73	33 – 49	> 0.4 – 0.6
D	0.9 – 1.4	69	49 – 66	> 0.6 – 0.8
E	0.5 – 0.9	46	66 – 82	> 0.8 – 1.0
F	≤ 0.5	≤ 46	Variable	Variable

Like the HCM 2010 methodology, the TCQSM methodology also does not account for and disaggregate the thresholds on the basis of traffic stream characteristics (cross-flows, bi-directional and multi-directional flows), flow composition (age, gender, disability, pushing, carrying), and walking infrastructure (grades beyond 3%, pavement surface quality, inclination – uphill or downhill, and separation from moving traffic).

2.4.3 European Thresholds for Pedestrian Level of Service (P-LOS) for Walkways

Pushkarev & Zupan (1975) published P-LOS thresholds for continental Europe that took account of the characteristics of European pedestrian streams. The European standards as shown in his work are slightly lower than the American standards.

The thresholds are shown in *Table 2-6,*

Table 2-7 and

Table 2-8 below.

Table 2-6: LOS for Standing Pedestrians (Pushkarev & Zupan, 1975)

Quality	**Spacing**	**Area per Person (m^2)**	**Description**
Unimpeded	1.2	1.2	Circulation is possible without disturbance
Impeded	1.0 – 1.2	0.9 – 1.2	Circulation fairly restricted
Constrained	0.6 – 0.9	0.3 – 0.7	Circulation severely restricted, pedestrians uncomfortably close to one another but no contact between standing pedestrians.
Congested	0.6	0.2 – 0.3	Circulation impossible, contact with others is unavoidable.
Jammed	0	0.2	No movement, standees pressed together.

Table 2-7: Characteristics of Pedestrian Flow in a Homogenous Stream (Pushkarev & Zupan, 1975)

Quality of Flow	**Space per Person (m^2/p)**	**Flow Rate (Persons/min/m of walkway width)**
Open	50	< 1.6
Unimpeded	50 – 12	1.6 – 6.5
Impeded	12 – 3.7	6.5 – 20
Constrained	3.7 – 2.2	20 – 33
Crowded	2.2 – 1.5	33 – 46
Congested	1.5 – 1.0	6 – 60
Jammed	1.0 – 0.2	60 – 82

Table 2-8: Space per Pedestrian at Max. Flow (Pushkarev & Zupan, 1975)

Type of Flow	Max. Flow (Persons/min/m of walkway width)	Space Allocation per Pedestrian at Max. flow (m^2)
Students, average	65.6	0.74
Students, extreme	86.6	0.85
Commuters	81.0	0.5
Shoppers, average	76.4	0.51
Shoppers, extreme	108.3	0.48
Mixed traffic, average	85.3	0.51
Mixed traffic, extreme	111.5	0.67

The innovation in this methodology introduction of more descriptive levels of service; open flow, unimpeded flow, impeded flow, constrained, congested, and jammed, to replace the denotations A – F in the American methodologies. The methodology has also disaggregated LOS thresholds on the basis of pedestrian stream characteristics (standing pedestrians and homogenous streams). The methodology has further stated maximum flow rates on the basis of trip purposes.

The methodology however does not account for and disaggregate the thresholds on the basis of other traffic stream characteristics such as cross-flows, bi-directional and multi-directional flows, flow composition (age, gender, disability, pushing, carrying), and walking infrastructure (grades beyond 3%, pavement surface quality, inclination – uphill or downhill, and separation from moving traffic).

2.4.4 Indian standards

The Indian (Kadiyali, 2002) provide the capacity of pedestrian subways or over bridges as follows

a) 50 persons per minute per meter width on level up to 1 in 20 ramp;
b) 35 persons per minute per meter width on steps or ramps steeper than 1 in 20.
c) A dead width of 0.75 m should be allowed adjoining any display windows in subways.

The gradients of continuous ramps should not be steeper than 1 in 10. If a landing is provided at mid-height, a maximum slope of 1 in 7 may be allowed. A minimum height of 2.30 m and a width of 2.45 m should be provided for subways up to 23 m in length, and for longer subways the dimensions need to be increased to 2.60 m height by 2.75 m width.

While the Indian standards cater for ramp gradients beyond 3% and pedestrian stream characteristics, it does not cater for traffic stream characteristics (cross-flows, bi-directional and multi-directional flows), flow composition (age, gender, disability, pushing, carrying), and walking infrastructure (pavement surface quality, inclination – uphill or downhill, and separation from moving traffic).

2.4.5 Gaps in the Literature on P-LOS Criteria / Thresholds

Table 2-9 below is a summary of the analysis of the literature on P-LOS Thresholds reviewed, and the gaps found.

Table 2-9: Gaps in the P-LOS Criteria Reviewed (Author, 2016)

Author	**Flow Composition** *(Age, Gender, Disability, Pushing, Carrying)*	**Trip Purpose** *(Shopping, Work, School, Recreation)*	**Pedestrian Stream Characteristics** *(Cross-flows, bi-directional & multi-directional flows)*	**Walking Infrastructure** *(pavement surface quality, inclination – uphill or downhill, and separation from moving traffic)*	**Platooning**
HCM 2010	x	x	x	√*	√
TCQSM (2003)	x	√**	x	x	X
Pushkarev & Zupan	x	√	√*	x	X
Kadiyali (2002)	x	x	√*	√*	X

√ - Area covered in the literature
√* - Area partially covered in the literature
√** - it is assumed that the criteria only applies to pedestrians on transit
X – Area not covered in the literature

2.4.6 Environmental Level of Service Methodologies

2.4.6.1 Highway Capacity Manual 2010

According to HCM (2010), the environmental factors that influence the walking experience and the quality of service perceived by pedestrians include comfort, convenience, safety, security, and economics of the walkway system. Comfort relates to factors such as protection from the vagaries of weather; proximity, volume, and speed of motor vehicle traffic; pathway surface; and pedestrian amenities. Convenience is related to factors that include walking distances, intersection delays, pathway directness, grades, sidewalk ramps, wayfinding signage and maps, and other features making pedestrian travel easy. Safety is provided by separating pedestrians from vehicular traffic both horizontally, by using pedestrian zones and exclusive pedestrian zones, and vertically, by using GSPC (overpasses and underpasses). Traffic control devices such as pedestrian signals can provide time separation of pedestrian and vehicular traffic, which improves pedestrian safety. Security features include lighting, open lines of sight, and the degree and type of street activity. The economics of pedestrian facilities relate to user costs brought about by travel delays and inconvenience and to commercial values and retail development influenced by pedestrian accessibility.

The HCM (2010) does not have procedures for assessing the quality of the pedestrian environment.

2.4.6.2 City of Fort Collins, Colorado, USA

The City of Fort Collins in the State of Colorado, US deemed the HCM methodology for P-LOS inappropriate and developed quantitative as well as qualitative P-LOS describing respective pedestrian requirements. According to Fort Collins Pedestrian Plan (City of Fort Collins, 2011), the pedestrian factors for which P-LOS are defined are as follows:

- Directness;
- Continuity;
- Street crossings;
- Visual interest and amenity;
- Security.

a) Directness

Directness measures how well an environment provides direct pedestrian connections between origins and destinations. The LOS for directness is based on the ratio of the actual distance from trip origin to trip destination divided by the measured minimum distance between those two points.

According to Fort Collins Pedestrian Plan, these destinations should be within approximately 400 meters. If no pedestrian destinations are within the immediate study area, the directness LOS is not applicable.

The E-LOS thresholds are illustrated in *Table 2-10* below:

Table 2-10: Directness Level of Service Thresholds (City of Fort Collins, 2011)

LOS	(A/M) Ratio	Description
A	<1.2	Excellent and direct connectivity, clear linear visual statements.
B	1.2 – 1.4	Excellent and direct connectivity, clear linear and visual connection.
C	1.4 – 1.6	Minimum acceptable directness and connectivity standard. Beginning of discomfort with visual clarity and lack of linearity.
D	1.6 – 1.8	Increasing lack of directness, connectivity and linearity, no clear direction and visual connection to pedestrian destinations.
E	1.8 – 2.0	Poor directness and connectivity.
F	>2.0	No directness or connectivity.

b) Continuity

Continuity is the measurement of the completeness of the walking facility from origin to destination. Continuity is a measure of both the physical consistency as well as the visual connection.

Qualitative E-LOS thresholds are described as shown in *Table 2-11* below:

Table 2-11: Continuity Level of Service Thresholds (City of Fort Collins, 2011)

LOS	Description
A	Single and continuous walkways/sidewalks between origins and destinations
B	Quality continuous stretches of walkways/sidewalks that are physically separated by barriers or obstacles.
C	Continuous stretches of walkways/sidewalks with variable widths
D	Poorly connected pedestrian corridors, with several breaches in pedestrian network.
E	Significant breaks in the system.
F	Complete breakdown in the pedestrian flow, no pedestrian network exists.

c) Visual Interest and Amenity

The facility’s attractiveness can range from visually appealing to appalling. Compatibility with local architecture, landscaping, beautiful additions to the site such as lights, benches and fountains, improve visual interest.

Qualitative E-LOS thresholds based on Visual Appeal and Amenity are described as shown in *Table 2-12* below

Table 2-12: Visual Appeal and Amenity Level of Service Thresholds (City of Fort Collins, 2011)

LOS	Description
A	Visually attractive and well-matched with local architecture. Adequate facility width, presence of active uses, lighting, trees, and street furniture.
B	Adequate facility width, landscaping, street furniture, visual clarity, some street furniture, no blank walls.
C	Functionality operational, no consideration for visual interest or amenity.
D	Design ignores pedestrian needs.
E	User needs completely overlooked, comfort and convenience nonexistent.
F	Total discomfort and intimidation

d) Security

Pedestrians require a sense of security, both through clear visibility between two activity points, visibility from the general streetscape to the facility entrance, separation from motor traffic, and presence of other people adjacent to the facility.

Qualitative E-LOS thresholds based on Security are described as shown in *Table 2-13* below

Table 2-13: Security Level of Service Thresholds (City of Fort Collins, 2011)

LOS	Description
A	Good lighting, clear sight lines and presence of other people in the immediate vicinity of the facility.
B	Good lighting and unobstructed lines of sight.
C	Unobstructed lines of sight
D	Facility configuration and other obstructions may hinder vigilance from the highway.
E	Major obstructions in pedestrian visibility from the highway, adjacent properties, and activities.
F	Pedestrian intolerant streetscape.

2.5 Width Design

2.5.1 New York State DOT Methodology

The New York State Department of Transport recommends effective design width based on the desired P-LOS and the hourly design flow. The design width is read off a chart as illustrated in *Figure 2-9* below:

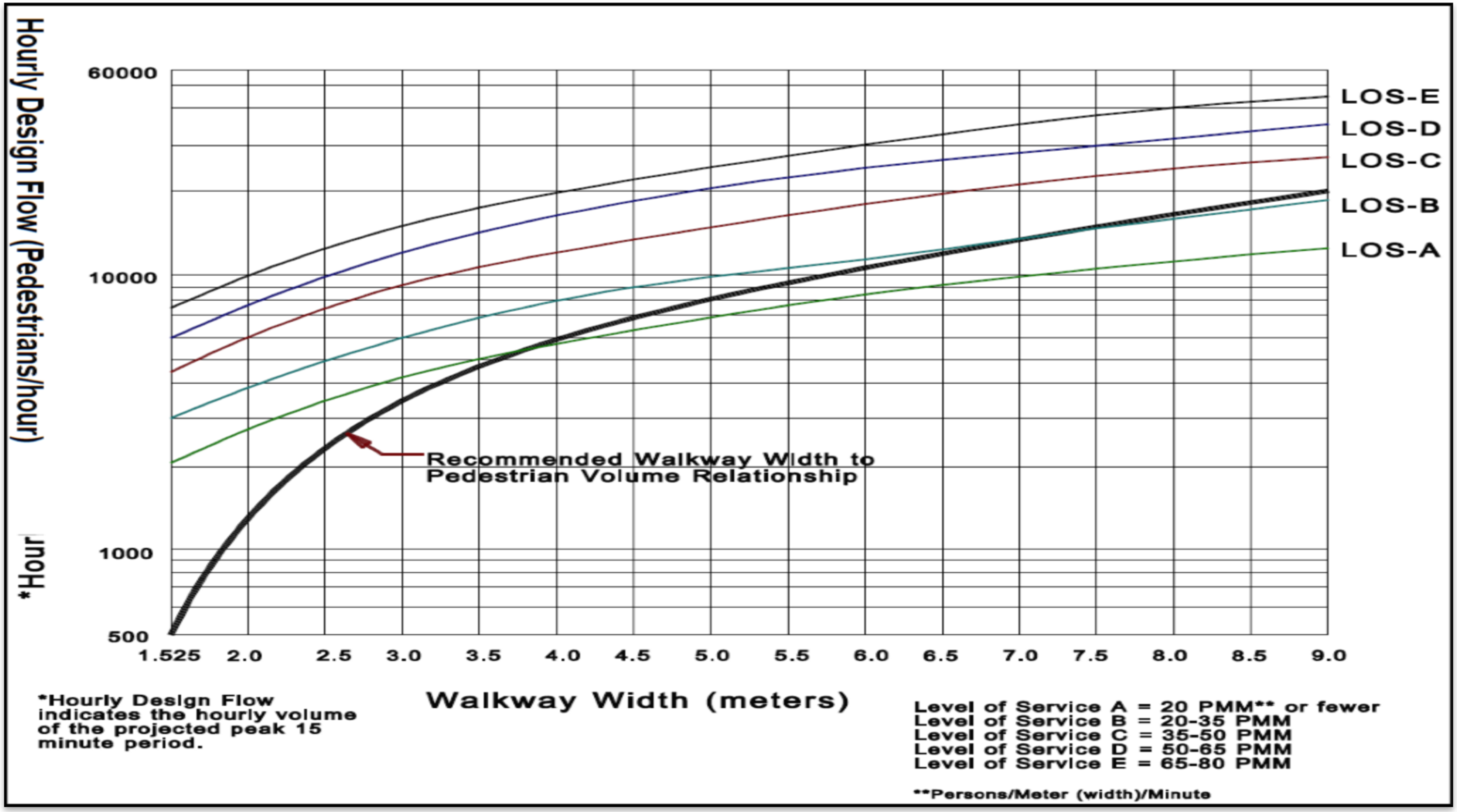


Figure 2-9: Relationship between Walkway Width and Pedestrian Volume (New York City, 2006)

2.5.2 HCM 2010 Methodology

Based on the desired P-LOS and the peak 15 – min pedestrian volume at the facility, *Equation 2 – 4* is worked backwards to obtain the effective width of the designed facility.

2.6 Design Principles for GSPC

2.6.1 Structure Type

According to Zegeer and Zegeer (1988), the structure types that can be applied to effect grade separation are as follows:

a) Bridges and overpasses: These are structures with crossing platform above existing ground level, stairs or ramps used for climbing and descending. In some cases, the structure is at-grade and the road is depressed/sunken.
b) Underpasses and tunnels: These are structures which are general below the existing ground level, stairs and/or ramps are used to effect access to the underground entrance. In some cases, the structure is at-grade and the road is elevated.
c) Below-grade networks: These are underground walkways devoid of motor traffic.
d) Elevated walkways: These are walkways that are located above ground level.
e) Skyways and skywalks: These are enclosed walkways that connect buildings at different levels.

2.6.2 Design Criteria for Tunnels

According to City of Fort Collins (2001), the design characteristics of a GSPC structure must take cognizance of various factors such as the general topography of the area, the barrier to be crossed, the length of the structure, the adjoining drainage features, visibility, constructability and maintainability.

Van De Voordt and van Wegen (1983) summarizes the design guidelines for tunnels as shown in

Table *2-14* below.

Table 2-14: Design Guidelines for Underpasses (van De Voordt & van Wegen, 1983)

1. Access Area		
Goal	***Derived Goals***	***Means***
Visibility	Visual Clarity	▪ Visual continuity for routes with the same function; ▪ Visual differentiation for routes with different functions.
	Visibility	▪ Adequate lighting.
	Identity and character	▪ Indication of the underpass by name or signage.
Distinctness	Clear functions	▪ Clear distinction between public and private spaces.
	Clear reference to ownership	▪ Indication of planned functions.
Accessibility	Prevention of physical and psychological barriers	▪ Direct routes; ▪ Attractive arrangement of the area to shorten perceived long distance.
Amenity	Integration of the tunnel in its surrounding	▪ Provision of housing and uses in the immediate vicinity of the facility; ▪ Superseding the traffic function through by creating a residential character in the immediate vicinity of the facility.
	Social control	▪ User participation during planning to instill a sense of ownership and responsibility among users.
	Ownership	▪ Regular and proactive maintenance; ▪ Immediate repair whenever damage occurs of damage; ▪ Installation of waste bins.
2. Entrance and Tunnel Tube		
Goal	***Derived Goals***	***Means***
Visibility	Visibility from the environment to the entrance	▪ Avoidance of high closed walls on both sides of the entrances;
	View from the entrance to the other end	▪ Elevating the crossing road to enhance user convenience; ▪ Avoiding bends on the alignment to guarantee inter-visibility within the tunnel; ▪ Proper lighting, especially in the long tunnels.
Accessibility	Accessibility for fit ambulant, PWDs, pushers (prams, wheelchairs)	▪ Use of ramps; ▪ In case of stairs, special attention to the size of risers and treads; ▪ In case of escalators, facilities are required to guarantee continuous use ▪ Avoiding slipperiness.
	User convenience	▪ Elevating the crossing road rather than the GSPC.
Penetrability	Easy and comfortable passage for pedestrians and	▪ Sufficient free headroom; ▪ Adequate width of footway and cycle path;

	cyclists	▪ Physical or visual separation of pedestrians and cyclists; ▪ Tough and flat pavement e.g. asphalt
Amenity	Avoidance of a “tunnel effect”	▪ Avoidance of high closed walls at the entrance routes; ▪ Optimum accessibility (ramps); ▪ Optimum tunnel length to width ratio; ▪ Straight tunnel alignment; ▪ Appropriate lighting; ▪ Continuity in transition from exterior to interior places (ramps, pavement and lighting) ▪ Provision of adequate ventilation system; ▪ Application of noise absorbent ceilings.
	Promoting frequent use of the tunnel	▪ Integration of different user categories through the single tube.
	Openness and spaciousness	▪ Proper width of the tunnel tube; ▪ Optimum ratio between the height and width; ▪ Adequate lighting; ▪ Application of vivid and bright colors.
	Optimal conditions in order to decrease graffiti and vandalism	▪ Regular maintenance; ▪ Immediate repair in case of damage ▪ Application of vandal proof and easy to replace materials; ▪ Tough finishes.

City of Fort Collins (2001) published a comprehensive design criteria for GSPC facilities that takes cognizant of the following pedestrian requirements.

a) Security design provisions include lighting, emergency phones, vehicle registration system and active uses, obstruction restrictions, optimal width/height ration based on the tunnel length and protective barriers.
b) Aesthetic appeal and amenity design provisions include landscaping, wall treatments, provision of rest benches, artwork, facility/street naming, vandalism deterrence through material choice and lighting.
c) Comfort is achieved through appropriate ramp gradients (3–5%, maximum 8.3%), provision of landings every 12 meters, appropriate cross slope (2% at the entrance, 1% inside the tube), hard pavement devoid of slipperiness, satisfactory approach alignment (6 meter straight alignment from the tunnel entrance), adequate drainage provision, handrails, universal design and adequate effective tunnel width.
d) Accessibility: direct and convenient accessibility to/from the barrier being crossed. The paths must meet the comfort requirements. The cross street accessibility concept is illustrated in *Figure 2-10* below.

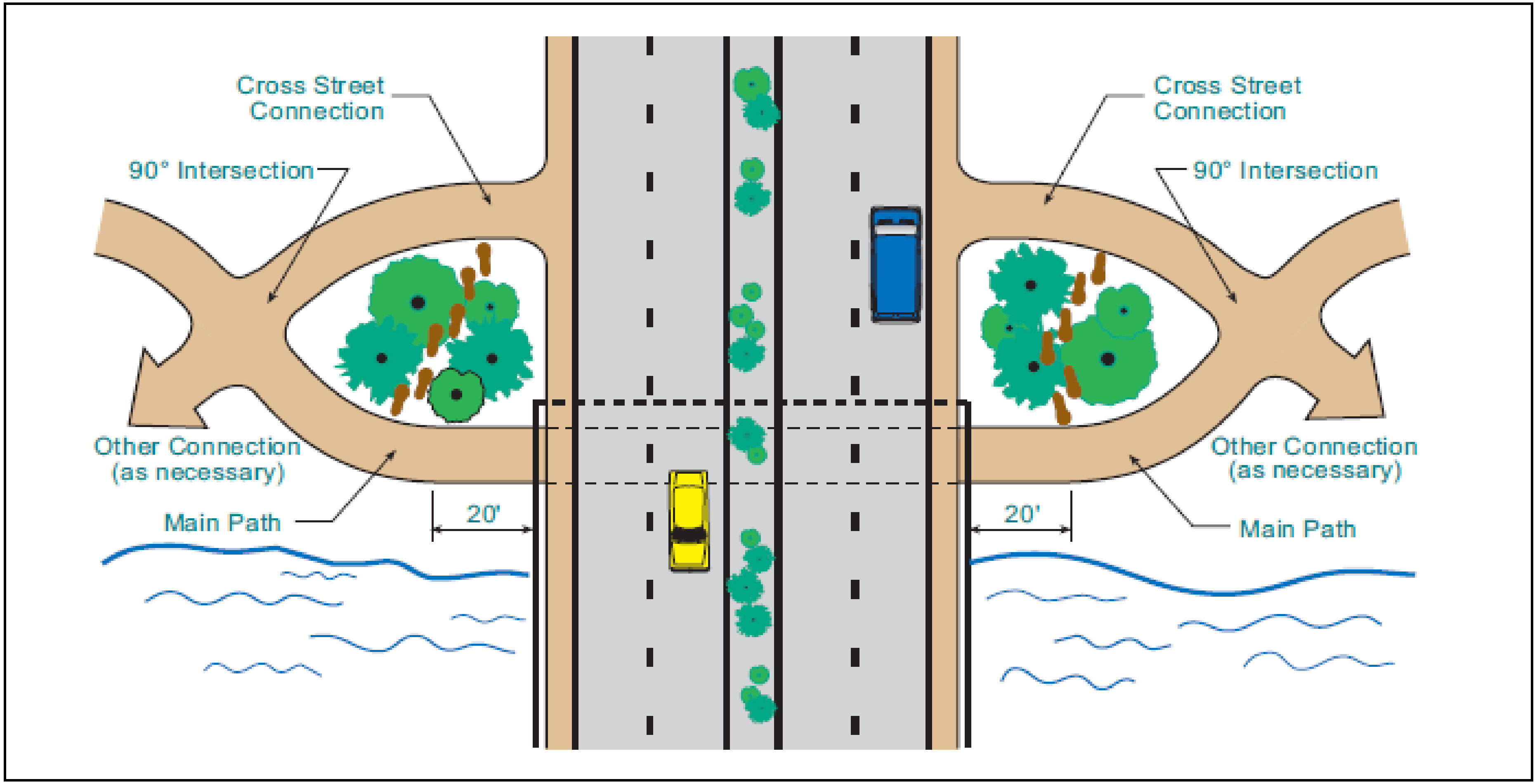


Figure 2-10: Illustration of cross street accessibility (City of Fort Collins , 2001)

3 METHODOLOGY

3.1 Preliminary Planning

Preliminary planning of this study included review of existing information and selection of survey techniques depending on resources and technology available. Elements of the survey such as sample size were determined at this stage.

3.1.1 Sample Design

The study was based on a random sample calculated using the following statistical formulae:

$$n = \frac{N}{1+Ne^2}$$

Equation 3-1 (Richrardson, Ampt, & Mayberg)

Where
n – Sample size.
N – Pedestrian/vehicle population using the facility
e – Margin of error, based on 95% Confidence level, i.e. 5%.

Data collected from Students Welfare Authority (SWA) of the University of Nairobi indicate that the student population residing at the hostels within main campus is 6,147, while the student population of Chiromo Campus is 1,044.

For the purposes of this study, it was assumed that 10% of Chiromo Campus students may want to use the tunnel during peak periods. This assumption was based on the fact that tuition periods coincide and therefore majority of students would be travelling to their respective tuition blocks, save for a few. Reconnaissance surveys also showed that approximately 12% of potential users are non-students.

- Main campus students (100%) = 6,147
- Chiromo Campus students (10% of 1,044) = 104
- Non Students (12% of total population) = 852
- Total Population (N) = 7,103

The sample size was therefore computed as follows:

$$n = \frac{7{,}103}{1 + 7{,}103\,(0.05^2)} = 378, say\ 380$$

From the above result, there will be 380 respondents required for this study at 95% confidence level.

3.1.2 Survey Worksheet Design

Data collection sheets were designed for all survey parameters including for physical / geometric data as well as pedestrian traffic data. The sheets are shown in *Appendices 4 - 7* of this thesis report.

3.1.3 Pilot Survey

The pilot study was intended for familiarizing the research team with the prevailing site conditions. The data collection team was trained on site during the pilot survey. The locations of identified census points were assessed to determine their suitability.

A mock survey was conducted to identify any likely challenges that may affect the collection of data at the stations. Any problem that the research Team encountered was observed and mitigated against and subsequently controlled or eliminated during the actual survey.

3.2 Research Methodology

3.2.1 General

Desk study was undertaken to assess the existing NMT situation in the country in terms of policy, legislative, institutional and regulatory framework, as well as technical standards and maintenance framework.

Site assessment was undertaken to establish the E-LOS. Pedestrian surveys were undertaken to establish critical flow parameters such as pedestrian characteristics, trip characteristics. Information on user perceptions was collected to help understand the level of usage of the tunnel, as well as reasons for non-usage.

The required data for the calculation of P-LOS at the tunnel include pedestrian volume and effective walkway width (W_E). The pedestrian volume was collected by conducting manual count during peak hours for normal days and weekend. The effective walkway width was determined from actual physical measurement and application of walkway width pre-emption in the presence of obstacles.

Pedestrian crossing time data was collected and used to calculate the speed. This involved recording time-in at the entrance and time-out at the exit for a particular pedestrian, and calculating the time taken to pass through the tunnel. The speed was calculated by dividing the length by the time taken, and was expressed in meters per second.

3.2.2 Steps

The stages involved in the survey include:

a) Review of Existing Information;
b) Site Assessment;
c) Pedestrian Surveys;
d) Volume data collection
e) Speed data collection
f) Spreadsheet Analysis;

The activities under each step are enumerated below.

3.2.3 Review of Existing Information

This was the first step in the research. It involved collecting and reviewing existing publications, reports, journals, theses and manuals on the subject so as to understand the concepts and ascertain any pre-existing information including any relevant baseline data, existing legislations, regulatory framework, institutional arrangements, technical standards and guidelines. Review of existing information was also crucial in establishing methodological procedures appropriate for the survey.

Other data to be determined from the review was the pedestrian population on the facility. Data on the historical and current volumes of pedestrians assisted in calculation of the sample size to be used during the survey.

3.2.4 Site Assessment and Determination of Environmental Level of Service

3.2.4.1 General

In this case, the University of Nairobi Pedestrian Tunnel across Uhuru Highway has been selected as the study site.

To carry out a Pedestrian Comfort assessment, data on the footway width and the location and type of street furniture is required, as well as static activity information to record the reduction in space available for walking from static activity unrelated to street furniture;

This is used to calculate the effective walkway width, which is the space available for walking after street furniture and its associated buffers are taken into account. This was measured on site. The Highway Capacity Manual figures for various obstacles (Transportation Research Board, 2010) were applied in this study. Other than that, observation was also made to get the overall situation of the tunnel.

3.2.4.2 Procedure

Site survey and record of all relevant local and traffic factors were made. The record formed the basis for the assessment framework and covered as much background information as possible, including information regarding the roadway, the crossing facility, the site location, the adjacent land use, alternative crossings and the linkages. The information collected is expounded in the following subtitles.

3.2.4.3 Site Location

Relevant information with respect to the site location that was collected includes the following:

a) Lighting status: availability and present working condition of artificial Lighting;
b) Landscaping and general maintenance of the exterior areas;
c) Presence of active uses such as retail shops, security installations;
d) Availability and existing conditions of seating opportunities.

These factors contribute to the general security perceptions, beauty and convenience of the facility.

3.2.4.4 General Pedestrian Areas

All relevant information with respect to the publicly accessible space between street kerb and boundary fence was collected, including the following:

a) Walkway type, surface quality/condition and width;
b) Obstacles or static activities within the walkway width;
c) Structural integrity, cleanliness, and aesthetic appeal of the retaining walls;
d) Lighting status: availability and present working condition of artificial Lighting;
e) Availability and present condition of pedestrian signage;
f) Presence of underpass art.

These factors are important in as far as accessibility, capacity, general security perceptions and convenience are concerned.

3.2.4.5 Bridge Structure

The following information with respect to the bridge structure / box culvert was collected:

a) The dimensions (length, width, and height);
b) Obstacles or static activities within the width;
c) Structural integrity, cleanliness, and aesthetic appeal of the internal walls;
d) Lighting status: availability and present working condition of artificial Lighting;
e) Availability and present condition of pedestrian signage;
f) Presence of underpass art;
g) Cleanliness and hygiene within the bridge structure;
h) Utility infrastructure integration with the bridge Structure;
i) Drainage condition;
j) Visibility (light dark contrast);
k) Floor surface condition of the tunnel.

These factors are important in as far as accessibility, capacity, general security perceptions, convenience and beauty are concerned.

3.2.4.6 Roadway Characteristics

The following information with respect to the roadway was collected:

a) Functional Classification of roadway;
b) Grade of Roadway at tunnel location;
c) Roadway cross sectional data;
d) Median barrier:
e) Roadway Lighting

These factors are important in assessing the difficulty of crossing / barrier effect, design benchmarking, pedestrian restrictions as well as general security perceptions.

3.2.4.7 Land Use

The survey included collection of land use information within the area of influence of the pedestrian tunnel. The percentages of the various land uses namely residential, institutional, commercial, transport, recreational, industrial and open spaces were estimated and recorded. The information is important in the assessment of latent demand for crossing facilities along the study section.

3.2.4.8 Alternative Crossing Facilities

Information regarding the nearest crossing facility was collected including facility type and distance from the tunnel. This information is important in assessing the availability of crossing opportunities.

3.2.5 Pedestrian Surveys

3.2.5.1 General

Information regarding pedestrian characteristics, trip information and pedestrian perceptions was collected through a questionnaire. A sample questionnaire for collecting this data is shown in *Appendix 4* of this report. Further pedestrian surveys include pedestrian counts as well as pedestrian speed data.

3.2.5.2 Pedestrian Characteristics

Information on the characteristics of the pedestrians using the tunnel was collected. Data on personal characteristics included gender, age group, person size, occupation, walking aide, personal items such as bags, phones, headphones, digital equipment, bottled drinks, cigarettes etc. other personal information include pushing items e.g. pram, wheelchair, bicycle, rolling suitcase, handcart etc.

Pedestrian characteristics have a direct bearing on the flow, and are therefore crucial to this study.

3.2.5.3 Trip Information / Origin – Destination Surveys

Information regarding the trip, including origins and destinations, trip purpose, platoon cases, impedance to movement, trip frequency, and crossing location was collected.

Respondents were asked about their origins and destinations to gain a better idea of their travel patterns.

3.2.5.4 User Perceptions

Perceptions of the pedestrians regarding the tunnel were collected using a pedestrian questionnaire. The information collected included reasons for not using the tunnel and the preferred crossing treatments.

3.2.6 Pedestrian Counts

3.2.6.1 General

To carry out a Pedestrian Comfort assessment, pedestrian flow data is required. Manual screen-line counts were used to determine pedestrian volumes. The manual counts were undertaken during peak periods. The data include the number of pedestrians entering and exiting the tunnel in both directions. A sample pedestrian count tally sheet is shown in *Appendix 6*.

3.2.6.2 Procedure and Data

The counting was done on selected weekdays and weekends. Peak hour data was collected during morning peak (7 – 9am), midday peak (12 – 2pm) and evening peak (4 – 6pm peak). Two 12hour counts (7am – 7pm was conducted, one during a weekday and the other a weekend.

Pedestrian volume counts ware conducted during warm and fair weather conditions to represent peak activity, and was scheduled to coincide with the period when the university campus is on session.

3.2.7 Pedestrian Speed

A sample sheet for collection of speed data is shown in *Appendix 7*. This involve recording time in at the entrance and time out at the exit for a particular pedestrian, and calculating the time taken to pass through the tunnel. The speed was calculated by dividing the length by the time taken, and was expressed in meters per second.

3.3 Spreadsheet Analysis

Using the data and information collected above, spreadsheets were used to calculate the pedestrian flow, density and space. Spreadsheets were also used to draw charts illustrating the relationships of speed against density, flow against space, and speed against space.

3.4 Sizing of Selected Crossing Treatment

The objective of design (WE) analysis is to estimate the minimum effective width of a facility, given a desired LOS. The maximum pedestrian unit flow rate for the desired LOS was determined first, then effective widths was computed by solving the pedestrian unit flow-rate equation backwards (TRB, 2010). The computed effective width was tested for accuracy using Time – Space analysis method.

4 RESEARCH FINDINGS, ANALYSIS AND DISCUSSIONS

4.1 Background

Pedestrian flow at any facility is ultimately an interaction between the environment and the user. Both the environment and the user characteristics have an influence on the speed and density characteristics of the flow. The relationship is illustrated in *Figure 4-1*below.

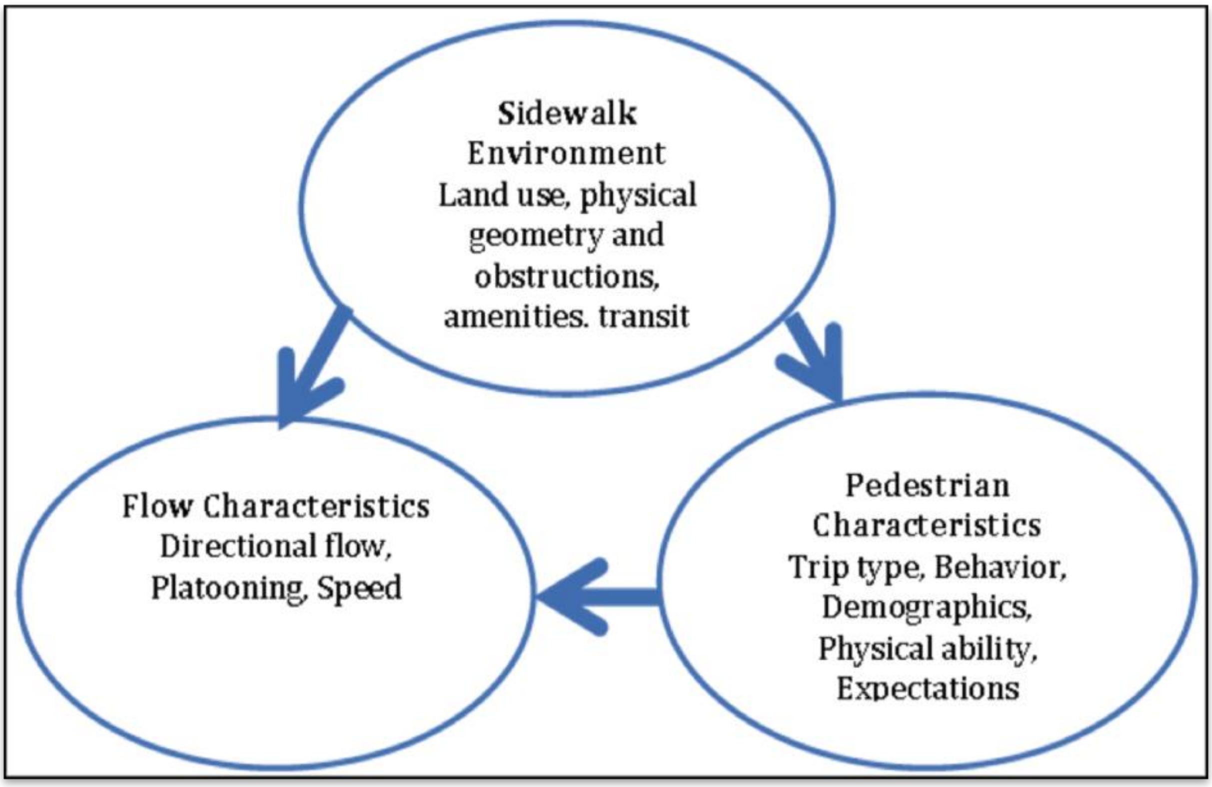


Figure 4-1: Relationship between the Sidewalk, Pedestrians and Flow (New York City, 2006)

This study has analyzed the tunnel in terms of its physical characteristics, user characteristics including trip making behavior, and user perceptions regarding the use of the facility.

4.2 Existing NMT Framework in Kenya

4.2.1 NMT Characteristics and it's Environment

According to (Servaas, 2000), NMT use and movement characteristics is an interaction between the activity environment, physical infrastructural environment, and the institutional setting. The relationship is illustrated *Figure 4-2* in below:

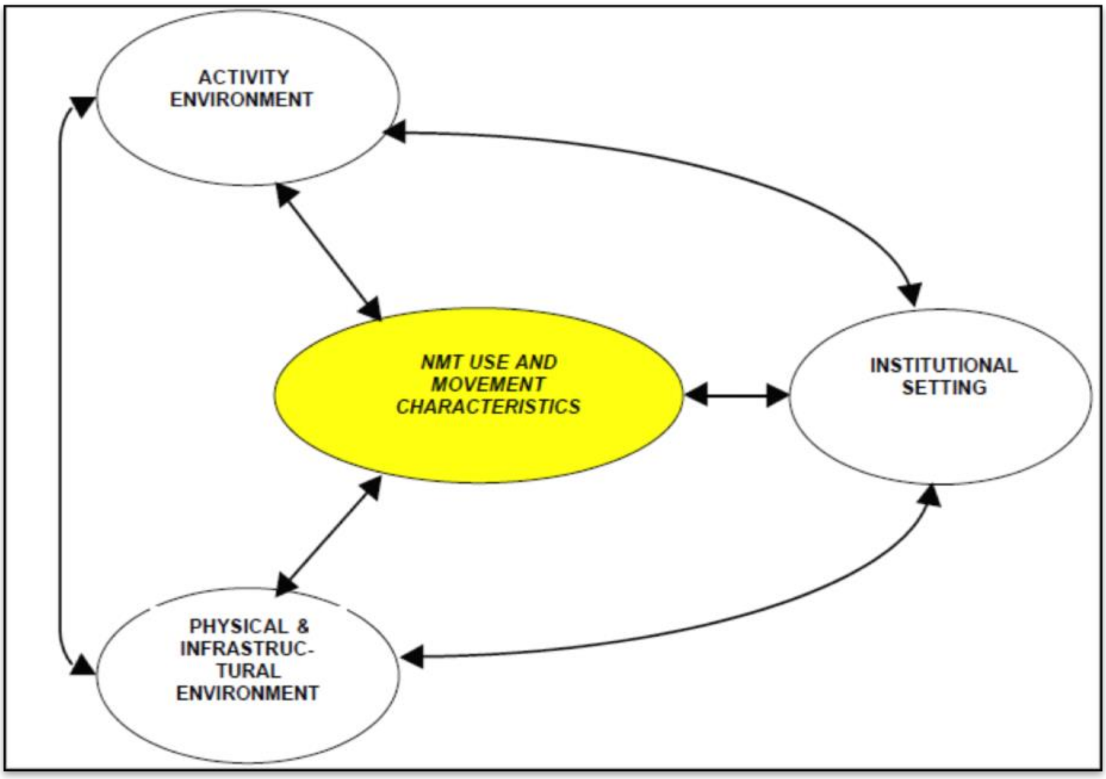


Figure 4-2: NMT Use Environments (Servaas, 2000)

The activity environment is composed of socio-economic conditions (income per capita, employment etc.); land-use patterns and density; demographic background (age profile etc.) and cultural values.

The infrastructure support environment consists of factors that enable people to walk or cycle. It includes NMT network with facilities that can be safely and efficiently used.

The institutional setting includes people, policy, laws and regulations that might foster (or hinder) the use and purpose of NMT (Servaas, 2000).

For an efficient and safe NMT movement, there is need for adequate policy, legislative, institutional, regulatory and technical arrangement to address the needs of NMT.

4.2.2 Review of the Existing Legal, Institutional and Regulatory Framework

4.2.2.1 The Constitution of Kenya 2010

The Bill of Rights of the Constitution of Kenya (2010), grants all Kenyans the right to freedom of movement. Based on this constitutional provision, NMT users have a right to appropriate facilities and space to enjoy their freedom of safe movement.

4.2.2.2 The Integrated National Transport Policy

This is Kenya’s overarching policy document on transport. It guides in the development of all the sub-sectors including road, NMIMT, rail, aviation, maritime and inland water transport, and pipeline transport system.

The document is cognizant of the main challenges in the NMT sector as composed of the following:

- Lack of a supportive legal, institutional and regulatory framework Non-Motorized and Intermediate Means of Transport;
- Failure to incorporate NMIMT in planning and development of transport infrastructure;
- Failure to develop NMIMT standards incorporating weather and climate considerations.

The document points out that “NMIMTs are not fully recognized by law to qualify for the Government’s technical and / or financial support. This applies also to NMITs infrastructure and attention is mainly focused on motorized transport and its infrastructure”. The document makes policy statements on a variety of NMIT issues namely:

a) Incorporation of NMT into the national transport policy;
b) Infrastructure development and maintenance;
c) Gender issues in NMT;
d) Legal, institutional and regulatory framework;
e) Supply and use of NMT services;
f) Human resource development in NMT;
g) Safety in NMT;
h) Incentives for NMT development;
i) Advocacy in NMT, and
j) Enforcement.

The document is comprehensive in terms of policy statements. However, it does not cover NMT security, which is a critical factor in NMT usage. It is also apparent that the policies have not been operationalized.

4.2.2.3 Nairobi NMT Policy 2015

The NMT Policy enacted by the Nairobi City County Government in March 2015 is a welcome step in the right direction. The policy covers a number of NMT issues including provision of leadership in the promotion of NMT, definite fund allocation for NMT development (20% of road infrastructure budget), planning including citizens participation, street design and maintenance, incentives for NMT usage, safety for NMT users, integration of NMT with other modes, education and awareness, regulation and enforcement including enactment of relevant by-laws, and monitoring and evaluation.

However, it does not cover NMT security, which is a critical factor in NMT usage. It is also apparent that the policies have not been operationalized.

4.2.2.4 Laws of Kenya: Land Act 2012

The Land Act was enacted "to give effect to Article 68 of the Constitution, to revise, consolidate and rationalize land laws; to provide for the sustainable administration and management of land and land based resources, and for connected purposes"

The Act, though makes mention of "land for public purposes", does not stipulate conditions for provision of land to transportation, NMT included.

4.2.2.5 Laws of Kenya: The Physical Planning Act, Cap 286

The Physical Planning Act, Cap 286 is the overarching law that provides for the "preparation and implementation of physical development plans and for connected purposes".

The Act does not stipulate specific provisions for allocation of land for NMT facilities.

4.2.2.6 Laws of Kenya: Kenya Roads Board Act, Cap 408

The Kenya Roads Act, Cap 408 gives the framework for distribution of the Road Maintenance Levy Fund (RMLF), which is the main source of funding for road maintenance in Kenya. The act specifies the proportions of funding to the various roads authorities.

The funding proportions are skewed in favor of national highways followed by rural road network, giving disproportionally low consideration to urban road network, where NMT is a priority.

4.2.2.7 Laws of Kenya: Traffic Act, Cap 403 Laws of Kenya

The Traffic Act, Cap 403 forms the overarching regulatory framework for road transport in Kenya.

Even though the Act recognizes NMT, it does not include the definition of a pedestrian in the preliminary section. The act outlines offences regarding roads, encroachment on and damage to roads and prohibition on use of tracked vehicles.

In relation to NMT, one of the provisions is that that "no person shall willfully or negligently lead or drive an animal or vehicle on footpath". Driving on pedestrian walkway attracts a penalty of KShs. 80,000 or 3-6 months imprisonment. The act also outlines the aspect of causing death by driving and reckless driving.

The Act however does not prohibit crossing at undesignated points. This flies in the face of recent statistics that indicate that crossing pedestrians constitute the highest proportion of fatalities on the roads. It is also clear that the Act is skewed towards vehicular transport, to the detriment of NMT, either through omission or commission.

The responsibility for enforcement of traffic laws is the mandate of Traffic Police**.** The weak enforcement observed within the country can be attributed to a number of factors, including lack of personnel and corruption.

4.2.2.8 General Nuisance By-Laws, 2007 City Council of Nairobi

The by-law stipulates that any person who fails to observe traffic lights or zebra crossing or any other directional signs, shall be guilty of an offence.

The by-laws does not have provisions on crossing at undesignated locations, as commonly happens among pedestrians, and the penalty thereof.

The responsibility for enforcement of the by-laws is the mandate of local authorities and their predecessor, the county governments**.** The weak enforcement observed everywhere can be attributed to a number of factors, including lack of personnel and corruption.

4.2.3 Review of the Existing Technical Standards and Guidelines

4.2.3.1 Technical Guidelines and Standards

The following manuals and specifications are generally used in the design and construction of roads in Kenya:

a) Road Design Manual Part I: Geometric Design for Rural Roads;
b) Road Design Manual Part III: Materials and Pavement Design for New Roads;
c) Road Design Manual Part IV: Pavement Rehabilitation and Overlay Design;
d) Manual for Traffic Signs in Kenya Part I: Road Markings;
e) Manual for Traffic Signs in Kenya Part II; Informatory, Warning & Regulatory Signs;
f) Standard Specifications for Road and Bridge Construction.

All these documents do not incorporate the design of or construction specifications for NMT facilities. The closest the documents come to touching NMT is in the manual for traffic signs, where provision is made for zebra crossing markings and pedestrian crossing signs.

From the above, it is apparent that NMT issues have not been recognized in Kenya. There's need to develop planning and design tools such as manuals and guidelines that take account of both the environmental (E-LOS) and operational (P-LOS) requirements for pedestrians.

Design of pedestrian facilities is critical to their usage. Technical standards and guidelines should be formulated and adopted for use by professional in the process of providing NMT facilities. As a minimum, such technical guidelines and standards should ensure the resulting facilities are safe, secure, comfortable, attractive, interconnected and direct. The facilities should blend well with the existing environment without causing environmental or social disruption.

4.2.4 Review of Existing Maintenance Framework

4.2.4.1 Laws of Kenya: The Roads Act, 2007

The Roads Act, 2007 provides for maintenance works to be undertaken by Three (3) roads authorities, Kenya National Highways Authority (KeNHA), Kenya Rural Roads Authority (KeRRA) and Kenya Urban Roads Authority (KURA), and the Kenya Wildlife Service

(KWS). KeNHA has mandate over all national highways, KeRRA rural roads and KURA urban roads, except where those roads are national roads.

The Pedestrian Tunnel under study is institutionally under KeNHA. However, maintenance of the same has been undertaken variously by the City Council of Nairobi, the then Ministry of Nairobi Metropolitan Development (MoNMED), and the University of Nairobi.

4.2.4.2 Subsidiary Legislation on Road Classification, 2016

The Subsidiary Legislation on Road Classification, 2016 classifies the entire road network within the country as either National or County roads. The responsibility for maintenance of national roads vests in the Three (3) roads authorities mentioned above, while maintenance of county roads is the responsibility of the Forty Seven (47) county governments.

4.2.4.3 Pitfalls with the Maintenance Framework

The arrangement has many pitfalls, right from funding to back-passing. The funding system for maintenance favors KeNHA and KeRRA whose networks do not incorporate NMT facilities.

Under the new classification, the responsivity over the Tunnel remains with KeNHA.

A policy should be enacted to grant ownership and maintenance responsibility of NMT facilities abutting public institutions to those institutions. The institutions should be funded directly for the same.

4.3 Site Assessment and Determination of E – LOS

The physical context relates the underpass to the spatial setting, local character and existing policy guidelines.

4.3.1 Design and Existing Physical Conditions

The physical context of the tunnel is analyzed in terms of the roadway which forms the barrier to pedestrian movement, the exterior interfaces, the bridge structure, the entrance / exit walkways, the adjacent land use, the linkages and the alternative crossing options.

4.3.1.1 Design and Existing Condition of the Barrier (Uhuru Highway)

The roadway is an international trunk road, and it forms a major urban arterial through the urban setup. At the tunnel location, it consists of a dual carriageway, with three lanes in the northbound carriageway and 4 lanes in the southbound carriageway, and no internal or external shoulders on either carriageway. Each lane measures 3m width, making a crossing length of 9m on the northbound carriageway and 12m on the southbound carriageway. The median is 6m wide. See *Plate 4-1* for illustration.

At the tunnel location, the roadway elevation follows the existing ground level (at-grade) while the tunnel is below the existing ground level (sunken). The roadway median has no pedestrian barrier. The infrastructures for street lighting exist, but are not working due to vandalism.

Plate 4-1: Road Cross Sectional Characteristics (Author, 2016)

Both qualitative and numerical warrants reviewed have shown that grade separated pedestrian crossings are recommended on roads where there exists high pedestrian and vehicular traffic, as well as roads with high vehicular speeds and many lanes. Other considerations for GSPC include places with high pedestrian demand; places with high number of children crossing; defined pedestrian routes; and routes that link second campus from the main campus. Such roads are characterized by inadequate gaps in the traffic stream to allow for safe crossing.

Considering these requirements, the best treatment for pedestrian crossing on Uhuru Highway is GSPC.

It should be noted that pedestrians prefer to travel on level grade with minimal or no changes in elevation. Unfortunately, Uhuru Highway is not elevated, meaning the tunnel is below grade. "Sunken" or depressed tunnels pose drainage problems whereby runoff water from the adjacent catchment areas pools within the tunnel tube underneath. This situation partly explains the flooding observed during rains. From the observations, the current gravity flow is not effective, and therefore, a pump system is necessary. This obviously implies high maintenance costs.

Studies have shown that many pedestrians will not use an overpass or underpass if they can cross at street level in about the same amount of time. Fences, median barriers, railings, or other forms of barriers are necessary to prevent pedestrians from crossing at-grade. The pedestrian walkways approaching the tunnel are fenced. This helps in channeling pedestrians to the tunnel. However, the roadway does not have a physical barrier at the median to prohibit at-grade crossing. A good underpass design should include a median barrier.

Lighting of traffic lanes is essential for comfort and safety. Street lighting acts as a crime deterrent by increasing the visibility of the tunnel area. The existing street lights are not functional as they have been vandalized. This means that the overall tunnel location is not well lit, and therefore poses both psychological and functional sense of insecurity to pedestrians.

4.3.1.2 Existing Condition and Design of the Exterior Pedestrian Areas

An observation of the exterior area (the open space between the fence and the access walkway) revealed that requirements of an attractive and comfortable pedestrian places such as storm water drainage facilities, artificial lights, actives uses (for example shops), pedestrian signages, pedestrian seats and beautiful streetscape do not exists. It was also observed that the area is

Plate 4-2 and *Plate 4-3* below illustrate the existing condition of the exterior areas of the tunnel.

Plate 4-2: Bushy Exterior on the Eastern Portal (Author, 2016)

Plate 4-3: Bushy Exterior on the Western Portal (Author, 2016)

The existing atmosphere of dereliction and neglect evokes negative feelings of insecurity and crime, hence pedestrian safety. Poor maintenance also symbolizes a lack of personal touch that generates undesired consequences such as vandalism and graffiti, which are signs of a crime area.

Areas with active uses such as shops contribute to a sense of safety and social control. An active edge is characterized by continuous, pedestrian-oriented shops along both sides of an underpass street with windows and doors facing directly to the sidewalk. As a pedestrian accessible area, it requires additional design components such as pedestrian signage, lighting, street furniture, landscaping, art, etc., which contribute to the pedestrian friendliness. The more activities take place, the more people, the higher level of social control, and the less opportunity for criminal activities. The existing situation of darkness, desertedness and dereliction contributes to feelings of unpleasantness and insecurity.

The tunnel is also isolated from the built environment, a situation that elicits the feeling of a facility in “no-man’s land”, and contributes to the sense of insecurity.

Landscaping of the verge between the roadway and the abutting developments, including any vacant lands is essential for purposes of increasing the level of pedestrian comfort and attractiveness.

4.3.1.3 Existing Design and Condition of the Tunnel Flanges

The access walkways on either side of the tunnel tube are ramp type, with uneven surface pavement of asphalt concrete. The ramp gradient is approximately 7%. The walkway widths are approximately 2m, with a single hawker either side constituting the only static activity on the walkway width (See *Plate 4-4*).

Plate 4-4: Ramp Type, Pavement Distresses (Cracks), and Static Activity (Vendor) on the Walkway (Author, 2016)

The high concrete retaining walls on the eastern portal have undergone moderate cracking and faulty alignment of structural panels (See *Plate 4-5* and *Plate 4-6)*. The wing walls on the eastern portal are structurally sound with no visible distress signs. The paint layer on the surface of the retaining wall and wing walls is old and dirty, defaced with posters, and visually unappealing.

The walkway has no artificial lighting or pedestrian signage, while the retaining and wing walls have no art or any other form of beautification on the surface.

Plate 4-5: Lateral Displacements of the Retaining Wall Panels (Author, 2016)

Plate 4-6: Cracks on the Retaining Wall Panels (Author, 2016)

Pedestrians should enter and leave the tunnel with ease. Tunnel access is therefore very important, not only for the fit ambulant, but also the handicapped and those with prams and wheelchairs. In this regard, ramps are preferred to stairs. The accesses should also be free from all forms of obstructions, whether permanent or temporary, including static activities such as hawking.

It is imperative that the pavement surface of the ramps be smooth and devoid of irregularities that could affect the comfort and safety of pedestrians. Where there is a likelihood of flooding or wetness, concrete surface is preferable. Other surfaces should be provided with a texture to resist slipping.

Lighting provides a welcome atmosphere where tunnel entrances /exits, and also provides a sense of personal safety and security. Artificial lights at the access also improve the aesthetic image as well as nighttime visibility. Access walkways can also be lighted to provide guidance. Dark environment like the existing situation at the tunnel conjure feelings of insecurity.

Good signage can play an important role in supporting pedestrian movement and contributing to a distinctive local identity. Informatory signs to direct and orient pedestrians to surrounding key destinations, as well as the public transit network such as bus stations are important. Warning signs are essential in as far as prohibiting pedestrians and other users in concerned. Interpretive signage can be used to celebrate local heritage of the university.

Art in underpasses is any work of art or design that is created by an acknowledged artist specifically to be sited on the retaining walls, wing walls or tunnel tube walls. Underpass art are meant to give pedestrians a direct or subconscious feeling of comfort and safety. These could include mosaics, murals, carvings or photo installations of events or historic figures to give the underpass character and context.

4.3.1.4 Existing Design and Condition of the Bridge Structure

The bridge structure consists of a box culvert measuring 2.2m wide by 2.3m high by 40.6m long across the road. There exist no obstacles or static activities within the walkway width. The utility infrastructure is well integrated with the bridge structure, leaving no obstructions or protrusions into the walkway.

The tunnel has no artificial light. The existing skylight on the roof is not adequate, and the transparent cover is broken (See *Plate 4-7* and *Plate 4-8*). The entrance is not visible from the exit.

Plate 4-7: Damaged Skylight on the Tunnel Roof (Author, 2016)

Plate 4-8: Light / Dark Contrast caused by Poor Lighting within the Tunnel

The tunnel is fairly clean, with only small amounts of litter and debris. However, one inspection chamber without cover is extremely filthy with litter and debris as illustrated in *Plate 4-9*.

Plate 4-9: Filth inside a Manhole within the Tunnel (Author, 2016)

The box culvert is structurally sound, with no visible signs of cracking, spawling, disintegration or faulty alignment of structural members.

The paint layer of the internal walls of the tunnel is in fair condition, but the walls are generally dirty with posters and graffiti. The tunnel is visually unappealing with no underpass arts. The condition is illustrated *Plate 4-10* below.

Plate 4-10: Graffiti on the tunnel walls (Author, 2016)

Poor drainage within the tunnel is demonstrated by flood water mark on the tunnel walls *Plate 4-11.* The tunnel floor is smooth, with no skid resistance.

Plate 4-11: Flood Marks on the Tunnel Wall (Author, 2016)

The catch basins at the portals have no covers, and are filthy due to dumping of debris and litter as illustrated in *Plate 4-12* and *Plate 4-13* below.

Plate 4-12: Condition of the Catch Basin at the Eastern Portal (Author, 2016)

Plate 4-13: Condition of the Catch Basin at the Western Portal (Author, 2016)

The longitudinal drainage pans run along the entire length of the tunnel. However, they are shallow, rough and are not differentiated from the travel path, leaving them exposed dirty, as shown in *Plate 4-14*.

Plate 4-14: Longitudinal Drainage Pan within the Tunnel (Author, 2016)

Underpasses are more efficient when designed to feel safe, open, accessible and attractive. An attractive, safe and easily accessible tunnel exerts high demand on its cross section in terms of pedestrian flow.

Easy accessibility for both the fit ambulant/ordinary pedestrian, as well as the physically handicapped, and pedestrians with prams and wheelchairs is crucial to the function of an underpass. This is normally achieved by using ramps. The open catch basins at the entrance/exit hinder accessibility to the tunnel by such groups thus prohibiting its use.

The perceived ease of use based on the level difference between the tunnel floor and the adjoining walkway level is another important aspect of accessibility. Pedestrian tunnels should ideally be on the normal path of pedestrian movements. Pedestrians will normally weigh the perceived safety of using and underpass against the extra effort and times required, and cross at locations they believe to be more direct and less difficult. Convenience in use of pedestrian tunnels is created by elevating the crossing road partially to obtain smaller difference in level between tunnel floor and outer pedestrian routes, or fully to ensure the tunnel floor remains at the same level with the pedestrian route. The phenomena are illustrated in *Figure 4-3* and *Figure 4-4* below.

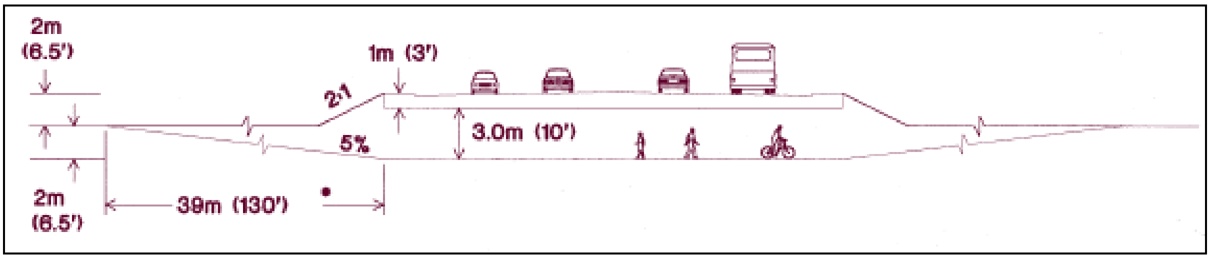


Figure 4-3: Partially Elevated Roadway combined with Partially Depressed Pedestrian Tunnel (Oregon Department of Transportation, 1995)

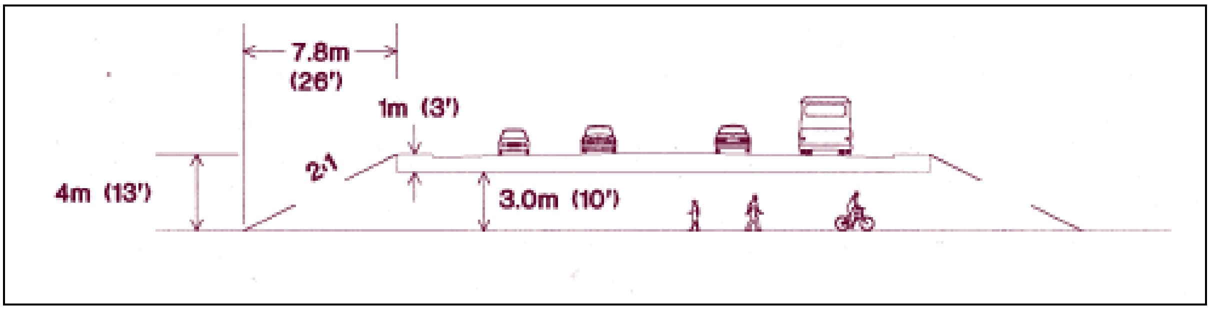


Figure 4-4: Fully Elevated Roadway combined with At-Grade Pedestrian Tunnel (Oregon Department of Transportation, 1995)

The two aspects of visibility of the tunnel, i.e. the view from the environment to the entrance, and from the entrance to the other end are very important aspects of a pedestrian tunnel. Closed spaces bring about claustrophobic feelings. Poor visibility from the spatial landscape to the entrance stirs feelings of anxiety and insecurity among pedestrians resulting from the “black hole window” effect, a phenomenon which describes a dark tunnel located in space.

The design of pedestrian tunnels should ensure that there is a clear view from the approaching walkways to the tunnel entrance, and between both entrances. A straight-line, clear view between the entrances is necessary for averting the “tunnel effect”, which are feelings associated with claustrophobia. Adequate illumination of the tunnel tube is therefore necessary to create sufficient degree of spaciousness, thereby eliminating the “tunnel effect”.

The intensity of both natural and artificial lighting should be synchronized in a manner that does not create a light / dark contrast, or a “black frame’ impact within the tunnel as is the case with the tunnel under study.

The cross section is an extremely important aspect of a pedestrian tunnel not only with regard to the capacity, but also the elimination of the “tunnel effect”, or claustrophobic feelings of anxiety and insecurity. Narrow pedestrian tunnel with low ceiling and poor lighting is a recipe for claustrophobia. While different manuals dictate varying minimum headroom values, the minimum is 2.4m. In very long tunnels, some additional headroom is advised to create more spaciousness. The width is determined on the basis of the expected pedestrian flow and the desired level of service. A "shy" and drainage distance of approximately 0.5m from the wall should be incorporated. However, a minimum width of 2.3m is recommended for a narrow tunnel with low pedestrian traffic volume. The width is also dependent on the length, with longer bridges having wider minimum widths to create more spaciousness. A width of 3.3m is recommended for normal sections with tunnel length more than 23m. For the box culvert type, wide flanges at either end of the tunnel allows for natural light into the tunnel thereby reducing negative feelings of claustrophobia and perceptions of insecurity. The wing walls should therefore designed to visually minimize the "tunnel" effect.

The tunnel tube or the bridge structure is less of structural element than a decorative one. The finishes of the structure should enhance beauty and character. High sidewalls of concrete covered with cracks and peeling paint on the walls should be avoided. Underpass public art including mosaics, murals, carvings and photo paintings should be introduced to enhance the beauty and character of the tunnel.

Poor drainage results in water pooling within the tunnel during rainy season, a situation that makes the tunnel unattractive. Covers for the open catch-basins/sumps at either portal should be reinstated. The catch-basins should be cleaned regularly of debris and litter. The longitudinal drainage pans should be constructed well and cleaned regularly. The drainage pans shall be constructed of colored concrete to differentiate between the drainage and traveled path for easy identification.

Unkempt and run-down appearance will elicit feelings of negative feelings of neglect and lack of personal touch. Poor maintenance may therefore generate undesired results such as vandalism and criminal activities. On the contrary, a well maintained area sends a perception of control, ownership and responsibility. Regular maintenance to improve access, cleanliness and attractiveness is therefore important. Immediate repair in case of mischievous or unintended damages is necessary to halt a probable declining spiral.

4.3.2 Land Use Characterization

Figure 4-5 and *Table 4-1* below illustrates the land use distribution within the study area.

Table 4-1: Land Use Distribution within the Tunnel Catchment Area (Author, 2016)

	Land Use Category	**Western Side (%)**	**Eastern side (%)**	**Total (%)**
1	Residential	25	1	26
2	Transportation	4	5	9
3	Commercial	1	12	13
4	Industrial	0	0	0
5	Institutional	8	21	29
6	Recreational	15	0	15
7	Open Spaces	0	8	8
	Total, All Categories			100

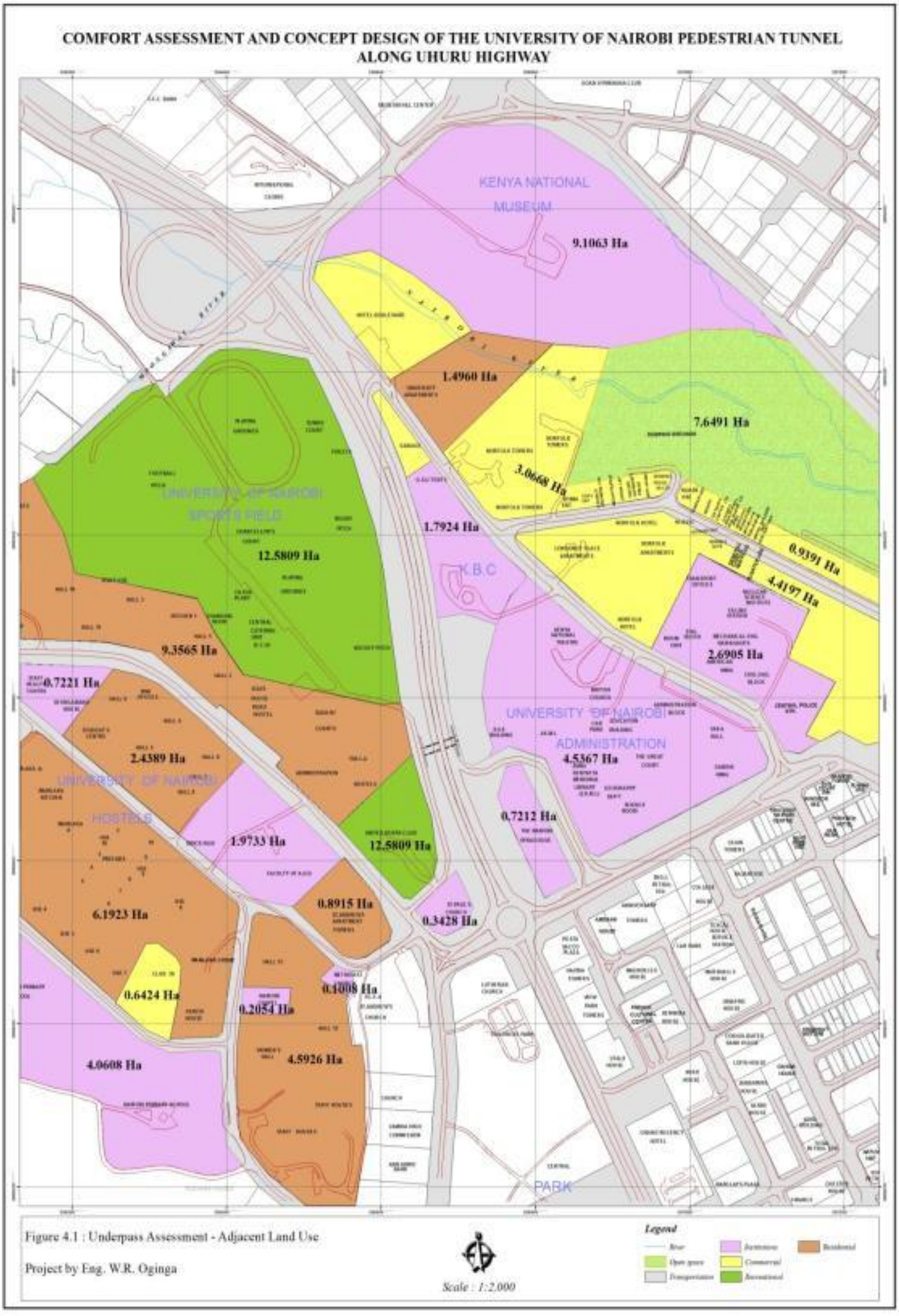


Figure 4-5: Land Use Distribution within the Catchment Area of the Tunnel (Author, 2016)

The spatial activities within the study area are dominated by institutional and residential uses taking approximately 29% and 26% respectively. Other uses include recreational (15%), commercial (13%) transportation (9%) and open spaces (8%).

The institutional land use is dominated by the University of Nairobi's administrative, tuition and health facilities. A few churches, a synagogue and government buildings / facilities constitute a minor portion of the institutional land use. The residential area is also dominated by the University of Nairobi's hostels that range from bungalows to multistory buildings. A few private hostels, apartments and maisonettes constitute a minor percentage of the residential land use. These are mostly low density residential facilities. Commercial uses are 100% local stores and retail shops. The University playground is the sole recreational and use. The riparian land for Nairobi River constitutes the only open space. The same is currently being used for dumping of garbage. Transportation land use is composed of the University of Nairobi parking lot, and the road facilities including bus bays.

The temporary prefabricated hostels sitting on approximately 5acres represent the only redevelopment opportunity that is likely to increase the need for pedestrian crossing.

4.3.3 Directness and Connectivity

The pedestrian tunnel is the single most important crossing facility linking the Western, mostly residential quarter of the campus to the Eastern side which is predominantly institutional. The tunnel is linked with a continuous walkway from the furthest reach of the residential neighborhoods, as well as the neighboring Chiromo campus on the Western side to the administrative and tuition facilities on the Eastern side. A similar tunnel is used to effect pedestrian crossing along State House Road. *Plate 4-15* illustrates the condition of the tunnel along State House Road.

Plate 4-15: Pedestrian Tunnel along State House Road (Author, 2016)

4.3.4 Alternative Crossing Facilities

Alternative crossings along the study section include the pedestrian crosswalk located at the rotary intersection at University Way, approximately 230m from the tunnel, and jaywalking which is common near the Museum Hill Road interchange, approximately 600m from the tunnel. The crosswalk is illustrated by the photo in *Plate 4-16* below.

The crosswalk at the University Way Intersection is signalized, but the signals do not function due to vandalism. Both pedestrian and vehicular traffic rely on Traffic Police Officers for green time signal.

Plate 4-16: Pedestrian Crosswalk at University Way Rotary Intersection (Author, 2016)

4.4 Pedestrian Characteristics

4.4.1 Introduction

Normal pedestrian flow is very much a factor of pedestrian characteristics as it is of other others such as the walking environment and trip characteristics. The pedestrian characteristics that have impact on the overall flow of the pedestrian stream include age, gender, person size, occupation of trip maker, and the physical condition of the pedestrian including use of walking aids and personal items.

This paper examines the pedestrian characteristics, and their impact on the flow, and the ultimate impact on the usage of the tunnel.

The total respondents interviewed for the questionnaire was Four Hundred Eighty One (481), slightly more than the Three Hundred Eighty (380) determined from the Sample design. This was meant to assure the confidence level in case of any abnormal situation.

4.4.2 Age Profile of Users

From *Figure 4-6* below, it is shown that majority of users belong to the 19 – 35 years age group, constituting approximately 90.9%, followed by 36 – 55 years (7.3%) and 13 – 18 years (1.5%). The other age groups; 0 – 12 years and over 55 years are insignificant at approximately 0.2% each.

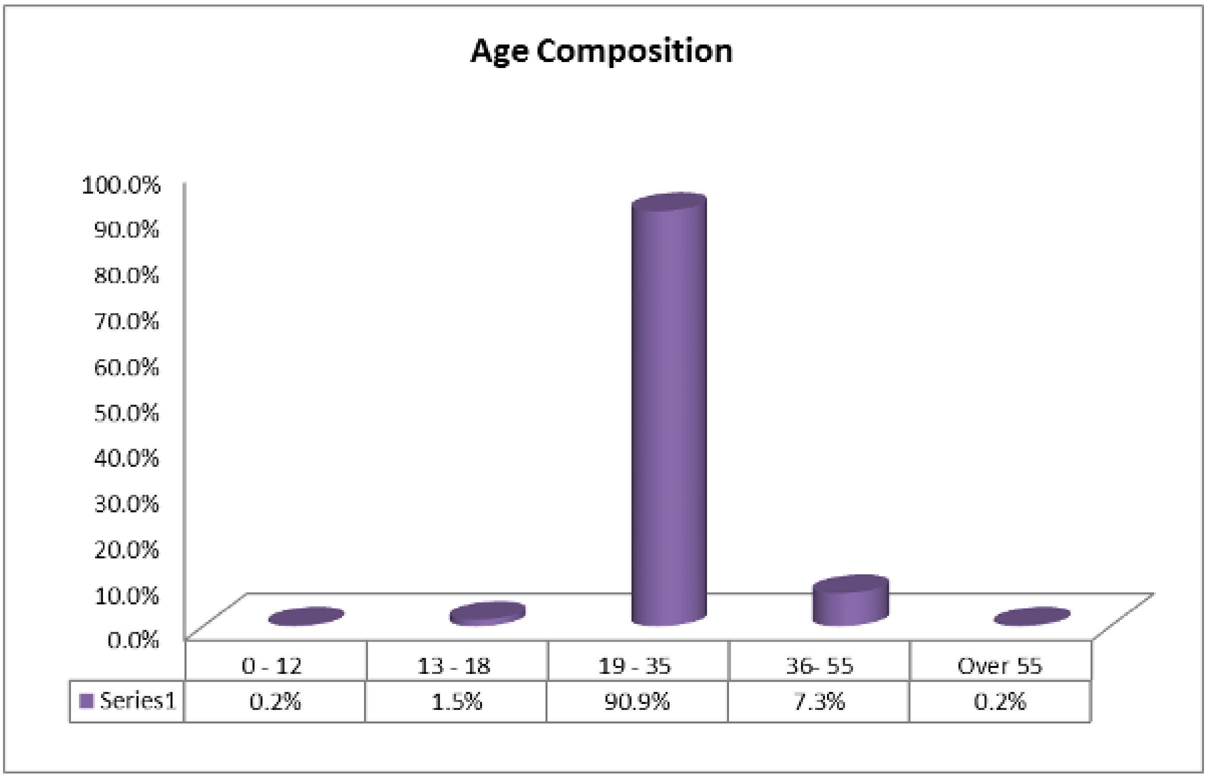


Figure 4-6: Age Profile of Users

The walking characteristics and abilities of the various age groups impact on the overall pedestrian flow. Young children lack perceptive and cognitive capabilities necessary for making sound judgments and therefore tend to be impulsive and unpredictable. They are therefore exposed to higher risk as they walk purely on the basis of age. Young adult pedestrians are more active, can travel at higher speeds and walk longer distances, and are risk prone due to a feeling on invincibility and overestimated abilities. The elderly pedestrian experiences some reduced capabilities in terms of visual acuity, agility, strength and speed. A significant proportion of old pedestrians in a traffic stream will substantially reduce the speed, hence the flow.

According to Nagui *et al*, a walking speed value of 1.0 m/s is recommended in areas with large numbers of older pedestrians, a nearly 30% decrease from HCM values. The study qualifies “large numbers of older pedestrians” as when the elderly proportion begins to significantly affect the overall speed distribution in the pedestrian traffic stream, and quantifies the same as 20% of the total pedestrian population.

The age profile confirms that students are predominantly using the tunnel. This also explains the average speed of 1.5m/s registered in the study.

4.4.3 Gender Profile

From the chart shown in *Figure 4-7* below, it is shown that out of the total users, males and females constitute approximately 63% and 37% respectively.

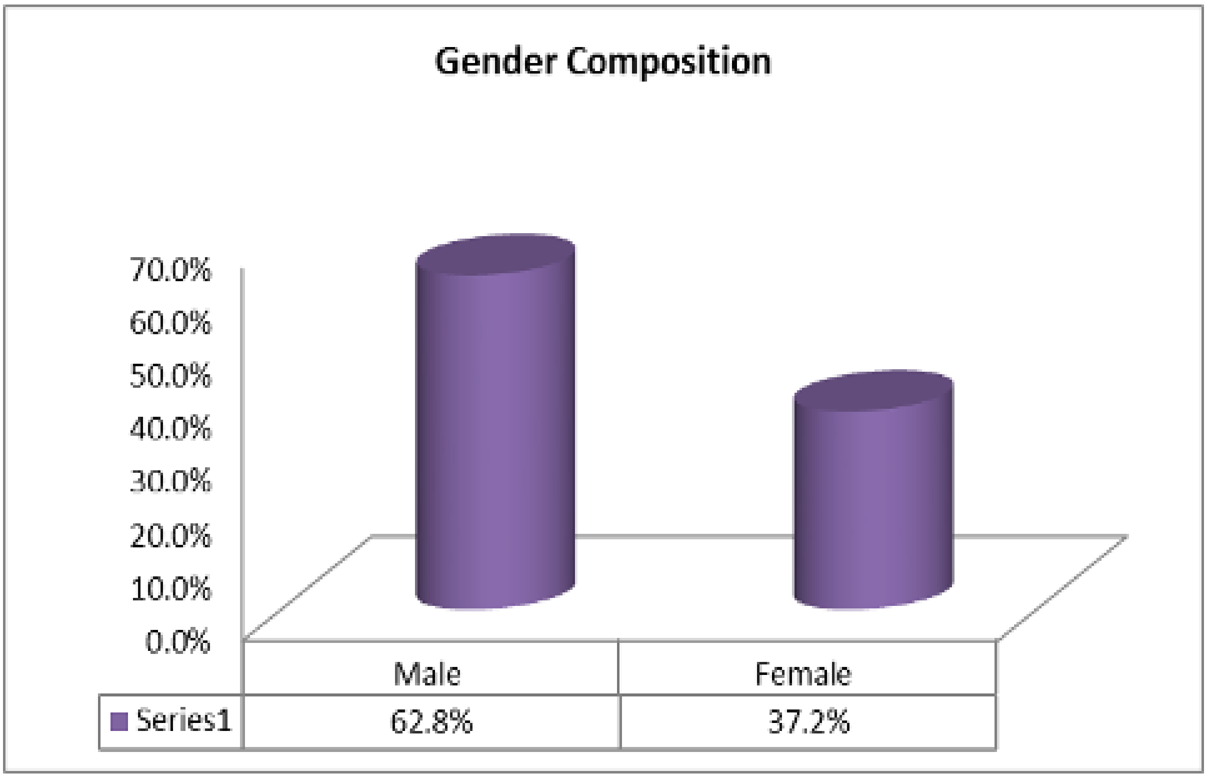


Figure 4-7: Gender Distribution of Users

Gender is an important factor that influences walking. Research has shown that women complete fewer walking trips, and that men walk further than women (Demetsky, 1974). Research has also shown that women walk at lower speeds than men (Fitzpatrick, et al, 2006). According to (Fruin, 1971), walking speeds of females are slower than males, and the speeds of pedestrians decrease with age.

The percentage of females is lower than males in this study. The same can be attributed to the general population profile, rather than the the modal choice considering that there are no other modes of transport on this section.

4.4.4 Person Size Profile of Users

The study established that majority (99.4%) of users are of normal size as opposed to small (0.4%) and large (0.2%).

The person size distribution at the tunnel is illustrated in *Figure 4-8* below.

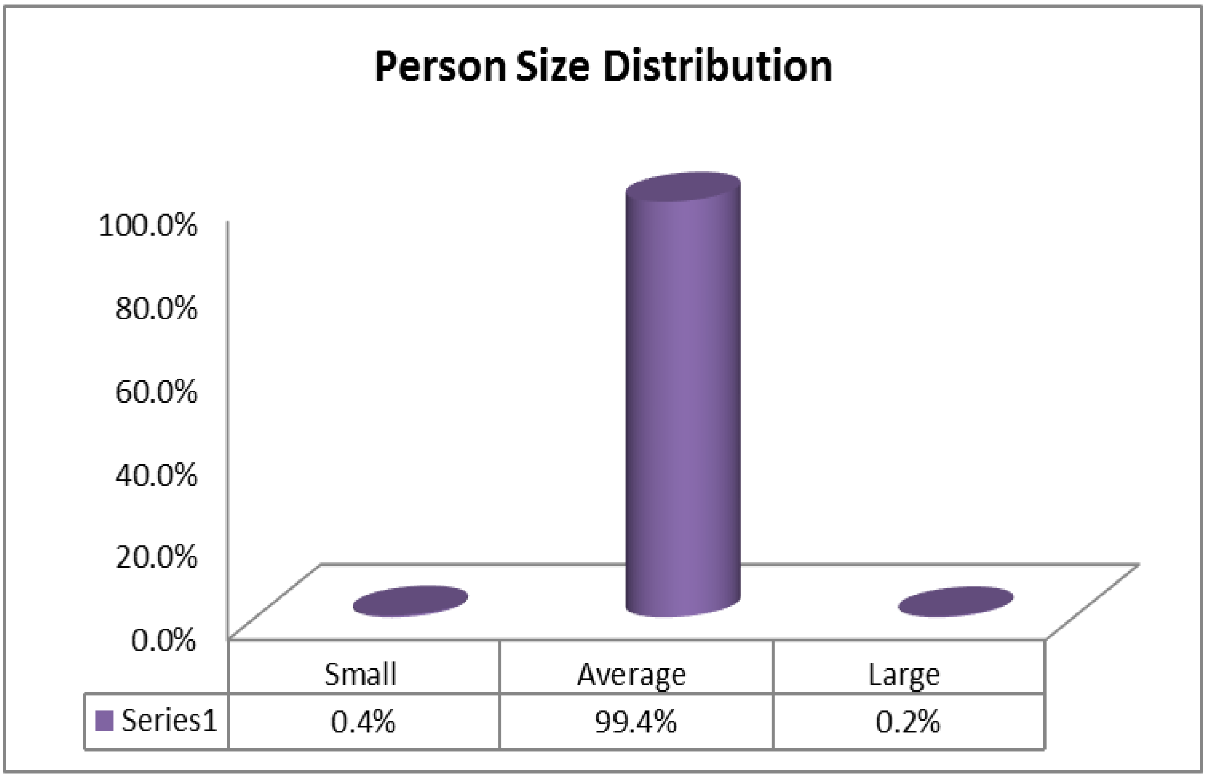


Figure 4-8: Person Size Distribution of Users (Author, 2016)

The person size is correlated to space requirement for pedestrians, hence pedestrian density and flow. The pedestrian flow is inversely proportional to the space available. It has been shown that as pedestrian space decreases, the flexibility in movement per individual pedestrian reduces, hence reduction in the average speed of the pedestrian traffic stream (TRB, 2010).

In HCM 2010, a standing area design of a simplified body ellipse of 0.5m by 0.6m, with a total area of 0.03m^2, approximately 108% percent of the ellipse suggested by Fruin (Fruin, 1971). HCM 2010 also recommends a body buffer zone of 0.8 m^2 for walking.

In this study, the proportion of persons of abnormal size is insignificant, hence does not impact on the overall flow of the pedestrian stream.

4.4.5 Occupation Profile of Users

Students constitute the majority of pedestrians using the tunnel at 87.5%, followed by workers / employees at 11.2%. The other groups such as traders and non-workers form an insignificant component of the pedestrian stream. Students and University staff aggregated together constitute 93.9%of the users.

Figure 4-9 below illustrates the occupation profile of users.

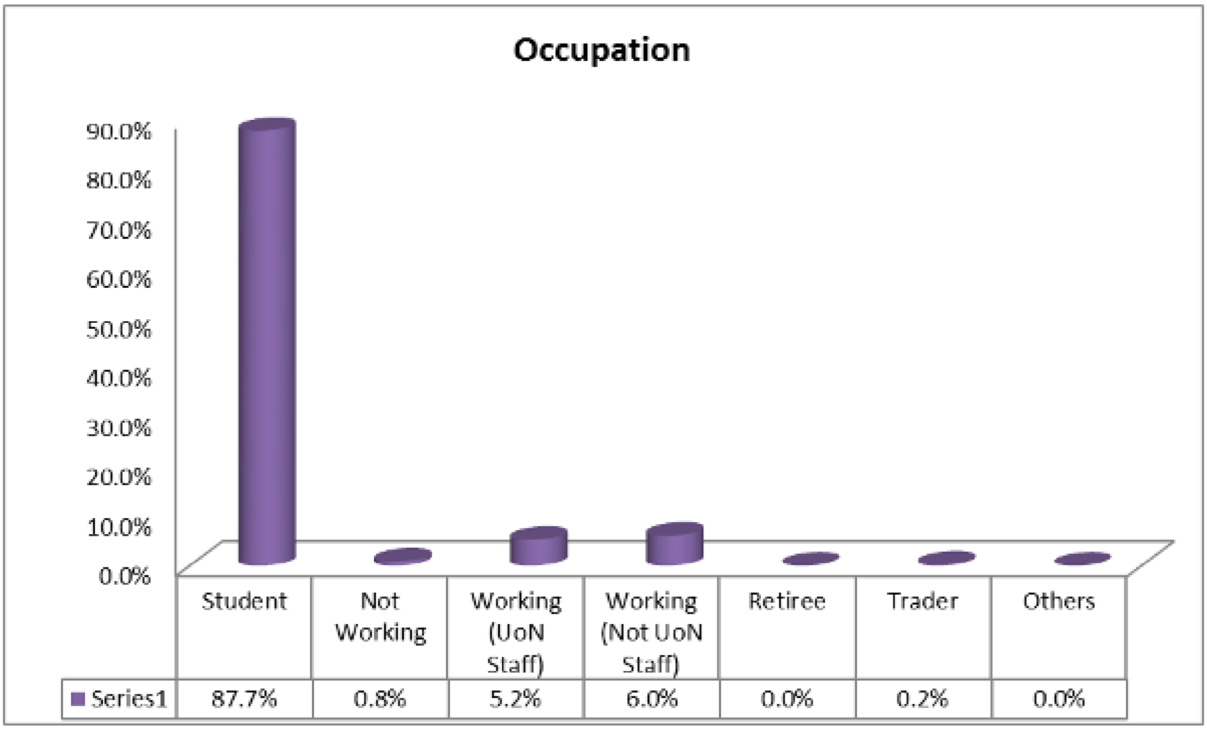


Figure 4-9: Occupation Profile of Users

Trip generation is associated with socio-economic factors, including employment. According to (Mousavi, 2012), working pedestrians are likely to make more trips, while college tend to make more trips and stops.

The findings in this study are consistent with the general observations above. It is a given that employees and students must make daily trips by virtue of their daily engagements. The high percentage of students is consistent with the fact the tunnel mainly serves students, who must cross the highway to receive tuition, as well as administrative services. Other categories of pedestrians make trips whenever necessary, while retires rarely make trips.

4.4.6 Disability Profile of Users

The fit ambulant constitutes the majority of pedestrians at the study section at 99.6%, with only 0.4% being persons with disabilities. Of the disabled pedestrians, 0.2% were on crutches while another 0.2% were using cane walkers. It is worth noting that no pedestrian on wheelchair was recorded.

Figure 4-10 below illustrates the distribution of pedestrians based on walking aid.

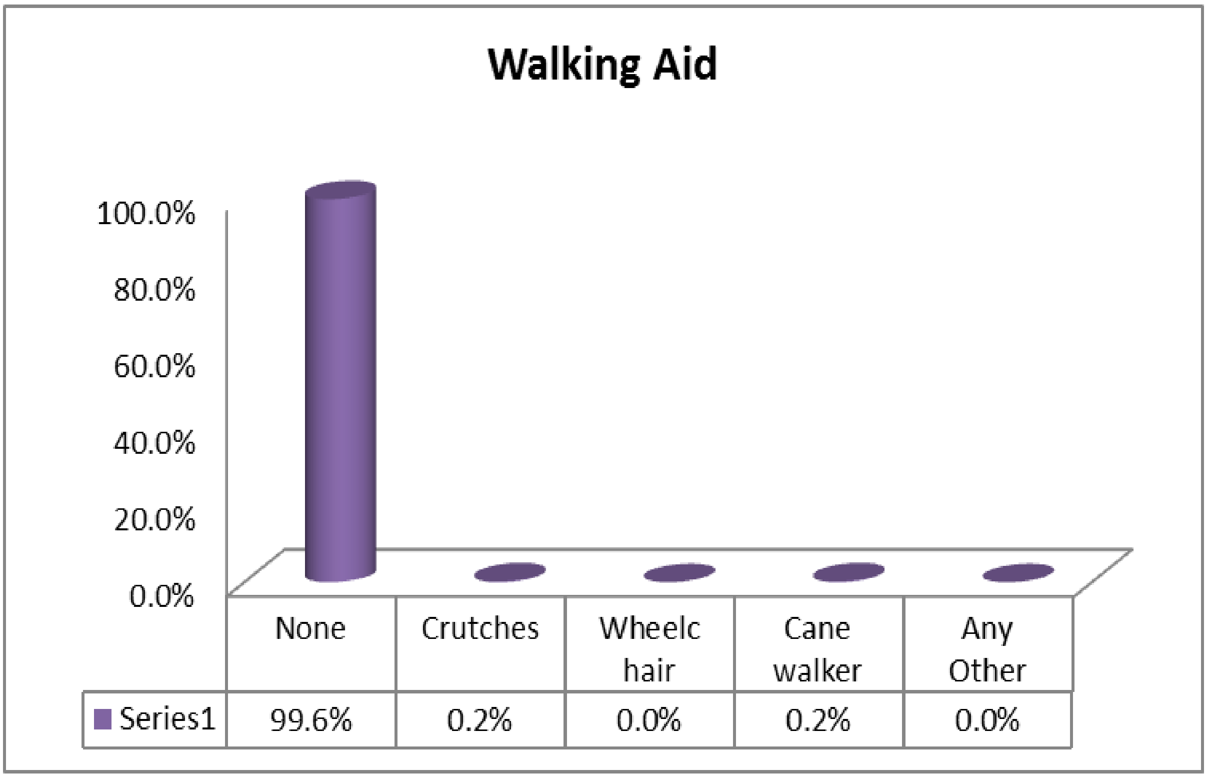


Figure 4-10: Disability Profile of Users

The environmental conditions at the tunnel, namely the uneven and irregular pavement surface, high ramp gradients, obstruction by static activities on the walkway (hawkers), flooding at the entrance and inside the tunnel, as well as the broken catch basin covers at the portals are considered to be the main hindrances to the use of the tunnel by the handicapped pedestrians to a large extent, and to the fit ambulant to a smaller extent.

The disability profile is also a factor of the mean walking speed of pedestrian stream, hence pedestrian flow. As expected, the walking speeds for pedestrians with disabilities are lower than the average walking speed assumed for the design of pedestrian crosswalk signal timing (Fitzpatrick, et al, 2006).

Table 4-2 below shows some average walking speeds for those with various disabilities and assistive devices.

Table 4-2: Mean walking speeds for PWD (Fitzpatrick, et al, 2006)

Disability or Assistive Device	Mean Walking Speed (m/s)
Cane or Crutch	0.8
Walker	0.63
Wheelchair	1.08
Immobilized Knee	1.07
Below Knee Amputee	0.75
Above Knee Amputee	0.6
Hip Arthritis	0.68 – 1.16
Rheumatoid Arthritis (Knee)	0.75

Walking aid is also a factor of pedestrian space, hence pedestrian flow. Cane walker, wheel chair and other such assistive devices will require increased circulation space.

4.4.7 Physical Condition of Users

4.4.7.1 Baggage-Carrying Users

From the study, 58.2% of the respondents carry no bags while 41.2% carry light bags which have no impact on the walking speeds. A paltry 0.6%, or 3 pedestrians out of the 481 pedestrians interviewed were carrying bags with effect on their walking speeds. This number is insignificant on the overall speed of the traffic stream. The distribution is shown in *Figure 4-11* below.

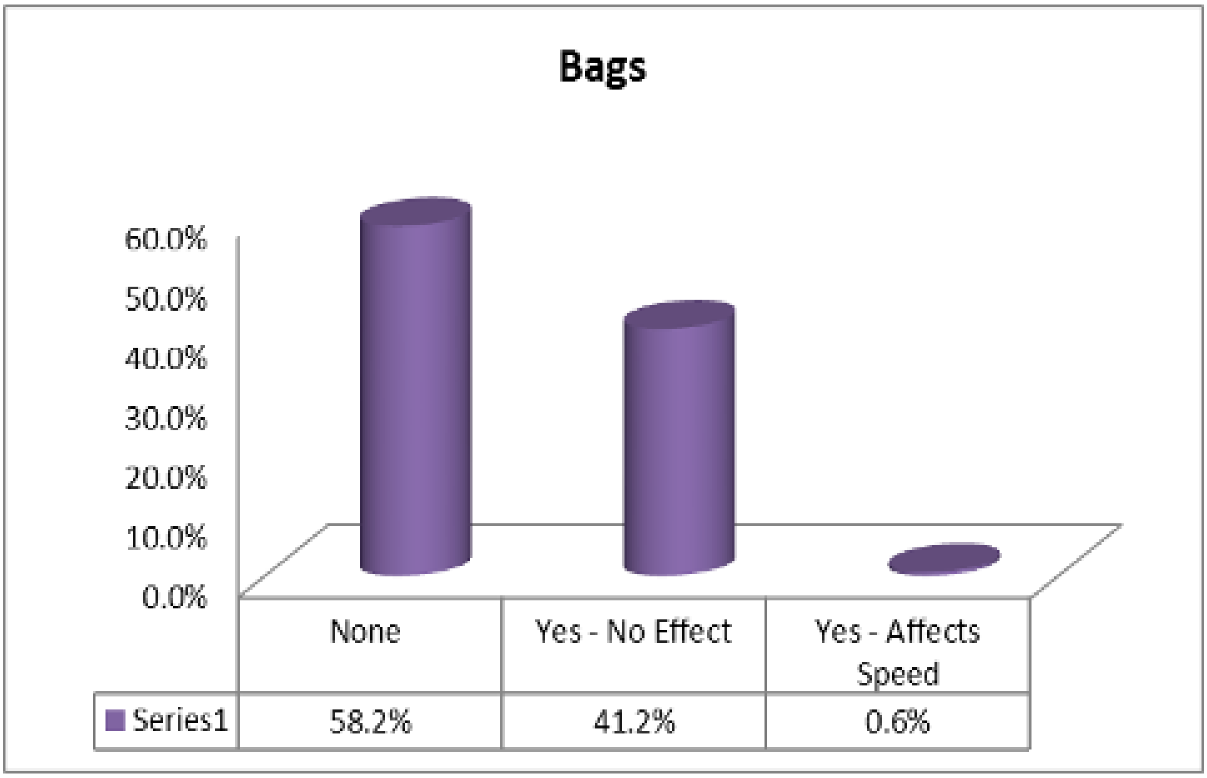


Figure 4-11: Distribution of Users by Baggage (Author, 2016)

Small luggage has little or no effects on walking speed. However medium to large luggage or trolley cases significantly reduce the speeds of pedestrians carrying them compared to those without luggage. According to Ye et al, small, medium, large luggage and trolley case reduce mean walking speed by 2%-3%, 5%-8%, 10-14%, and 3-8% respectively when compared to no luggage. The effects of luggage-carrying on pedestrian space is even more significant. From experimental observations, small luggage increases the pedestrian space occupation by 50-100%. Medium and large luggage increases pedestrian space occupation by 100-150% and 300-650% respectively (Ye et al., 2012).

4.4.7.2 Users carrying/operating Personal Items

The study shows that majority (91.3%) of those in the pedestrian stream do not carry personal items, while 8.1% were on phone calls, and another 0.4% on earphones. The distribution is shown in *Figure 4-12* below:

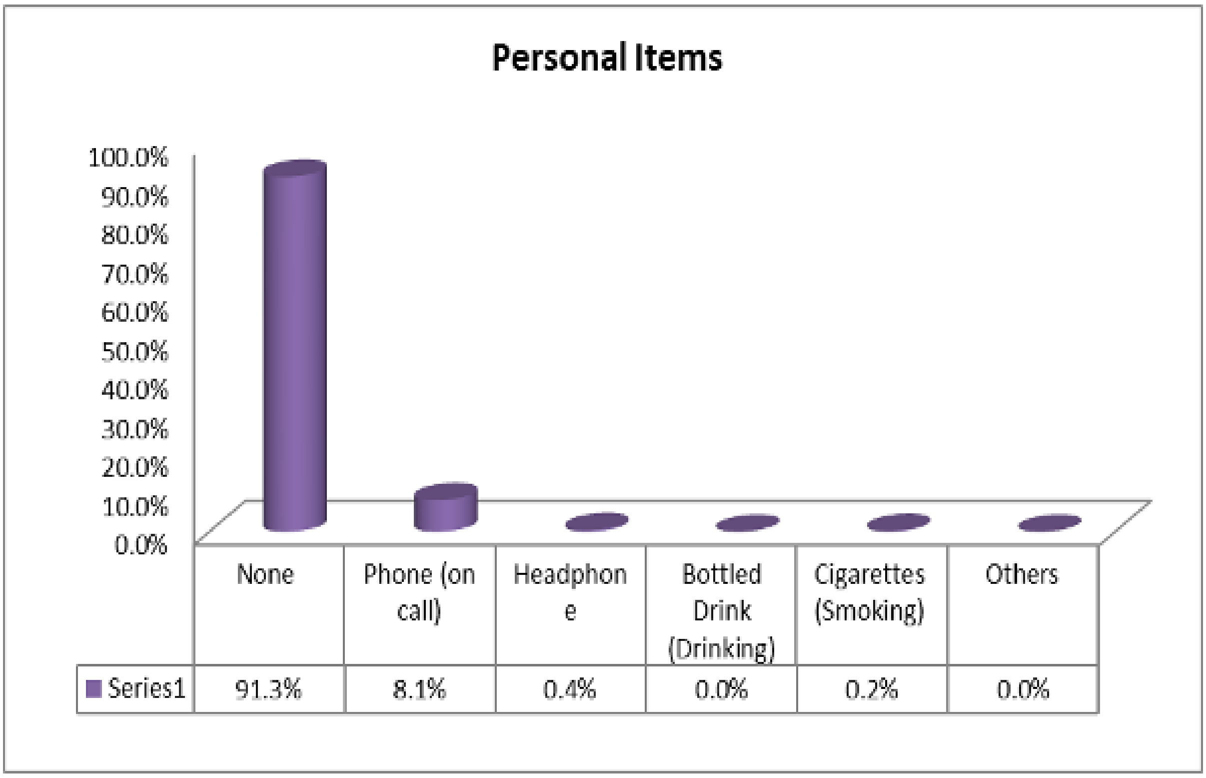


Figure 4-12: Distribution of Users by Personal Items Carried (Author, 2016)

Studies have established that the use of certain personal items such as mobile phones often distract the pedestrian, who tend to lower their natural speeds thus causing intermittent static obstruction, thereby reducing the overall flow in the pedestrian stream.

4.5 Trip Characteristics

4.5.1 Origins and Destinations of Users

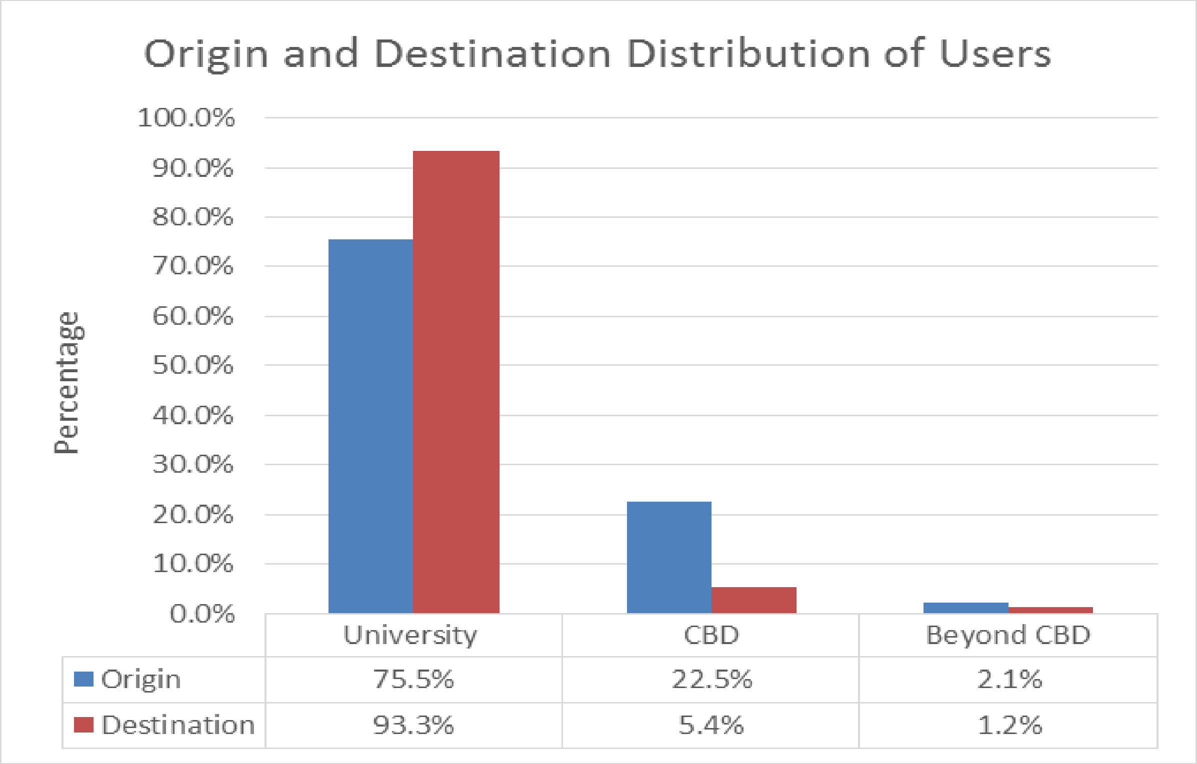
The origin – destination matrix for the survey is shown in the *Table 4-3* below.

Table 4-3: Origin - Destination Matrix for Users

	DESTINATION			
ORIGIN	*University*	*CBD*	*Beyond CBD*	*TOTAL*
University	347	16	0	363
CBD	102	0	6	108
Beyond CBD	0	10	0	10
TOTAL	**449**	**26**	**6**	**481**

From the study, about 75.5% of trips originated within the University, and almost 93.3% had the University as their destination. Of those starting or ending their trips at the University, 22.5% started within the CBD and 5.4% ended their trip within the CBD. Only 2.1% of the trips started beyond the CBD, while 1.2% had their destinations beyond the CBD.

The origin – destination profile of users is illustrated in *Figure 4-13* below.



	University	CBD	Beyond CBD
🟦 Origin	75.5%	22.5%	2.1%
🟥 Destination	93.3%	5.4%	1.2%

Figure 4-13: Origin and Destination Profile of Users

Local O – D survey is essential for establishing the travel pattern within a study area. The travel pattern within an area can be classified into through movements, external – internal movements, internal – external movements, and internal movements.

From this study, internal movements are dominant, and involve movements where pedestrians begin and end their walking trips within the neighborhood of the University. It is interesting to note that the University, and by extension the tunnel attracted more pedestrians than it generated by roughly17.8%. While the 75.5% internal movements represent the development traffic, the 17.8% external – internal movements represent the attracted traffic.

The development (generated), attracted and diverted traffic are all important in determining the future demand for a facility.

4.5.2 Trip Purpose

School based trips contribute almost half of the trips at 49.5%, followed by social trips (19.1%), transit (14.6%), work (10.6%), shopping (4.2%) and others (2.1%).

The distribution is shown in *Figure 4-14* below:

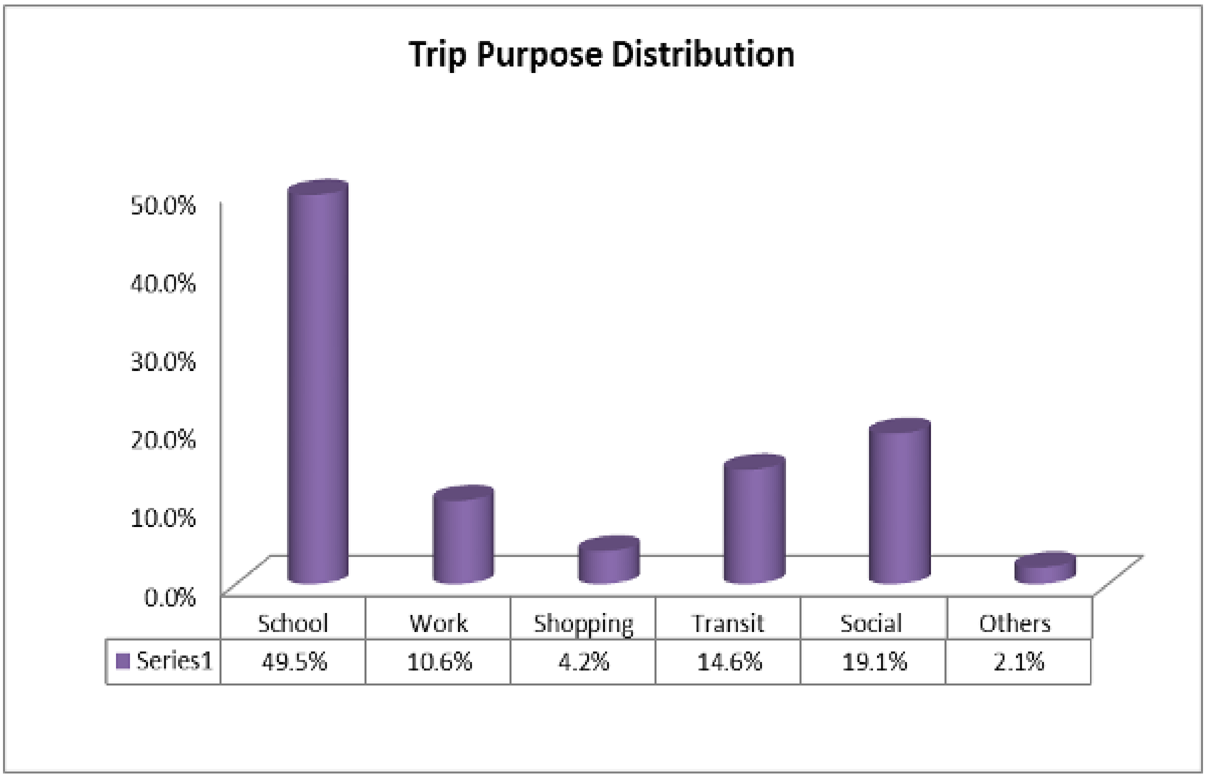


Figure 4-14: Distribution of Users by Trip Purpose (Author, 2016)

According to Kadiyali (2012), a trip is defined as a one-way person movement by one or more modes of travel, with two trip ends – the origin and the destination. These trips are divided into home based and non-home based trips. Home based trips have either their origin or destination at home, while non-home based trips have none. Some important trip purposes include work, school, business, social or recreational, transit and others.

Trip purpose is closely related to land use associated with trip origin and destination. The number of trips generated or attracted by an activity depends on its size and type. The predominant land use in the study area is institutional (29%), composed mainly of the University of Nairobi's administrative, tuition and health facilities. Residential facilities for the University occupy approximately 24%, while recreational and open spaces associated with the university constitute approximately 23% of the land uses. All land uses associated with the university contribute approximately 76% of the total land use. This explains the high number of school-based trips recorded.

Trip purpose has a fundamental impact on pedestrian traffic flow, and the overall performance of a pedestrian facility. As has been shown in the Highway Capacity Manual, users tend to adopt different speeds depending on trip purpose.

Figure 2-5 illustrates the relationship between speed and trip purpose, and the overall effect on flow.

The figure illustrates that within the bracket of fast moving and slow moving pedestrians, which could be composed of social trips, students (school trips) tend to walk at much higher speeds always, as opposed to shoppers who always tend to walk at the slowest speeds.

4.5.3 Trip Frequency

Most users (48%) make trips more than twice a day, followed by those who make trips twice a day (32%), occasional trip makers (14%), one trip a day (4%), and finally those rare trip makers (2%).

Figure 4-15 below illustrates the distribution of trip frequency by users.

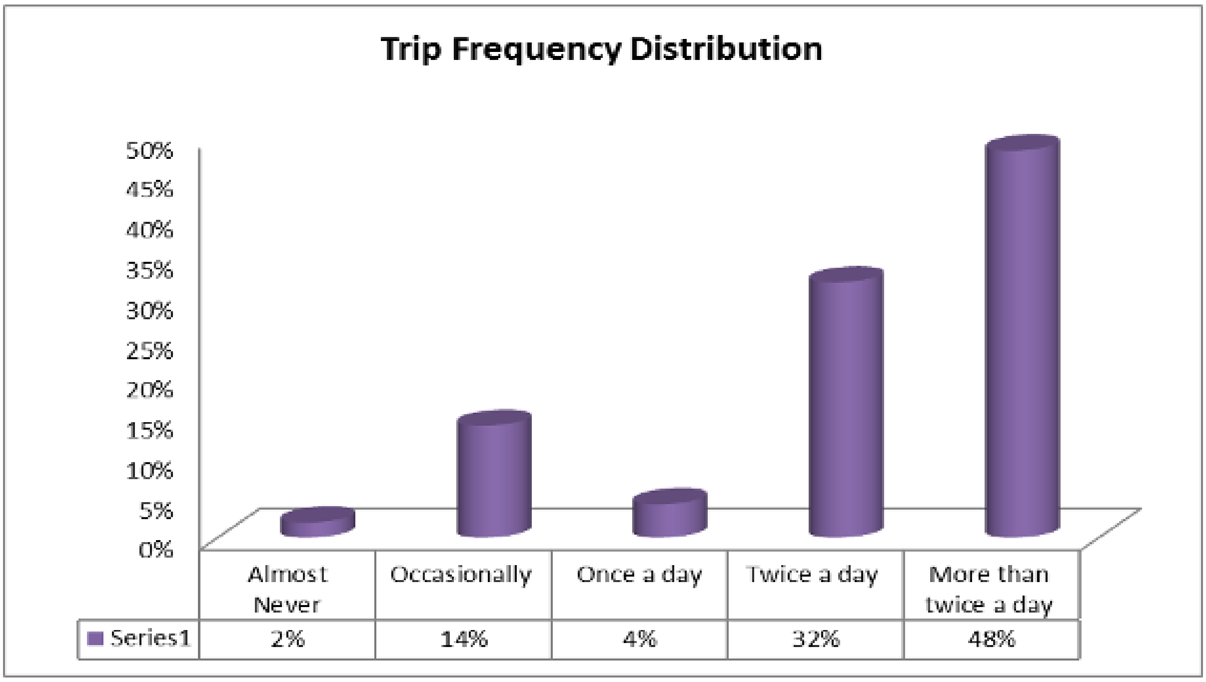


Figure 4-15: Distribution of Trip Frequency by Users (Author, 2016)

Trip frequency is closely related with trip purpose. In this study, school related trips closely ties with a frequency of more than twice a day, while insignificant trip purposes also ties with the rare trip frequency at 2%.

According to Mousavi (2012), work and school related trips are more likely to be more compared to the other trips. Findings on trip purpose and trip frequency confirm this.

4.5.4 Platooning

The study indicates very low level of platooning in the traffic stream, with 90.9% of pedestrians walking alone. 4.2% of pedestrians were walking in groups of two, while 3.5% were walking in groups of three to four. Those walking in groups of more than five pedestrians constituted only 1.5% of the pedestrians.

Figure 4-16 below illustrates the platooning profile of the pedestrian stream.

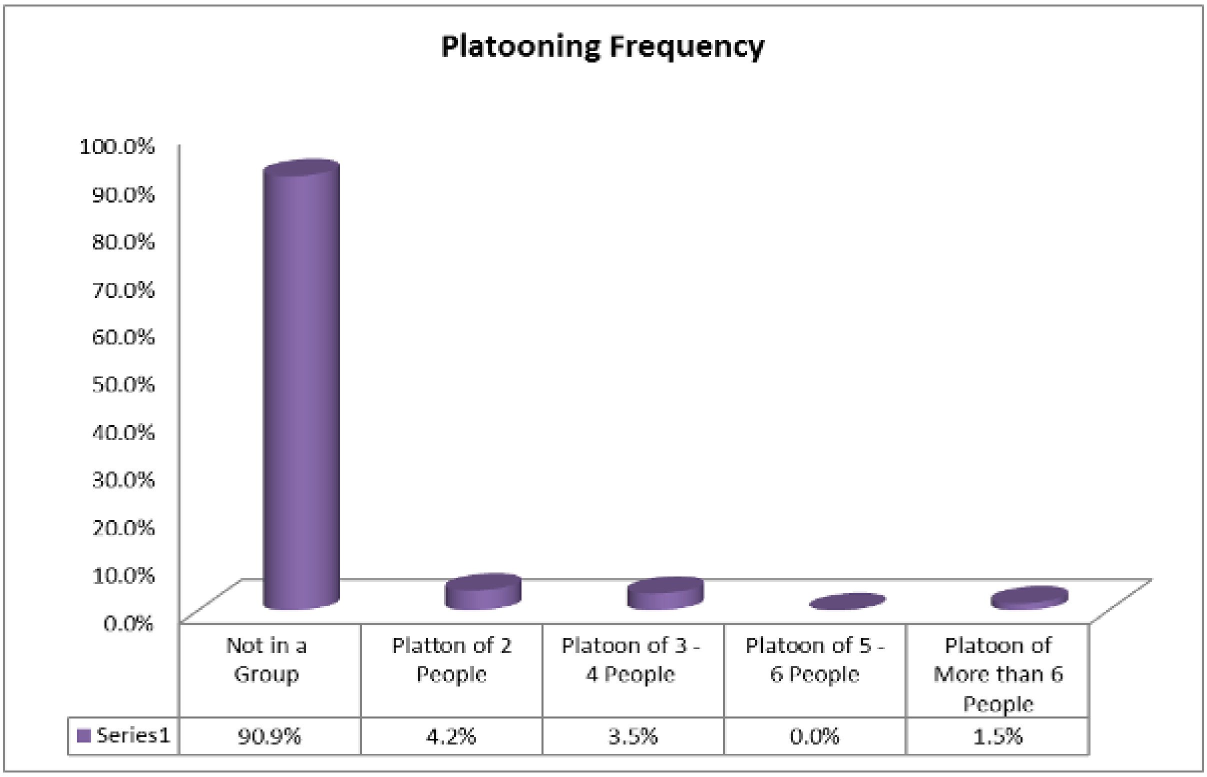


Figure 4-16: Platooning amongst Users (Author, 2016)

Platoon flow is defined as the grouping of pedestrians because of internal or external traffic impedances. Increasing behavioral uniformities exhibited in the adoption of a group speed and positioning arrangement characterize platoons. Platooning behavior will be exhibited by reduction in speed and the acceptance of smaller pedestrian space modules at a given speed (Davis & Braaksma, 1987).

According to Davis and Braaksma (1987), designers use the following methods to account for platooning;

a) The Rule of Thumb method which considers that the LOS in platoon situation is approximately one LOS lower than the average flow LOS;
b) The Adjustment factors Ratio, which computes platoon flow to average flow, ranging between 1.1 to 1.6;
c) The Additive Adjustment, which increases average flow by 13.1ped/min/m of effective width to determine platoon flow.

The overall effect of platooning on either the speed or the flow is the reduction in LOS.

In this study, the extent of platooning in the pedestrian stream is considered minimal, hence insignificant effect on the overall speed or flow.

4.5.5 Difficulties in Trip Making/Impedance

From the study, 86% of the respondents indicated that they were not experiencing any impedance. 14% of all pedestrians interviewed indicated that other pedestrians impeded them.

The situation is shown in *Figure 4-17* below.

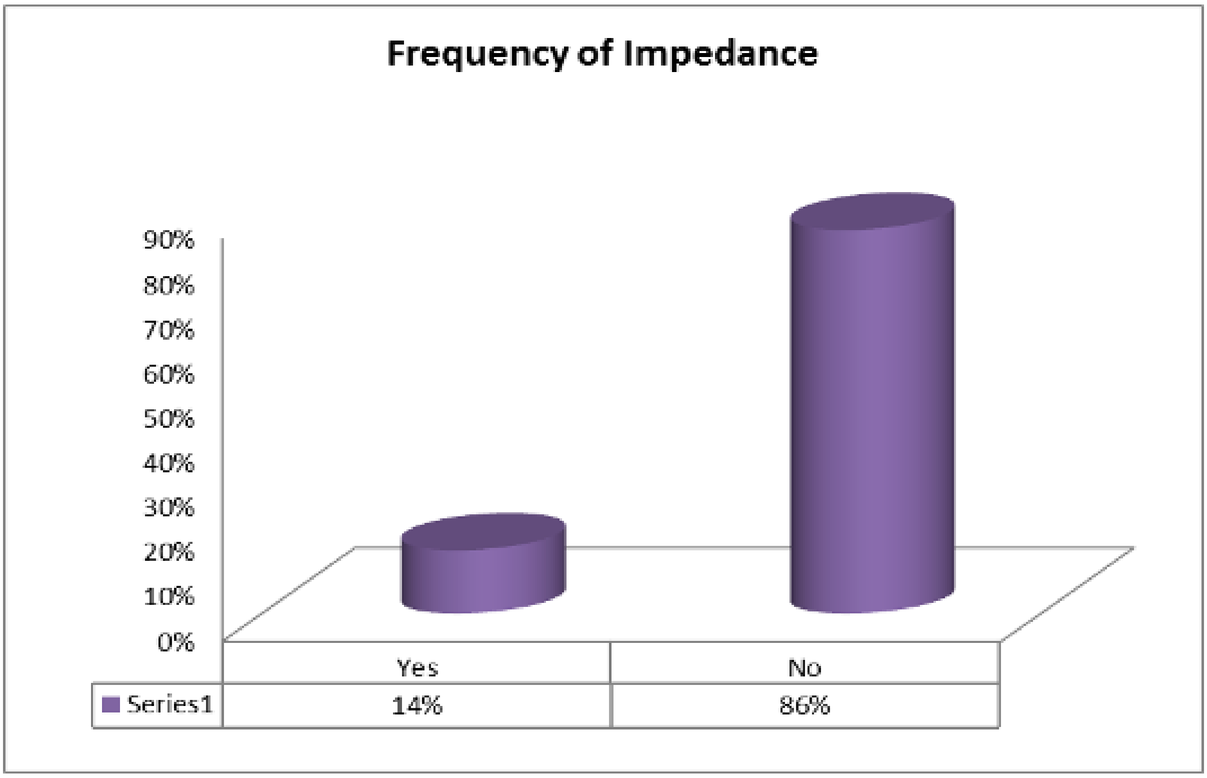


Figure 4-17: Frequency of Impedance to Pedestrian Movement (Author, 2016)

Impedance is defined as the pedestrian being involuntarily slowed by conditions on the sidewalk. Impedance is negatively correlated with mean speed and positively correlated with flow rate. In other words, when a location's overall mean speed increases, the proportion of impeded pedestrians at that location decreases (New York City, 2006).

In this study, the extent of impedance in the pedestrian stream is considered minimal, hence insignificant effect on the overall speed or flow.

4.6 Tunnel Usage vis-à-vis Alternatives

4.6.1 Extent of Usage of the Tunnel

The study shows that 59% of the respondents use the tunnel compared to 38% who use the signalized crosswalk at the University Way Rotary Junction. Jaywalkers constitute 3% of the respondents.

Figure 4-18 below shows the distribution of usage of the available crossing options.

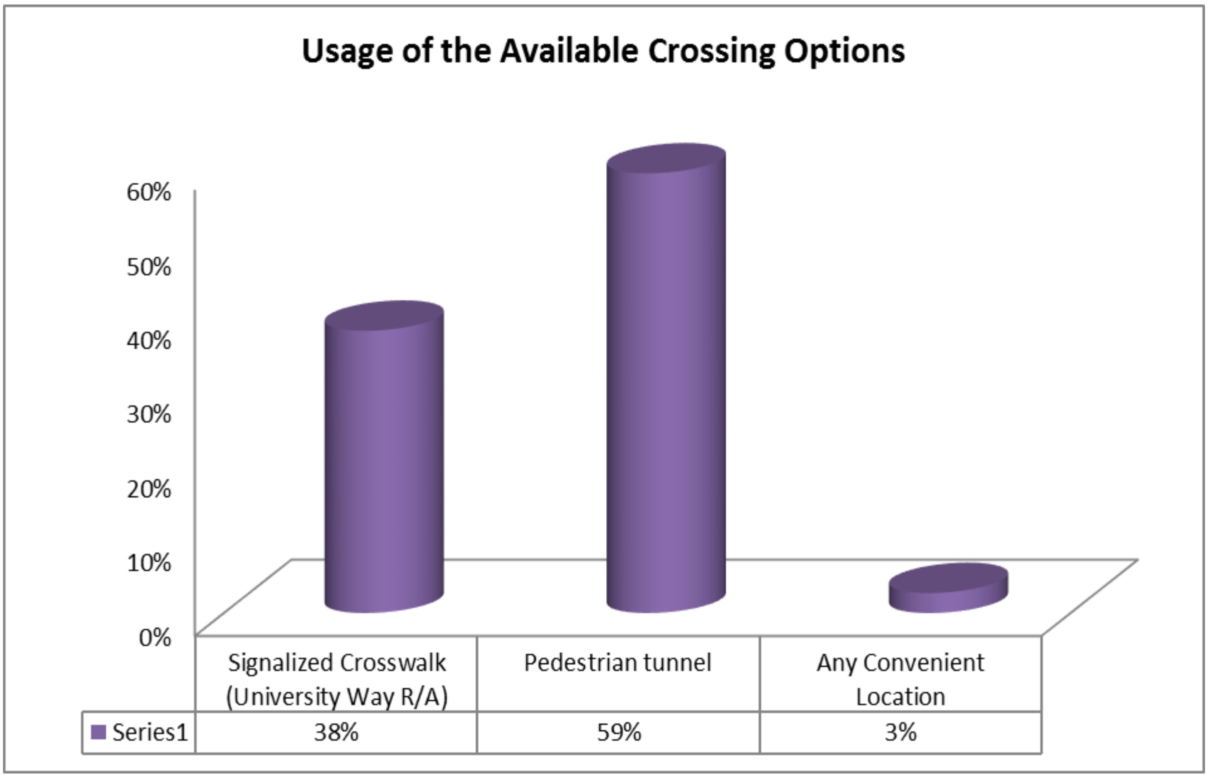


Figure 4-18: Distribution of Usage of the Available Crossing Options by Users (Author, 2016)

The location of GSPC in relation to other crossing alternatives has a major impact on its degree of use. Studies have shown that the GSPC will not be used merely because it guarantees safety of users. Pedestrians will mentally weigh the perceived safety benefits derived from the GSPC use with the extra effort required.

A study by Moore and Older (1965) shows that effectiveness of GSPCs depend upon the perceived effort and time to use it. It defines a convenience factor denoted R, as the ratio of time taken to travel on the GSPC to the time taken to travel at-grade. According to the study, 95% of pedestrians are likely to use underpass while 70% are likely to an overpass if the Convenience Factor R = 1 (zero time difference). However, no pedestrian would use the overpass if R = 1.5, implying 50% time difference in favor of at-grade crossing.

The relationship is shown in *Figure 4-19* below.

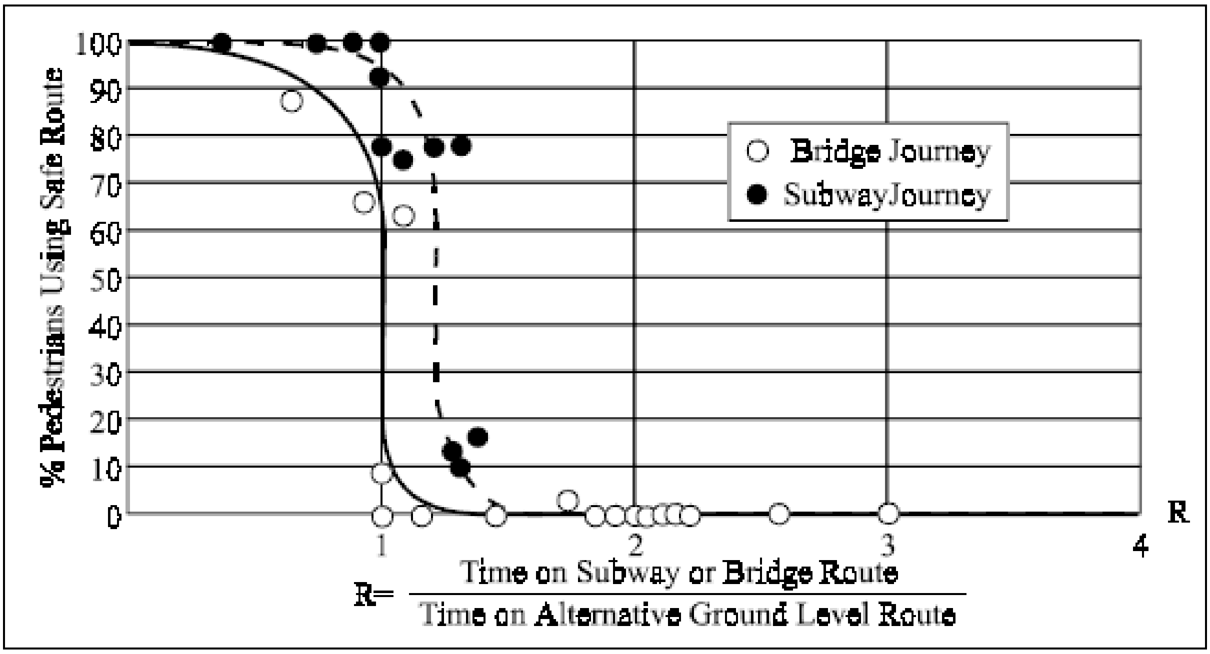


Figure 4-19: Pedestrian Use of GSPC (Turner & Carlson, 2000)

Other studies also have shown that pedestrians would more likely use GSPC if the elevation change can be minimized or maintained at the existing level of pedestrian movement.

From the study, the average, minimum and maximum Convenience Factors for the Tunnel are 0.16, 0.12 and 0.19 respectively.

The data is illustrated in *Table 4-4* below.

Table 4-4: Convenience Factor, R for the Tunnel

	Average Crossing Time using the Tunnel (Mins)	Crossing At – Grade			R
		Waiting Time (S)	Crossing Time (S)	Total Time (Mins)	
Average	0.54	187	16	3.37	0.16
Min	0.44	155	12	2.86	0.12
Max	0.58	216	18	3.90	0.19

The study shows that it is much easier to cross the highway using the Tunnel compared to crossing at-grade. Coupled with the unsafe conditions, it is a paradox that such a high percentage of pedestrians opt to cross at-grade. It can be deduced that this population represents revealed demand for the tunnel, the potential users who are driven away by one or more factors.

4.6.2 Frequency of Usage of Alternatives

From the study, 45% respondents use the alternative crossing facility sometimes, 20% almost always, 20% rarely, 11% often and 3% never.

Figure 4-20 below illustrates the frequency of usage of alternative crossing facilities by users.

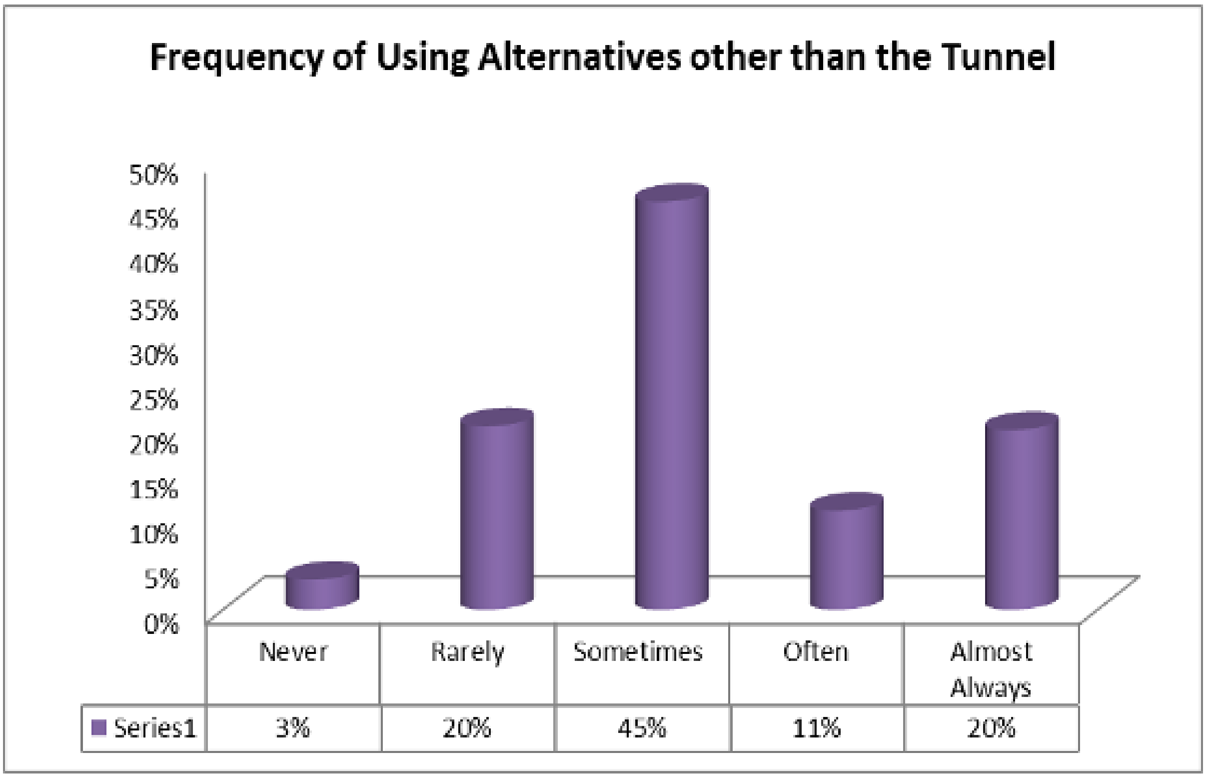


Figure 4-20: Frequency of Usage of Alternative Crossing Facilities (Author, 2016)

Save for the 20% that uses the alternative crossing almost always, and the 3% that never uses the alternative entirely, the remaining segment of users accounting for approximately 77% are potential users.

The 20% segment most likely represent users whose trip desire line is far removed from the tunnel. Student's hostels such as Hall 13, women's Hostels (Box) and Stela Awinja; Lecturer's Quarters; YWCA Hostels; and ADD Block are some of the trip generators / attractors that contribute to this segment of users.

It is therefore safe to estimate that any facility at the current location would take approximately 77% of the entire population of users. Compared to the 59% currently using the tunnel, it can be deduced that the revealed demand is actually approximately 18% of the population.

4.7 User Perceptions

4.7.1 Reasons for Non-Usage of the Tunnel

The questions were fashioned on the basis of E-LOS requirements for a facility namely continuity, directness, security and comfort and attractiveness. 40% of the respondents indicated that they do not use the tunnel due to insecurity, followed by those that deemed the tunnel to be out of their desire line (24%), filthy and waterlogged during rainy season (17%), lack of accessibility and connectivity (7%), congestion and lack of capacity (6%), difficult to use (4%), and finally other considerations (2%).

The response is illustrated in *Figure 4-21* below.

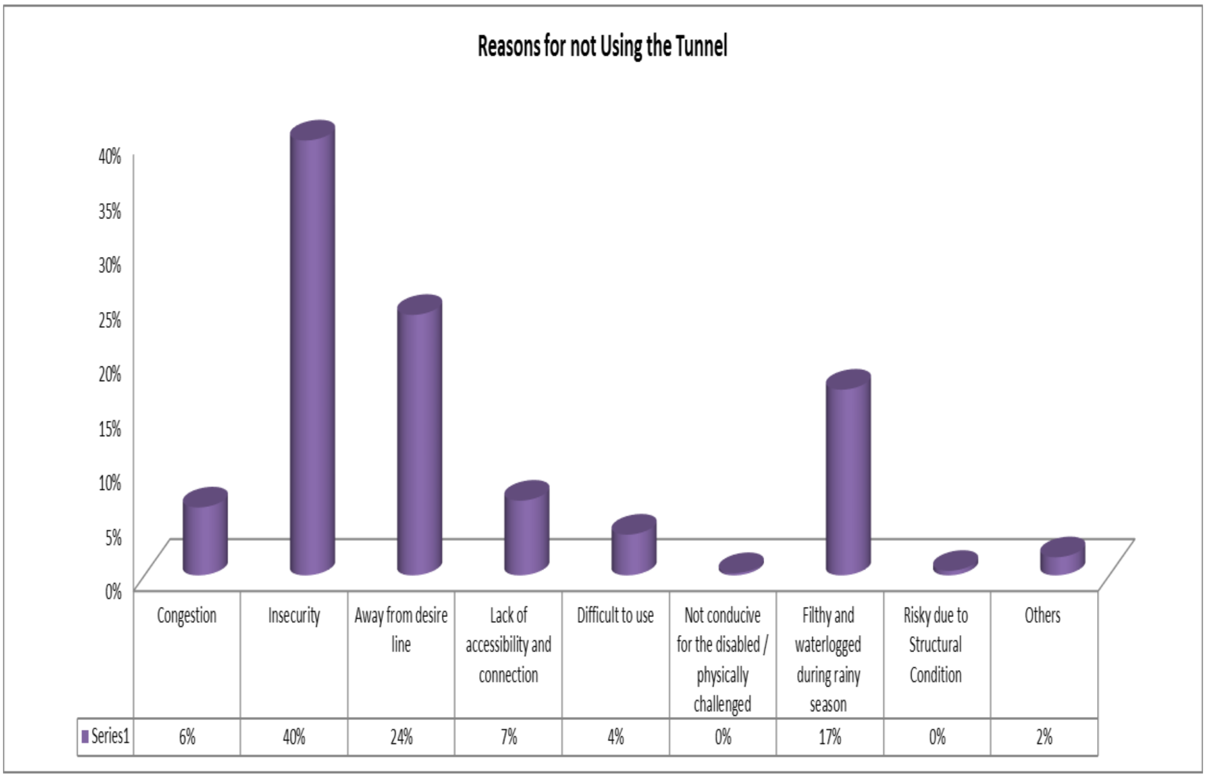


Figure 4-21: Reasons for non-usage of the Tunnel (Author, 2016)

The study shows that a large proportion (40%) of users shy away from the tunnel due to perceptions of insecurity. The perception of security at a pedestrian facility is a factor of the good lighting both inside and outside, presence of other users, visibility from adjacent facilities / areas, and clear sight lines. As has been widely discussed, the following conditions are the main contributors to perceptions of insecurity at this facility:

a) Dark conditions due to poor/absence of artificial lighting, both inside and outside the tunnel;
b) Poor visibility from the spatial landscape to the tunnel entrances due to the sunken / depressed elevation of the tunnel, creating a "Black Hole Window" effect, a phenomenon which describes a dark tunnel located in space;
c) Lack of inter-visibility between the entrances which, which induces a "tunnel effect", a feeling associated with claustrophobia;
d) Light/dark contrast or "Black Frame" impact inside the tunnel due to lack of synchronization of lighting within the tunnel;
e) The tunnel is isolated from the built environment, a situation that elicits the feeling of a facility in "no-man's land";
f) Lack of Maintenance: The bushy adjacent environment evokes feeling of dereliction and insecurity;
g) Absence of Active Uses: There exist no activities at the facility, which would attract more users, thereby creating a "lonely" and insecure facility.

The 24% of users who indicated that the tunnel is not aligned with their desire line is consistent with the existing land uses as well as the findings regarding the usage of alternative crossing facilities.

The next significant segments are the users who avoid the tunnel due to filthiness and poor drainage during rainy seasons (17%). This statistic is also consistent with the physical / environmental assessment, where open manholes and catch sumps filled with filth and debris, and flooding within the tunnel box and the entrances were observed.

Lack of accessibility and connectivity contributes 7% of non-usage. It can be deduced that this segment represents students residing in State House Hostel, which has no direct link to the main pedestrian route that links through the tunnel under consideration.

From user perceptions, it is clear that the main reasons for non-usage of the tunnel are related to E-LOS, contributing approximately 92%. Operational discomfort, or congestion contributes a paltry 6%.

4.7.2 Willingness to Use the Tunnel among Pedestrians

The study enquired from the respondents their willingness to use the tunnel should their concerns be addressed. 42% indicated that they would use the tunnel sometimes, followed by those who would rarely use it (28%), those who would use it often (17%), those who would always use it (10%), and finally those who would never use it (2%).

The situation is illustrated in *Figure 4-22* below.

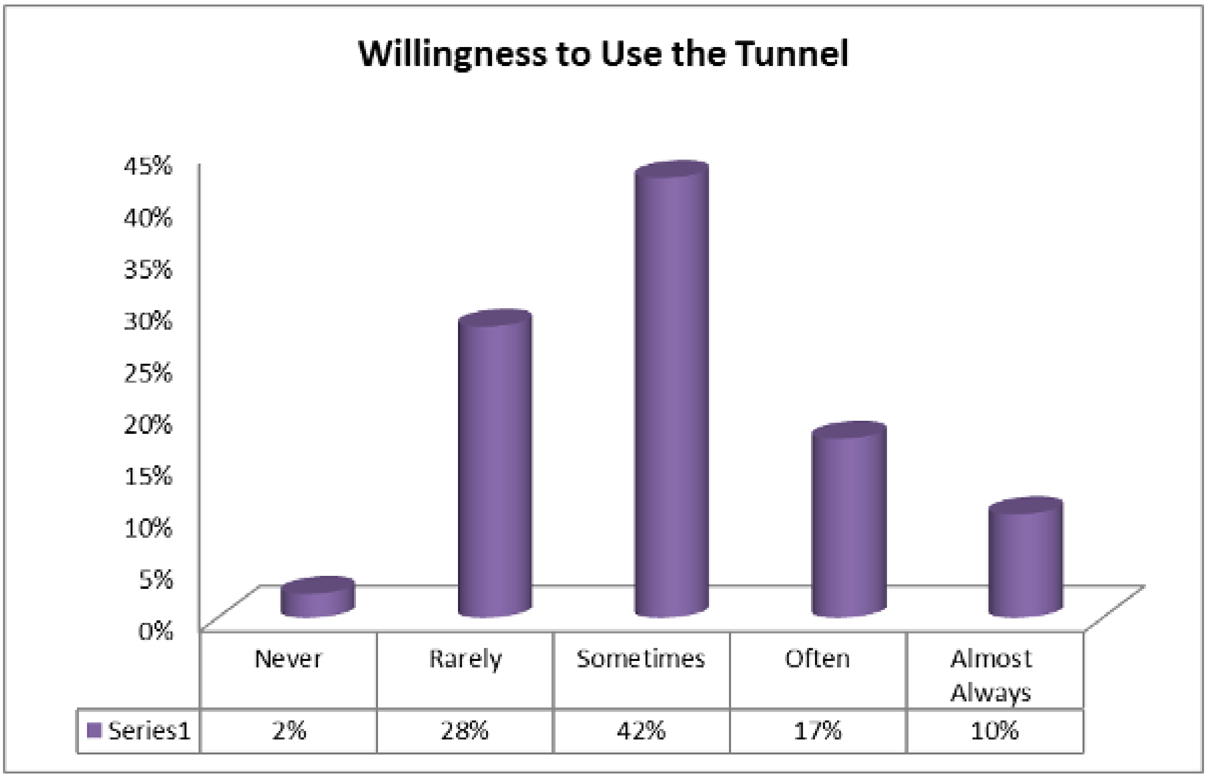


Figure 4-22: Willingness to use the Tunnel among Pedestrians (Author, 2016)

From the study, 69% of the respondents who indicated sometimes, often an always actually represent the actual demand. This is consistent with the findings regarding reasons for non-usage, frequency of usage of alternative crossings and the extent of usage of the pedestrian tunnel.

4.7.3 Desired Treatments

From the study, a massive 61.5% of the respondents prioritized installation of lights to improve security, followed by 23.5% who preferred improvement of the drainage. Only 5.2%

prioritized expansion to increase capacity, same as those who preferred cleaning and maintenance (5%).

The position is illustrated *Figure 4-23* in below.

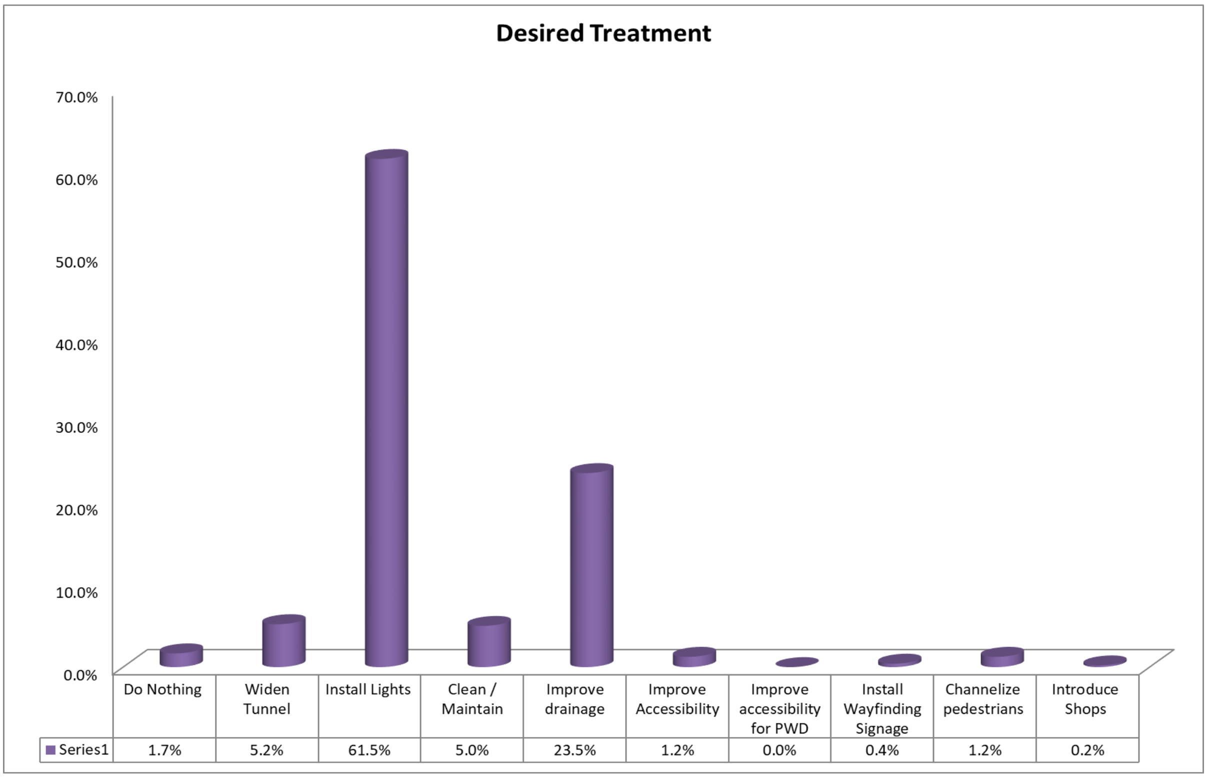


Figure 4-23: Desired Treatments by Users (Author, 2016)

This statistic is consistent with the findings on reasons for non-usage, where insecurity was cited as the major reason, while poor drainage filthiness contributed a significant proportion at 17%. Again, expansion / widening of the tunnel, which represents improvement in the operational comfort contributes and insignificant 5.2%, meaning that congestion is not a concern to users.

4.8 Characterization of the Environmental Level of Service (E-LOS)

Table 4-5 below illustrates the characterization of the E-LOS for the Tunnel based on the recommendations of Fort Collins Pedestrian E-LOS.

Table 4-5: Adjudged E-LOS for the Tunnel

E-LOS Parameter	Adjudged E-LOS	Justification
Connectivity (Directness, Continuity and Accessibility)	C	▪ Minimum acceptable connectivity between majority of origins (hostels) and destinations (Administration / Tuition / Library); ▪ The ratio of actual distance to measured distance (A/M) ranges between 1.4 for Mamlaka and Lower State House areas, to 1.5 for Halls 12, 13 and Women's Hostel (Box) areas; ▪ Less coherent urban space with little visual clarity between the origins and destination, and complete lack of linearity. ▪ Continuous pedestrian network between origins and destinations, composed of footpaths and sidewalks; ▪ Grade separated pedestrian crossing facilities on major roads such as State House Road and Uhuru Highway; ▪ Fair quality network, characterized by uneven and irregular pavement surface, slippery tunnel floor, and high gradient ramps; ▪ Lack of consideration for pedestrians with disabilities;
Security	F	Total discomfort and intimidation, needs of users not taken into account, as witnessed by: ▪ Darkness, even during daylight; ▪ Poor visibility from the spatial landscape; ▪ Poor inter-visibility between the entrances due to darkness and light / dark contrasts; ▪ Isolation of the tunnel from built environment; ▪ Lack of maintenance; ▪ Absence of active uses, hence no people; ▪ Absence of policing.
Visual Appeal and amenity	F	Unpleasant walking environment due to: ▪ Unpleasant streetscape due to lack of landscaping and beautification such as fountains; ▪ Absence of public art such as mosaics, murals and paintings;
Convenience	E	▪ Dirty and desolate seats along a short stretch of the walkway; ▪ Plain tunnel walls with poor coat of paint and ugly graffiti; ▪ Cracked and misaligned retaining walls; ▪ Bushy environment due to lack of maintenance; ▪ Poor drainage leading to flooding; ▪ Lack of way finding facilities such as pedestrian signage and street furniture; ▪ Irregular and cracked pavement surfaces; ▪ Slippery tunnel floor; ▪ Dilapidated and filthy entrance drainage sumps with broken covers; ▪ Rough, dirty and exposed drainage pans within the tunnel; ▪ Narrow tunnel with low clear height; ▪ Hawkers vending on the walkways.

4.9 Determination of Tunnel Effective Width

The fixed obstacles in this case are the culvert walls on either side. According to the HCM 2010, the width adjustment for walls above 1m tall is 0.5m. The TCQSM recommends a shy distance of 0.5m for all forms of obstacles. The actual tunnel width is 2.2m.

From the above and using Equation 2.3, the effective width in meters is calculated as follows:

$$W_E = 2.2 - 2(0.5) = 1.2.$$

4.10 Pedestrian Volume Analysis

Peak pedestrian counts were conducted for three (3) different working days, and one (1) weekend. The pedestrian volume data is shown in *Appendix 2*.

The volume data is shown in the *Table 4-6* below:

Table 4-6: Pedestrian Volume Data

	Tue Mar. 1, 2016		**Wed Mar. 2, 2016**		**Fri Mar. 4, 2016**		**Sat Mar. 5, 2016**	
Time Interval	V_{15}	V_{60}	V_{15}	V_{60}	V_{15}	V_{60}	V_{15}	V_{60}
0700 – 0715	65	720	66	732	63	659	26	238
0715 – 0730	86		116		83		38	
0730 – 0745	219		193		178		76	
0745 – 0800	350		357		335		98	
0800 – 0815	353	730	303	792	261	671	146	428
0815 – 0830	136		169		195		89	
0830 – 0845	117		141		103		120	
0845 – 0900	124		179		112		73	
1200 – 1215	159	829	190	866	139	845	101	468
1215 – 1230	173		207		198		94	
1230 – 1245	227		233		191		96	
1245 – 1300	270		236		317		177	
1300 -1315	255	1,251	362	1,689	216	1,182	137	755
1315 – 1330	244		245		287		127	
1330 – 1345	269		490		187		182	
1345 – 1400	483		592		492		309	
1600 – 1615	344	1,313	240	1,444	226	1,078	107	627
1615 – 1630	295		324		341		151	
1630 – 1645	316		394		239		237	
1645 – 1700	358		486		272		132	
1700 -1715	436	1,541	632	1,380	315	1,265	105	452
1715 – 1730	492		266		465		155	
1730 – 1745	396		349		270		122	
1745 – 1800	217		133		215		70	

The average, minimum and maximum 15-minute volumes for each study day are shown in *Table 4-7* below.

Table 4-7: Average, Maximum and Minimum 15-Min Pedestrian Volumes

Parameter	**Date and Day**			
	Tue March 1, 2016	***Wed March 2, 2016***	***Fri March 4, 2016***	***Sat March 5, 2016***
Average V_{15}	266	288	238	124
Minimum V_{15}	65	66	63	26
Maximum V_{15}	492	632	492	309

4.10.1 Time of Day Variations

It is shown from *Figure 4-24* below that evening peak periods recorded significantly higher volumes followed by midday and morning peaks in that order.

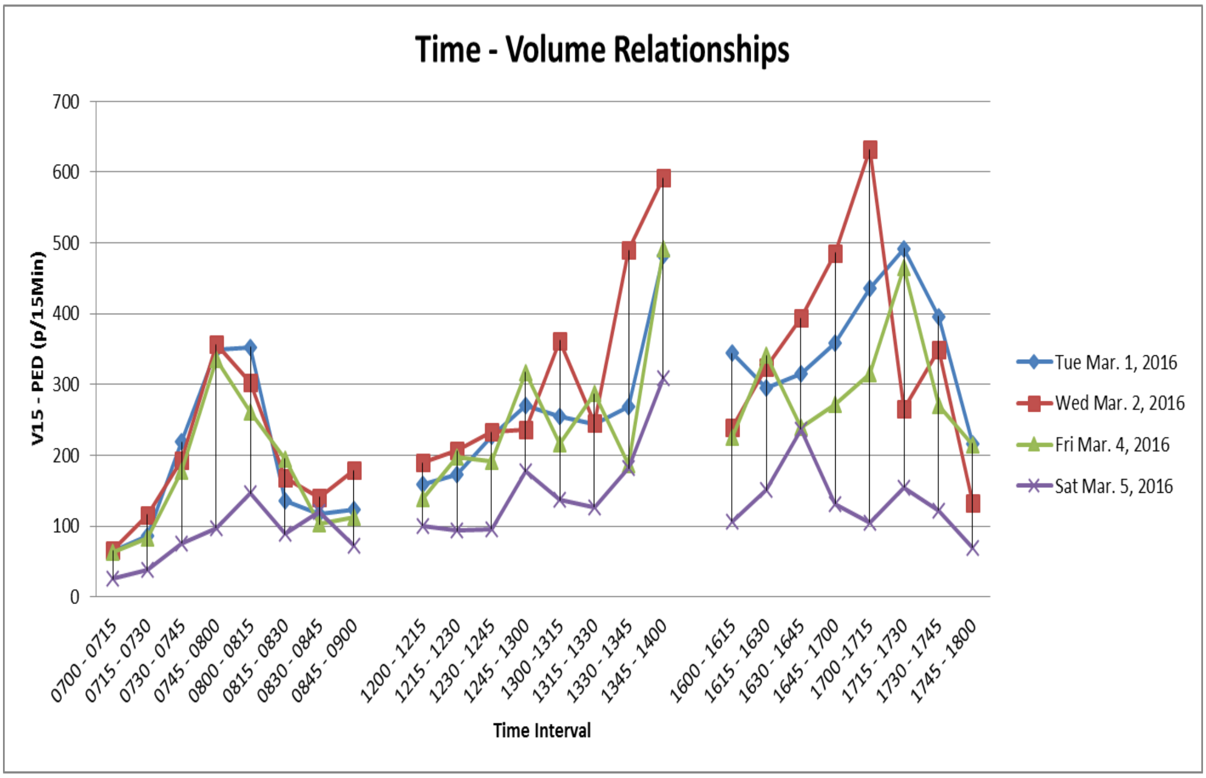


Figure 4-24: Time - Volume Relationships (Author, 2016)

Traffic changes as the day progresses, for example, traffic volumes increase during the day and decrease at night. This behavior is represented in a time-of-day pattern, where different patterns can exist within different places (Miranda & Carrasco, 2011).

4.10.2 Daily Variations

Figure 4-24 shows that weekday pedestrian volumes compare, though volumes experienced on Wednesday were marginally higher than the other weekdays. Low volumes were generally recorded on Saturday (weekend). This is attributable to the predominant land use, which is institutional.

According to Roess, et al., 2011, “daily variation patterns are caused by the type of land uses and trip purposes”. Patterns will differ during the week, mainly because the different alternatives activities that can be done in a week; for instance pedestrians will go more often to shops on weekends in contrast with weekdays when most of them are working, running errands or at school. Day-of-week patterns will also vary with land use.

In this study, trip making was principally influenced by school going, which is the predominant activity. Weekend trip making is lower than weekdays since only limited tuition takes place over the weekend. However, the weekends experience higher levels of recreational activities.

4.10.3 Monthly / Seasonal Variations

According to Roess, et al. (2011), volume patterns will vary during the year according to each season.

In this study, volume is highly dependent on the school calendar, and occasional activities like graduation ceremonies and public functions.

4.10.4 Directional Variations

Most streets exhibit differences in flow by direction. In this study, peak traffic is Eastbound during the morning peak (from home to tuition blocks). However, both afternoon and evening peaks are fairly balanced. This is attributable to variances in tuition periods for various courses.

4.10.5 Volumes within the Hour – Demand Versus Capacity

The highest weekday volume (632p/15min) was recorded on Wednesday evening peak between 1700 – 1715hours, while the lowest (63p/15min) was recorded on Thursday morning peak between 0700 – 0715hours. The highest weekend volume (309p/15min) was recorded during the midday peak between 1345-1400hours while the lowest (26p/15min) was recorded during the morning peak between 0700 – 0715hours.

In traffic engineering, volume studies are most of the time needed, for example to measure demand or usage of pedestrians. Roess *et al*. (2011), has defined the variables related to volume as follows:

- Pedestrian Volume is defined as “the number of persons passing a point during a specified time period”;
- Demand is defined as “the number of persons that desire to walk past a point during a specified period of time”
- Capacity is defined as “the maximum flow rate at which pedestrians can traverse a point or a short segment during a specified period of time under stable conditions”.

▪

The relationship is illustrated in *Figure 4-25* below.

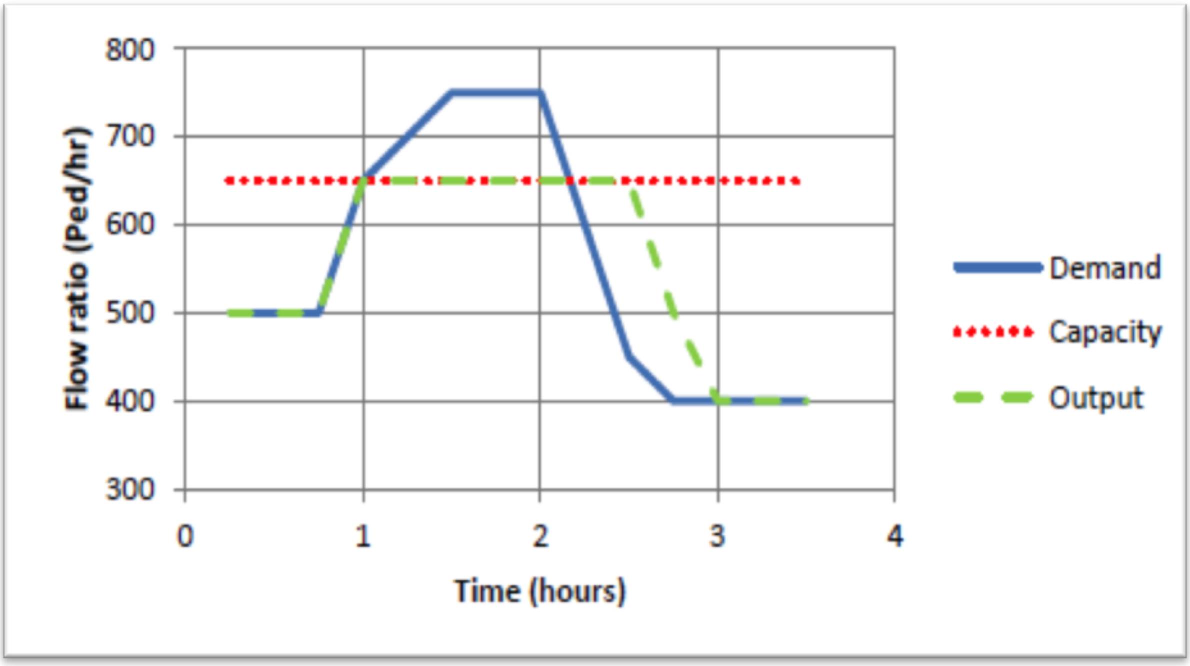


Figure 4-25: Demand and Capacity Relationship (Miranda & Carrasco, 2011)

According to Roess et al. (2011), the following can be deduced from the demand – capacity relationship:

- The volume cannot rise above capacity;
- The actual pedestrian counts peak at capacity. The consequence is a lengthened peak period of flow until all pedestrians shall have traversed the point. The pedestrian counts show that peak flow rate is approximately the same as capacity, and that it occurs over an prolonged period of time;
- The output reflects how the demand is delayed in time.

According to Miranda & Corrasco (2011), volume proportion patterns will be the same even though actual volumes can change in a specific location, unless the site is drastically modified. Garber & Hoel (2002) stated that “regular observation of traffic volumes over the years has identified certain characteristic showing that although traffic volume at a section of a road varies from time to time, this variation is repetitive and rhythmic”.

The demand is not a constant value; it changes together with the time (for instance time of day, week, month or year). Moreover, it can be influenced by external factors (planned or unplanned) such as accidents, occasional events, detours, or even by the weather (Roess, Prassas, & McShane, 2011).

Even though there seems to be no queue at the tunnel, it can be concluded that the tunnel is not serving the actual true demand, considering that a subtantial proportion of pedestrians have diverted to the alternative crossing at the University Way rotary Intersection.

4.11 Pedestrian Speed Analysis

Peak pedestrian speed data were collected for three (3) different working days, and one (1) weekend. The pedestrian speed data is shown in *Appendix 3*.

The mean, minimum and maximum speeds recorded, and standard deviation for both weekday and weekend speeds are shown in *Table 4-8* below.

Table 4-8: Summary of Statistical Analysis of Speed Data

	Date & Day			
Parameter	*Tue Mar. 1, 2016*	*Wed Mar. 2, 2016*	*Fri Mar. 4, 2016*	*Sat Mar. 5, 2016*
Mean Speed (m/s)	1.31	1.35	1.34	1.33
Min. Speed (m/s)	1.18	1.20	1.22	1.22
Max. Speed (m/s)	1.52	1.44	1.50	1.52
Standard Deviation	0.097	0.055	0.065	0.081

From the study, there is no significant difference in mean, minimum and maximum speeds for weekdays and weekends. The mean speed vary from 1.31 – 1.35m/s for the different days. The minimum and maximum speeds observed were 1.18m/s and 1.52m/s respectively.

The mean speeds observed in this study compare well with those quoted by various authors as shown in *Table* 4-9 below.

Table 4-9: Comparison of Mean Speeds observed from Literature (Daamen & Hoogendoorn, 2006)

Source	*Mean Speed (m/s)*	*Location*
Crow	1.4	Netherlands
FHWA	1.2	United States
Fruin	1.4	United States
Handerson	1.44	Australia
ITE	1.2	United States
Navin and Wheeler	1.32	United States
O'flaherty and Parkinson	1.32	United Kingdom
Older	1.3	United Kingdom
Sarkar and Janardhan	1.46	India
Tanariboon et al.	1.23	Singapore
Tanariboon and Guyano	1.22	Thailand
Lahm et al.	1.19	Hong Kong
Lahm et al.	1.25	Sri Lanka
Moral et al.	1.4	Canada
Koushki	1.08	Saudi Arabia

Figure 4-26 below shows the hourly and daily variations in speeds during peak periods.

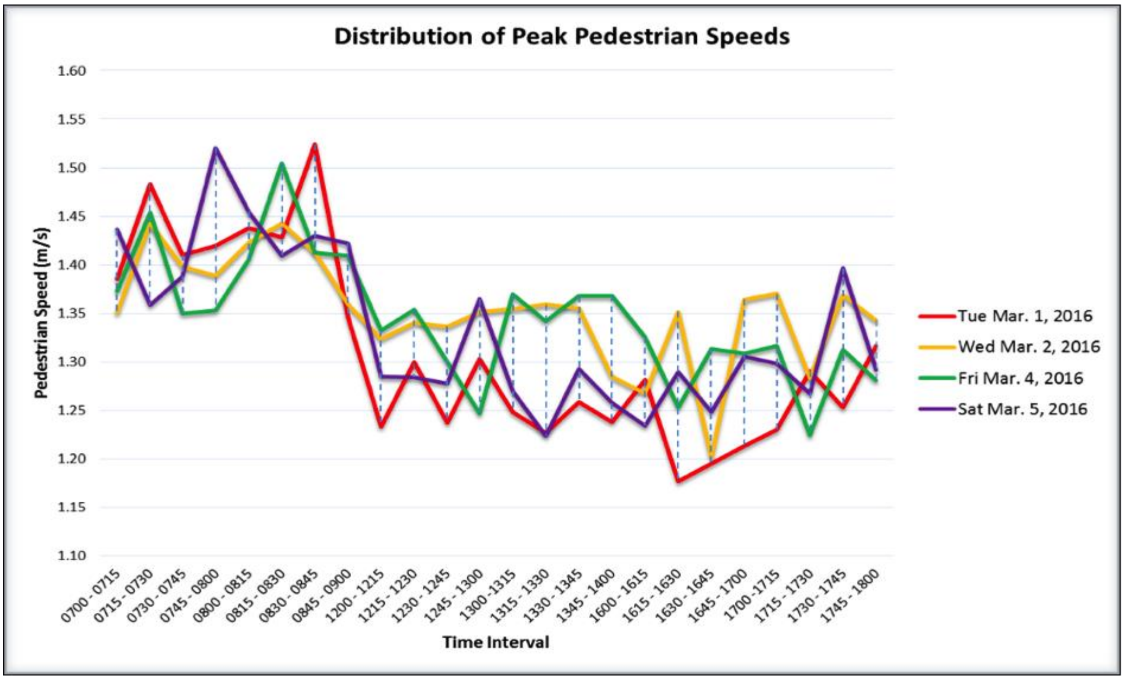


Figure 4-26: Distribution of Peak Pedestrian Speeds for Weekdays and Weekends (Author, 2016)

It shows that morning peak periods recorded significantly higher speeds compared to both midday and morning peaks, which are relatively the similar. The daily distribution of peak speeds exhibit similar pattern for both weekdays and weekends.

From the cumulative frequency distribution curve shown in *Figure 4-27* below, it can be observed that the walking speeds are normally distributed, with 68% of pedestrians walking at speeds ranging between 1.25m/s – 1.42m/s, while 99% walked at speeds ranging between 1.18m/s – 1.49m/s. A measly 1% walked at speeds below 1.18m/s or above 1.49m/s.

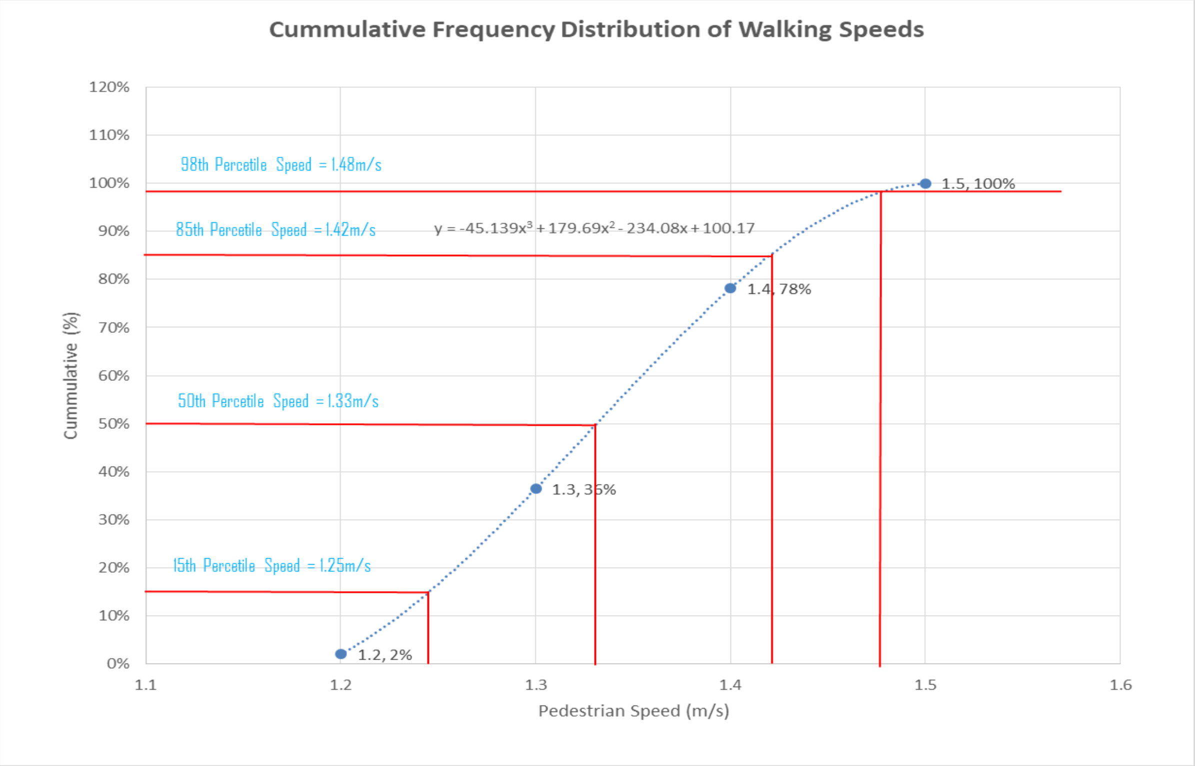


Figure 4-27: Cumulative Frequency Distribution of Walking Speeds

Other than density, it has been established that pedestrian speeds are correlated with a wide range of other conditions, including pedestrian age, sex, disabilities, trip purpose and environmental factors. Walking speeds decline with age, more so beyond 65 years. However, it has been shown that, but healthy elderly persons are capable of increasing their walking speed by 40% for short distances.

The impacts of gender and age on pedestrian speed is illustrated in *Figure 4-28* below:

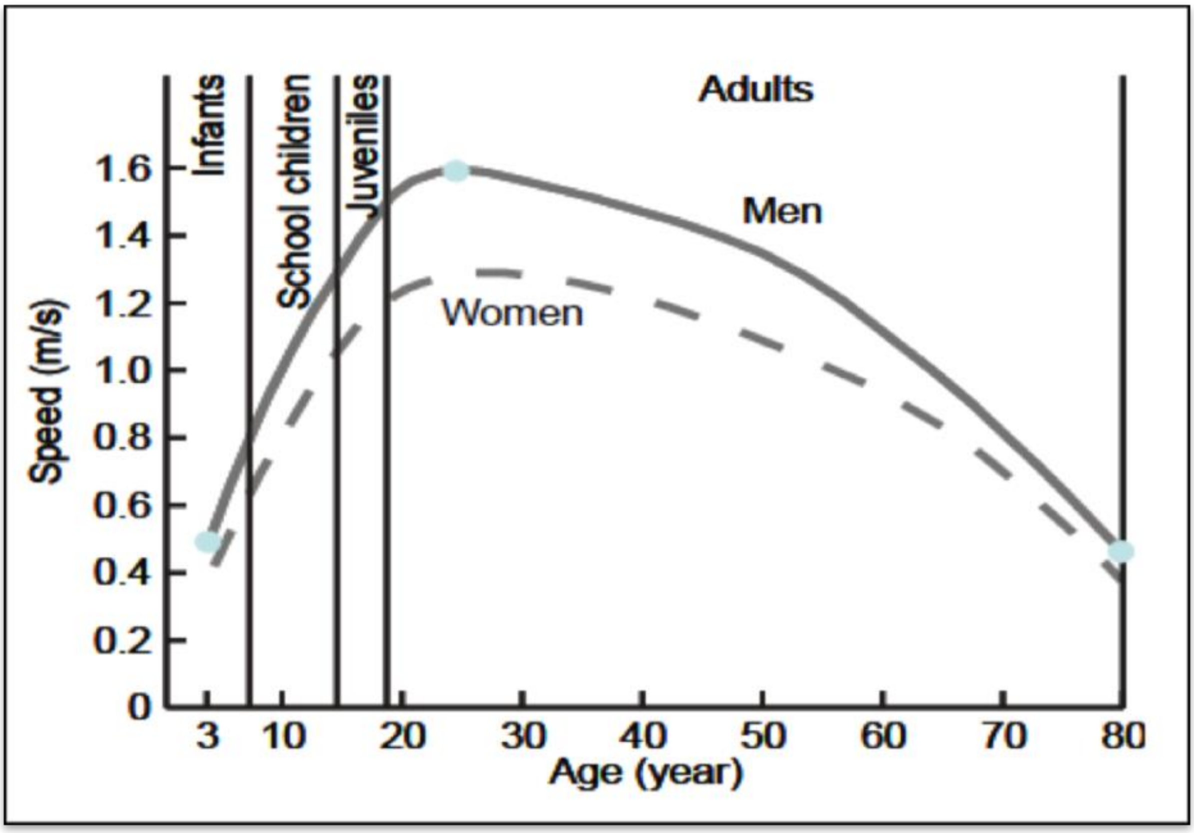


Figure 4-28: Impacts of Age and Gender on Pedestrian Speed (Hoogendoorn, 2012)

According to Fruin (1971), normal walking speeds unrestrained by pedestrian crowding vary between 0.76 and 1.76 m/s, with the average at approximately 1.37m/s. according to Kagan et al., (1978), pedestrians not limited by disabilities can vary their speeds from casual “stroll” at 0.6 - 0.9 m/s, to a purposeful fast pace of 1.5 – 1.8 m/s, while the average free flowing speed of the general population is found in most studies to be 1.4m/s.

In this study, the proportion of the in the pedestrian mix (over 55 years) was found to be insignificant, at about 0.2%. Several studies have shown that the population of the elderly will only affect the speed when the proportion reaches 20%. The population of young adults (19 – 35 years) constitute the major proportion of pedestrians at this section, hence the mean speed ranging between 1.31m/s – 1.35m/s for the days during which the study was undertaken. According to Fruin (1971), the smaller the personal space, the lesser the pacing distances and the lower the ability to pass slower moving pedestrians or to cross the traffic stream.

The average walking speed for a fit adult ambulant is 1.4 m/s, while walking speeds for elderly pedestrians ranges between 1.0 m/s to 1.2 m/s.

According to Main Roads Western Australia (2011), the slower walking speeds represent the 5th and 15th percentile walking speeds for all pedestrians. For assessment of crossing locations, a walking speed of 1.2 m/s is normally adopted, to cover 85% of pedestrian walking speeds. In case of locations known to exhibit higher proportions of slower moving pedestrians, a walking speed of 1.0 m/s is recommended (Main Roads Western Australia, 2011).

From the cumulative frequency distribution curve shown in Figure 4-27, it is seen that 34% of the pedestrians sampled were walking at a speed of 1.33 m/s (mean, or 50th Percentile), while 15% were walking at speeds below 1.25m/s (15th percentile).

4.12 Pedestrian Flow Analysis

4.12.1 Speed – Density Relationship

The Speed – Density relationship plotted from the data for both weekdays and weekends are shown in *Figure 4-29* and *Figure 4-30* below.

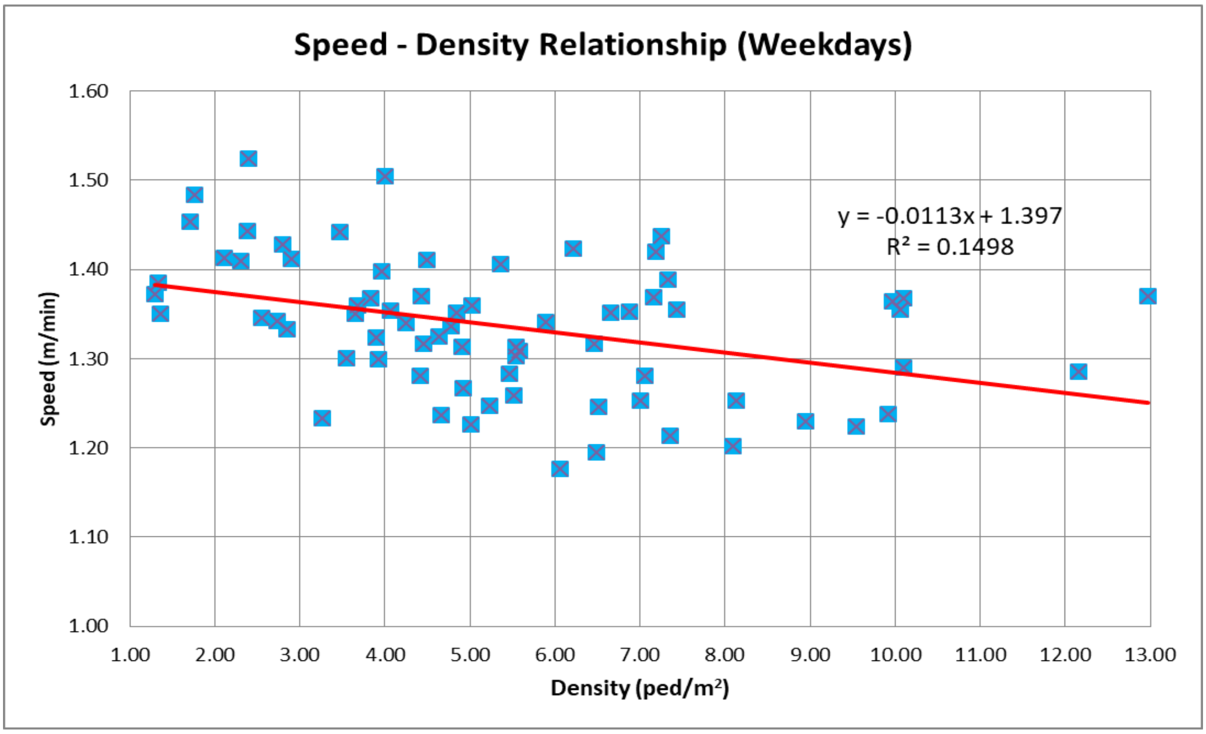


Figure 4-29: Speed - Density Relationship for Weekdays

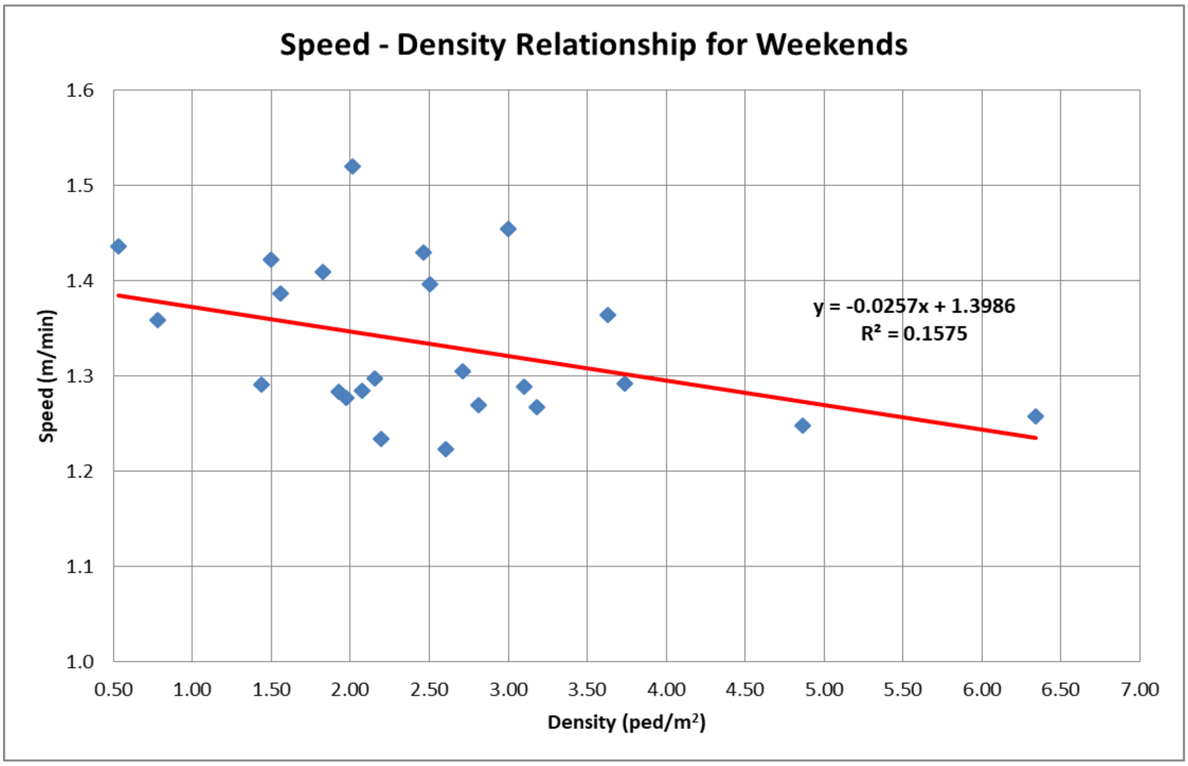


Figure 4-30: Speed - Density Relationship for Weekends

The linear inverse proportionality between speed and density observed is consistent with the general relationship that speed reduces with increasing density. The diagrams compare well with other studies, as shown in the *Figure 4-31* below.

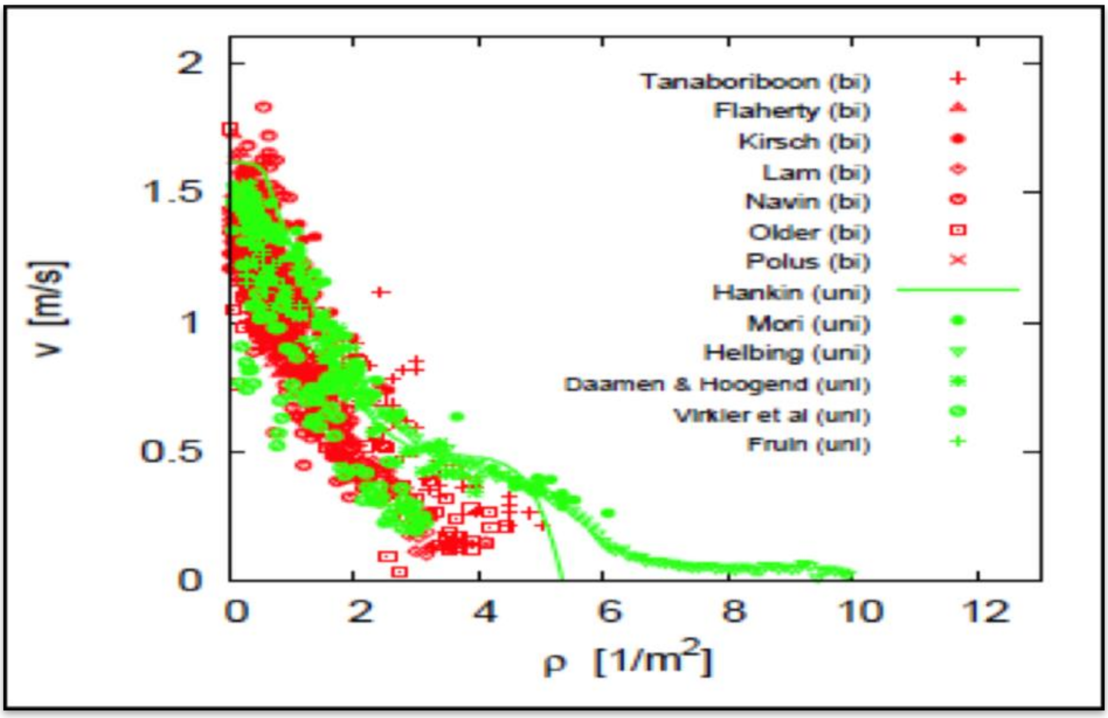


Figure 4-31: Comparison of Speed - Density Relationship with Observations from other Studies (Zhang & Seyfried, 2012)

The weekday minimum and maximum recorded densities are 1.29p/m^2 and 12.97p/m^2 respectively. The corresponding values for the weekend are 0.53p/m^2 and 6.34p/m^2.

It can be observed that in the case of lower densities pedestrian movement behavior exhibit a higher level of randomness (based on speed values) compared to the situation where higher densities are observed. This can be explained by the fact that pedestrians tend to relish more freedom of movement when they are few in number whereas a crowded flow forces them to act within given circumstance. This can also explain the interesting phenomena related to the observation that speed values never reach zero for high densities.

4.12.2 Flow – Space Relationship

The Flow – Space relationship plotted from the data for both weekday and Weekends are shown in *Figure 4-32* and *Figure 4-33* below.

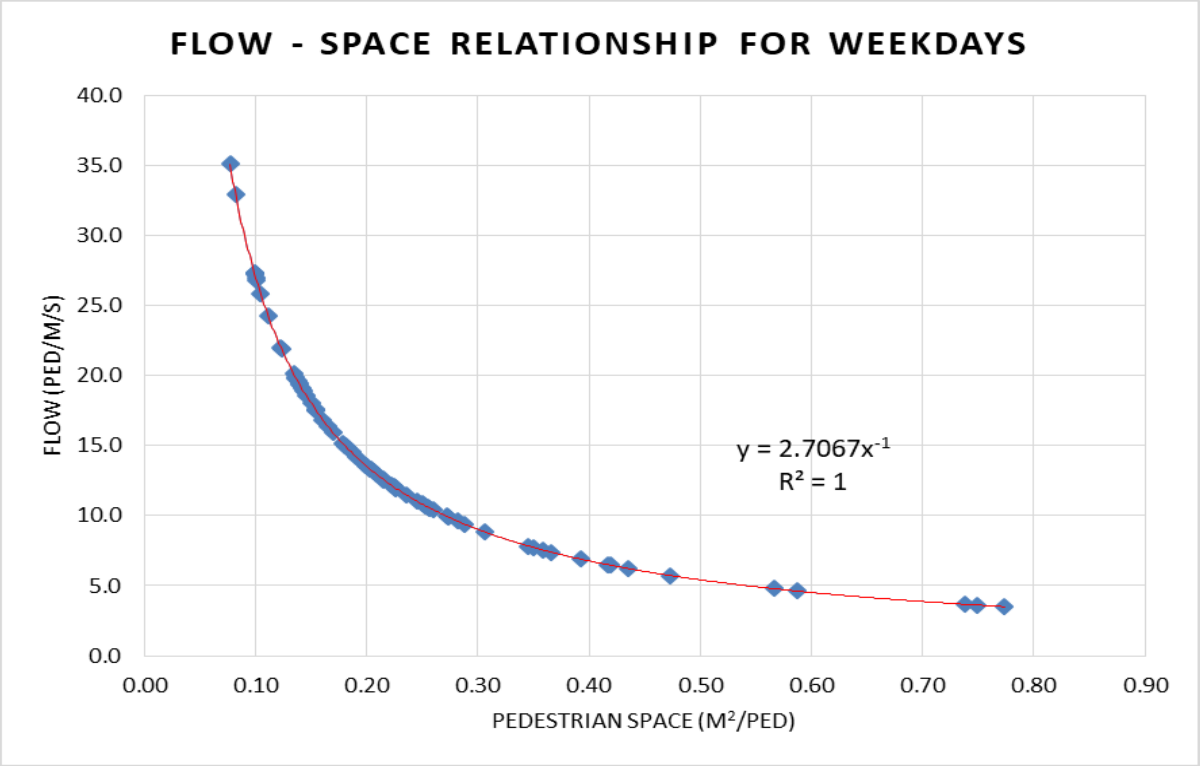


Figure 4-32: Relationship between Pedestrian Flow and Space for Weekdays

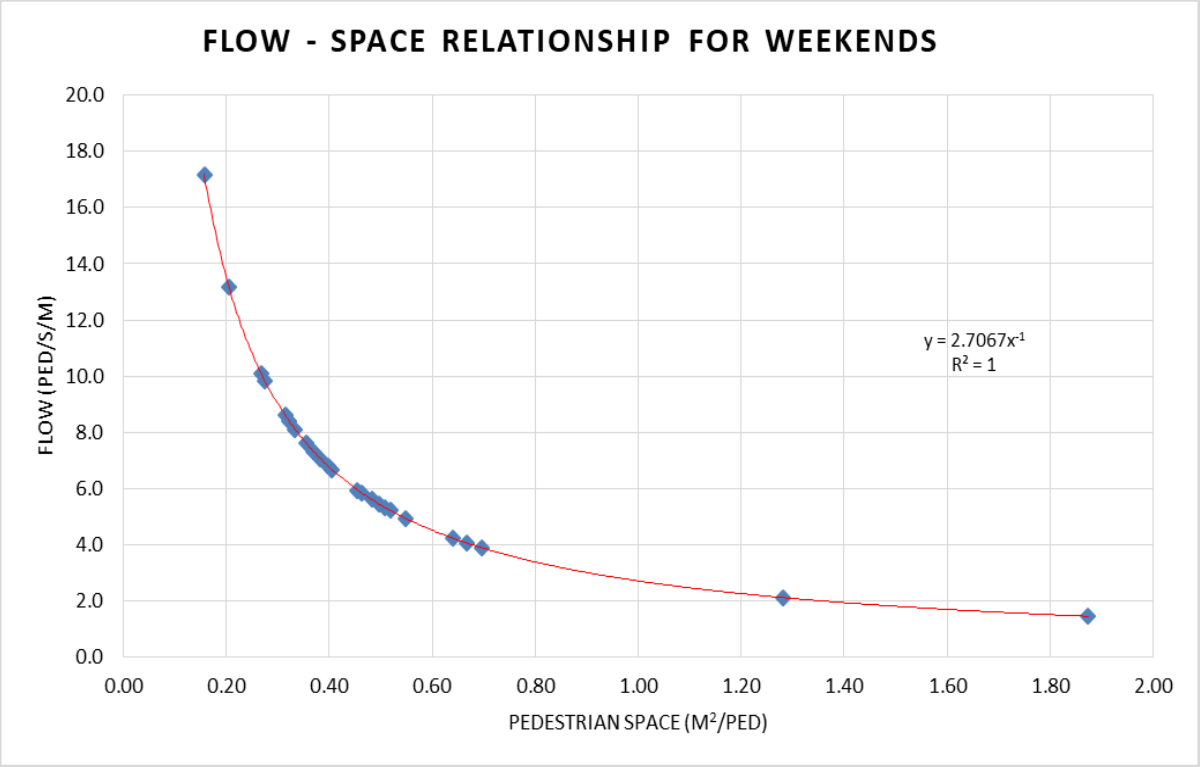


Figure 4-33: Relationship between Pedestrian Flow and Space for Weekends

The maximum flow for weekdays of 35.1p/s/m was recorded when pedestrian space was 0.08m^2/p for weekdays. The maximum flow for the weekend occurred at 17.2p/s/m when the space was 0.16m^2/p.

According to Rastogi et al. (2001), the minimum area of an average pedestrian (without bulky clothes and baggage) is approximately 0.085m^2. Since pedestrian body shape is assumed to be an ellipse, they cannot completely fill a specific area, hence a pedestrian area of 0.11m^2 and maximum density of 9.09p/m^2. According HCM (200), maximum unit flow fall within a narrow range of density, with the average space per pedestrian varying between 0.46 and 0.83m^2/p. the manual further states that as space is reduced to less than 0.46m^2/p, the flow rate declines precipitously. All movement effectively stops at the minimum space allocation of 0.19 to 0.37m^2/p. according to Pushkarev and Zupan (1975), the desirable body buffer zone space for pedestrians is 0.27 - 0.84m^2 including the pacing zone.

From the study, the maximum unit flow occurred within 0.08 – 0.12m^2/p range for the weekday, and 0.16 – 0.2m^2/p during weekend. The range for weekend goes below the minimum 0.11m^2/p, while the weekend pedestrian space is well above. Pedestrian space is therefore constrained during weekdays, but adequate during weekends.

4.12.3 Speed – Space Relationship

The Speed – Space relationship for both weekday and Weekend is shown in *Figure 4-34* and *Figure 4-35* below.

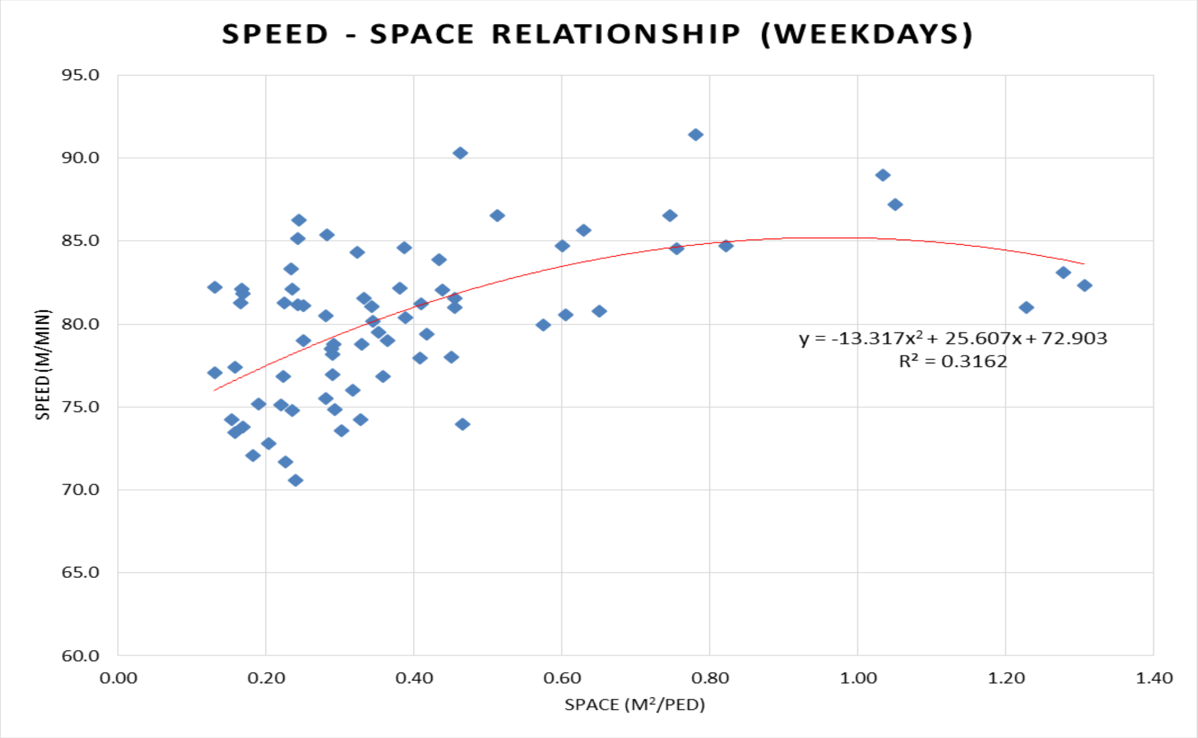


Figure 4-34: Relationship between Pedestrian Speed and Space for Weekdays

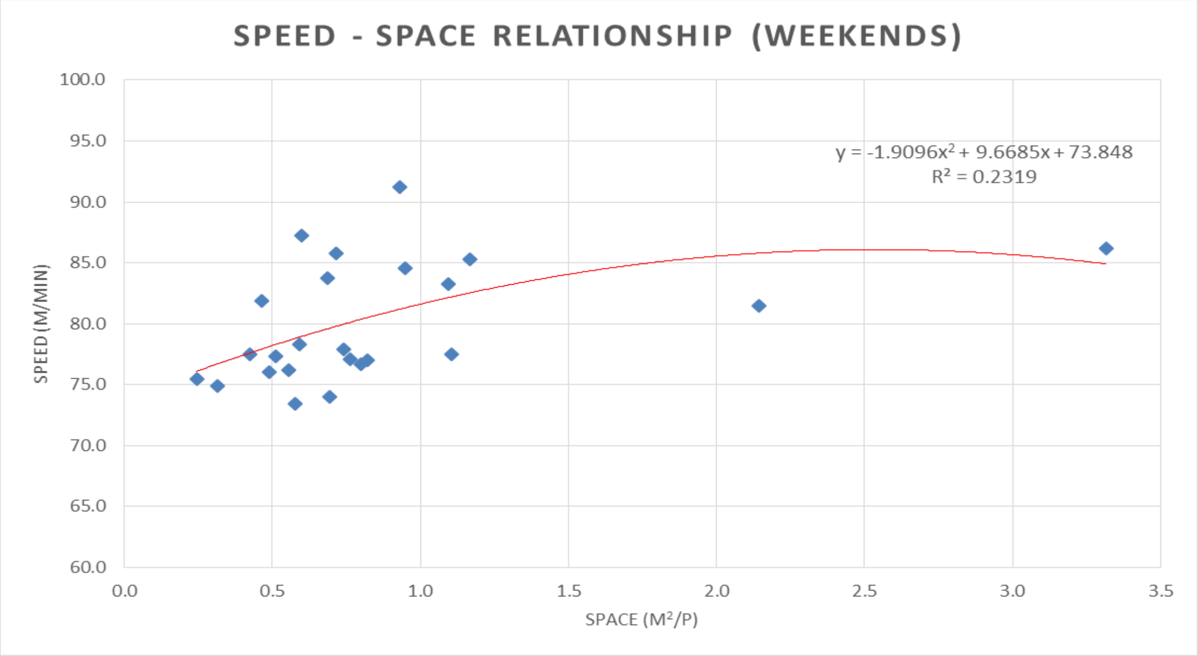


Figure 4-35: Relationship between Pedestrian Speed and Space for Weekends

The study shows that pedestrian movement behavior exhibit a lower level of randomness in speeds at space allocation between 0.18 – 0.5 m^2/p for weekdays and 0.5 – 0.8m^2/p for weekends. These speed values correspond with maximum flow rates according to HCM (2010). While HCM (2010) states that movement stop at minimum space allocation of 0.23m^2/p, this study shows that the least recorded space allocation was approximately 0.18m^2/p.

The higher randomness observed at higher space allocations is explained by the fact that pedestrians have more freedom of movement when they are few in number.

4.13 Capacity and Level of Service for the Existing Tunnel

4.13.1 Peak Hour Factor and Maximum Flow Rate

The mathematical relationship between the peak hour volume and the maximum rate of flow within the hour is defined by the peak hour factor (PHF) as follows (Miranda & Carrasco, 2011)

$$PHF = \frac{Vp}{p \text{ x } Vmn} \qquad \textbf{Equation 4-1}$$

where:

V_p *Peak Hour Volume;*

V_{mn} *Maximum volume for an "n" minute period; and*

p *number of Periods within the Hour.*

From *Table 4-7*, the Peak Hour volume is 1,689, while the maximum volume for a 15-min period is 632. The PHF is therefore computed as follows:

PHF = 1,689 / (632*4) = 0.67

The value shows that the pedestrian demand is fairly distributed within the hour, without extreme peaking.

The maximum rate of flow is computed as follows:

Maximum (design) Flow Rate = PHV / PHF

= 1,689/0.67 = 2,528 Ped / hr

4.13.2 Computation of Existing Capacity

The existing capacity is computed as shown in *Table 4-10* below:

Table 4-10: Determination of Tunnel Capacity

Step #	**Description**	**Calculation**	**Output**
1.	Compute Effective Tunnel Width W_E **(See Section 4.8)**		=1.2 m
2.	Calculate the design Pedestrian Flow by multiplying the effective width by the maximum Flow at LOS E, i.e. 75p/min/m	= 1.2m * 75p/min/m	90 p/min
3.	Adjust for bidirectional flow = 0.8	= 90 p/min * 0.8	72p/min
4.	Calculate Pedestrian Capacity (p/h) by multiplying the adjusted Design Flow by 60	= 72 p/min * 60	4,320 p/h

The maximum flow rate from volume counts is 2,528 p/h (see Section 4.13.1), while the tunnel capacity at LOS E is 4,320p/h. The volume to capacity ratio is 0.59. This implies that at the tunnel is operating at LOS D according to *Table 2-3*.

4.13.3 Pedestrian Level of Service

The computations for P-LOS for both weekdays and weekends is shown in *Appendix 1*. The P-LOS were computed based on HCM (2010) values shown in *Table 2-3*.

Figure 4-36 and *Figure 4-37* below illustrate the time distribution of P-LOS during weekdays and Weekends respectively.

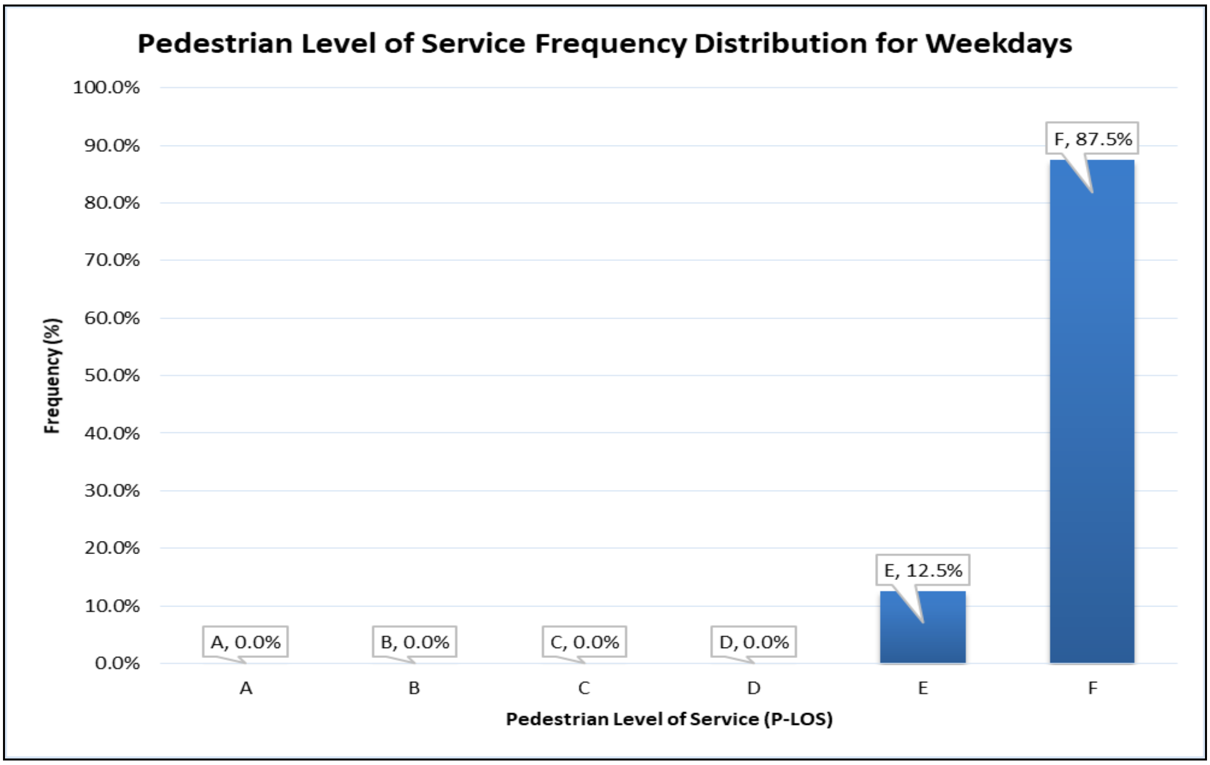


Figure 4-36: Frequency Distribution of P-LOS over Time for Weekdays

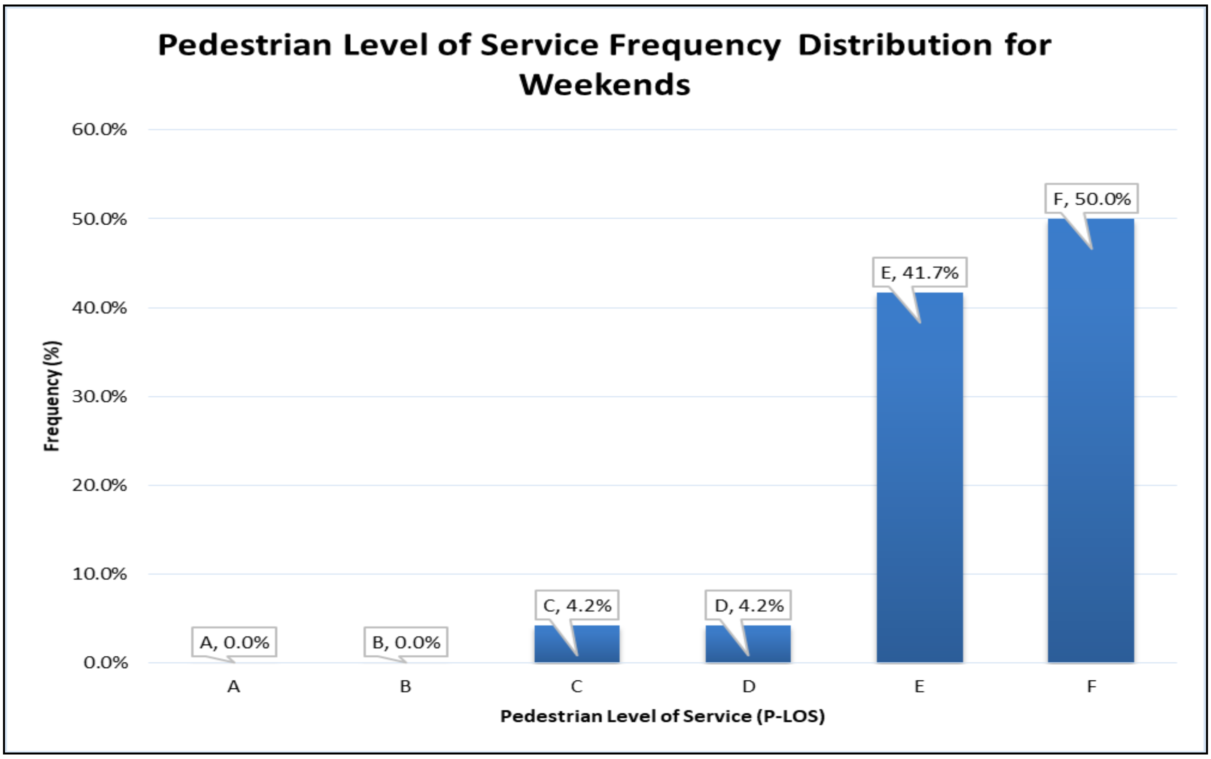


Figure 4-37: Frequency Distribution of P-LOS over Time for Weekends

Figure 4-36 shows that the facility operates at P-LOS E 12.5% of the times, and P-LOS F 87.5% of the times during weekdays, an indicator of capacity constraint. The situation is better over the weekends, when the P-LOS distribution over time reveals 4.2% for P-LOS C, 4.2% for P-LOS D, 14.7% for P-LOS E, and 50% for P-LOS F.

A graphical illustration of the P-LOS situation is shown in *Figure 4-38* below.

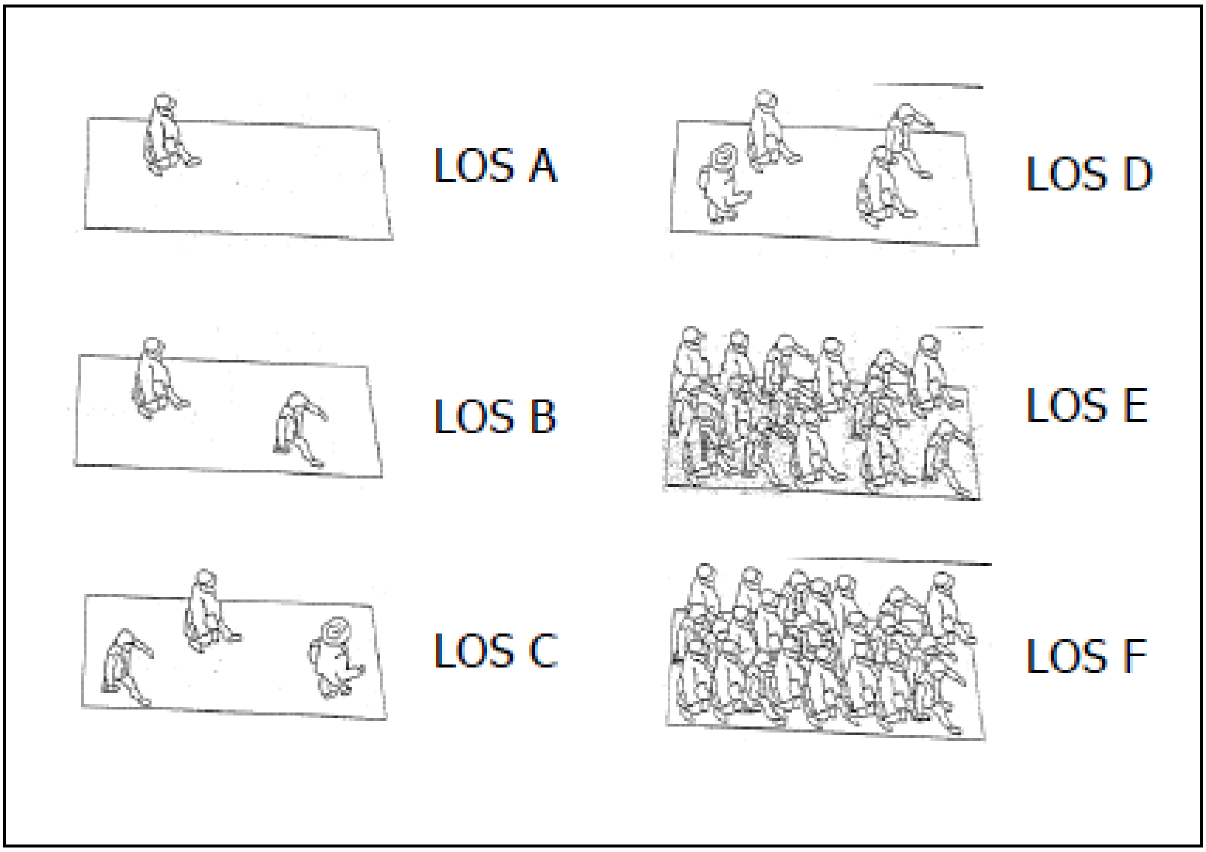


Figure 4-38: Graphic Illustration and Depiction of P-LOS (TRB, 2010)

4.14 Determination of Design Width

4.14.1 Estimation of Design Year Demand

According to Mathew (2014), the demand for pedestrian facilities is influenced by among other relevant factors adjacent land use, quality provision and security and safety.

According to O’flaherty (1997), demand estimation is a four stage process as follows:

a) Estimate the existing demand;
b) Determine the design year depending on particular local circumstances and planning context;
c) Predict the probable level of change in walking demand (growth rate) to the design year. In the case of this study, the growth rate will depend on the following:

- General growth of the university population;
- Planned / anticipated changes in land use;
- Inputs from attitude surveys.

d) Estimate design year demand. Compound population growth model can be used.

The demand prediction for the design year is shown in *Table 4-11*below:

Table 4-11: Prediction of Design Year Demand (Author, 2016)

Step	Description	Result
1.	Estimate the existing demand ▪ Peak 15 min pedestrian volume P_{2016} = *632p/15min* (**See Section 4.10**) ▪ Adjust for potential Diverted and Attracted Traffic, (Latent Demand = 18%) **See Section 4.6.2**. *Adjusted* P_{2016} *= 118% * 632 = 745.8, say 746* ▪ Adjust for potential Development Traffic due to undeveloped / underdeveloped land such as prefabricated houses within Mamlaka SMU. Assume 5% increase. *Adjusted* P_{2016} *= 105% * 746 = 783.1, say 784*	784p/15min
2.	Select Design Year *Based on Kenya's Development Blueprint, Kenya Vision 2030.*	2030
3.	Calculate design *Assume 2016 as base year*	14 years
4.	Predict growth rate ▪ The student population at the University of Nairobi's main campus was 2,768 and 7,103 in the year 1970 and 2015 respectively. Using the compound population growth model: $P_{2014} = P_{1970} * e^{r(t)}$, *therefore* $7{,}103 = 2{,}768 * e^{r(45)}$, *hence r = 2.1%.*	2.1%
5.	Calculated peak 15 min design year demand $P_{2030} = 784 * e^{(0.021*14)} = 1{,}052$, *say 2,614 p /15min*	1,052 p / 15 min

Therefore, pedestrian demand by the year 2030 is estimated to be 1,052 p/15-min peak.

4.14.2 Computation of Design Width

4.14.2.1 HCM Methodology

Computation of the tunnel width using HCM 2010 methodology and parameters is shown in *Table* 4-12 below:

Table 4-12: Computation of Design Width

Step #	Description	Calculation	Output
1.	Based on the desired P-LOS, select the maximum pedestrian flow rate from **Table 2-3**	Selected LOS – B Max flow rate = 23p/min/m	23p/min/m
2.	Estimate the Peak 15-min pedestrian demand	See **Section 4.14.1**	1,052p^{-}15min
3.	Apply adjustment factor to account for pedestrians who require extra space, for example, wheel chair users and pushers of prams.	Adjustment factor for the disabled = 1.1, hence 1,052* 1.1 = 1,158	1,158 p /15min
4.	Calculate unit pedestrian flow (per minute)	= (1,158/15)p/min = 77.2	say 78p/min
5.	Calculate required facility width using **Equation 2-4**	= (78/23) = 8.4m	3.4m
6.	Calculate total width by adding 1m to the effective walkway width to cater for 0.5m buffer on either side of the tunnel wall	= 3.4m + 1m	4.4m

4.14.3 Computation of Design Width Assuming Non-Uniform Flow

The HCM methodology assumes uniform flow. However, the new design shall incorporate other activities whining the system, hence non uniform flow.

Since the desired P-LOS, the length of the facility, and time for walking through the tunnel are known, and waiting times can be predicted, time - space analysis method shown in Equation 4-2 below will be applied to determine desired width:

$$w = \frac{ant}{Tl}$$

Equation 4-2 (Fruin, 1971)

Where:

- *w* *Desired facility width (meters);*
- *l* *Facility length (meters);*
- *a* *desired area per pedestrian based on design P-LOS (m^2/ped)*
- *n* *Number of pedestrians occupying the space or performing discrete functions*
  in *the space;*
- *t* *predicted occupancy times of pedestrians for functions performed during the analysis period*

- T *Time of analysis period, in this case 15minutes.*

For the pedestrian tunnel under study,

- Length of the Tunnel (l) = 40.6m;
- Period of Volume Counts (T) = 15minutes;
- Future Pedestrian Demand (n) = 1,052p/15-min;
- Design P-LOS B, Space (a) = 3.7 m^2/p for maximum flow rate;

Assuming 25% of the users will spend additional time, say 60 seconds shopping and undertaking other activities within the tunnel system:

Then the effective width is computed as follows:

$$W = ((3.7\ m^2/p * 1{,}052\ p^{-}15min * 0.521min) + (3.7m^2/p*25\%*1{,}052p\text{-}15min*1min))/(15\ min * 40.6m) = 4.9, \text{ say 5 meters}$$

Add 2m shy distance to cater for separation of directional flows, the design width is = 7 m.

Figure 4-39 below illustrates the cross sectional widths and depicting design concept for the overpass.

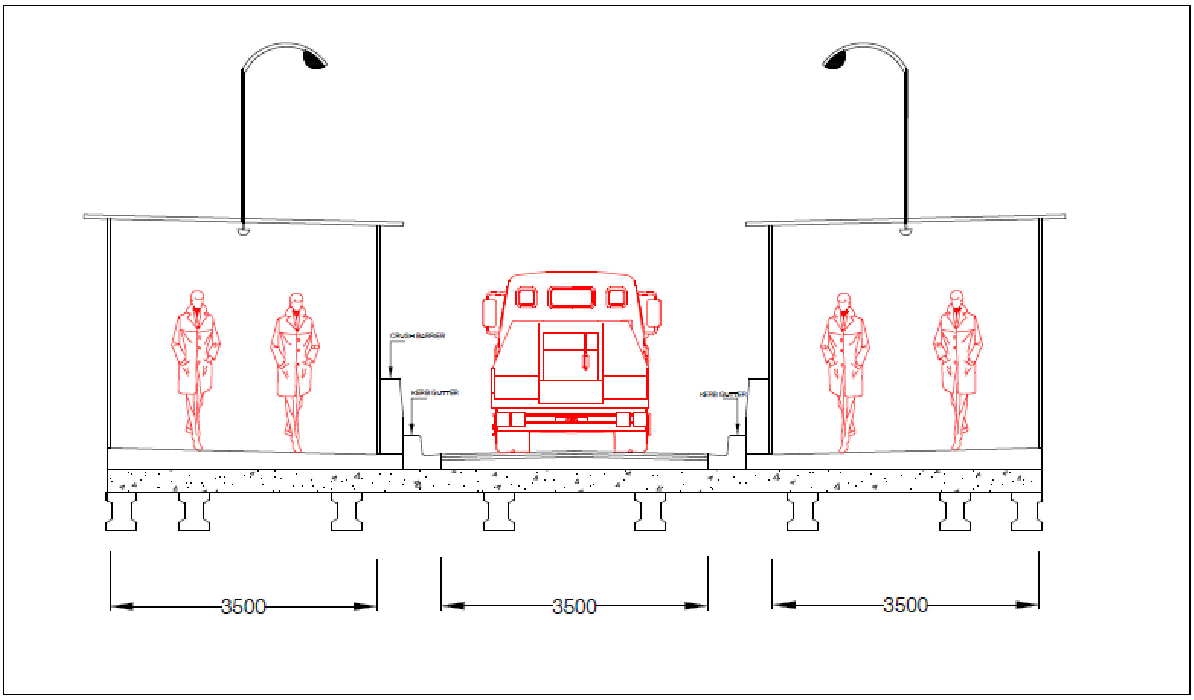


Figure 4-39: Design Width incorporating Cross Sectional Concept (Author, 2016)

4.14.3.1 Summary

From the calculations, it is observed that the Time – Space and HCM methods almost compare in terms of their outputs, except that Time – Space analysis yielded a slightly higher value. This is because the method accounts for time variabilities, while the HCM method assumes uniform flow.

Table 4-13 below illustrates the existing and designed width and LOS.

Table 4-13: Summary of Existing and Design Tunnel Width

Day of the Week	Current LOS	Current Tunnel Width (m)	Design LOS	Design Tunnel Width
Weekday	87.5% F; 12.5% E; 0% others	2.2	B	7.0
Weekend	50% F; 42% E; 8% others	2.2	B	7.0

4.14.4 Computation of Design Capacity

The computation of design capacity is shown in *Table 4-14* below.

Table 4-14: Capacity of Designed Tunnel

Step #	Description	Calculation	Output
1.	Compute Effective Tunnel Width W_E **(See Section 4.14.3)**		= 5 m
2.	Calculate Design Pedestrian Flow in one direction by multiplying half the effective width by the maximum Flow at LOS E, i.e. 75p/min/m	= 2.5m * 75p/min/m	187.5 p/min
3.	Adjust for bidirectional flow = 0.8	= 187.5 p/min * 0.8	150 p/min
4.	Calculate Pedestrian Capacity (p/h) by multiplying the adjusted Design Flow by 60	= 150 p/min * 60	9,000 p/h

For one directional flow, the designed tunnel will be able to carry 9,000 p/h at LOS E. using the current peak volume of 2,528p/h, the v/c ratio for the designed facility will be 0.28, or LOS B according to *Table 2-3*.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1 Existing Policy, Legal, Institutional and Regulatory Framework

a) The INTP (2009) is fairly comprehensive with regard to NMT issues. However, it is clear that the policies have not been operationalized;
b) The funding arrangement does not include specific provisions for NMT as a mode of transport;
c) The land system, and the physical planning system does not have specific provisions for allocation of land for NMT facilities;
d) The regulatory system does not have provisions for NMT movement.

5.1.2 Existing Technical Framework

The country lacks technical guidelines and standards necessary for planning and implementation of NMT facilities.

5.1.3 Existing Maintenance Framework

Maintenance is currently the mandate of KeNHA. The importance of the facility is seemingly lost in the magnitude of the authority's responsibility.

5.2 Site Assessment

5.2.1 Roadway Characteristics

Based on the warrants reviewed, both qualitative and numerical, Uhuru Highway fits the bill for GSPC considering the high pedestrian and vehicular traffic, high vehicular speeds and many lanes (Axler, 1984). GSPCs are also recommended on places with high pedestrian demand, defined pedestrian routes as well as routes that link second campus from the main campus (City of New York, 2006).

The sunken tunnel is a design faults, considering that it results to poor visibility, difficulty in using the tunnel and poor drainage. Studies have established that many pedestrians will not use an overpass or underpass if they can cross at street level in about the same amount of time.

The absence of median and verge barriers encourages jaywalking across the road, exposing users to risk of vehicle – pedestrian crashes. Physical barriers would also be important in protecting the pedestrian realm from intrusion by vehicles. A good underpass design should include a median barrier as an enforcement measure.

The absence of street lights leads to darkness and poses both psychological and functional sense of insecurity. Vandalism and graffiti evoke a sense of dereliction and absence of social control, hence a crime area that pedestrians will avoid.

5.2.2 Exterior Pedestrian Areas

Poor maintenance of the external areas symbolizes a lack of personal touch that generates vandalism and graffiti, which are signs of a crime area.

The absence of active uses such as shops means there’s nothing to attract pedestrians to the location, creating a sense of loneliness. The more activities take place, the more people, the higher level of social control, and the less opportunity for criminal activities.

The absence of pedestrian signage, lighting, street furniture, landscaping and public art contribute to the general pedestrian unfriendliness.

The tunnel is also isolated from the built environment, a situation that elicits the feeling of a facility in “no-man’s land”, and contributes to the sense of insecurity.

5.2.3 Tunnel Flanges and Entrances

The broken sump covers and manholes means the Tunnel access is not user friendly, not only for the fit ambulant, but also the handicapped and those with prams and wheelchairs.

The presence of static activities (hawking) on the walkway reduces the effective walkway width, thereby affecting pedestrian flow negatively.

The irregular and cracked pavement surface of the ramps contributes to the general discomfort of pedestrians, especially those with disabilities. The slippery tunnel floors is a personal risk to the users.

The absence of artificial lighting at the access contributes to the general perception of insecurity and lack of visibility

The absence of warning signs prohibiting jaywalking means no offence is committed. The usage of the tunnel can therefore not be enforced.

Blank walls, as witnessed at the study tunnel are an end to themselves, and do not interact with the users. Blank walls proclaim the superiority of engineering over humanity. Public artwork or special design features on the retaining walls can be used not only to enhance beauty, but also to give character and identity to the place.

5.2.4 Tunnel Structure (Box Culvert)

The open sumps at the entrance / exit hinder accessibility to the tunnel by such groups thus prohibiting its use.

The Convenience factor for the tunnel ranges from 0.12 to 0.19, meaning it is much easier to cross the highway using the Tunnel compared to crossing at-grade. The proportion of pedestrians opting for alternative crossings, including jaywalking therefore driven by other reasons. However, good GSPC designs create convenience by elevating vehicular traffic while maintaining pedestrian crossing at-grade.

Poor visibility from the spatial landscape to the entrance stirs feelings of anxiety and insecurity among pedestrians resulting from the “black hole window” effect, a phenomenon which describes a dark tunnel located in space.

The absence of adequate illumination of the tunnel tube obstructs inter-visibility between the tunnel’s entrances, thereby creating the “tunnel effect”, a feeling associated with claustrophobia.

The lack of synchronization between natural and artificial lights inside the tunnel creates a light / dark contrast or “black frame’ impact, thereby causing of anxieties of crime and insecurity.

The narrow pedestrian tunnel with low ceiling and poor lighting is a recipe for claustrophobia. While different manuals dictate varying minimum headroom values, the minimum is 2.4m. In very long tunnels, some additional headroom is advised to create more spaciousness. A width of 2.3m is recommended for a narrow tunnel with low pedestrian traffic volume. A width of 3.3m is recommended for normal sections with tunnel length more than 23m.

The finishes of the structure lack a sense of beauty, character and identity. High sidewalls of concrete covered with cracks and peeling paint on the walls, as observed lead to unpleasantness. Underpass public art including mosaics, murals, carvings and photo paintings should be introduced to enhance the beauty and character of the tunnel.

Poor drainage, broken sump covers, filthy sumps and manholes, poorly engraved and filthy drainage pans all inconvenience the user.

Unkempt and run-down appearance within the tunnel elicits negative feelings of neglect and lack of personal touch, hence vandalism and criminal activities.

5.2.5 Land Uses

All land uses associated with the university, whether institutional (29%), residential (26%) or recreational (15%) contribute approximately 76% of the total land use. This explains the high number of school based trips recorded.

5.2.6 Connectivity

The tunnel is linked with a discontinuous walkways from the various tip generation centers of gravity on the Western side to the administrative and tuition facilities on the Eastern side. The network lacks sidewalks along Mamlaka Road, while walkways do not link up other locations such as Halls 12, 13 and State House Hostel. The actual routes are often too long compared to the desire lines, creating only a fair degree of directness to the users. A similar tunnel is used to effect pedestrian crossing along State House Road. No crossing treatment is provided across the other access roads.

5.2.7 Alternative Crossings

Alternative crossings along the study section include the pedestrian crosswalk located at the rotary intersection at University Way, approximately 230m from the tunnel, and jaywalking which is common near the Museum Hill Road interchange, approximately 600m from the tunnel.

5.2.8 Pedestrian Characteristics

5.2.8.1 Age Group

Users are primarily students with the age bracket of 19 – 35 years. Pedestrians in this age group are more active, can travel at higher speeds and walk longer distances. They are prone to risk due to a feeling of immunity and overestimated abilities. The age profile explains the relatively high mean speeds of approximately 1.33m/s observed in spite of the high pedestrian flows observed.

5.2.8.2 Gender Profile

The percentage of females is significatly lower than males the study location at 38% to 62%. This is attributable to the general population profile at learning institutions, rather than the the modal choice considering that there are no other modes of transport on this section.

5.2.8.3 Person Size

In this study, the proportion of persons of abnormal size is insignificant, hence does not impact on the overall flow of the pedestrian stream. This is attributable to the predominant age group of young adults, who are inherently very active.

5.2.8.4 Occupation Profile of Users

Students constitute the majority of pedestrians using the tunnel at 87.5%. Trip generation is associated with predominant land use and socio-economic factors, including employment and schooling. According to (Mousavi, 2012), college students tend to make more trips, something which was observed in this study. The high percentage of students is consistent with the observations on the predominant land uses.

5.2.8.5 Disability Profile

The population of disabled pedestrians at the tunnel is insignificant. This could be explained by the uncomfortable environmental conditions at the tunnel, namely the uneven and irregular pavement surface, high ramp gradients (7%), obstruction by static activities on the walkway (hawkers), flooding at the entrance and inside the tunnel, as well as the exposed sumps at the portals are considered to be the main hindrances to the use of the tunnel by the handicapped pedestrians to a large extent, and to the fit ambulant to a smaller extent.

Further enquiries established that the University has instituted a scheduled bus shuttle program for use by the disabled.

5.2.8.6 Physical Conditions of Users

The proportion of pedestrians carrying bags with effect on their walking speeds (0.6%) is insignificant, hence no effect on the overall speed of the pedestrian stream. Only 8.1% of the pedestrians were on phone calls, and another 0.4% on earphones, a proportion considered inconsequential to the overall speed of the pedestrian stream.

5.2.9 Trip Characteristics

5.2.9.1 Origin – Destination

From the study, about 75.5% of trips originated within the University, and almost 93.3% had the University as their destination, indicating that the tunnel is predominantly for the University’s use.

5.2.9.2 Trip Purpose

Macroscopically, home based trips contribute well over 70% of the trips, while microscopically, school based trips contribute almost half of the trips at 49.5%, followed by social trips (19.1%).

These high proportions at either level are explained by the predominant land uses in the study area which is composed of institutional (29%), mainly composed of the University’s administrative, tuition and health facilities; residential facilities for the University (24%), and recreational and open spaces (23%).

The high speeds observed can also be attributed to the user segment with strict timelines for tuition. Students (school trips) tend to walk at much higher speeds.

5.2.9.3 Trip Frequency

Most users (48%) make trips more than twice a day, followed by those who make trips twice a day (32%). This finding is consistent with Mousavi (2012), who observed that work and school related trips are more likely to be more compared to the other trips. Findings on trip purpose and trip frequency confirm this.

5.2.9.4 Platooning

In this study, only 4.2% of pedestrians were walking in groups of two, while 3.5% were walking in groups of three to four. Those walking in groups of more than five pedestrians constituted only 1.5% of the pedestrians. The extent of platooning in the pedestrian stream is minimal, hence insignificant effect on the overall speed or flow.

5.2.9.5 Impedance

In this study, the extent of impedance in the pedestrian stream is considered minimal, hence insignificant effect on the overall speed or flow.

5.2.10 Tunnel Usage vis-à-vis Alternatives

5.2.10.1 Extent of Usage of the Tunnel: The Convenience Factor

From the study, 59% of the respondents use the tunnel compared to 38% who use the signalized crosswalk at the University Way Rotary Junction. Jaywalkers constitute 3% of the respondents.

The mean Convenience Factor (R) for the Tunnel is 0.16, implying that it is much more convenient to cross the highway using the Tunnel compared to crossing at-grade. The 41% crossing at-grade is attributed to the revealed demand, the potential users who are driven away by other factors.

5.2.10.2 Frequency of Usage of Alternatives Crossings: The Revealed Demand

From the study, approximately 77% are potential users, while 20% represent users whose desire lines are not aligned with the tunnel location. This proportion that lacks directness accounts for Student’s hostels such as Hall 13, women’s Hostels (Box) and Stela Awinja; Lecturer’s Quarters; and YWCA Hostels.

It is therefore estimated that any facility at the current location would take approximately 77% of the entire population. Compared to the 59% currently using the tunnel, it can be deduced that the revealed demand is actually approximately 18% of the population.

5.2.11 User Perceptions

5.2.11.1 Reasons for Non–Usage of the Tunnel

The main reason for non-usage of the tunnel is insecurity. This is attributable to absence of lighting, poor visibility from the spatial landscape, poor inter-visibility between the entrances due to darkness and light / dark contrasts, isolation of the tunnel from built environment, lack of maintenance, and absence of active uses.

The next reason for non-usage is lack of directness for some segment constituting approximately 24% of the population. This is consistent with the existing land uses, especially those who reside in Student's hostels such as Hall 13, women's Hostels (Box) and Stela Awinja; Lecturer's Quarters; and YWCA Hostels.

The third reason for non-usage is due to lack of convenience resulting from filthiness and poor drainage during rainy seasons. This statistic is also consistent with the physical / environmental assessment, where open manholes and catch sumps filled with filth and debris, flooding within the tunnel box and the entrances, as well as uneven and irregular pavement surface, or slippery tunnel floor were observed.

Adequate, proactive and high quality maintenance regimen should be put in place to ensure cleanliness and timely repairs whenever required. There is an urgent need to fix the broken sump covers and manholes, fix and realign the cracked retaining walls, fix the irregular and rough pavement, fix the slippery tunnel floor, cut the overgrown bushes and apply a fresh coat of paint on the exposed walls.

Lack of accessibility and connectivity contributes a meagre 7% of non-usage. It can be deduced that this segment represents students residing in State House Hostel, which has no direct link to the main pedestrian route that links through the tunnel under consideration.

5.2.11.2 Predisposition to Use the Tunnel

From the study, the actual demand for the facility is approximately 69% of the population. The remaining proportion explains the segments of the population that lack linkage and continuity to the facility, and those for whom there is no directness.

5.2.11.3 Desired Treatment

From the study, majority of respondents would wish to see the security at the Tunnel improved through installation of lighting, followed by those who prioritize the improvement of drainage and cleanliness. Congestion is not a concern to users.

5.2.12 Environmental Level of Service (E-LOS)

The facility is adjudged to operate at E-LOS C with regard to directness and continuity, E-LOS E on convenience, and E-LOS F on security and visual appeal and amenity. Pedestrian perceptions factually confirm these findings.

5.2.13 Operational Level of Service (P – LOS)

The facility operates at P-LOS F most of the time during weekdays, with a mean pedestrian space of 0.24m^2/p and mean speed of 1.33m/s, while it operates at P-LOS F 50% of the time during weekends, with mean speed of 1.35m/s and mean pedestrian space of 0.52m^2/p.

The capacity of the existing facility is 4,320 p/h, while the peak pedestrian volume is 2,528 p/h giving a to v/c ratio of 0.59. This implies that the tunnel is generally operating at P-LOS D.

5.2.14 Design Width and P-LOS

For one directional flow, and a desired P-LOS B, the tunnel design width is 3.5 m. The capacity of the designed tunnel will 9,000 p/h. If the current peak hourly volume is considered against the design capacity, the v/c ratio would be 0.28, meaning it would generally operate at P-LOS B.

5.3 Recommendations

5.3.1 Existing Pedestrian Tunnel

From pedestrian interviews, an overwhelming 92% of the respondents cited issues related to environmental level of service as their main reasons for not using the tunnel. It follows therefore that the immediate interventions should be aimed at addressing the E-LOS related factors to improve security, visual appeal, convenience, directness and continuity at the tunnel and its linkages. These proposed interventions include:

5.3.1.1 Security Improvements

a) Illumination: interventions include provision of artificial illumination to enhance security and visual safety both inside the tunnel and general pedestrian areas, including the entire pedestrian network that links to the facility.

- A new skylight should be installed inside the tunnel to provide natural light during the day, in addition to artificial lights.
- External floodlights should be provided to enhance nighttime visibility, and act as crime deterrence measure.
- The quality of lights should be properly designed to ensure appropriate contrast, brightness adaptation, glare and light source color.
- The lights should be environmentally sensitive so as to minimize light trespass, light pollution, and application of green energy like solar.
- Finally, the lights provided should enhance aesthetic appeal and beauty of the tunnel.

Plate 5-1: Illustration of Median Skylight (City of Fort Collins , 2001)

b) Visibility: A clear and direct line of sight within the tunnel, and at-grade (across the road) maintained. This can be done through provision of lighting inside the tunnel, as well as maintaining the entrance flanges from overgrown bushes and unnecessary structures.

Clear visibility and inter-visibility between activity points will greatly increase feelings of security.

Plate 5-2: Illustration of Visibility (New Zealand Transport Agency, 2009)

c) Creation of Activity Points / Active Uses at the Tunnel: Activity points such as shops will attract people to the tunnel site. Studies have shown that what attracts people most is the presence of other people, hence security;

d) Policing: the University authorities should provide private security as well as work with the police department to enhance security;

e) Proper Maintenance: To provide a sense of ownership and social control, hence security.

5.3.1.2 Visual Appeal and Amenity

a) Attractive Improvements: Landscaping to create a pleasant walking experience for the users;

Plate 5-3: Illustration of Landscape Amenity (City of Fort Collins , 2001)

b) Special Design Features: Incorporate special design features, public arts such as mosaics, murals and fountains to enhance beauty, and add character and identity to the tunnel.

Plate 5-4: Illustration of External Artwork on the Retaining Wall (City of Fort Collins , 2001)

Plate 5-5: Illustration of Internal Artwork (City of Fort Collins , 2001)

5.3.1.3 Convenience Improvements

a) Drainage: the following actions are recommended:
   - The open skylight should be fixed to ensure rain water doesn't fall inside the tunnel;
   - Since the tunnel is depressed from the existing ground level, the adequacy and functionality of the existing drainage system should be assessed by a professional, and a new drainage system designed and implemented;
   - Drainage sumps and manholes should be fixed;
   - The capacity and quality of internal drainage pan should be improved;

Plate 5-6: Illustration of Underpass Drainage Pan (Author, 2016)

b) Provision should be made for the disabled in accordance with the local laws and regulations as well as best practices for design e.g. Americans with Disabilities Act (ADA) standards;

c) Maintenance: The University of Nairobi should be granted ownership of the existing tunnel, and funded for its maintenance.

d) Provision of Rest Benches: Benches should be provided along the entire network to attract elderly and disabled pedestrians, as well as add to the aesthetics;

Plate 5-7: Illustration of Rest Benches that add to Aesthetics (City of Fort Collins , 2001)

e) Physical Buffers and / or Barriers: Physical buffers or barriers such as rails should be provided at appropriate locations, such as between the sidewalk and the road;

f) Wayfinding: Install pedestrian way finding signage and street furniture along the entire network from origins (hostels) to destinations;

g) Enforcement: Regular enforcement to remove hawkers from the walkway width.

5.3.2 New Tunnel

5.3.2.1 Policy

There is need to operationalize the INTP (2000) on NMT issues, most importantly;

a) Transportation – land use planning, especially allocation of land for development of NMT facilities;

b) Proportionate funding for development and maintenance of NMT facilities;

c) Institutional responsibility development and maintenance of NMT facilities;

d) NMT Safety;

e) Safe Routes to School: Communities must have safe routes to School

There is an even more urgent need to formulate and enact policies that guarantee NMT security.

5.3.2.2 Planning and Design

There is need to develop planning and design tools such as manuals, guidelines that take account of both the environmental and operational requirements for pedestrians.

Design manuals and Technical guidelines should be formulated and adopted for use by professional in the process of providing NMT facilities. As a minimum, design manuals should ensure the resulting facilities are safe, secure, comfortable, attractive, interconnected and direct. The facilities should blend well with the existing environment without causing environmental or social disruption.

Operationally, a 4.4m width will yield a P-LOS B, and a capacity of 11,880 pedestrians per hour as per the design. However, a width of 3.5m in one direction will yield a P-LOS B with a capacity of 9,000 pedestrians per hour.

5.3.2.3 Maintenance

A legislation should be enacted to grant owners or occupants of property abutting NMT facilities responsibility for repair and maintenance of such facilities when those owners are public institutions. Funding arrangements by the Government should be put in place for the same.

The Government should directly fund the University to undertake the construction of the new design, and subsequent maintenance.

5.3.3 Concept Design of the New GSPC Facility

The concept design of a new GSPC (overpass) is shown in *Figure 5-1, Figure 5-2, Figure 5-3, Figure 5-4, Figure 5-5, Figure 5-6* and *Figure 5-7* below. The design takes cognizant of the following considerations;

a) To avoid the friction associated with bi-directional pedestrian flows, dual walkways have been provided, one for each direction;
b) A one-way roadway for the exclusive use of the university has been introduced in the design to cater for the following observed / revealed needs:
    - Bus shuttle for PWD. The study revealed that the University has instituted a bus shuttle system between the hostels and the administration / tuition facilities to cater

for PWD. The provision of a roadway will ensure exclusive and timely movement of the PWDs without the traffic delays associated with city roads;

- Bus shuttle for teaching/administrative staff between Chiromo and Main Campus. The study revealed that both teaching and administrative staff face a lot of challenges shuttling between Chiromo and Main Campus, especially during examinations due to parking problems at both ends. A scheduled bus shuttle system can be introduced by the University between the two campuses for use by staff attending to administrative, teaching and examination purposes;
- Cycle traffic. Even though the study recorded insignificant number of cyclists, there exists a possibility of mode shift among users. The design preempts this probable mode shift from walking to cycling. The roadway is therefore necessary to cater for future mode shift to cycling;
- Emergency Traffic. The roadway can be used as an exclusive emergency route for fire engines, ambulances and other emergency traffic.

c) Shops have been provided at both ends to enhance vitality at the crossing, as well as provide extra income to the University and provide employment for students.

Figure 5-1: Location of the New GSPC (Author, 2016)

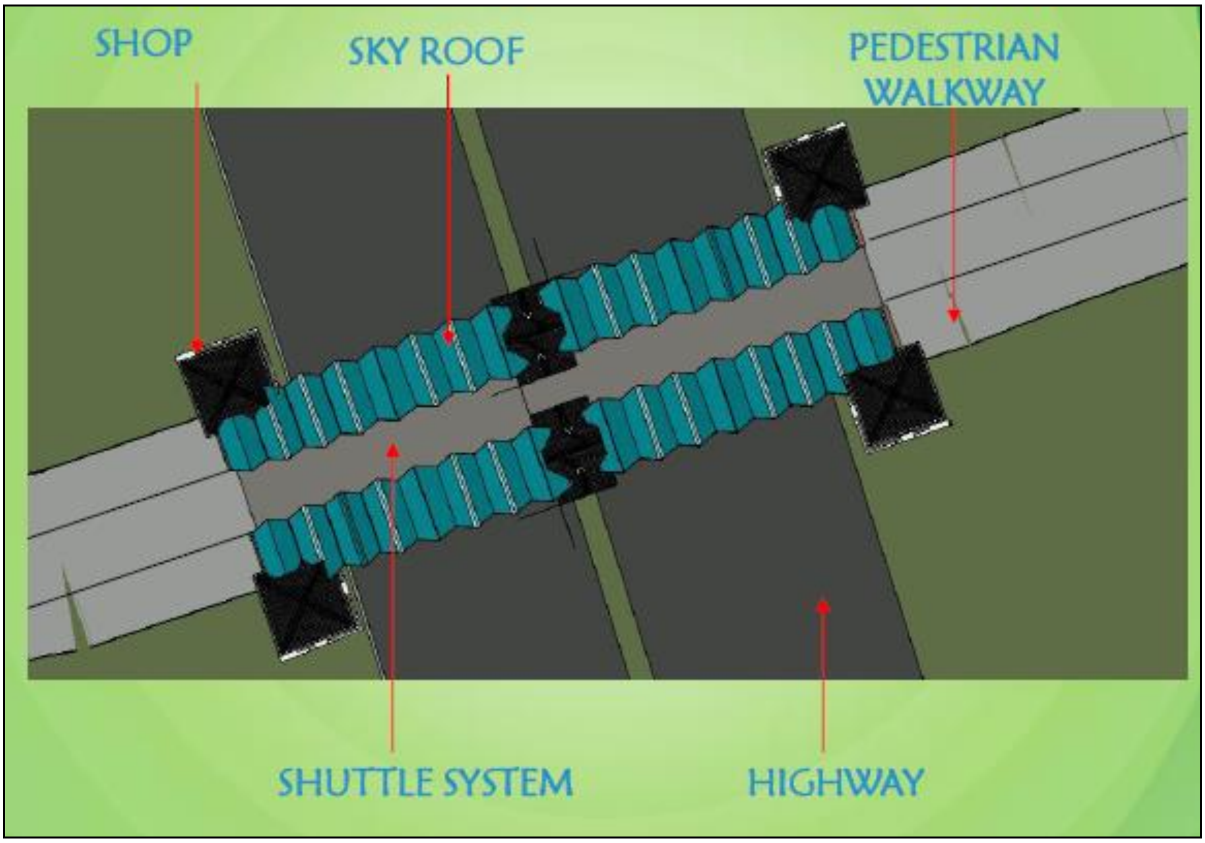


Figure 5-2: Plan View of the Overpass indicating Two–Way Walkways, Roadway and Shops (Author, 2016)

Figure 5-3: Side View of the Overpass Depicting Context and Identity of the University (Author, 2016)

Figure 5-4: Cross Sectional View illustrating Two-Way Walkways, Roadway and CCTV Cameras (Author, 2016)

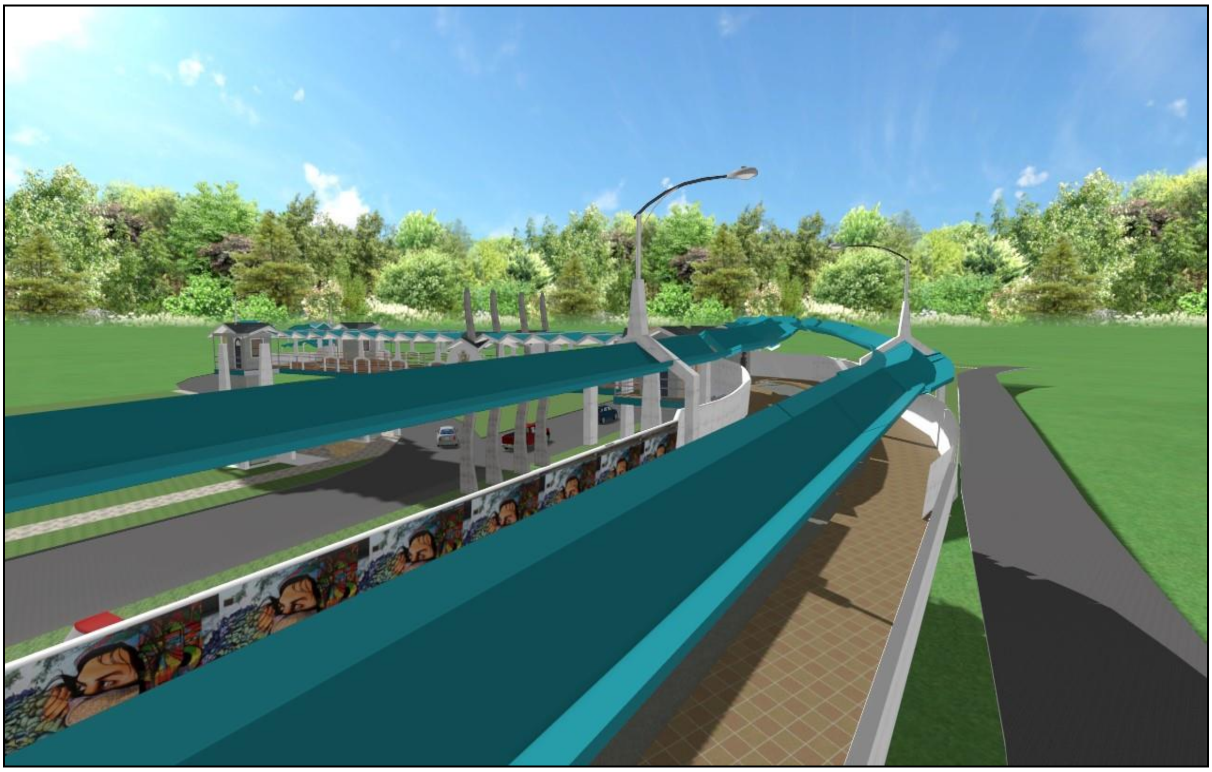


Figure 5-5: Security (Lighting), Aesthetic Appeal (Public Art) and Comfort (Walkway Canopy) (Author, 2016)

Figure 5-6: Active Uses (Shops), Security (Infra-Red Security Check Point) and Comfort (Rest Benches) (Author, 2016)

Figure 5-7: Panoramic View Depicting the Ramps (Author, 2016)

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Appendix 1: Computations of Volume, Speed, Space, Flow and P-LOS

Appendix 2: Pedestrian Volume Data

Appendix 3: Pedestrian Time Data

Appendix 4: Pedestrian Survey Questionnaire

Appendix 5: Underpass Assessment Check List

Appendix 6: Pedestrian Volume Tally Sheets

Appendix 7: Pedestrian Time Tally Sheets