A MODEL TO PRIORITIZE PEDESTRIAN FACILITIES REQUIREMENTS IN AN URBAN AREA

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DECLARATION OF THE CANDIDATE & SUPERVISOR

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Abstract

The model share of pedestrians in developing cities has the tendency of being very high as opposed to developed cities. For example, between 25-50% of trips in major Indian cities and about 50% of all trips in major African cities are made entirely on foot. However, though a significant number of trips are made by foot in majority of developing cities, pedestrian infrastructure, amenities, and services are often neglected in municipal planning and budgets (Fang, 2005). Pedestrian facilities in an urban area have a significant influence on the traffic flow and socio-economic environment. Improved walking facilities not only will generate new pedestrian flows, but it will also increase the comfort of the current walking population. Consequently, it will result in increasing of public transit usage and decrease in private vehicle trips. Herewith a need has arisen to measure the performance of pedestrian facilities for improvements and priority setting. In response, this study developed a model to prioritize road links for provision of pedestrian facilities in small and medium cities.

The model developed with three basic parameters namely; pedestrian demand, connectivity and evaluation of existing pedestrian facilities. When developing the model, a GIS based model for pedestrian demand was developed using six selected land uses. Moreover, GIS spatial analysis tools were employed to identify the shortest path where pedestrians prefer to walk as per their route choice preferences examination. The relative safety and convenience of routes could then be evaluated with respect to road prioritization for the provision of pedestrian facilities.

Finally a point scoring frame work was developed for prioritization of road links with an evaluation of existing pedestrian facilities. The model estimated and validated in this study can be applied to other developing countries with same socio-economic conditions. Since the six selected land uses are characteristically visible in most of the urban areas it should be a very rapid and simple process to apply this model and select road links to provide pedestrian facilities requirements or improvements

Keywords: Pedestrian demand, Connectivity, Point scoring framework, Developing countries

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LIST OF ABBREVIATIONS

Abbreviation	Description
ADB	Asian Development Bank
GIS	Geographical Information System
UDA	Urban Development Authority
MC	Municipal Council
UC	Urban Council
GND	Grama Niladari Division
O-D	Origin – Destination
CNR	Connected Node Ratio
PRD	Pedestrian Route Directness
LOS	Level of Service
PLOS	Pedestrian Level of Service
BLOS	Bicycle Level of Service

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1 INTRODUCTION

1.1 Background

> **"Isn't it really quite extraordinary to see that, since man took his first steps, no one has asked himself why he walks, if he has ever walked, if he could walk better, what he achieves in walking… questions that are tied to all the philosophical, psychological, and political systems which preoccupy the world?"**
>
> ***Honorè de Balzac, Thèorie de la Dèmarche***

The quotation by Balzac and Demarche has insinuated walkers to become conscious of walking, an activity that is performed automatically. In fact, almost every trip in a person's routine life requires some walking either directly to a destination or to another transport mode. Walking has been considered as the most efficient mode of transport for shorter distance which is environmentally friendly, requires minimal energy, cost nothing and is accessible to all irrespective of the age, gender and ability if facilities are provided appropriately. Thus, pedestrian facilities in an urban area would make a significant influence to the traffic flow and socio-economic environment of the area. As a result of good pedestrian facilities, the quality of life of the particular community would be enhanced.

Walking receives a considerable interest as a non-polluting transportation mode with the experience of the impact of climate change. Furthermore, it is believed that non-motorized transport system improves public health by increased levels of walking. (Kevin et al, 2009; Evans-Cowley, 2006; Handy et al, 2002, Frank et al, 2000) However, non-motorized transportation is more frequently used for exercise and recreation rather than for travel (Kevin et al, 2009). In Today's context non-motorized transportation is being used in a relatively restricted manner. Many researches carried out in order to promote walking have concluded that a favourable walking environment is an essential pre condition to promote pedestrian trips (Christopher, 2008; Clifton et al, 2007; William et al, 2005; Moudon and Lee, 2003). A multitude of factors influence the choice to walk which includes attractiveness of the route, route choices for variety and safety, and the number of destinations within a walkable distance. (Kevin et al, 2009).

1.2 Walking and Health

Walking has been viewed as a programmed, characteristic human capacity which serves, numerous functional parts. However unusual it is the present day man seems resolved to stroll as meager as could be expected under the circumstances. Relatively few walkers would walk five miles to work — yet astoundingly few walk even a half mile to a companion's home or neighborhood store. The advantages of strolling augment numerous parts of wellbeing and wellness. Fusing strolling into one's every day routine is a satisfactory beginning stage. “Sedentary lifestyles in industrialized countries are increasingly becoming a major health risk, and it is estimated that insufficient physical activity causes 1.9 million deaths worldwide annually” (US Department of Health Physical Activity and Health Improvement and Promotion, 2004). Local streets have been consistently identified as the most common place for engaging in physical activity (Giles-Corti and Donovan, 2002, Brownson et al., 2001)

The sprawling development and streets filled with cars create a negative environment for walking or bicycling as a major means of transportation. With the trends showing the increased levels of obesity, America has now declared obesity as public health issue at a national level. Physical inactivity or walking less is resulting in the increased percentage of children who are obese or overweight. It is the same scenario with adults as well. Moderate physical activity has been linked to a wide range of benefits, including lowering the risk for heart disease, stroke, colon and breast cancer, diabetes, and high blood pressure. Studies have also shown its benefits in warding off high cholesterol and depression. According to the *Surface Transportation Policy Project*’s report, the medical costs of physical inactivity are estimated at about $76 billion per year. Meanwhile, the federal transportation program, which weighs in at about $46 billion per year, spends less than one percent of that – about $240 million annually – on creating safer places to walk and bicycle.

There is no such term use planning for pedestrians, bicycle and transit facilities that would encourage walking and make walking safer. For that to happen there is every need to design broader sidewalks, improved lighting, safe crossings and attractive transit wait areas combined to improve the experience of walking. Communities that are designed with an emphasis on other travel options – walking, biking and transit improves physical activity and better health (Ernst, 2004).

1.3. Need for Walkable Communities

Everybody walk and some walk as an activity and activity walking rate is expanding. It is frequently appreciated as one of the best exercises types of activity and is prescribed for a solid way of life .The Shaped, Token-Based Transport Protocol (STTP) states that the reasons behind such low percentages of pedestrians in U.S.A. are believed to be because getting places on foot is still difficult in many parts of the U.S.A., and in far too many cases, unsafe. Recent public health studies have found that per mile, people out walking in the United States are three times as likely to be killed as in Germany, and over six times as likely to be killed as in the Netherlands. Transportation engineering solutions to the problem of the unsafe walking environment do exist, but implementation has been spotty and slows (Ernst, 2004).

In U.S.A. amid the period in the vicinity of 1998 and 2003, just 1.1 percent of government transportation financing was put into upgrades in walker and bicycle facilities, in spite of the way that more than 13 percent of all movement passing’s are individuals by walking or bike. Indeed, 17 percent of activity fatalities among individuals 65 and over were people on foot and bicyclists in 2002. (FARS, 2002). Improving the walking and bicycling environment is already a high priority among the general population. In a poll released in 2011, 42 percent of Americans reported that "dangerous intersections make crossing the street difficult in the area close to where I live." Almost 9 out of 10 (87 percent) supported the proposal to "use part of the transportation budget to design streets with sidewalks, safe crossing and other devices" (STTP 2003).

1.4 Benefits of evaluating and improving pedestrian facilities

There have been negative arrangements for people on foot, bike and travel facilities that would support walking and make walking more secure. For that to occur there is each need to give pertinent facilities. The outlines of better walker facilities can possibly expand the share of non-mechanized modes and diminishing car travel. This can help reduce car related issues of movement clog, contamination, sprawl, and commotion. Moreover, as non-motorized trips substitute for short, emission-intensive, motor vehicle trips, increased walking mode share may displace a disproportionately high amount of emissions and fuel consumption. For most people, however, automobiles are generally much more convenient than walking even for short distances because the transportation infrastructure is designed primarily to accommodate personal automobiles. Making sheltered, agreeable, and advantageous courses for people on foot inside this vehicle situated foundation is a testing errand. In any case, giving improved walking courses is basic for empowering walking. Keeping in mind the end goal to give better walking courses passerby offices must be enhanced or at the end of the day it is evident to give better and enhanced walker facilities to energize walking.

Conventional planning has a tendency to overlook or underestimate advantages, for example, wellness and general wellbeing of dynamic transportation, delight in walking and cycling, and enhanced versatility choices for non-drivers. The part that non-motorized travel plays in supporting open travel and rideshare travel is regularly disregarded. Numerous transportation financial assessment models even overlook advantages, for example, lessened blockage, stopping cost reserve funds and customer cost investment funds that outcome when travel shifts from heading to non-mechanized modes. (Litman 2003). To improve these pedestrian facilities, an increase of pedestrian flow is a prerequisite. The responsible authorities need to have a selection or evaluation criteria in prioritizing the routes that need new or improved pedestrian facilities.

1.5 Problem Statement

From 2003 to 2013, the number of vehicles on roads have doubled in Sri Lanka (Department of Motor Vehicle, 2013 June) hence the congestion in urban and sub urban areas have been increased which has paved the way to encourage more walking for travelling. The model share of pedestrians in developing cities is relatively higher as opposed to developed cities. For example, between 25-50% of trips in major Indian cities and about 50% of all trips in major African cities are made entirely on foot. In medium and smaller cities, the share of all walking trips can be as high as 60-70% (Gwilliam, 2002). However, though a significant number of trips are made by foot in majority of developing cities, pedestrian infrastructure, amenities, and services are often neglected in municipal planning and budgets (Fang, 2005).

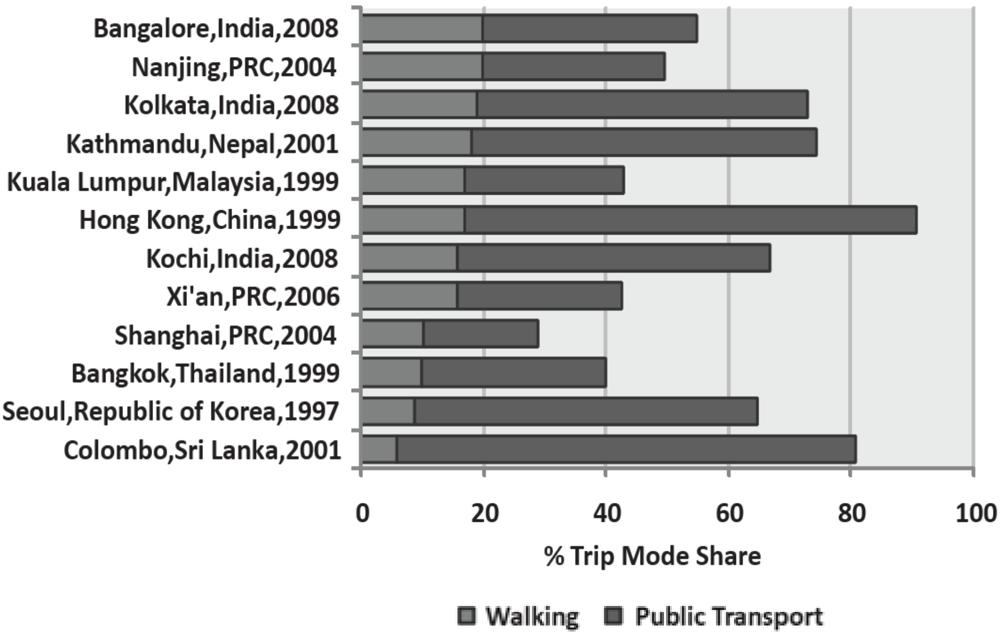


Figure 1.1: Public Transport and Pedestrian mode share in selected Asian Cities

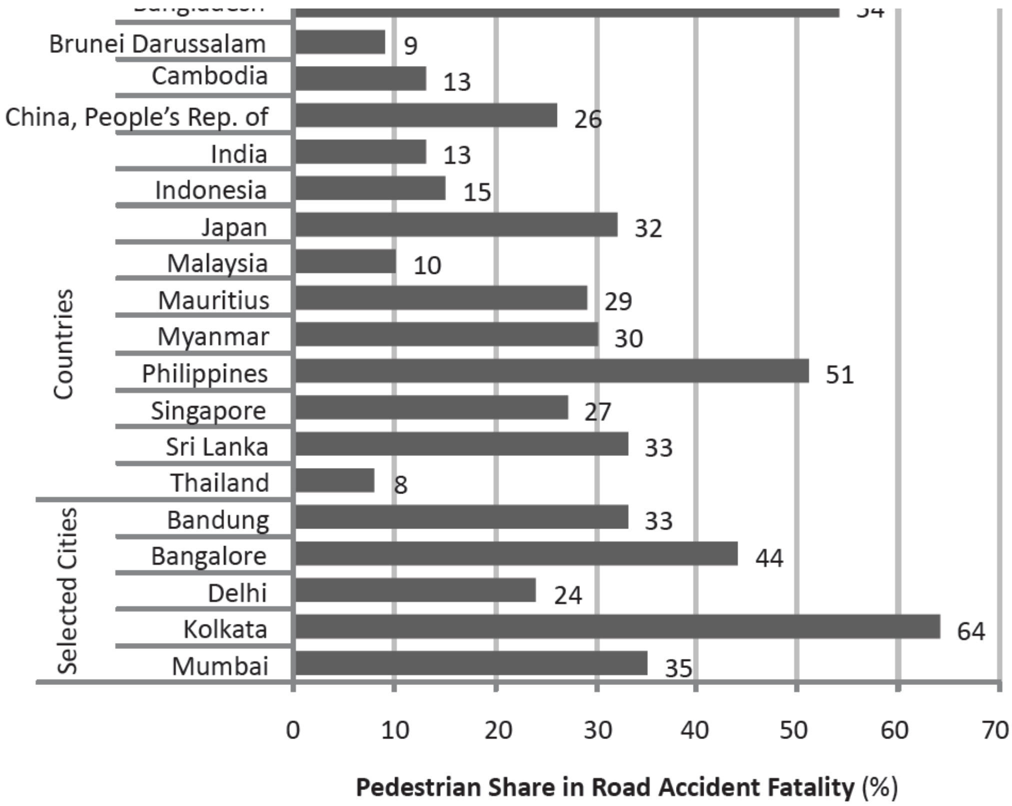
Source: ADB Working Paper Series-Walkability and Pedestrian facilities in Asian Cities

Figure 1.1 shows public transport and pedestrian mode share in selected Asian cities indicate that Sri Lanka has the lowest mode share of walking as compared to other Asian cities. Today, this condition may have reduced further as the public transport mode share has reduced by 8% (from 21% to 13%) during the last 10 (2000-2010) years. This is not the trip mode share, but the average percentage of buses in the traffic flow obtained from many manual classified counts in roads in Colombo - Sri Lanka. Railway transportation highly contributes the transportation system in Colombo as a public transportation system and that is not included in this percentage either. According to Leather et al. 2011, in some Asian cities, such as Bangalore, Changzou, Chennai, Delhi, Nangchang, Shanghai and Xi‘an, the annual reduction of the walking trip mode share is 2% on average and it‘s been replaced mostly by two-wheelers and cars. The main reason for this decline which has been identified by authorities is the inadequacy of facilities for pedestrians and public transport. This decline must be prevented by ensuring that the built environment allows people to walk and that there are walking opportunities available to them.

In addition Figure 1.2 indicates that Sri Lanka’s pedestrian fatality share of road accidents is averagely high compared to the other Asian Countries. This happens again when pedestrians are not provided with a safe and protective walking environment. In order to encourage more pedestrians on the road with safety, relevant pedestrian facilities have to be provided. In this regard, it is crucial to evaluate pedestrian facilities and their requirements to encourage walking and to make walking environment safe and attractive. For achieving this, responsible authorities need to understand the pedestrian facility requirements. Being a developing country, the challenge to implement is always monetary constraints and therefore need to have evaluation criteria in prioritizing the pedestrian facility requirements.

Many walkability studies carried out in evaluation of pedestrian facilities. Many qualitative and few quantitative approaches utilized in these studies. These studies lacked in complete walkability evaluation.

Figure 1.2: Pedestrian fatality share of road accidents in selected Asian countries and selected cities (%)



Source: Ministry of Urban Development. 2008. Study on Traffic and Transportation Policies and Strategies in Urban Areas in India; World Health Organization. 2009. Global Status Report on Road Safety: Time for Action.

1.6 Research Question

To attract more pedestrians there is every need to design broader sidewalks, improved lighting, safe crossings and attractive transit wait areas to improve the experience of walking. The research questions are formed with reference to this statement and the research need as follows.

(1) What variables are most appropriate for evaluating pedestrian facility requirements?

(2) How could a walking trip generation and attraction rates be developed for different land uses in an urban area?

(3) How could a criterion be developed to prioritize pedestrian facility requirements or improvement priorities in road links?

1.7 Research Aims and Objectives

The main aim of this research is to develop a model to prioritize pedestrian facility requirements in an urban area. The walkability measures will be utilized for the development of this model. This model could be used by decision makers to identify the priority areas for improving and maintaining pedestrian facilities.

The key objectives include,

- Developing a walking trip generation and attraction rates for different land uses in an urban area.
- Developing a methodology to estimate the demand for walking based on the land use distribution in a given urban area
- Developing a criterion to prioritize road links that need improvements in pedestrian facilities that require regular maintenance.

2 LITERATURE REVIEW

2.1 Purpose and Scope

The purpose of this literature review is to study in detail the meaning of the term walkability, its characteristics and the various elements and measures of walkability. The chapter also deals with the measures used to prepare the model to prioritize pedestrian facilities requirement. The chapter proves to be essential in determining the various aspects of walkability as it lays the foundation for identifying the measures and preparing the final model.

2.2 Walkability

2.2.1 Definition

Walkability has been defined in many ways taking different factors into consideration under different scenarios. Walkability reflects the overall support for pedestrian travel in an area. Walkability takes into account the quality of pedestrian facilities, roadway conditions, land use patterns, community support, security and comfort for walking.

Walkability does not have a clear cut definition and it often differs according to the context. According to Mackmillan Dictionary walkability is a measure of how easy it is to walk around in an area easily and safely. Some urban planners tend to think of walkability in terms of a city's spatial land use arrangement, favoring mixed-use zoning over segregated uses. In the Walkability Index project, walkability is considered in its most basic sense: the safety, security, economy, and convenience of traveling by foot. As per the Healthier worksite Initiative, walkability is a measurement of the transportation and recreation opportunities for pedestrians, and considers pedestrian safety, convenience, and route aesthetics.

2.2.2 Elements of walkability

"In practice and in research, the term walkability appears in relation to a variety of settings displaying a range of features. A clear understanding of what walkability is and what elements define its form and function would enhance the practical value of the concept". (Shay et al., 2003). From the walking behaviour literature Shay et al found that following factors are affecting walkability.

1. Accessibility, convenience (proximity to destinations within walking distance)
2. Mixed land use
3. Density (employment or residential)
4. Pedestrian facilities (sidewalks, crosswalks, walking trails)
5. Aesthetics (friendly feel, attractive architecture, landscaping, street trees)
6. High connectivity (access to destinations, intersections, block length)
7. Low traffic volume and speed
8. Company (walking with another individual)
9. Access to public open space
10. Access to transit
11. Other (freedom from obstacles, crime safety, access for special populations)

Walkability can be evaluated at various scales. At a site scale, walkability is affected by the quality of pathways, building access ways and related facilities. At a street or neighborhood level, it is affected by the existence of sidewalks and crosswalks, and roadway conditions (road widths, traffic volumes and speeds). At the community level it is also affected by land use, accessibility, roadway Connectivity, such as the relative location of common destinations and the quality of connections between them (Litman, 2004). Chris Bradshaw, in his paper presented to the 14th International Pedestrian Conference, mentions that walkability has four basic characteristics:

1. A "foot-friendly" man-made, physical micro-environment which has wide, level sidewalks, small intersections, narrow streets, adequate trash cans, good lighting with no obstructions on the roads.
2. A full range of useful, active destinations within walking distance: shops, services, employment, professional offices, recreation, libraries.
3. A natural environment that moderates the extremes of weather- wind, rain, sunlight - while providing the refreshment of the absence of man's overuse. It has no excessive noise, air pollution, or the dirt, stains, and grime of motor traffic.
4. A local culture that is social and diverse. This increases contact between people and the conditions for social and economic commerce.

In my research study, I have identified four main elements of walkability; Infrastructure, Destinations, Journey and Environment. A complete walkability evaluation criterion must address all these four aspects. Physical properties of sidewalks, pedestrian crossings, other pedestrian amenities provided etc. come under infrastructure. The destinations are the service providers located in the neighborhood that attracts pedestrian trips and dependent on the land use distribution and residential or employment density. Journey represents the trips between trip generators and attractors and represents the pedestrian flow or demand for walking. It further includes connectivity, convenience and accessibility to destinations. Environment represents aesthetics and safety. Priority for pedestrian facilities must be provided based on all of the above four aspects. Table 1 illustrates the four elements in a detail manner.

Table 1: Features of Four Main Walkability Elements

Element	Features
Infrastructure	Physical properties of sidewalks, street lighting, disability facilities, pedestrian crossings, other pedestrian amenities provided
Destination	Land use distribution and floor area, residential or employment density
Journey	Pedestrian flow, demand for walking, connectivity routes and networks, accessibility to destinations, convenience
Environment	Aesthetics (Pleasant atmosphere, air quality, attractive architecture, landscaping) Safety (from crimes, vehicle volume and speed)

2.2.3 Measures of Walkability

There have been numerous studies on walkability taken up in the past. In this part an effort is made to emphasize some of these studies that form the base for identifying the quantifiable measures of walkability.

In a paper presented at the 14th International Pedestrian Conference, Colorado, Bradshaw (2003) came up with a rating system to measure the walkability index of a neighborhood. Apart from including the aspects of proximity and connectivity as the measures of walkability, he used the following set of indicators to measure the walkability index of a neighborhood:

- Density, persons per acre
- Parking spaces off-street per household
- Number of sitting spots per household
- Chance of meeting someone while walking
- Age at which a child is allowed to walk alone
- Women’s ranking of safety
- Responsiveness of transit services
- Number of neighborhood places of significance
- Acres of parkland
- Sidewalks

Saelens et al (2003) examined the correlation between environmental factors of walking and biking from transportation, urban design and planning studies. The main aspect of this study was linking health with planning research. The prominence of neighborhood design and land use in affecting the transportation choices is also examined in this study. The factors that affected the preferences of the user between motorized and non-motorized transportation were categorized into the following:

- Proximity
    - Density
    - Land use
- Connectivity
    - Ease of moving between origins and destinations

Giles-Corti and Donovan (2003) examine individual, social environmental, and physical environmental correlates of walking. A cross-sectional survey was conducted among healthy workers and homemakers residing in metropolitan Perth for this study. It was found that most respondents walked for transport or recreation, but only 17.2% did a sufficient amount of walking to accrue health benefits. In this study the variables used to examine the measures were:

- Presence of sidewalks
- Presence of trees
- Land use diversity
- Access to river
- Access to public open space
- Access to beach
- Access to golf club
- Quiet surrounding roads
- Street lighting
- Dog ownership

In Leslie et al (2005) report on Residents' perceptions of walkability attributes in objectively different neighborhoods (2005), GIS was used to measure the features of the built environment that may influence adults' physical activity. In this study, the measures that were used to calculate the walkability index were:

- Connectivity
- Dwelling density
- Land Use attributes
- Net retail area

Moudon, et al (2006), reviewed the theories that defined neighborhoods and proposed an empirical approach to identify measurable attributes and thresholds of walkable neighborhoods. This study is a step ahead of the previous ones, as it not only which identified environmental attributes that are positively associated with walking, but also came up with values for residential density, street-blocks lengths around homes, distances to food and daily retail facilities from home and threshold distances for eating/drinking establishments and grocery stores. Measures and threshold values were calculated for the following:

- Residential Density
- Block size
- Sidewalks

- Attractor Destinations
- Deterrent destinations
- Perceived Number of Central Activities in
- Geographic Extent of Walkable Neighborhood

In a paper presented at the 6th International space syntax symposium named Walking Initiatives:A quantitative movement analysis, Ozlem, O. and Ayse, S. K. came up with an analytical model that could shed fresh light for future research on walkability. The aim of this research is to shed light on key variables that affect the attractiveness of an area for pedestrian movement. In this analytical model they have used following measures to develop an objective methodology to evaluate walkability.

- Pedestrian movement
- Spatial accessibility
- Land use
- Gradient of road
- Safety and security
- Visual quality, attraction and comfort values

According to the studies mentioned above, there are a wide range of measures and variables that are correlated to the walkability of an area. Throughout the studies on walkability and models developed; there is a consistent emphasis on connectivity, pedestrian infrastructure, proximity, land use, density, environment and safety. Table 2 indicates the measures of walkability employed by various authors in their studies. This table was developed on the basis of broad group of measures that have been mentioned consistently in the research literature.

Table 2: Measures of walkability employed by various authors

Measure	Author
Connectivity	Saelens, Sallis and Frank (2003), Giles-Corti and Donovan (2003), Leslie, Saelens, Frank, Owena, Baumand, Coffee, Hugo (2005), Ozlem, O., & Ayse, S. K. (2007)
Proximity	Giles-Corti and Donovan (2003), Chris Bradshaw (1993), Ozlem, O., & Ayse, S. K. (2007)
Density	Saelens, Sallis and Frank (2003), Leslie, Saelens, Frank, Owena, Baumand, Coffee, Hugo (2005), Chris Bradshaw (1993), Moudon, Lee, Cheadle, Garvin, Johnson, Schmid, Weathers, Lin(2006)
Pedestrian Infrastructure	Giles-Corti and Donovan (2003), Chris Bradshaw (1993)
	Moudon, Lee, Cheadle, Garvin, Johnson, Schmid, Weathers, Lin(2006)
Land use	Giles-Corti and Donovan (2003), Leslie, Saelens, Frank, Owena, Baumand, Coffee, Hugo (2005), Ozlem, O., & Ayse, S. K. (2007)
Environmental & Safety	Giles-Corti and Donovan (2003), Chris Bradshaw (1993), Ozlem, O., & Ayse, S. K. (2007)

After reviewing all literature finally three measures are selected for the preparation of the model; namely Pedestrian Demand, Connectivity and Available pedestrian facilities.

2.3 Pedestrian Demand

2.3.1 Introduction

Pedestrian mobility is a significant part of multimodal transportation system. The planning and designing of pedestrian oriented facilities is very important to create livable and safe areas. The proper estimation of pedestrian speed-flow-density and pedestrian demand relationships is of vital importance, because such relationships play an important role in developing useful tools for analyzing and improving pedestrian facilities in terms of efficiency and safety.

One important aspect for developing pedestrian plans is estimating the amount of pedestrian traffic that can be expected in a particular area given the land use, transportation and social context. Pedestrian demand is also an important component for safety analysis. The aim of transport modeling is to predict patterns of movement and the functioning of movement systems, yet research in this field until now has been almost exclusively focused on motorized transport to the exclusion of other modes. Perhaps the neglect of pedestrians in the research arose because modeling started at the same time as automobile dependence became a key feature of transport, so attention was focused on understanding vehicular traffic.

2.3.2 Measures of pedestrian demand

A handful of pedestrian demand models were developed in the 1960s and 1970s for forecasting pedestrian flows and prioritizing pedestrian improvements in CBD areas. These models were developed with a structure similar to standard transportation planning models, including zonal trip generation based on land use characteristics and trip distribution and assignment over a network based on a gravity model approach.

A variety of pedestrian sketch-plan methods have been developed to estimate pedestrian volumes under existing and future conditions in a pedestrian activity area. These methods generally use pedestrian counts and regression analysis to predict pedestrian volumes as a function of adjacent land uses (e.g., square feet of office or retail space) and/or indicators of transportation trip generation (parking capacity, transit volumes, traffic movements, etc.). Alternatively, data on surrounding population and employment may be combined with assumed trip generation and mode split rates to estimate levels of pedestrian traffic. These sketch plan methods can be used to identify areas of high pedestrian demand based on existing land use data without carrying out pedestrian counts on all facilities. They can be also used to forecast changes in pedestrian volumes as a result of future land use and trip generation changes.

Kagan et al (1978) outlined a formal Pedestrian Planning Process (PPP), including demand modeling phase and a design and evaluation phase. The PPP was intended to help cities develop a network of pedestrian facilities, particularly in their downtown core area, which would "ensure and foster effective exchange for pedestrian trip-making between and within planned and existing activity centers." The PPP includes a comprehensive evaluation of existing and forecast pedestrian travel patterns and movement requirements. The PPP can be used to predict changes in trip patterns as a result of pedestrian facility improvements or land uses and identify and prioritize actions for improvements to facilities.

In current literature the mostly used tool for identifying pedestrian demand is geographic information systems (GIS), which are tools for managing and analyzing data. GIS can be used to improve pedestrian demand forecasting and facility analysis by permitting spatially-based analysis. Broadly, GIS relate environmental and population data in a spatial framework, using location points, lines (commonly roadway links and corridors), and polygons (surface areas and analysis zones). These geographic values are linked to measurable environmental and population characteristics and analyzed by spatial relationship. Within the field of transportation, GIS are employed as a mechanism for the physical inventory of transportation facilities, as a planning tool to relate available environmental, personal transportation and household characteristics data, as a spatial analysis tool for calculating distances and areas, as a network performance monitor, and as a vehicle for the graphic display of data and analysis in a geographic context.

Currently, non-motorized-oriented GIS applications serve a variety of functions:

- Inventory and evaluate facilities within the non-motorized network using existing condition indexing and evaluation methods. Roadway conditions, such as pavement condition, average traffic volume, and outside-lane width, are linked to specific network links. Analysis of this data and subsequent analysis can be displayed graphically in the form of a visual map.

- Establish spatial relationships between the location of roadway network links and their condition to off-network features (activity centers, etc.) and area population characteristics.

• Calculate and assign probabilistic gravity values of activity centers (trip generation or attraction) to geographic areas, roadway links, and location points. Roadway links are assigned a composite score based on their proximity to trip generators and attractors.

• Assess total network performance and identify optimal routes. This use of GIS is currently limited by available technology, as it must be adapted from motor-vehicle oriented network modeling applications.

• Develop network measures (street density, connectivity, etc.) and land use measures (mix, balance) that can be related to the likelihood of walking or bicycling.

Using GIS applications requires the development of a foundation data base of geographic features within the study area, including municipal boundaries, geocoded roadway links, bodies of water, and others. This information becomes the base layer upon which subsequent layers of information and analysis will be superimposed. Additional layers can attribute values or data to established roadway links, identify and classify population groups (by income, housing value and tenure, etc.) and activity centers (by trip generation characteristic). Each layer can be manipulated individually, displayed on the computer screen in any combination or printed out to meet the needs of the analyst.

Clifton et al (2008) developed a method to estimate pedestrian demand using readily available data at the sub regional scale. This pedestrian demand model was builds upon the traditional four-stage urban transportation modeling process, used extensively in regional travel demand models. However the proposed model functioned at the pedestrian scale, utilizing readily available archived data and operates entirely within a geographic information systems framework. This developed model has three components; trip generation, trip distribution and network assignment. The pedestrian demand model was differs from the traditional vehicular model as it does not include all four steps because pedestrians travel does not need to segment travel by modes after the trip distribution step. Therefore, this model includes only trip generation, trip distribution and network assignment steps.

2.3.3 Demand Estimation Methods

To identify existing best practices relating to the generation of walking trip rates. Data relating to walking has been collected for many years mainly on an area-wide or corridor basis for transport modeling or monitoring purposes which did not necessarily relate to individual land use activities. A number of researchers have proved that proximity to nonresidential land uses, specifically retail uses, has been linked to higher walking rates for utilitarian purposes in the general population (Patricia et al (2008), Leslie et al (2003), Pendall and Chen (2003)). Beyond the presence of specific land uses, others have argued that the proportion of land devoted to different uses within a given distance from a home location may also affect levels of walkability (Chris Bradshaw (1993), Saelens et al (2003), Metaxatos and Morocoima (2008)).

Since transport modeling has been developed in the 1950s, techniques have been focused on motorized transportation modes such as private car and public transportation (Bates, 2000). Past studies have brought effective traffic management, and rapid progress of the demand forecasting methods. However, non-motorized transportation has been excluded from the main stream of the general transportation planning as there has been no standard technique for estimating non-motorized transportation demand.

Often ignored in traditional transportation demand models, a pedestrian oriented demand modeling could be useful in understanding the issues related to walking and other non-motorized modes thereby contributing to research and development of alternative transportation modes. An appropriate pedestrian demand model is an essential tool for pedestrian planning. According to Ewing (1997), pedestrian and bicycle-friendly design could be constructed only if demands are estimated. According to Raford (2004), the prediction of pedestrian demand makes calculation of exposure of pedestrian risk possible (The term “exposure” results from the field of epidemiology and is defined as “the rate of contact with a potentially harmful agent or event” Raford, N., (2004)). Through estimating walking demand, the places that impede walking could be examined and appropriately redeveloped.

Past and recent research has used a combination of surveys, travel behavior models and regression analysis when developing pedestrian trip generation rates. Some researchers have conducted surveys by using trip diaries and stated and revealed preferences surveys to understand how individuals' travel behavior varies under different land use and accessibility circumstances. Most of these travel behaviour or demand models are focused on automobile while the techniques used in planning for pedestrians are underdeveloped. Since walking has been considered essential, the effort to develop and improve pedestrian demand models should be undertaken.

Further, in order to develop pedestrian facilities it is imperative to know the demand and for finding pedestrian demand for roads we need to know the trip

Table 3: Pedestrian demand estimation techniques employed by various authors

ng trip rates . Some of the pedestrian demand estimation techniques are given in table 3.

Researcher	Study Level	Time period	Data		Technique
			Pedestrian volume	**Land use and socio economic data**	
Behnam and Patel, 1977	Block (CBD of Milwauke e)	Hourly	Pedestrian counts (real counts)	Commercial space, Office space Cultural and entertainment space, Manufacturing space, Residential space, Parking space Vacant space, Storage and maintenance space	Linear regression
Davis, King and Robertson, 1991	Crosswalk level(Was hing ton D.C)	5 to 10 minute time segment s during Peak hours	Pedestrian counts (real counts)	Vehicle traffic counts	Simple Equation
Matlick 1996	Corridor-level	Daily	Transportatio n mode share information (Census)	Housing type, density, persons per household unit, retail, recreation, social facilities, schools, employments and churches	Linear Regression

Ercolano, Olson, Spring, 1997	City level (Plattsburgh, New York)	Hourly (peak hour)	Vehicles per hour from traffic counts and mode share from Census	Vehicle traffic counts	Computation using spread sheets
Targa and Clifton, 2005	City level (Baltimore City)	One day	The number of walk trips from NHTS 2001	Car ownership in household, type of housing unit, household income, age, sex, driver status, education status, attitudes/ perceptions of pedestrians, household density, street connectivity, land use diversity, proportion of commercial units	Poisson regression

According to Cervero and Radisch (1995), the effect of neighborhoods on travel demand was practically initiated by Levinson and Wynn (1963). They found that neighborhood density is closely associated with decreasing vehicle trips. In the high density city, decreasing vehicle trip frequency means increasing transit trips and non-motorized trips. Ewing and Cervero (2001) summarized empirical findings and provided synthesis of the relationship between travel and built environment. Their synthesis focused on the effect of walking trips on four kinds of category: prototypical neighborhoods, activity center, land use variables, and transportation network variables. According to them, walking trips are associated with transit-oriented neighborhood, the distance between commercial districts and residential areas, higher density areas, land use mixing areas, and multi-story buildings. Even though several empirical studies do not use a trip generation method but mode choice technique, several findings supports that pedestrian demands are associated with land use characteristics.

Moudon, Hess, Snyder, and Stanilov (1997) showed effects of site design on pedestrian travel in mixed-use, medium-density environments. They selected 12 neighborhood centers or sites in the Puget Sound area in Washington by some criteria: residential density, income, automobile ownership, and intensity and type of commercial development. Six urban areas out of 12 neighborhood sites show 37.7 pedestrians per hour per 1,000 residents on average, while other 6 suburban areas show

12.5 pedestrians per hour per 1,000 residents. They found a “clear break” of pedestrian volumes per hour per 1,000 residents as 16 to 22 pedestrians.

Most literature concludes that walk trips are closely related to socioeconomic data and land use variables. However, they differ in the level of study area like neighborhood level or local level and time period like hours or number of days. Nevertheless, some variables such as density, mixed land use, and car-ownership are considered steadily. However, there are limitations to collect those data. Pushkarev and Zupan (1975) used aerial photography data collection techniques which is difficult to apply to city or regional level analyses. In addition, since they focused on the high-density CBD site, there are limitations in applying to other areas. Similarly, the model of Behnam and Patel (1977) is also limited in low density areas.

Since Ercolano, Olson, and Springa (1997) do not use a regression technique, it is impossible to predict the pedestrian change with respect to other factors (land use and socio-economic data). In other words, the model only depends on other mode share. Since utility function including the travel time and the travel distance should be estimated to calculate mode share percentage, this technique is also limited to estimate the pedestrian demand.

The limitation of these two previous studies was the data collection. Since the real count data usually reflect both general and unique characteristics of the area where the data are collected, it is hard to apply the model estimated in one place to the other places. The unique characteristics are usually unknown, thus this study tries to overcome this disadvantage focused on general measures such as socioeconomic factors and land use factors from various urban forms. In addition, the study area of previous studies is blocks, corridors, and a city. This study tries to model the same topic for metropolitan level (Baltimore city and 5 neighboring counties). The considerable quantity of data from NHTS Baltimore add-on reflects the general characteristics of pedestrians.

2.3.4 Pedestrian Trip rates

Targa and Clifton (2005) found that lower vehicle ownership, college dorm home type, and lower household income are associated with higher walking frequency. In addition, denser urban area, higher street connectivity, and more mixed land use generate more walk trips.

In general, the conceptual model, which is based on the empirical studies, is that walking frequency is a function of socio-economic data and land use variables. Socio-economic data consists of age, income, race, education, and car ownership. Land use variables include population density, household density, non-residential unit density, and mixed land use. On the other hand, it was found by Targa and Clifton (2005) that the Poisson regression model can be an appropriate model for walk trips. Therefore, it is assumed that walking trip frequency is followed by Poisson distribution.

In current literature the mostly used tool for identifying pedestrian demand is geographic information systems (GIS) for managing and analyzing data. GIS can be used to improve pedestrian demand forecasting and facility analysis by permitting spatially-based analysis. Broadly, GIS related environmental and population data in a spatial framework, uses location points, lines (commonly roadway links and corridors), and polygons (surface areas and analysis zones). These geographic values have been linked to measurable environmental and population characteristics which could be analyzed by spatial relationship. Within the field of transportation, GIS has been employed as a mechanism for the physical inventory of transportation facilities, as a planning tool to relate available environmental, personal transportation and household characteristics data, as a spatial analysis tool for calculating distances and areas, as a network performance monitor, and as a vehicle for the graphic display of data and analysis in a geographic context.

Dasgupta et al (1996) reviews methodological practices and factors determining trip attraction rates, modal split, travel times and trip lengths to specific developments. It describes 'trip generation' as meaning something quite explicit in terms of traffic models, but suggests this is not strictly accurate when considering land uses as these are usually 'trip attractors'. 'Trip attraction' is therefore more applicable when describing trip rates to different land uses. Peachman et al (1997) reviewed three survey methods available for the purposes of household travel surveys, such as face-to-face interviews, drop off/mail back and mail out/mail back. Also, travel and activity diaries were tested for each of the three survey types. The research stated that face-to-face questionnaires using a travel survey method was the most suitable for a household travel survey as this provides the highest response rate, data quality and range of items for a similar cost to other methods.

It is clear that organizations, which have traditionally focused only on developing motor vehicle trip rates, are now beginning to recognize the need to include non-motorized trips as well. The Road and Traffic Authority (RTA) in New South Wales, Australia has commenced a series of trip generation and parking demand studies, to update the background research in the widely recognized and adopted Guide to Traffic Generation Developments. The institute of Transportation Engineers' (ITE) published trip generation rates for various types of land uses. However, all these rates do not include pedestrian data and they are currently in the process of including walking trip rates as well.

2.4 Connectivity

2.4.1 Introduction

It is difficult to bicycle and walk safely and comfortably around a community where connections are few and far between. The Victoria Transport Policy Institute states that, "*Connectivity* refers to the directness of links and the density of connections in path or road network. A well connected road or path network has many short links, numerous intersections, and minimal dead ends (cul-de-sacs). As connectivity increases, travel distances decrease and route options increase, allowing more direct travel between destinations, creating a more accessible and resilient system."

(Online TDM Encyclopedia, www.vtpi.org, viewed 23/05/12)

Table 4: Connectivity Definitions

Word/Phrase	Definition
Link	A roadway or pathway segment between two nodes. A street between two intersections or from a dead end to an intersection
Node	The endpoint of a link, either a real node or a dangle node
Real Node	The endpoint of a link that connects to other links. An intersection
Dangle Node	The endpoint of a link that has no other connections. A dead-end or cul-de-sac
Circuit	A finite, closed path starting and ending at a single node

The terminologies used in connectivity definitions are given in Table 4.The term "street connectivity" suggests a system of streets with multiple routes and connections serving the same origins and destinations. Connectivity not only relates to the number of intersections along a segment of street, but how an entire area is connected by the transportation system. A well-designed, highly-connected network helps reduce the volume of traffic and traffic delays on major streets (arterials and major collectors), and ultimately improves livability in communities by providing parallel routes and alternative route choices. By increasing the number of street connections or Local Street intersections in communities, bicycle and pedestrian travel also is enhanced a well-planned, connected network of collector roadways allows a transit system to operate more efficiently.

Connectivity affects the degree to which transportation networks such as streets, walking and cycling paths, connect people to their destinations (including intermediate destinations such as public transport services). Good connectivity provides easy access to key destinations for pedestrians. Excellent connectivity actively seeks to discourage car use by making local trips easier and more pleasant by foot than by car.

2.4.2 Measures of connectivity

Transportation and urban planners have focused more attention on the issue of street or network connectivity with the rise of concepts such as smart growth, New Urbanism, and neo-traditional development. Several measure of connectivity can be found when reviewing planning and transportation literature. Here, the task is to evaluate measures of connectivity for the purpose of how it affects walkability. A review of the planning and transportation literature found several measure of connectivity. The purpose is to examine the different methods used in measuring connectivity, and to evaluate the effectiveness and limitations of those methods.

Table 5 contains the ten different connectivity measures, out of which majority (8) draw heavily upon the work of Dr. Jennifer Dill (2005). , School of Urban Studies and Planning, Portland State University.

Table 5: Connectivity Measures

Measure	Definition	Calculation	Comments
Intersection Density	Number of intersections per unit of area	Number of Real nodes area / area	A higher number would indicate more intersections, and presumably, higher connectivity
Street Density	Number of linear miles of street per square mile of land	Total street length per unit of area / area	A higher number would indicate more streets, and presumably, higher connectivity
Connected Node Ratio (CNR)	Number of street intersections divided by the number of intersections plus culde-sacs	Number of Real Nodes / Number of Total Nodes (real + dangle)	The maximum value is 1. Higher numbers indicate that there are relatively few cul-de-sacs and dead ends, and presumably a higher level of connectivity
Link-Node Ratio	Number of links divided by the number of nodes within a study area	Number of links per unit of area (streets) / Number of Nodes per unit of area	A perfect grid has a ratio of 2.5. This measurement does not reflect the length of the link in any way
Average Block Length	Block lengths can be	Sum of link length per unit of area / Number of nodes	Shorter blocks mean more

	measured from the curb or from the centerline of the street intersection. The GIS measures the street length from center of intersection to center of intersection.	per unit of area	intersections and therefore a greater number of routes available
Effective Walking Area (EWA)	A ratio of the number of parcels within a one quarter mile walking distance from an origin point to the total number of parcels within a one quarter mile radius of that origin point	Tax lots within ¼ mile walking distance of origin point / Tax lots within ¼ mile radius	Values range between 0 and 1, with a higher value indicating that more parcels are within walking distance of the Pre-defined point. The higher value reflects a more connected network
Gamma Index	Ratio of the number of links in the network to the maximum possible number of links between nodes	Number of Links per unit of area / 3*(Number of Nodes - 2)	This measure comes from geography. Values range from 0 to1
Alpha Index	Ratio of the number of actual circuits to the maximum number of circuits	(Number of Links - Number of Nodes) + 1 / 2*(Number of Nodes)-5	This measure comes from geography. Values range from 0 to 1
Connectivity Ratio (CR)	The ratio between the number of links and the	(Number of links)/ Total possible links	When all possible links are available, CR equals to 1. But CR doesn't

	total possible links		reflect the attraction between O-D pairs
Weighted Connectivity Index	A measure of how well the alternative network connects land uses between which there is likely to be travel	$WCI = \sum_{\substack{\text{for all} \\ i,j \\ i \neq j}} \left[\frac{\sum_{\substack{\text{for all} \\ m,n}} K_{mn} A_{mi} A_{nj}}{D_{ij}^2} \right]$ K_{mn} = factor that represents the intrinsic attractiveness between land use types m and n *i,j*= block pairs that are connected by the alternative network	Measures how well the alternative connects land uses. Here pedestrian flow was taken but no measure on pedestrian demand.

Understanding intersection and dead-end densities is fairly straightforward; areas that are more walkable would tend to have higher intersection densities and lower dead-end densities. One would expect that areas with more roads would have more intersections, yet, independently analyzing intersection densities is important because it gives insight into the connectedness of the mobility network that might not be evident from simply looking at the length of the network.

Block length is used in a number of ways to promote or measure connectivity. Several communities have adopted maximum block length standards for new development (Handy et al., 2003). Standards usually range from 300 to 600 feet and apply to every block, with some exceptions. The theory behind using block length as a standard is that shorter blocks mean more intersections and consequently, shorter travel distances and a greater number of routes between locations. The concept of a maximum block length is attractive from a policy standpoint because it is easy to understand.

A few researchers have used block density as a proxy measure for connectivity. Frank et al. (2000) used the mean number of census blocks per square mile. The authors assert that census block density is a good proxy for street connectivity, since census blocks are typically defined as the smallest fully enclosed polygon bounded by features such as roads or streams on all sides. Cervero and Kockelman (1997) use blocks defined more traditionally – areas of land surrounded by streets. In either case, increased block density is thought to represent increased connectivity – more blocks means smaller blocks and more intersections.

The Connected Node Ratio (CNR) is the number of street intersections divided by the number of intersections plus cul-de-sacs. The maximum value is 1.0. Higher numbers indicate that there are relatively few cul-de-sacs and, theoretically, a higher level of connectivity. The INDEX model calls this Internal Street Connectivity and recommends against networks with values less than 0.5. Values of 0.7 or higher are favored (Criterion Planners Engineers, October 2001). Link-Node Ratio is an index of connectivity equal to the number of links divided by the number of nodes within in a study area. Links are defined as roadway or pathway segments between two nodes. Nodes are intersections or the end of a cul-de-sac. Ewing (1996) suggests that a link-node ratio of 1.4, about halfway between extremes, is a good target for network planning purposes. At least three cities have adopted the link-node ratio as a standard, with values of 1.2 and 1.4 (Handy et al., 2003).

Pedestrian Route Directness (PRD) is the ratio of route distance to straight-line distance for two selected points. The lowest possible value is 1.00, where the route is the same distance as the "crow flies" distance. Numbers closer to 1.00 indicate a more direct route, theoretically representing a more connected network. PRD is the same as the "circuity factor" sometimes applied in logistics to approximate travel distances between cities (Ballou et al., 2002).

Portland's Metro allows PRD to be used as an option to the maximum block length design standard, with 1.5 as the maximum (Handy et al., 2003). Randall and Baetz (2001) found that neighborhoods with grid street patterns and relatively short blocks had PRDs of 1.4-1.5. Neighborhoods with more curvilinear streets and cul-de-sacs had PRDs between 1.63 and 1.88. The INDEX model recommends PRDs of 1.2-1.5, with values of 1.6-1.8 characterized as indirect (Criterion Planners Engineers, October 2001). An even simpler measure is walking (or cycling) distance. Aultman-Hall et al. (1997) calculated mean walking distance, maximum walking distance, and the share of homes with minimum walking distances above a 400 meter standard. The analysis chose three destinations (a school, the nearest open space, and the nearest transit stop) and calculated the shortest path distance for each home using GIS software.

Geographers have developed the gamma index and alpha index as measures of connectivity. The gamma index is a ratio of the number of links in the network to the maximum possible number of links between nodes. The maximum possible number of links is expressed as 3 * (# nodes – 2) because the network is abstracted as a planar graph. In a planar graph, no links intersect, except by nodes (Taaffe and Gautheir Jr., 1973). This feature represents a transportation network well. Values for the gamma index range from 0 to 1 and are often expressed as a percentage of connectivity, e.g. a gamma index of 0.54 means that the network if 54 percent connected. The alpha index uses the concept of a circuit – a finite, closed path starting and ending at a single node. The alpha index is the ratio of the number of actual circuits to the maximum number of circuits. As with the gamma index, values for the alpha index range from 0 to 1, with higher values representing a more connected network. Both indices could be applied as measures of connectivity for bicycling and walking. Table 6 indicated the connectivity measures used by different authors.

Table 6: Connectivity measures used in literature

Measure	Literature
Pedestrian route directness	Randall et al (2001)
Weighted Connectivity Index	Bandara et al (1994)
Block length (mean)	Cervero and Kockelman (1997)
Block size (mean area) Block size (median perimeter)	Hess et al. (1999) Reilly (2002) Song (2003)
Block density	Cervero and Kockelman (1997) Cervero and Radisch (1995) Frank et al. (2000)
Intersection density	Cervero and Radisch (1995) Cervero and Kockelman (1997) Reilly (2002) Leslie et al (2005)
Percent four-way intersections	Cervero and Kockelman (1997) Boarnet and Sarmiento (1998)
Street density	Handy (1996) Mately et al. (2001)
Connected Intersection Ratio	Allen (1997) Song (2003)
Walking distance	Aultman-Hall et al. (1997)

2.5 Pedestrian Facilities

2.5.1Introduction

Walking should be promoted as a dominant mode of travel for short trips. Many professionals point out that walking is a great way to reduce the carbon foot print. As Walkscore.com states it, *"cars are a leading cause of climate change and your feet are zero-pollution transportation machines"*. Walking can be promoted as green transportation where the environment is not affected in any way. Moreover, a pleasant environment attracts more people to walk

Utility-related walking includes household, transportation, or occupation purpose walking and that has now become a solution in sustainable transport systems. Presence of facilities for pedestrians is a vital importance in both utility-related walking and recreational walking. Pedestrian facilities in an urban area have a significant influence on the traffic flow and socio-economic environment. Measure of "walkability" has been used to evaluate pedestrian facilities. Majority of such measures are qualitative in nature and rank road segments based on the level of service concept. A recent attempt to develop a scorecard based on measurable aspects of walkability is available but it focuses only on comparing roads based on the facilities available for pedestrians. Communities with good pedestrian facilities will enhance the quality of life. Pedestrians enjoy a high degree of freedom of movement even in a highly congested area as opposed to vehicles. Accordingly, more alternative paths are available for pedestrians between any origin-destination (O-D) pair.

Improved walking facilities not only will generate new pedestrian flows, but it will also increase the comfort of the current walking population. The ridership of buses will increase with the comfortable last mile connectivity from busses. Furthermore, it will reduce dependency of cars while less car use leading to reducing congestion and pollution. More equity will be given by providing public spaces and amenities to all sections of the society.

People who live in walkable neighborhoods make four times as many walking and bicycle trips, three times as many transit trips, take fewer car trips, and drive fewer miles (Quade & Douglas 1993). Improved facilities could lead in to a long term solution for traffic congestion, thus public transport will be complemented and private car use would be reduced.

Since the late 1990s, bicycling and walking have received increased attention as part of an effort to meet the challenges of congestion, air quality, and quality of life (Sisiopiku VP et al, 2002). Consequently, a need has arisen to measure the performance of pedestrian facilities for improvements and priority setting. Traditionally, pedestrian facilities operations were evaluated on the basis of the level-of-service (LOS) concept. However, the LOS methods used in assessment of pedestrian facilities are examined in detail to develop criteria to be used for this research study.

2.5.2 Measures of Pedestrian Facilities

In most research pedestrian facility measures are qualitative in nature. The Global Walkability Index (Krambeck 2006) is used in walkability surveys around the world by Clean Air Initiatives and Asian Development Bank. The GWI mainly consists of a field survey, a stakeholder survey and a pedestrian interview survey. Pedestrian facilities are evaluated under nine elements, as follows;

1) Walking path modal conflict
2) Security from crime
3) Crossing safety
4) Motorist behavior
5) Amenities (Cover, benches, public toilets, street lights)
6) Disability Infrastructure and Sidewalk Width
7) Maintenance and Cleanliness
8) Obstructions
9) Availability of Crossings

All the above elements are in the form of a Level of Service (LOS) unit, on a scale from 1 to 5. Hence, the GWI is a relaxed score card which does not consume much time. In fact, a surveyor can just walk along the road segment while observing the content and can fill out a form by the end of the road segment based on the observations. Apart from the observations, there is a pedestrian questionnaire to be filled by interviewing pedestrians. Although GWI is a simple tool, there are some draw backs as many of the factors considered in it are substantially subjective. If the first element in GWI is considered, walking path modal conflict measures the extent to which pedestrians are mixed with other modes. The second element, Security from crimes is to be assessed by questioning a road user as pedestrians, vendors, policemen etc. about their perceptions and experience, particularly at night. Therefore, due to these factors it could be subjective in this scenario.

The third element, crossing safety is considered through three key factors; (i) exposure to other modes, (ii) exposure time and (iii) sufficient time at signalized crossing. There is no recommendation for a minimum delay or minimum number of passing or meeting events to say it is safe. All the amenities are evaluated under the fifth element, about their presence or function. Shelter, trees, street lights, benches, public toilets, pedestrian signage, and other amenities are listed under the pedestrian amenities. Evaluating a broader element like ―pedestrian amenities‖, via LOS will not represent the actual situation. Observers' satisfaction does not reflect the presence of amenities. One might give a high score for a shady road, without considering the other possibilities (e.g. street lights, benches) that could have been there to make the road more convenient for walking. It seems to a challenging task for relevant authorities to identify the required improvement by looking at an LOS value.

Infrastructure for disabled people is a wide area, however GWI has not given sufficient attention to it. And also, sidewalk width is another major element related to walkability. However, these two parameters are embedded in one element in GWI as element number six. This approach has given equal importance to both the factors. Hence, those two elements (disability Infrastructure and sidewalk width) are given lesser importance as compared to other elements. Maintenance and cleanliness is listed under the seventh element. Maintenance is implied as the presence of sidewalk space or pavement and cleanliness is supposed to coincide with the images given in the guide book and its descriptions. Assessing cleanliness in this method can be accepted even though, the conditions may vary within 500 m. Therefore, confusions might occur when recording a single score for the entire road section.

There are two methods of scoring for obstructions which includes temporary obstructions permanent obstructions. On the other hand, in the GWI score card, there

is only one place to enter the score. The ninth element, ―availability of crossing has scored the highest mark when there are ample opportunities to cross the street. It scores the lowest, when there are no opportunities for *"very long"* distance. It is also mentioned that there should be crossings available at least every 300m, to be considered acceptable. In addition, the score for the ninth element is not reliable when the surveyors do not measure the length between adjacent crossings.
Apart from those, GWI itself warns about three other limitations:

1) The notion of walkability is not well understood, thus paving the way for widespread misunderstanding‖. The notion of walkability is new to the stakeholders.
A pilot survey was carried out while developing the proposed model. It was noticed that the concept of walkability was new to the surveyors.

2) The Index requires data to be collected in the field.

Although some prefer indices like ―Walkscore (walkscore.com 2010), since it does not require data to be collected in the field, it is not always accurate. Hence, this is not considered as a limitation in the proposed model and all the evaluations in the proposed model are to be done using field data.

3) The simplicity of data collection methodologies for practical purposes results in a less-robust index, and may diminish its usefulness as a tool for investment and policy reform.

This third point could be considered a limitation.

Being a qualitative tool GWI cannot be taken to compare two roads since the results are subjective and may not be replicable.

The score card model (Dias et al, 2012) consists of quantitative measures for pedestrian facilities unlike GWI. The research discusses the major pedestrian facilities involved in utility-related walking and proposes a scoring model to evaluate the pedestrian facilities in urban environment using walkability measures. The proposed model can be used to evaluate pedestrian facilities in road links to compare different road links and to identify deficiencies in a given road. The facilities evaluated in the proposed model are:

1. Sidewalks
2. Crosswalks
3. Pedestrian amenities and aesthetics
4. Disability infrastructure
5. Security from crimes

The features of sidewalks are: presence & continuity of raised sidewalks, obstructions, effective width of sidewalks, modal conflict, surface condition of sidewalks, and Albedo of the paving material. The features of crosswalks are: availability of crosswalks, and delay at signalized crossings and un-signalized crossings. Availability of pedestrian facilities including, benches, shades, bus halts with seats, pedestrian information boards, proper street lighting add scores to a road link. And also, aesthetics is assessed as a qualitative factor. In addition, tactile paving, uniformity of the paved sidewalks, cross slopes, curb ramps, drainage, and overhead obstructions are the features under infrastructure for the disabled people.

The direct use of this score card is to evaluate the pedestrian facilities of a road link. This could be used in detail to compare two or more road links. This is a micro level walkability assessment where, only road links get evaluated.

This score card has some imitations a follows;

(1) This cannot be used to evaluate pedestrian facilities in subways or pedestrian bridges.
(2) Further studies should be carried out to figure out the necessity of grade separation and/or space separation of pedestrian flow from the motor traffic flow and the quality of such facility.
(3) Special road links such as, pedestrian only streets, boulevards or park roads also cannot be evaluated using this, since they should be specially designed for pedestrians with wider pathways and sometimes like a recreational area
(4) This survey tool can evaluate the available pedestrian facilities but it does not evaluate the pedestrian demand in a road link.

2.5.3 Pedestrian Level of Service

Several methods for assessment of pedestrian facilities on the basis of pedestrian level-of-service (LOS) have been developed. Most of these methods have used the principles of vehicular traffic and other methods are more concern with the facility design and walking environment. In fact, some of the factors related to pedestrian quality of service can be qualitative rather than quantitative and are often difficult to measure. Determination of the LOS of pedestrian facilities can thus be a complex but important. Critics suggest that current pedestrian LOS determination methods are modeled too closely after vehicular LOS determination methods, often resulting in inadequate and contradictory assessments or even showing good LOS values in an inhospitable walking environment (Kroll J., 2004).

Analyses of pedestrian-related issues have been gaining much attention from researchers in recent years, particularly studies of pedestrian safety and pedestrian level of service (LOS) in developing countries. Crosswalks (namely, signalized, unsignalized, and midblock) are complex locations because of the interaction of pedestrians with the vehicle flow. Pedestrian LOS at crosswalks is quite different from that on sidewalks. A measure of effectiveness (MOE) is usually adopted for evaluation of pedestrian facilities, and the MOE changes with the type of facility. Pedestrian delay and space at the corner are considered as MOEs for signalized intersections. The MOE might depend on pedestrian safety, delay, available vehicle gaps (crossing difficulty), and behavior of pedestrians as well as that of vehicle drivers at unprotected midblock crosswalks. Many researchers argue that an effective pedestrian LOS determination method should consider both the operating conditions of a system and how the users perceive such condition (Pushkarev B and Zupan J., 1975).

Usually in developing countries, pedestrians share the vehicle lane because of the absence of sidewalks, and crossing the road at unprotected crosswalks because of roadside development and crossing because of nearness to the destination are difficult. Because of the mixed traffic, it is very rare to get an adequate gap at unprotected crosswalks and pedestrian behavior changes when they cross the road under mixed traffic conditions. In India, studies found that 60% of accidents related to pedestrians were in an urban area and of these, 85% were noted at midblock crossings (Mohan D et al, 2009). This indicates high pedestrian vehicle conflict at cross walks in developing countries. There are various types of studies at sidewalk locations by different researches (Table 7). Some of the LOS methods applied for evaluation of operations at pedestrian facilities are the HCM 2010 method, the Australian method, the Landis model, and the conjoint analysis approach.

Table 7: Pedestrian LOS studies at sidewalk locations

Author	Sidewalk type	Type of survey	Factors considered	Limitations
TCQSM report (1999) HCM 2000 Shanin (2006)	Roadway segment, public transit areas	Video	Capacity based	These studies are limited to a quantitative approach based on capacity and quantitative variables as flow, space and density. Some of these studies explored the importance of bi-directorial effect.
Sarkar (1993) Khisty (1994)	Roadway segment	Opinion	Environmental	These studies are limited to qualitative parameters only.
Mozwe D (2014)	Roadway Segment	Opinion	vehicle, pedestrian behavior and roadway geometry	This study did not examine the effect of pedestrian vehicle interaction
Botma H (1995)	Roadway Segment	Opinion	Vehicle and roadway geometry	This did not consider pedestrian vehicle interaction
Jensen (2007) Asadi-Shekari et al. (2013)	Roadway corridor Segment, sidewalk	Video & opinion	Environmental, vehicle, pedestrian behavior and roadway geometry	These studies were more focused on pedestrian qualitative measures. The study by Asadi- Shekari et al included pedestrians with disabilities without any quantitative analysis.
Landis et al. (2001) Talevska and Todorova (2012)	Roadway Segment, area based, sidewalk, walkways	Observational, Simulation, Web-based	Environmental, pedestrian behavior and roadway geometry	In the Landis study quantification was not considered and the other one did not consider pedestrian perception.
Muraleetharan et al (2005)	Roadway Segment	Video	Capacity based, Environmental, vehicle, roadway geometry	Regression based model was developed without considering the pedestrian behavior characteristics
NCHRP (2008) Florida Department of Transportation(2009)	Roadway Segment Intersection	Video & opinion	Capacity based, Environmental, vehicle, pedestrian behavior and roadway geometry	This is an extensive study various factors. However, the degrees of satisfaction among different modes were not quantified till 2012.

In the latest HCM2010 many changes were done in answer to critiques of 2000 edition. To encourage HCM users to consider all travelers, the HCM 2010 incorporates tools for multimodal analysis along highway facilities. This is the first edition of the HCM that takes into account the effects of cars on bicyclists and pedestrians. The stand-alone chapters for the bicycle, pedestrian, and transit modes have been eliminated—instead, the methods applicable to bicycles, pedestrians, and transit have been incorporated into the analyses of the various roadways. To calculate Pedestrian Level of Service (PLOS) or Bicycle Level of Service (BLOS) is to assign a grade, A through F, to a portion of roadway. This grade is meant to correspond to the perceived level of service that that roadway provides to pedestrians or bicyclists, respectively. PLOS and BLOS comprise a portion of the HCM's Multimodal Level of Service methodology (MMLOS).

Pedestrian Level of Service (PLOS) determined by most important variables as follows.

- At an intersection, where the crosswalk is essentially the unit of analysis: the number of lanes crossed typically has the greatest contribution, while high speeds and volumes can also play a large role in determining the final grade.

- On a link: this is co-determined by a calculation of pedestrian space (a measure of crowding) and a pedestrian quality-of-service score. The worst predominates. The score is heavily influenced by the width of the walking area and its separation from vehicles. High traffic volumes can also play a large role.

- On a segment: a polynomial function of intersection PLOS and link PLOS, which also incorporates a roadway crossing delay factor

- On a facility: co-determined by 1) a weighted sum of segment PLOS scores and 2) pedestrian space. The worst predominates.

PLOS and BLOS are data-intensive, mathematically involved, multi-stage calculations. They generally are not sensitive to the full range of variables of interest to planners and policymakers, and particularly in an unsatisfactorily way with innovative treatments. The validity of dealing with specific variables, such as sidewalk widths and striping of bicycle lanes cannot be taken as they are in Asian context. In addition, the extent to which these methods are useful for analyzing proposed changes to a street depends to a great extent on the analyst's ability to predict changes in operational variables that are not directly controlled by street design, such as traffic volumes and speeds. Finally, the PLOS model is quite specific to formal units of analysis such as the intersection and link, and is specific to a side of the street.

The Australian method of pedestrian LOS determination primarily depends on three factors, namely, the physical characteristics, location factors, and user factors. Pedestrian conditions are described by LOS grades A (ideal pedestrian condition) to E (unsuitable pedestrian conditions), based on an assessment of the factors affecting the LOS.

The physical characteristics considered in this method include path width, surface quality, obstructions, crossing opportunities, and support facilities (Galin N, 2001). Location factors address issues related to connectivity, the path environment, and the potential for vehicle conflict. The term "connectivity" refers to the degree to which the path provides a useful, direct, and logical link between the attractors and the producers of pedestrian trips. The path environment is a measure of the degree of pleasant- ness of the surrounding environment and often relates to the distance from the roadway. User factors take into consideration pedestrian volume, the mix of path users, and personal security. After these factors have been evaluated, each factor is scored by using the criteria given in Table 8 and is multiplied by the respective weight. Addition of these values results in a combined score that is used to assign the corresponding LOS grades, according to Table 8.

The Landis method is a good attempt to quantify objectively a pedestrian's perception of safety and comfort in the roadside environment. The quantification provides a measure of how well roadways accommodate pedestrian travel (Landis et al, 2000). This model is developed through a stepwise multivariable regression analysis of 1,250 observations. The Landis method determines the quality of sidewalk operation by taking into consideration the perception of safety and comfort that a pedestrian experiences. These factors contribute to a complex assessment of a roadway segment as expressed in the proposed model shown below.

$$\text{Ped LOS} = -1.2021 \ln [W_{ol}+W_l+(f_p*OSP)+(f_b*W_b)+f_{sw}*W_s)]$$
$$+0.253 \ln (Vol_{15}/L) + 0.0005SPD^2+5.3876$$

where:

W_{ol} = Outside lane width (feet)

W_l = Shoulder or bike lane width (feet)

f_p = On-street parking coefficient = 0.20

% OSP = Percent of segment with on-street parking

f_b=Buffer area barrier coefficient = 5.37 for trees spaced 20feet on center

W_b = Buffer width between edge of pavement and sidewalk (feet)

f_{sw} = Sidewalk presence coefficient = 6 – 0.3 W_s

W_s = Sidewalk width (feet)

Vol_{15} = Average 15min motor vehicle traffic

L = Total number of through lanes for street

SPD = Averaging running speed of motor vehicles (miles per hour).

It should be noted that the term $W_{ol} + W_l + f_p * \%OSP + f_b * W_b + f_{sw} * W_s$ is an expression of the lateral separation. This term refers to barriers, buffers, and the presence of sidewalks and determines the ability of a pedestrian to have a separate, protected place to walk comfortably along the roadway. As the separation from the motor vehicle traffic increases, the pedestrian safety and comfort levels increase as well. The presence of on-street parking, a line of trees, or even a roadside ditch between the areas for motorized and non-motorized travel provides additional safety perceptions. The term including the Vol_{15}/L portion is the motor vehicle factor. In this configuration, a 50/50 directional split is assumed. In cases where the split is different, $(Vol_{15}/L_d) * D$ should be used, where D is the directional factor and L_d is the total number of directional lanes for the street.

The resulting Model Score is then compared to a chart to determine LOS with LOS A for a score of 1.5 or less and LOS F for a score greater than 5.5 as shown below.

A	B	C	D	E	F
≤1.5	>1.5 but ≤2.5	>2.5 but ≤3.5	>3.5 but ≤4.5	>4.5 but ≤5.5	>5.5

The LOS model equation is created with a statistical significance of 95 percent level. The formula was calibrated and validated extensively in field studies of 24 road segments. Traffic along the segments ranged from an average daily traffic (ADT) of 200 to 18,500 ADT with speeds ranging from 25 to 125 kph (15 to 75 mph). Overall, this method is one of the most extensively studied and written about methods for assessing pedestrian LOS other than the HCM 2000 method.

Conjoint technique is a dominant way of capturing user's perception of the value of any product or service. Conjoint analysis estimates an individual's "value system", which specifies how much a user puts on each level of attributes (Gustafsson A. et al, 2001). This technique can be used to determine Pedestrian LOS for sidewalks and crosswalks by combining multiple attributes affecting pedestrian travel.

By conjoint analysis, what attributes are important and what not to the pedestrians can be determined. Both sidewalk and crosswalk evaluations consider two attributes that depend on traffic and two that are not traffic related. Accordingly, these factors are under three general performance measures describing the roadside pedestrian environment; 1) sidewalk capacity, 2) quality of the walking environment, and 3) the pedestrian's perception of safety (or comfort) with respect to motor vehicle traffic (Landis B.W. et al., 2000). LOS on sidewalks evaluated on a 6-point ("A" to "F") scale how safe / comfortable they felt as they traveled each segment. Level "A" was considered the most safe / comfortable (or least hazardous). Level "F" was considered the least safe / comfortable (or most hazardous).

A	B	C	D	E	F
5.36-4.78	4.78-4.19	4.19-3.61	3.61-3.02	3.02-2.44	< 2.44

Table 8: Pedestrian demand techniques employed by various authors

	Weight	0 Points	1 Point	2 Points	3 Points	4 Points
Path width	4	No path	0 –1 m	1.1–1.5 m	1.6–2.0 m	Over 2.1 m
Surface quality	5	Unsealed,	Poor quality	Moderate quality	Acceptable	Excellent quality
Obstructions (per km)	3	Over 21	11 to 20	5 to 10	1 to 4	None
Crossing opportunities	4	None, difficult	Poorly located	Some, but not enough	Adequate	Dedicated crossings
Support facilities	2	Nonexistent	Few and far between	Few and well located	Adequate	Many well located
Connectivity	4	Nonexistent	Poor	Reasonable	Good	Excellent
Path environment	2	Unpleasant, close to vehicles	Poor, less than 1 m of road	Acceptable, within 1 or 2 m of road	Reasonable, within 2or3m of road	Pleasant, over 3 m from road
Potential for conflict	3	Severe, over 25 per km	Poor, 16 to 25 per km	Moderate, 10 to 15 per km	Reasonable, 1to10 per km	No vehicle conflicts
Pedestrian volume	3	Over 350 per day	226 to 250 per day	151 to 250 per day	81 to 150 per day	Less than 80 per day
Mix of users	4	Majority of non-pedestrians	51% to 70% of non-pedestrians	21%–50% of non-pedestrians	Under 20% non-pedestrians	Pedestrians only
Personal security	4	Unsafe	Poor	Reasonable	Good	Excellent

3 RESEARCH METODOLOGY

Walkability has been gaining a great importance in recent years and is becoming an important component of planning and designing communities in order to make them more pedestrian and bike friendly. In this regard availability of pedestrian facilities becomes an integral part of attracting people to walk. Given below are the steps followed in developing the model to prioritize pedestrian facility requirements in an urban environment.

To develop a model it is a pre-requisite to understand the road network and travel behaviour of the people in that particular area. In addition the number of pedestrian trips needs to be known to understand the pedestrian flow. For the pedestrian demand estimation there was no any convenient method established. For this research study a new pedestrian demand estimation method is proposed, which requires household travel surveys, trip diaries, traffic counts and activity surveys to be carried out. Once the trip rates are identified based on the above method, an understanding of pedestrian trip demand of the area can be fulfilled. It is proposed to use a geographic information systems (GIS) based methodology. GIS will facilitate to find the pedestrian demand in road segments based on land use distribution using network analyst tool. Next an evaluation criterion proposed to rank road links based on available pedestrian facilities. All steps carried out in developing the new methodology are given below.

Step 1

Conducting a thorough literature study on the concept of walkability, including its various elements, characteristics, indicators, benefits, and barriers in order to assist the framing of the concept.

Step 2

Reviewing the walkability models developed in the past, and studying the measures, and indicators used for evaluating walkability and fine tuning them to develop a transferable model.

Step 3

Establishing a set of measures of walkability based on steps 1 & 2 which would later be used as the measures to be used to develop the model to prioritize pedestrian facility requirements in an urban environment.

Step 4

Conducting household and road side surveys along with an assessment of available pedestrian facilities along the roads to identify pedestrian trip attraction and generation rates and identifying pedestrian flows in terms of volumes.

Step 5

Developing a GIS based methodology to estimate demand for walking based on land use distribution by inter connecting land uses with their pedestrian trip generation and the household number and travel behavior of the dwellers in the area.

Step 6

Developing a methodology using network analysis tools to identify pedestrian flows along road links. This would be developed by considering the shortest links and the connectivity of the links in the road network of the area which will also identify alternative routes.

Step 7

Developing an evaluation criterion to rank road links based on available pedestrian facilities. This would be a weighted ranking criterion, which will facilitate the selection of routes to improve pedestrian facilities or to provide facilities as per the budget constraint or the objective of the development.

The whole study research flow was presented in Figure 3.1

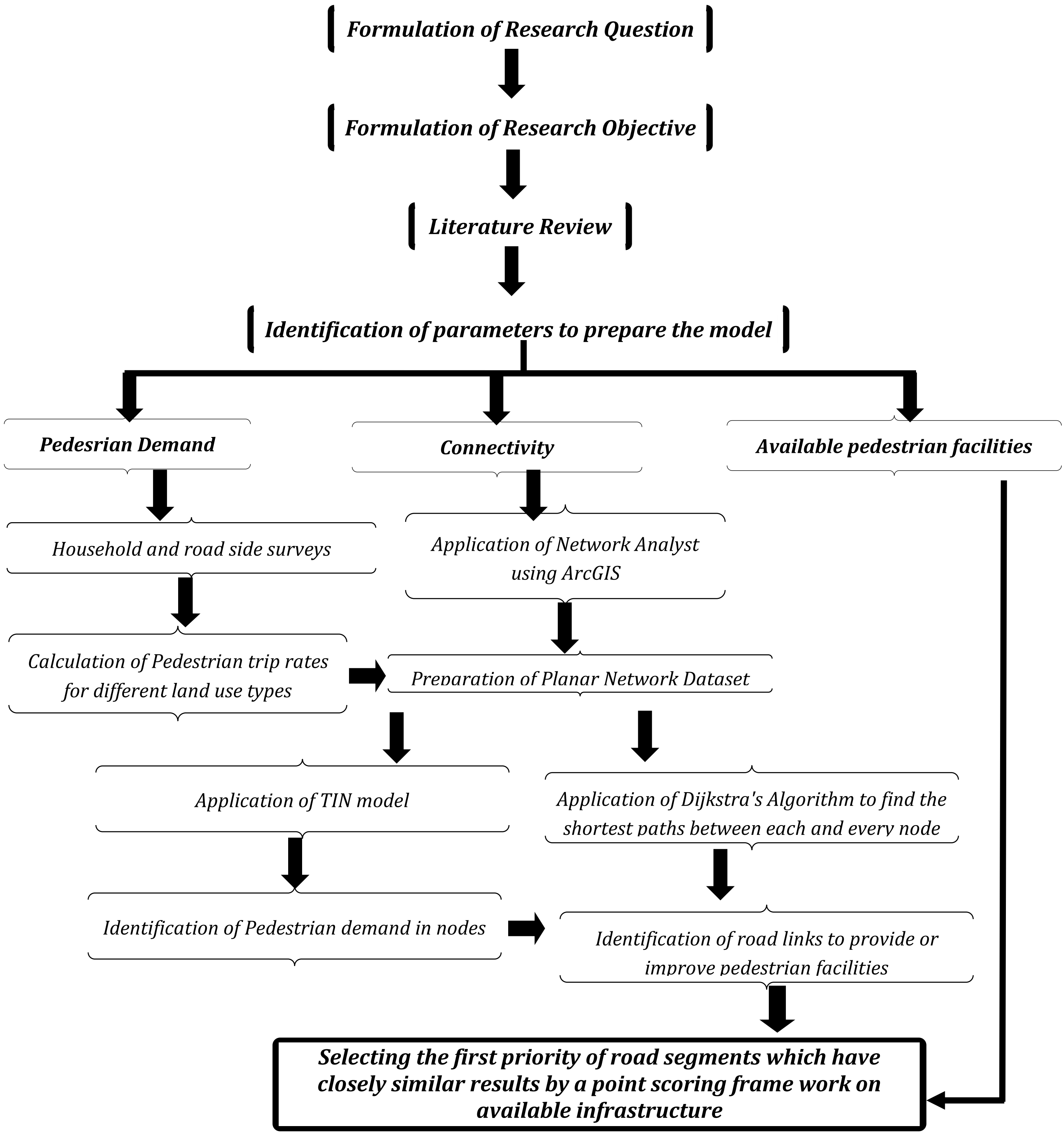


Figure 3.1: Research Flow

3.1 pedestrian demand models

Incorporation of pedestrian concerns into the transportation planning process is significantly important. The aim of transport modeling is to predict patterns of movement and the functioning of movement systems, yet research in this field until now has been almost exclusively focused on motorized transport to the exclusion of other modes. Perhaps the neglect of pedestrians in the research arose as modeling started at the same time as automobile dependence became a key feature of transport, thus attention was focused on understanding vehicular traffic. However, there has been growing social pressure to develop more sustainable transport polices in response to automobile dependence and this is beginning to change the agenda for transport modeling.

The substance of this part is an attempt to fill methodological gaps through the development of a pedestrian demand model with the aid of Arc GIS software. The overall goal of this part of the study is to develop a trip generation model for pedestrians at the individual level by using survey data and supplementary land use data. This pedestrian demand model is applied on an area-wide basis in any small and medium city, which is sensitive to land use variables.

The main objective of this part is to identify walking trip rates for land uses in Sri Lankan context as there are no reliable trip rates developed for small and medium cities in Sri Lanka. Accordingly, this part discusses the methodology of developing walking trip rates for six chosen land use, namely residential, commercial, institutional, recreational, transportation and religious and uses.

The second objective is to apply the model to any small and medium sized city in Sri Lanka and to any small and medium sized city of a developing country with similar conditions.

In this research study, the independent effects of land use and accessibility variables on household trip rates are tested using data from household travel surveys and trip diaries. To collect data on travel behavior of the dwellers, household travel surveys and trip diaries were used. After developing the household travel survey form and trip diary form, a pilot study was carried out to finalize the survey forms. By analyzing these data household trip rates were developed and also for trip rates generation of other selected land uses, O-D surveys on those activities along with road side surveys were used.

3.2 Development of walking trip rates

3.2.1Surveys It was found out from the literature that while methods for finding trip rates for motor vehicles are well established, there are not many established procedures for measuring and predicting trip rates for non-motorized trips. There are household surveys and census results that are of limited use when finding trip rates. Even though developed countries use household travel surveys regularly, countries like Sri Lanka does not have such surveys carrying out other than the census. Since this is an initial effort in finding trip rates for selected land use categories in Sri Lankan context, survey design became a vital component. Household travel surveys, trip diaries, face-to-face questionnaires, observer surveys, activity surveys and pedestrian counts were used to gather data for the development of pedestrian trip rates.

3.2.2 Trip rates of residential land use

Residential land use always acts as a trip generator. Thus, household travel surveys and trip diaries were used to collect data on travel behavior of residential land use. After developing the household travel survey form and trip diary form, a pilot study was carried out to finalize the survey forms. It was clear from the initial surveys that there was a clear lack of such experience except for the national census carried out every 10 years. Respondents find it difficult to understand; especially the trip diaries and the survey sheets were further simplified. In the survey sheets first travelling pattern was questioned as an open question and partial or incomplete answers were given. Once the error was identified a new systematic question format introduced. Due to this lack of understanding, the survey questions were further simplified and in trip diaries the instruction given were simplified with more clarifications. Finalized Household survey form (Figure 3.2) and Trip Diaries (Figure3.3) were used for the data collection.

House hold travel survey - 2013

This survey is conducting for the purpose of preparing a model to prioritize pedestrian facility requirements in an urban environment which is a Ph.D research of a student attached to the Department of Civil Engineering, University of Moratuwa

A. House Hold Information

Location					
No. of Vehicles		Type	[ ] Car	[ ] Van	[ ] Three wheeler
			[ ] Motor Bike	[ ] bicycle	[ ] Cab
			[ ] Lorry	[ ] bus	[ ] Other

B. House hold person details

	Person1	Person 2	Person 3	Person 4	Person 5	Person 6	Person 7	Person 8
Age								
Gender								
Status								

1 - Adult- Working full time	2 - Adult- Not Working
3 - Retired	4 - Adult - Tertiary Education
5 - Child - Primary School	6 - Child - Secondary School
7 - Child - Under 6	8 - Other(specify)

C. For what purpose you walk in this area?	D. Approximate dicstance you walk in this area?				
Purpose	1. Everyday	2. Several times per week	3. Once a week	4. Monthly	5. Several times per month
Work					
Education					
Sell Products					
Buy Provisions					
Buy raw materials					
Recreation					
Religious					
Social					
Other					

	Good	No Problem	Bad	Very bad
E. How do you feel about available facilities?				
F. Do you feel it safe walking?				
G. Do you feel it easy/convenient to walk arround?				
H.How do you feel about the walking area/surrounding?				

Figure 3.2: Household Survey Form

Person 1 - Trip Diary						
				I began the day at:	Home	
Enter ALL trips made on the day					Other:	
Each separate destination should have a separate trip entered						
If no trips were made, enter NONE in first address						
Trip 1	I left at	[ ] : [ ]	am / pm	I went to:		
	Travel mode					
	[ ] Car- D	[ ] Motor Bike		Purpose		
	[ ] car - P	[ ] Three Wheel		[ ] home	[ ]Recreation	[ ]personal business
	[ ] Bus	[ ] Taxi		[ ] work	[ ] education	[ ] drop off/pick up
	[ ] Van	[ ] Bicycle		[ ] shopping	[ ]social/visiting	[ ]connect to/ change
	[ ] Walk	....		[ ]other:		public transport
Trip 2	I left at	[ ] : [ ]	am / pm	I went to:		
	Travel mode					
	[ ] Car- D	[ ] Motor Bike		Purpose		
	[ ] car - P	[ ] Three Wheel		[ ] home	[ ]Recreation	[ ]personal business
	[ ] Bus	[ ] Taxi		[ ] work	[ ] education	[ ] drop off/pick up
	[ ] Van	[ ] Bicycle		[ ] shopping	[ ]social/visiting	[ ]connect to/ change
	[ ] Walk	....		[ ]other:		public transport
Trip 3	I left at	[ ] : [ ]	am / pm	I went to:		
	Travel mode					
	[ ] Car- D	[ ] Motor Bike		Purpose		
	[ ] car - P	[ ] Three Wheel		[ ] home	[ ]Recreation	[ ]personal business
	[ ] Bus	[ ] Taxi		[ ] work	[ ] education	[ ] drop off/pick up
	[ ] Van	[ ] Bicycle		[ ] shopping	[ ]social/visiting	[ ]connect to/ change
	[ ] Walk	....		[ ]other:		public transport
Trip 4	I left at	[ ] : [ ]	am / pm	I went to:		
	Travel mode					
	[ ] Car- D	[ ] Motor Bike		Purpose		
	[ ] car - P	[ ] Three Wheel		[ ] home	[ ]Recreation	[ ]personal business
	[ ] Bus	[ ] Taxi		[ ] work	[ ] education	[ ] drop off/pick up
	[ ] Van	[ ] Bicycle		[ ] shopping	[ ]social/visiting	[ ]connect to/ change
	[ ] Walk	....		[ ]other:		public transport
Trip 5	I left at	[ ] : [ ]	am / pm	I went to:		
	Travel mode					
	[ ] Car- D	[ ] Motor Bike		Purpose		
	[ ] car - P	[ ] Three Wheel		[ ] home	[ ]Recreation	[ ]personal business
	[ ] Bus	[ ] Taxi		[ ] work	[ ] education	[ ] drop off/pick up
	[ ] Van	[ ] Bicycle		[ ] shopping	[ ]social/visiting	[ ]connect to/ change
	[ ] Walk	....		[ ]other:		public transport

Figure 3.3: Trip Diary Form

For the data collection from households, stratified sampling was used which was done by using the smallest administrative division that is Grama Niladari Division (GN) level. All the surveys were done in one selected day and trip diaries were filled to get travel data only for that particular day only.

Residential trip generation rates defined herein as the total number of walking trips per household during a 24-hour period. The residential trip rates were calculated using the following multivariate equation. This equation was developed by using linear regression equations.

$$Yi= b_0 + b_1X_i +...+b_kX_n$$

The column vector Yi represents the trip rate as the dependent variable of the i^{th} observation and matrix X_i represents the variables of household size, household vehicles and floor area of the households. The column vector b represents the parameters. However, the dependent variables, the walk trip frequency, can be regarded as discrete response variables that represent the number of occurrences of some event within a given domain. Thus, Poisson regression can also be used without loss of generality because it is assumed that the number of events that occur to each case in a given observation to be governed by a rate of event occurrence. Table 9 represents the developed residential walking trip rates.

Table 9: Residential Walking Trip Rates

HH Size	**Floor Area (m^2)**		
	1-6	**6-20**	**20-50**
1-2 (No Vehicles)	2.36	2.43	1.98
1-2 (With Vehicles)	1.41	1.32	0.98
3-4 (No Vehicles)	2.84	2.97	2.73
3-4 (With Vehicles)	1.71	2.04	1.98
5> (No Vehicles)	3.02	2.76	2.93
5> (With Vehicles)	2.97	2.31	1.91

3.4.3 Trip rates for other selected land uses

<u>Land uses and site selection</u>

Both the theory and practice concludes that although land cover (LC) and land use (LU) are closely related, many proposed land use classifications mixes land cover and land use. Natural and semi-natural vegetation are described in terms of land cover whereas agricultural and urban areas in terms of land use. The definition of forests is a combination on land cover and land use as natural vegetation and eco-tourism spots or monasteries are included within such forests. However, it is necessary to develop LU classification separately from LC classification due to the differences between these two. In this research six land uses were selected to develop walking trip rates. Since the rates were selected for medium size urban areas, the land use were categorized as, Residential (single- and multi-family housing) Commercial (supermarket, fair, retail shop) Institutional (educational, financial, medical and other public offices) Recreational (playground, cinema, children park, beach Park) Transportation facilities (bus/rail stations, parking) and Religious (temple, church, kovil, mosque).

The process for site selection of these land use categories except for residential land use was determined considering the physical characteristics of the particular land use activity. Data collection varies according to the specifics of the subject land use. Pedestrian counts and face-to-face interviews were used and they were compiled to determine daily pedestrian trip rates for those land uses. Depending on the specific land use, the independent variables being floor area, number of employees, number of beds, number of trains/buses per day, etc. All these observer surveys, face-to-face questionnaire surveys and pedestrian counts at the selected sites were done by selecting a week day. Although observational surveys require less staffing and are comparatively less expensive, face-to-face questionnaire surveys were the preferred method for the research due to improved levels of accuracy and hence cost effectiveness. Also, subsequent surveys concentrated on the face-to-face questionnaire methodology. It was also clear from the initial surveys that interviewing was reliable only for the inbound direction as people are in a hurry to leave the premises once their need was done. The enumerators mentioned that people leaving were less inclined to answer the questions because they are in a hurry to leave once their work or purchase is done. For that reason surveys one direction only was chosen.

In the site selection stage, sites were selected using a selection form which is represented in Figure 3.4. The response rate for all land use activity sites are given in table 10. The time periods of the surveys were 12 hours, from 6am to 6pm. In the institutional land use, surveys at the schools were done at 6-9am and 12-3pm time slots.

Site Information	
Activity Name	
Activity type classification	
Address	
Public transport opportunities	High ☐ Low ☐ ☐ Moderate ☐ Nil ☐ ☐
Pedestrian activity	High ☐ Low Moderate ☐ Nil
Frontage road	Major arterial ☐ Minor arterial ☐ Local ☐
Total no. of access points	Vehicular only ☐ Shared Veh & Ped ☐ Pedestrian only ☐
Floor area	
employees/students/beds/buses	
Other information	

Figure 3.4: Site selection form

The data for commercial, institutional, recreational, transportation and religious sites were collected from the sites selected to carry out the surveys and the results are specific to Panadura Urban area and these rates may be used as a reference for a similar land use elsewhere. The general survey facts are given in Appendix A.

Table 11 illustrates the trip rates for other land uses. When calculating these trip rates natural logarithmic equation was used. This was due to a majority of the trip generation rates for classified land uses depends on its size and its relationship is continuous. The formula reflects that the number of trips do not increase proportionally to increases in the size of the land use activity, especially in super markets.

Table 10: Overall site response rate

Site	Total Pedestrians	Interviewed	Percentage (%)
Commercial			
Supermarket (02)	70	48	68.57%
Fair	102	42	41.17%
Retail (02)	46	28	60.86%
Hardware	17	10	58.82%
Restaurant/ snack bar (02)	22	20	90.90%
Institutional			
School (03)	1833	245	13.36%
Hospital (02)	378	102	26.98%
Medical center	32	27	84.37%
Bank	47	31	65.95%
Leasing company	28	23	82.14%
Library	21	20	95.23%
Town Hall	36	29	80.55%
DS Office	86	72	83.72%
Post office	34	29	85.29%
Recreational			
Play ground	62	41	66.12%
Park	27	18	66.66%
Cinema	83	48	57.83%
Transportation facilities			
Bus stand	196	58	29.59%
Railway station	118	63	53.38%
Parking	14	14	100%

Religious			
Temple	23	16	69.56%
Church	41	27	65.85%
Kovil	62	40	64.51%
Mosque	48	22	45.83%

The trip rates were developed for the selected land use categories by using statistical software. First the variables were recoded and grouped on number of trips per one day after doing a Chi-square analysis. This was done in order to find out the relationships and their significance for groping and those grouped variables were then used to find out the trip rates. Additionally, multivariate regression analysis was used to find out trip rates for these selected land use categories.

Table 11: Walking Trip Rates for other land uses

Land use	Trip Rates
Commercial	
Super market	1.96 trips per 100m^2
Retail	16.9 trips per 100m^2
Hardware stores	8.7 trips per 100m^2
Fair	16.4 trips per 100m^2
Restaurant	13.3 trips per 100m^2
Institutional	
Banks	2.68 trips per 100m^2
Insurance and leasing companies	2.56 trips per 100m^2
Primary Schools	1.37 trips per student
Secondary Schools	3.7 trips per student
Hospitals	0.74 trips per bed/ 1.36 trips per 100m^2
Medical centers	4.15 trips per 100m^2
Town hall	0.71 trips per 100m^2
Library	0.62 trips per 100m^2
Government offices	1.13 trips per 100m^2
Post office	2.28 trips per 100m^2
Recreational	
Play ground	0.54 trips per 100m^2
Children park	0.47 trips per 100m^2
Cinema	0.71 trips per seat / 2.15 trips per 100m^2
Transportation	
Bus Depot	4.21 trips per bus
Bus Station	18.87 trips per bus

Railway station Parking	37.59 trips per train 2.66 trips per vehicle
Religious Temple Church Kovil Mosque	 3.7 trips per $100m^2$ 1.4 trips per $100m^2$ 3.5 trips per $100m^2$ 4.2 trips per $100m^2$

3.3 Application of Geographical Information System (GIS)

Many decision support systems are based upon a model integrated with a Geographical Information System (GIS). GIS is a system of hardware, software and procedures designed to support the capture, management, manipulation, sophisticated analysis and modeling and display of spatially-referenced data suitable for solving complex planning and management problems. It is now a maturing mix of technology and is being a widely applied tool in the fields of government, emergency services, environmental, business, industry, education and transportation.

3.3.1 Building Planar Network Dataset

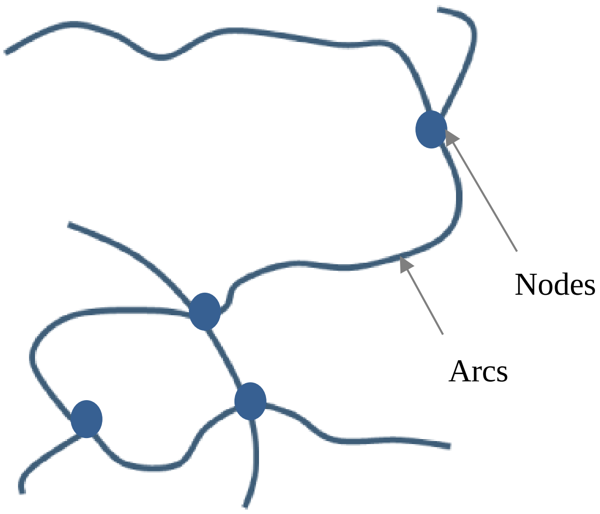


Figure 3.5: Representation of Planar Network

A transportation network consists of nodes and links. Nodes are access points to the road network and links are the connections between the nodes. The spatial data model for the pedestrian demand was prepared as a planar network where the arcs represent the road segments and the nodes represent street intersections (Figure 3.5).

3.3.2 Population walking trip generation at nodes

The approach of estimating the population walking trip rates at each node was elaborated under the following sub headings. By aggregating walking papulation to small groups with the use of Thiessen polygons the pedestrian demand per node identified. Then in order to identify the pedestrian flow minimum path algorithm was used as people would select the most efficient route in terms of shortest distance to walk.

3.3.2.1 Generating Thiessen polygons

In this model, population is aggregated into small groups. One approach of aggregating population in GIS network analysis studies is to assign and aggregate residents to their nearest street intersection using Thiessen polygons (Flowerdrew and Green, 1992), centered on the street intersections as shown in the Figure 3.6.

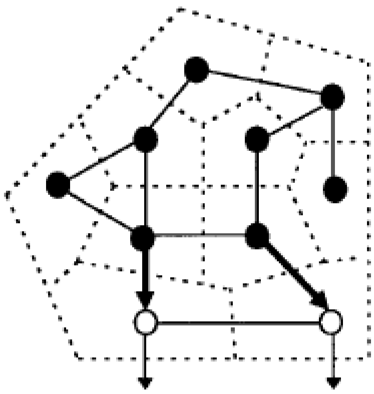


Figure 3.6: Thiessen polygons centered on the street intersections

A Thiessen polygon is a Voronoi Diagram that is also referred to as the Dirichlet Tessellation. Given a set of points, it defines a region around each point. A Thiessen polygon divides a plane such that each point is enclosed within a polygon and assigns the area to a point in the point set. Any location within a particular Thiessen polygon is nearer to that polygon's point than to any other point. Mathematically, a Thiessen is constructed by intersecting perpendicular bisector lines between all points.

The following diagrams (Figure 3.7) illustrate how Thiessen polygons would be generated manually. Population distribution was simplified by the tessellation obtained from the Thiessen polygons. It was assumed that the concentrated residents live at the center of this tessellation and the walking trips will be generated from there.

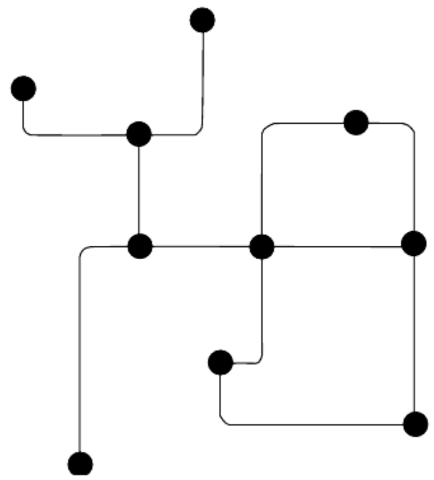
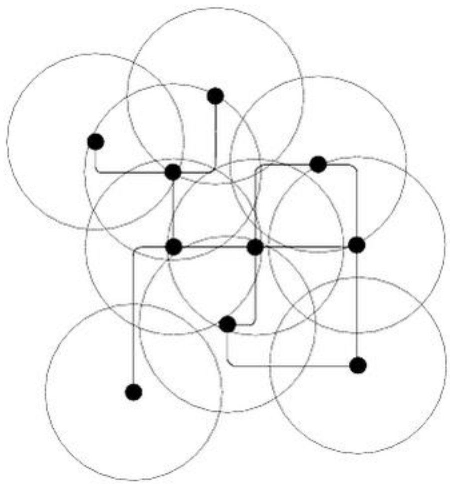
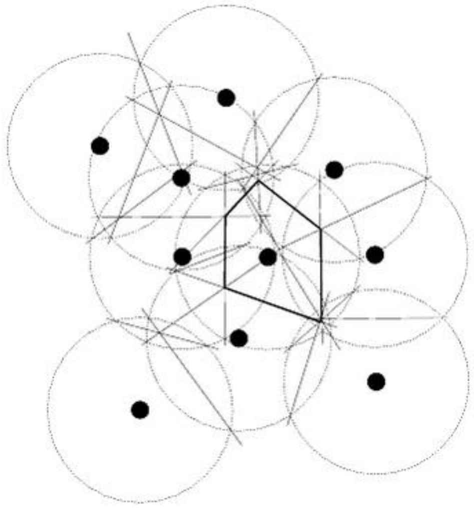
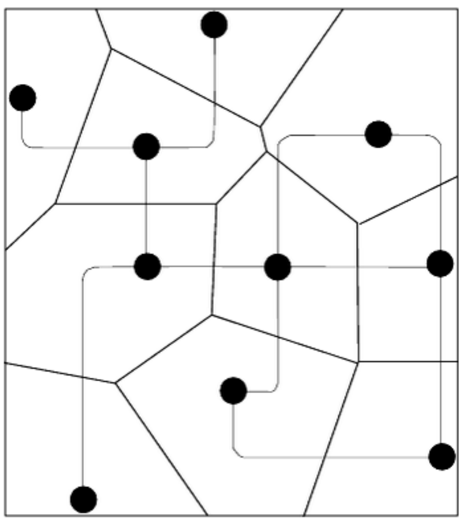
	
The first diagram shows a road segments and junctions in a network	In the second diagram, the circles are drawn around each junction
	
In the third diagram, bisector lines are added by drawing a line where the circles inter-join	In the final diagram, the network is overlaid with the polygons that are created by connecting the bisector lines

Figure 3.7: How Thiessen polygon manually generated

The tool constructs the Thiessen polygons are as follows:

- The input points are scanned from left to right and top to bottom. However, points closer than the chosen proximal tolerance to previously scanned points are ignored.
- All points are triangulated into a triangulated irregular network (TIN) that meets the Delaunay criterion. The Delaunay triangulation ensures that no vertex lies within the interior of any of the circumcircles of the triangles in the network. If the Delaunay criterion is satisfied everywhere on the TIN, the minimum interior angle of all triangles is maximized. The result is that long, thin triangles are avoided as much as possible.
- The perpendicular bisectors for each triangle edge are generated, forming the edges of the Thiessen polygons. The locations at which the bisectors intersect determine the locations of the Thiessen polygon vertices (Figure 3.8).

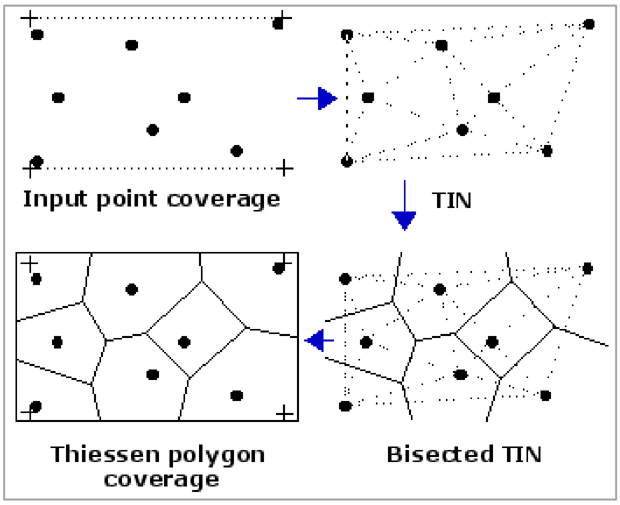
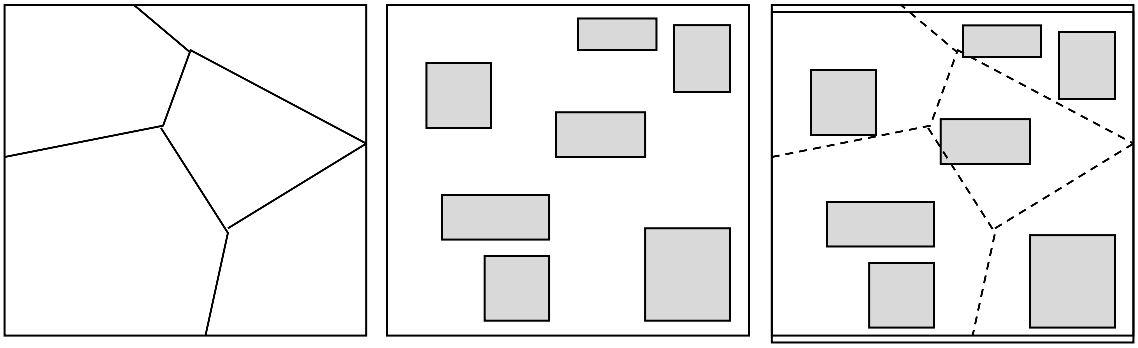


Figure 3.8: Creating Thiessen polygons using ArcGIS software

3.3.3.2 Identification of buildings within each Thiessen polygon

Both building layer and the Thiessen polygon layers need to be intersected to determine the residential buildings which belong to each Thiessen polygon. The resulted intersected layer is made up of both Thiessen polygons and residential buildings (Figure 3.9).



Thiessen polygon layer *Residential Building layer* *Intersected layer*

Figure 3.9: Process of intersecting Thiessen polygon layer with the building layer

Before the intersection, the polygons in the Thiessen polygon layer and the polygons in the building layer have its own ID number recorded in their attribute table. After the process of intersection, ID numbers in the Thiessen polygon layer and residential building layer are added to the attribute table of the intersected layer. Although, it is impossible to see the boundary lines of the Thiessen polygons in the intersected layer, the buildings will assign into its respective Thiessen polygon during the intersection process. Hence, by examining the Thiessen polygon's ID number in the intersected layer, it is easy to identify the number of different buildings belong to each Thiessen polygon. In this manner number of buildings within each Thiessen polygon were counted and recorded.

The buildings which belong to more than one Thiessen polygon were assigned to its respective Thiessen polygon which owns the highest proportion of the building area. For an example if a building has its 1/3rd of the area on Thiessen polygon 1 and the remaining 2/3rd on Thiessen polygon 2, that building was assigned to Thiessen polygon 2. The number of residential buildings, which obtained from this approach, was taken to estimate the number of residential waking trip rates within Thiessen polygons.

3.3.3.3 Estimation of number of population within each Thiessen polygon

The number of buildings under each selected land use category, which was obtained from the previously described approach, was taken to estimate the number of pedestrians within Thiessen polygons. Then the population value at each Thiessen polygon was assigned in to its center node (origin node). Shortest path obtained from the Dijkstra's Algorithm and the population estimated for origin nodes were used to calculate the population demand at road segments and destinations.

3.4 Application of Dijkstra's Algorithm to find the optimum route

The next stage of the model is determining the optimum routes from origin nodes to the nearest destination nodes. It could be noted that people would select the most efficient route in terms of shortest distance to walk.

The optimum routing of the dwellers were determined by Dijkstra's Algorithm, which is a fundamental shortest path algorithm. The algorithm computes the shortest path from one node to all other nodes in the network. It assumes that the link lengths are always non-negative.

In this method, every node is assigned a label with two components (x, y). A label could either be temporary or permanent. The algorithm halts when all labels are permanent. After completion, the labels give information on the shortest distances as well as the shortest paths from a particular node to all the other nodes. Also a node is referred to being in the open state if its associated label is temporary; it is to be in the closed state if the label is permanent.

The Dijkstra algorithm is comprised of the following 5 steps. The notations used in the steps are:

$l_{(i,j)}$:length of the link joining node i to node j.
a: node for which we are investigating the shortest paths to all other nodes.
d_{ai}: the shortest known path from node a to node i found in the network, so far.
q_i: the immediate predecessor node of node i on the shortest known path from node a to node i found so far.
c: the last node to have moved to being in the closed state.
x: $x = d_{ai}$
y: $y = q_i$

Step 1: The process starts from node a. Since the length of the shortest path from node a to node a is 0, then $d_{aa} = 0$. The immediate predecessor node of node will be denoted by the symbol + so that q_a = +. Since the lengths of the shortest paths from node a to all other nodes i ≠ a on the shortest path are unknown, q_i = - for all i ≠ a. The only node which is now in a closed state is node a. Therefore, it could be concluded that c = a.

Step 2: In order to transform some of the temporarily labels into permanent labels, it requires the examination of all branches (c, i) which exit from the last node which is in a closed state (node c). If node i is also in a closed state, the examination is passed on to the next node. If node iis in an open state the first label d_{ai} based on the below equation is obtained:

$$d_{ai} = min[d_{ai}, d_{ac} + l(c,i)]$$

The left side of the equation is the new label of node i. The d_{ai} appearing on right side of the equation is old label for node i.

Step 3: In order to determine which node will be the next to go from an open to a closed state, the value d_{ai} for all nodes which are in an open state is compared and choose the node with the smallest d_{ai}. Let this be node j. Node j passes from an open to a closed state since there is no path from a to j shorter than d_{aj}. The path through any other node would be longer.

Step 4: It is ascertained that j is the next node to pass from an open state to a closed one. Then the immediate predecessor node of node j and the shortest path which leads from node a to node j is determined. The length of all branches (i, j) which lead from closed state nodes to node j are examined until the following equation is satisfied:

$$d_{ai} - l_{(i,j)} = d_{ai}$$

This equation could be satisfied for node t. This means that node t is the immediate predecessor of node j on the shortest path which leads from node a to node j. Therefore, it is possible to conclude that q_j = t.

Step 5: Node j is in a closed state. When all nodes in the network are in a closed state, the process of finding the shortest path is completed. Should any node still be in an open state, it is required to return to step 2.

This research has utilized two routing solvers - Origin Destination Cost Matrix solver and Route solver in ArcGIS Network Analysis Extension to find the optimum path from origin nodes to destination nodes. The algorithms in both solvers are based on Dijkstra's Algorithm. These solver tools can be used to find the quickest, shortest or even the scenic route depending on the impedance you choose to solve for. In this case, distance was taken as the impedance and the shortest route from origin nodes to destination nodes were found.

3.4.1 Application of Origin-Destination Cost Matrix Tool

The O-D cost matrix solver uses a multiple-origin, multiple-destination algorithm which based on Dijkstra's algorithm. It has options to only compute the shortest paths if they are within a specified cutoff or to solve for a fixed number of closest destinations. The output of the Origin-Destination cost matrix is a layer which shows nearest destinations of each origin by means of straight line. The values stored in the attribute table of the output give the shortest network distance of each O-D pair. In here the attribute table only stores the information related to its nearest destination. Hence, it is easy to identify the nearest destination node of each origin node.

3.4.2 Application of Route Tool

Since the result of the O-D cost matrix solver only shows the nearest destination of each origin, it is required to find the network path which leads to that destination. Hence, the Route tool was utilized for the purpose of visualizing the shortest network path between O-D pairs.

The "Route" tool in ArcGIS Network Analyst finds the best route between two locations based on the Dijkstra's Algorithm. Since the model in this research has used distance as the impedance, the output of the route tool gives the shortest network path.

3.5 Calculation of population walking demand at road segments & destinations

Shortest path obtained from the Dijkstra's Algorithm and the trip demand estimated for origin nodes were used to calculate the population demand at road segments and destinations. The paragraph given below elaborates the method of calculating population walking demand at road segments along the shortest network path and D_1, D_2 destination nodes in the sample planar network as given below. (Figure 3.10)

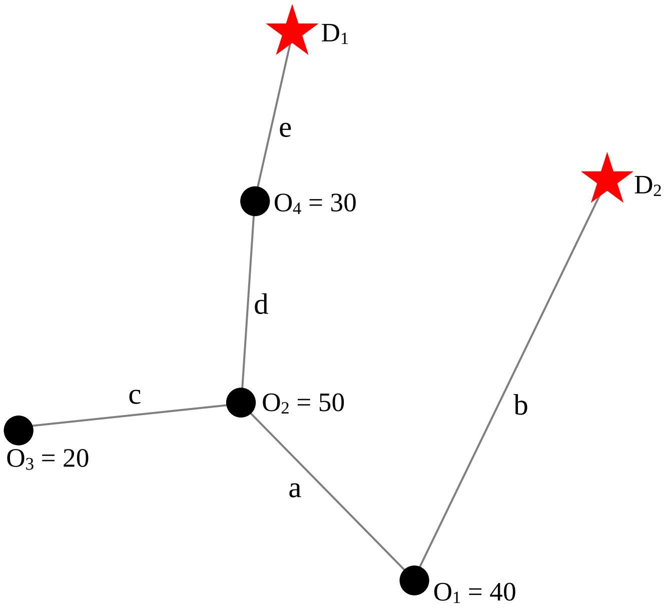


Figure 3.10: Simple Planner network

O_1, O_2, O_3 & O_4 are the origins and D_1& D_2 are the destinations of a transportation network. The estimated walking trip demand at origin O_1, O_2, O_3 & O_4 are 40, 50, 20 & 30 respectively (Table 12).

Table 12: Shortest Paths from Origin to Destination

Origin	Nearest Destination	Shortest Path
O_1	D_2	O_1-b- D_2
O_2	D_1	O_2-d-e- D_1
O_3	D_1	O_3-c-d-e- D_1
O_4	D_1	O_4-e- D_1

The cumulative population calculated for each road segments considering both shortest path and the estimated population at origin nodes, is illustrated in Figure 3.11.

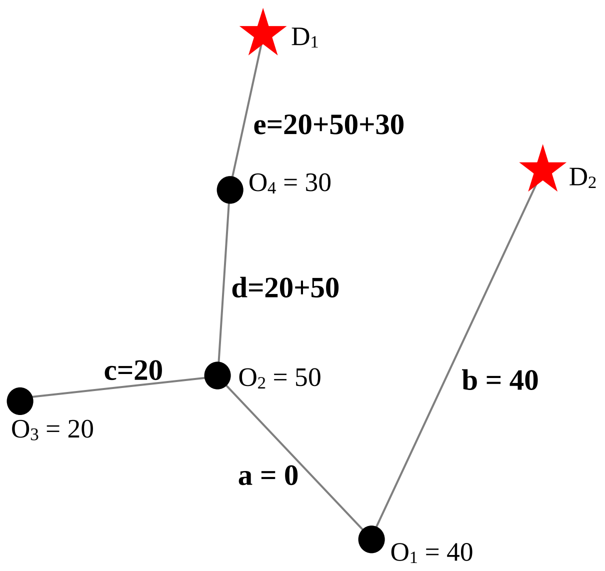


Figure 3.11: Cumulative population at each road segment

Accordingly, the populations demand at road segments and the D_1, D_2 destination nodes are as follows (Table 13 & 14).

Table 13: Population walking demand at road segments

Road Segment	Population Demand
D_2O_1	40
O_1O_2	0
O_3O_2	20
O_2O_4	70
O_4D_1	100

Table 14: Population walking demand at destinations

Road Segment	Population Demand
D_2O_1	100
O_1O_2	40

3.6 Measures of the pedestrian facilities

This is the last parameter in developing the model. In the literature most of the studies highlighted that pedestrians are concerned about their safety, comfort and convenience. In this study, the selection of most appropriate indicators is done in four major groups, namely; pedestrian amenities, physical properties of sidewalks, pedestrian cross walks and pedestrian safety. This was done based on the literature review. These groups consist of nine indicators as shown in Table 15.

Table 15: Indicators description

Group	Indicator description
Pedestrian amenities	- Bus stops per 1km length of road - Presence of disability facilities
Physical Properties of sidewalks	- Presence and condition of sidewalks - Effective width of side walks
Pedestrian cross walks	- Distance between cross walks - Delay at cross walks
Pedestrian Safety	- Distance between light poles - Level of Service of pedestrians on urban streets - Pedestrian accidents per year

These indicator measures are used to quantify available pedestrian facilities in order to prioritize road segments. This evaluation will be used when the closely similar values are scored in more than one road link after applying the GIS based model. The overall evaluation will be based on the scores calculated for those road links using a point scoring system which can be flexible for the decision makers.

3.7 Point Scoring system

This point scoring system is to be used for evaluating the pedestrian facilities of roads which scores similar values. The application of indicators has little or no meaning unless they are set against a scoring system. Thus, any road link can be evaluated by scoring of indicators. An ordinal Likert scale of 0 to 5 was used, where 0 represented less priority road link and 5 represented the high priority road link. These Likert items were considered as interval level data (Table 16). As this scoring is using for the model the results should be case sensitive. Finally, road links which obtain highest score will acquire first priority.

Table 16: Point scoring for evaluation of existing pedestrian infrastructure

Indicator description	**Points scoring frame work**
Bus stops per 1km length road	≥ 5 = 5 points 1-3 = 3 points 0 = 0 points
Presence of disability facilities	≤ 25% = 5 points 25-50% = 3 points ≥75% = 0 points
Presence and condition of sidewalks	No = 5 points Damage = 3 points Good = 0 points
Effective width of sidewalk	≤1m = 5 points 1m- 3m = 3points ≥ 3m = 0 points
Distance between cross walks	≥ 300m = 5 points 150-250m = 3 points ≤150m = 0 points
Delay at cross walks	≥ 90 seconds = 5 points 60-90 seconds = 3 points ≤ 60seconds = 0 points
Distance between light poles	≥ 200m = 5 points 100-200m = 3 points ≤100m = 0 points
Level of Service of pedestrians on urban streets	LOS E-F = 5 points LOS C-D = 3 points LOS A-B = 0 points
Pedestrian accidents per year	> 5 = 5 points 2 -4 = 3 points 0 = 0 points

4 DEVELOPMENTS OF THE MODEL

4.1 Introduction

After a comprehensive literature research, parameters were identified for the development of the model. They are pedestrian demand, connectivity and evaluation of existing pedestrian facilities. Chapters 4, 5 and 6 present details of these parameters with the methodology of using them for the model. Using these parameters the model was developed with the assistance of Arc GIS software.

4.2 The Final model

This study aims to measure the walkability based on infrastructure facilities, land use distribution and demand for walking which could be used by the decision makers to identify the priority areas for improving and maintaining pedestrian facilities. In developing countries where this model is to be applied, prioritization of improvements has to be done due to financial restrains. After assembling all the three parameters the final model is developed as shown in Figure 4.1 with road prioritization.

4.3 Model Application

Model will be applicable to small and medium size towns in developing countries. This applied for a population size of more than 400 inhabitants per square kilometer. This model will be applicable to small and medium size towns with the population size of 50,000 – 200,000 inhabitants and definitely at least an urban council area. In Sri Lanka these will cover UDA declared areas as well.

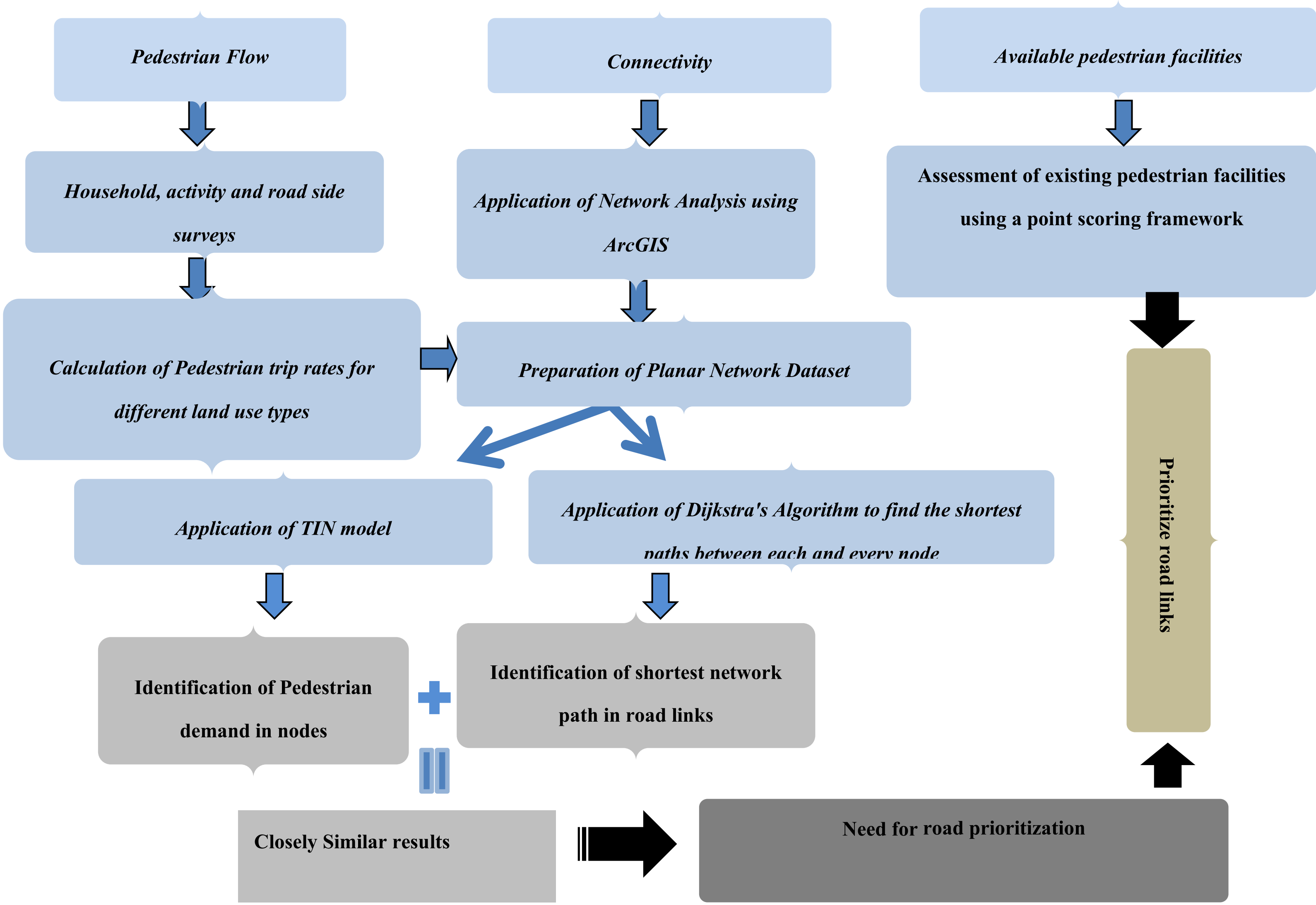


Figure 4.1: Model to Prioritize Pedestrian Facilities Requirements

4.4 Model Validation

Using the estimated model parameters the final model validation was done. Hence, GIS based model for pedestrian demand was validated using five Thiessen polygons each in three small and medium size towns in Sri Lanka. The predicted trip demand and observed trip demand were compared. However, there is a difference between the predicted values based on model estimated and the observed data but having the same trends.

4.4.1 GIS based pedestrian demand model

In order to validate GIS based model actual observations were done in three selected town centers. Piliyandala, Katubedda and Panadura town centers were selected for this validation process. All these centers are vibrant in character with all selected six land uses identified for the finding of pedestrian trip rates. The six land use categories and details of trip rates calculation is given in section 3.2 of this thesis. Finally, Mean Absolute Forecast Error (MAFE) calculated.

$$\text{Mean Absolute Forest Error} = \frac{1}{n}\sum \left| \frac{\textit{the\_predicted}\text{\_trips} - \text{the\_observed\_trips}}{\text{the\_observed\_trips}} \right|$$

where,

n is the number of buildings in a Thiessen polygon

Predicted demand is the aggregated number of trips per one day

Observed demand is the actual pedestrian counts per one day

MAFE for Pedestrian walk trips are 29.3%. Since these trip generation rates are developed at the individual level, the numbers of predicted trips in the Thiessen polygons show a slight error (MAFE of 29.3%). This error will not affect for the final model significantly as the routes will be selected for the whole urban area. This unexpected great discrepancy may be caused by insufficient sample size and geographically biased sample distribution when developing trip rates and the trip rates were developed only for common six identified land uses. The observations and predictions are also showed in a graphical representation in Figure 4.2.

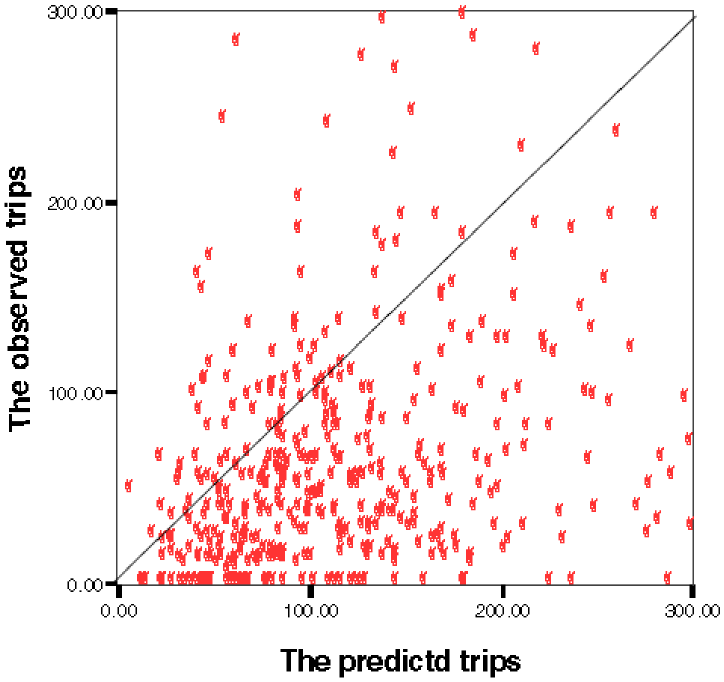


Figure 4.2: Plot of the Observed vs. the Estimated Trips

4.4.2 Point Scoring framework

The third parameter that is valuation of existing pedestrian facilities is done by using a Likert scale. The Likert scale cannot be manipulated when using this model as represented in Table 17.

Table 17: Usage of different Likert Scales

Scale	Road1	Road2	Road3	Road4
0,3,5	26	29	20	8
1,2,3	18	20	16	12
2,5,7	44	45	38	24
2,4,6	36	38	32	22

As indicated, whatever the scale use for the evaluation of road links final result will give the same priority. This clearly indicates that if an interval level Likert scale is used the results will give the same priority.

4.5 Summary

The model was developed by using three parameters i.e. pedestrian demand, connectivity and evaluation of existing pedestrian facilities. The model has both GIS base and theoretical base back ground. Pedestrian demand for each node was calculated by aggregating demand of different land uses include in Thiessen polygon. Secondly, the node demand was assigned to the shortest road link identified, using Origin Destination Cost Matrix solver and then the shortest route employing Route tool was found. Lastly for the road prioritization when more than on road having same values, a point scoring system was applied with the application of GIS network analyst tools.

5 OBSERVATIONS & RESULTS

5.1 Study Area

The model applied to Panadura Municipal Council area. At the time of the study the city center had a day time working population of approximately 80,000 and 3,500 residents. When looking at the main land uses of the city center it can be identified that the center has three main land uses, as main retail core, public land uses and residential area. (Figure 5.1)

Panadura City Center

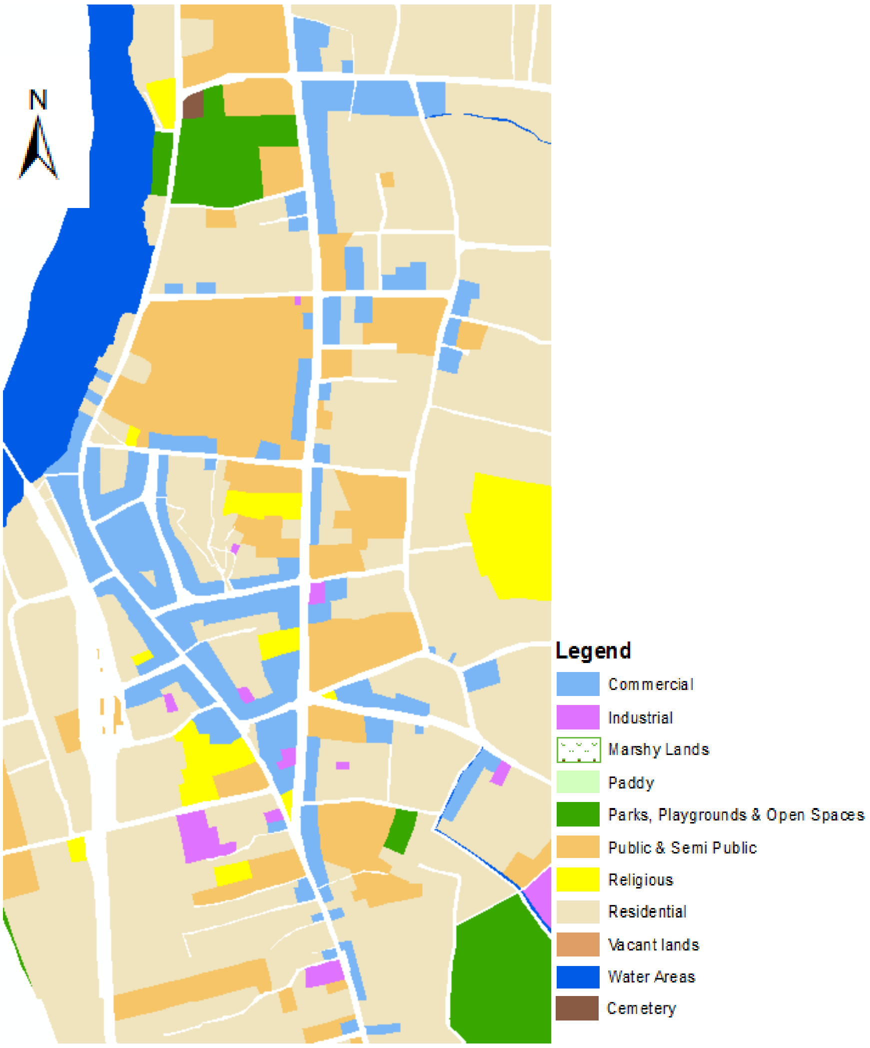


Figure 5.1: Land uses of Panadura City Center

When looking at the whole Panadura Urban Council (UC) area, the major land use activity could be considered as residential land use.

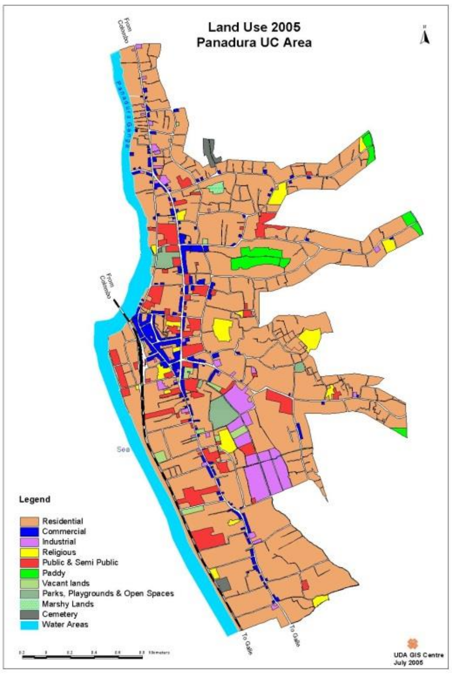


Figure 5.2: Land use map – Panadura MC
Source: Urban Development Authority

Figure 5.3: Road network map- Panadura MC
Source: Urban Development Authority

While developing the model, road based transportation network which consists of major and minor roads was formed simplified in to nodes and arcs. The Planar Network Dataset prepared for Panadura UC area using Network Analyst tool is illustrated in Figure 5.4.

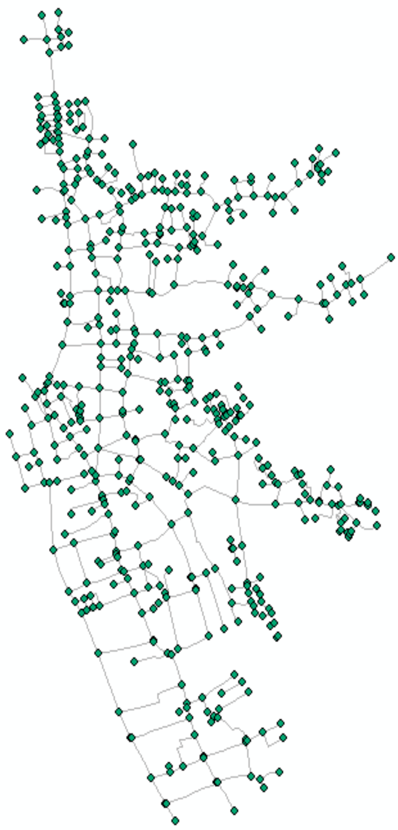


Figure 5.4: Planner Net work
Source: Compiled by the Author

The dots in black color represent the 'nodes' or 'intersections', and the 'arcs' which are in between two nodes represent the road segments. The Planar network based data set is the initial outcome of the model preparation. The nodes and the road segments in this data set were used to develop the model. The second step of the model was the preparation of GIS based pedestrian demand model. Accordingly, the pedestrian demand at each and every node was calculated. The Thiessen polygons generated for the purpose of aggregate pedestrian trip rates as illustrated in Figure 5.5. This was completed after identifying building layers of six identified land uses.

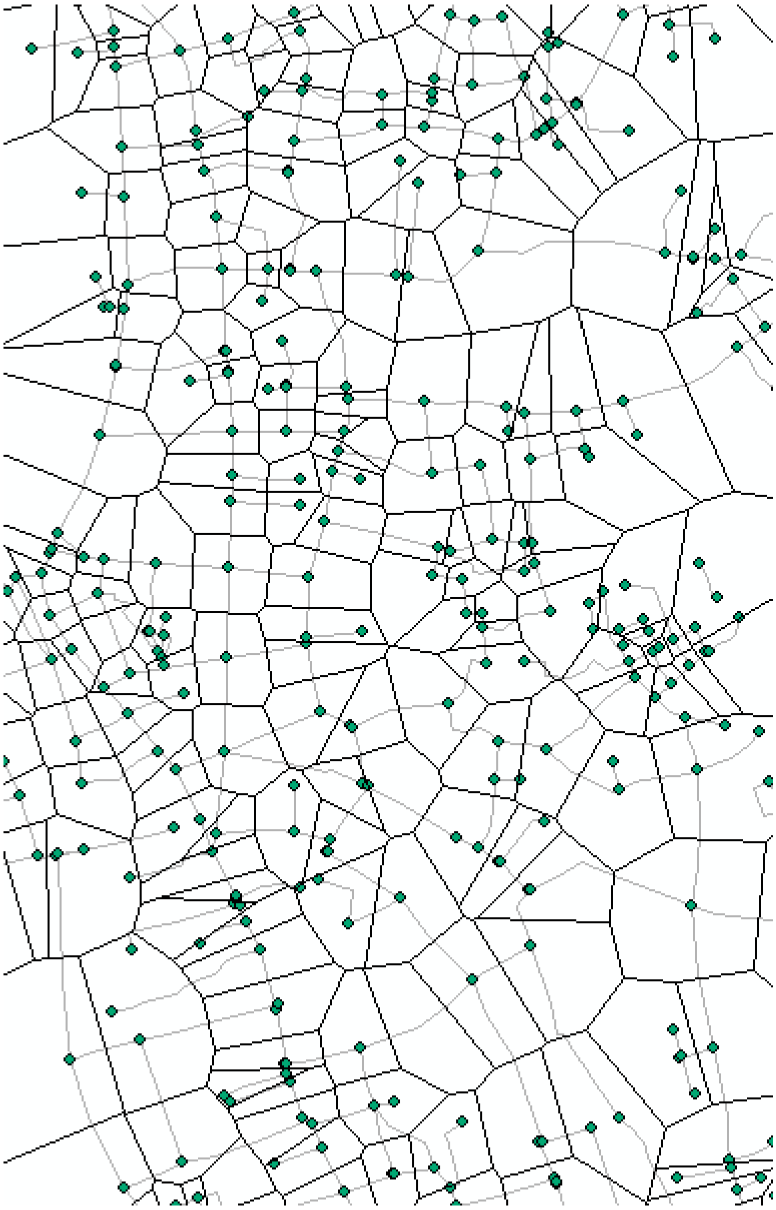
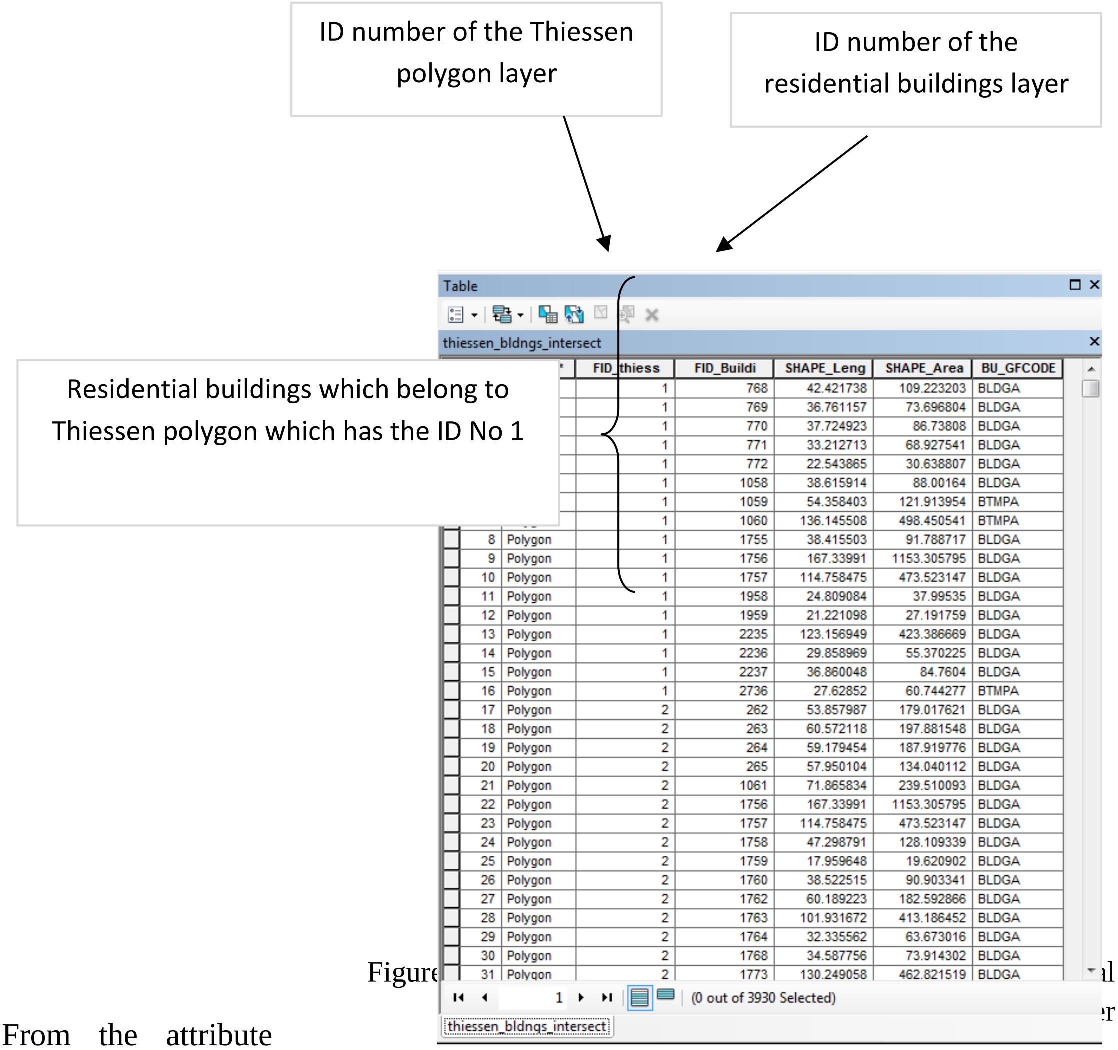


Figure 5.5: Thiessen polygons generated for Panadura Town center
Source: Compiled by the Author

Then both the Thiessen polygon layer and the building layer were intersected to find the number of buildings inside each Thiessen polygon. The attribute table of the intersected Thiessen polygon layer and the residential building layer is shown in Figure 5.6. The same process was done to other buildings and all trip rates assigned and aggregated.



	*	FID_thiess	FID_Buildi	SHAPE_Leng	SHAPE_Area	BU_GFCODE
		1	768	42.421738	109.223203	BLDGA
		1	769	36.761157	73.696804	BLDGA
		1	770	37.724923	86.73808	BLDGA
		1	771	33.212713	68.927541	BLDGA
		1	772	22.543865	30.638807	BLDGA
		1	1058	38.615914	88.00164	BLDGA
		1	1059	54.358403	121.913954	BTMPA
		1	1060	136.145508	498.450541	BTMPA
8	Polygon	1	1755	38.415503	91.788717	BLDGA
9	Polygon	1	1756	167.33991	1153.305795	BLDGA
10	Polygon	1	1757	114.758475	473.523147	BLDGA
11	Polygon	1	1958	24.809084	37.99535	BLDGA
12	Polygon	1	1959	21.221098	27.191759	BLDGA
13	Polygon	1	2235	123.156949	423.386669	BLDGA
14	Polygon	1	2236	29.858969	55.370225	BLDGA
15	Polygon	1	2237	36.860048	84.7604	BLDGA
16	Polygon	1	2736	27.62852	60.744277	BTMPA
17	Polygon	2	262	53.857987	179.017621	BLDGA
18	Polygon	2	263	60.572118	197.881548	BLDGA
19	Polygon	2	264	59.179454	187.919776	BLDGA
20	Polygon	2	265	57.950104	134.040112	BLDGA
21	Polygon	2	1061	71.865834	239.510093	BLDGA
22	Polygon	2	1756	167.33991	1153.305795	BLDGA
23	Polygon	2	1757	114.758475	473.523147	BLDGA
24	Polygon	2	1758	47.298791	128.109339	BLDGA
25	Polygon	2	1759	17.959648	19.620902	BLDGA
26	Polygon	2	1760	38.522515	90.903341	BLDGA
27	Polygon	2	1762	60.189223	182.592866	BLDGA
28	Polygon	2	1763	101.931672	413.186452	BLDGA
29	Polygon	2	1764	32.335562	63.673016	BLDGA
30	Polygon	2	1768	34.587756	73.914302	BLDGA
31	Polygon	2	1773	130.249058	462.821519	BLDGA

Figure … al … er

From the attribute table, it is easy to count the number of residential buildings which belong to each Thiessen polygon. Some of the buildings are coming under more than one. Thiessen polygon; such buildings were assigned to its respective Thiessen polygon which owns the highest proportion of the building area. All the other five major land uses were identified and categorized the same way.

The next step of the model was the determination of optimal route. The optimal routing procedure could be viewed by adopting the most efficient route in terms of the shortest distance as per the pedestrian route choice.

By applying the Origin-Destination Cost Matrix tool in ArcGIS Network Analysis, shortest paths from multiple origins to multiple destinations were identified. The O-D (Origin-Destination) Cost Matrix layer of ArcGIS Network Analyst Tool is illustrated in Figure 5.7. The sub layers "Origins", "Destinations" and "Lines" show the origin nodes, destination nodes and the O-D lines respectively.

The attribute table (Figure 5.8) of the sub layer "Lines" has the information on nearest destination of each origin with their shortest path distance. These output O-D lines show the nearest destination of each origin node.

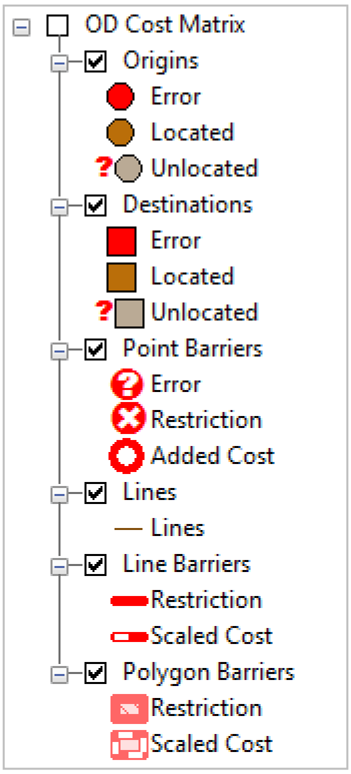
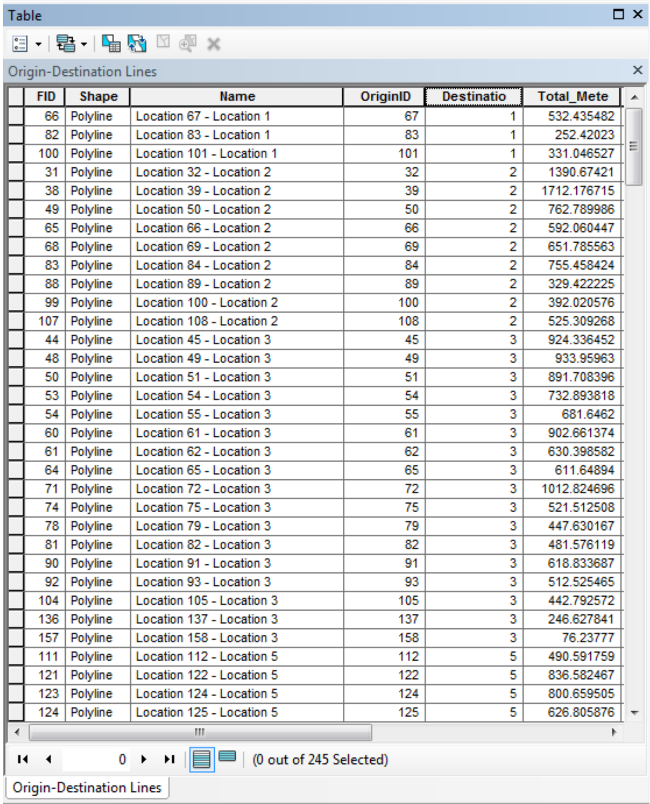


Figure 5.7: OD Cost Matrix Layer



Table

Origin-Destination Lines

FID	Shape	Name	OriginID	Destinatio	Total_Mete
66	Polyline	Location 67 - Location 1	67	1	532.435482
82	Polyline	Location 83 - Location 1	83	1	252.42023
100	Polyline	Location 101 - Location 1	101	1	331.046527
31	Polyline	Location 32 - Location 2	32	2	1390.67421
38	Polyline	Location 39 - Location 2	39	2	1712.176715
49	Polyline	Location 50 - Location 2	50	2	762.789986
65	Polyline	Location 66 - Location 2	66	2	592.060447
68	Polyline	Location 69 - Location 2	69	2	651.785563
83	Polyline	Location 84 - Location 2	84	2	755.458424
88	Polyline	Location 89 - Location 2	89	2	329.422225
99	Polyline	Location 100 - Location 2	100	2	392.020576
107	Polyline	Location 108 - Location 2	108	2	525.309268
44	Polyline	Location 45 - Location 3	45	3	924.336452
48	Polyline	Location 49 - Location 3	49	3	933.95963
50	Polyline	Location 51 - Location 3	51	3	891.708396
53	Polyline	Location 54 - Location 3	54	3	732.893818
54	Polyline	Location 55 - Location 3	55	3	681.6462
60	Polyline	Location 61 - Location 3	61	3	902.661374
61	Polyline	Location 62 - Location 3	62	3	630.398582
64	Polyline	Location 65 - Location 3	65	3	611.64894
71	Polyline	Location 72 - Location 3	72	3	1012.824696
74	Polyline	Location 75 - Location 3	75	3	521.512508
78	Polyline	Location 79 - Location 3	79	3	447.630167
81	Polyline	Location 82 - Location 3	82	3	481.576119
90	Polyline	Location 91 - Location 3	91	3	618.833687
92	Polyline	Location 93 - Location 3	93	3	512.525465
104	Polyline	Location 105 - Location 3	105	3	442.792572
136	Polyline	Location 137 - Location 3	137	3	246.627841
157	Polyline	Location 158 - Location 3	158	3	76.23777
111	Polyline	Location 112 - Location 5	112	5	490.591759
121	Polyline	Location 122 - Location 5	122	5	836.582467
123	Polyline	Location 124 - Location 5	124	5	800.659505
124	Polyline	Location 125 - Location 5	125	5	626.805876

0 (0 out of 245 Selected)

Origin-Destination Lines

Figure 5.8: Attribute Table of the OD Cost Matrix

The “Route” tool was then applied to visualize the shortest network path between origin-destination pairs which received from the Origin-Destination Cost Matrix. The "Route" layer of ArcGIS Network Analyst Tool is illustrated in Figure 5.9. The sub layers "Stops" and "Routes" show the respective O-D pair and the shortest route respectively. The shortest route obtained for one O-D pair is illustrated in Figure 5.10.

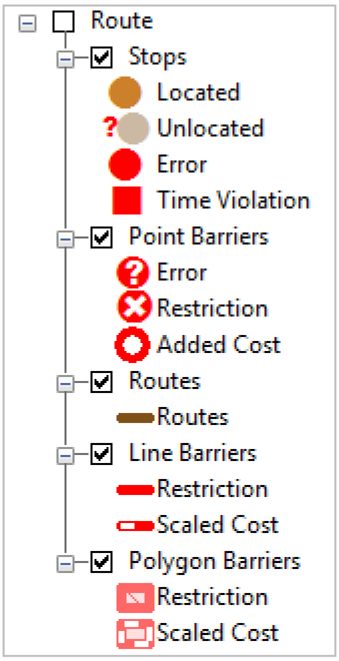


Figure 5.9: Route Layer

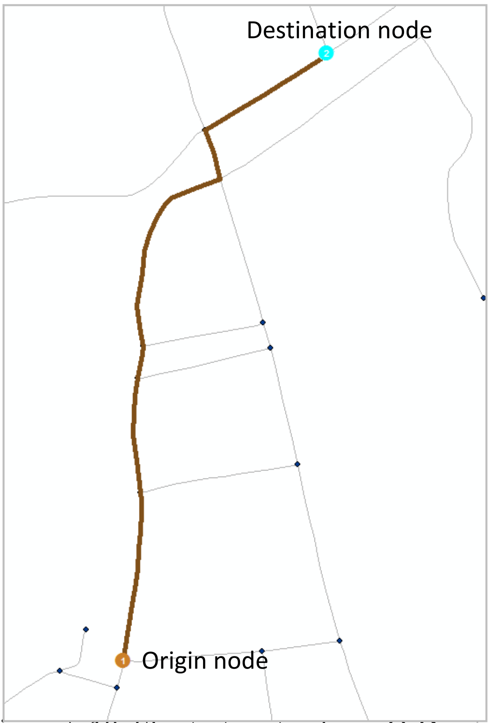


Figure 5.10: Shortest route of one O-D pair of a road link

After obtaining the shortest network path for each O-D pair, the pedestrian demand at each origin node was assigned along its shortest network path. After assigning demand for all the origins in this manner, cumulative pedestrian demand was calculated for each road segment in Panadura Urban Council area. Consequently , DS Senanayake road (48) gets first priority and four more roads receives the closely similar values of 42, 43, 44 and with the evaluation of available pedestrian facilities that is after applying the point scoring frame work (Table 18) they were prioritized. Accordingly Galle Road-Bus station to Royal College and Susantha Mawatha to Kethumathie Hospital road segment received the second and third priority with the highest scores. Likewise all the road segments were ranked and identified for development on par with pedestrian facilities.

Table 18: Application of point scoring framework to road segments with same value

Road	Pedestrian amenities		Physical Properties of sidewalks		Pedestrian cross walks		Pedestrian Safety			**Score**
	Bus stops per 1km length road	Presence of disability facilities	Presence and condition of sidewalks	Effective width of sidewalk	Distance between cross walks	Delay at cross walks	Distance between light poles	LOS of pedestrians on urban streets	Pedestrian accidents per year	
1st Cross street to railway station	3 (2)	3 (30%)	3 (Damaged)	3 (2.5)	3 (250m)	0 (45sec)	3 (200m)	3 (D)	0 (0)	**21**
Galle Road-Bus station to Royal College	3 (1)	0 (18%)	3 (Damaged)	3 (2.5)	5 (400m)	3(60sec)	5 (250m)	3 (C)	0 (0)	**25**
Town center to Sachithra Hospital - Horana Road	3 (1)	3 (40%)	3 (Damaged)	3 (3)	3 (150m)	0 (45sec)	5 (300m)	0 (B)	3 (2)	**23**
Susantha Mawatha to Kethumathie Hospital	0 (0)	3 (10%)	0 (Good)	0 (0)	5 (350m)	3 (75sec)	5 (250m)	5 (F)	3 (3)	**24**

( ) for actual value and normal value is the relevant Likert scale

Source: Compiled by the Author

6 CONCLUSIONS & RECOMMENDATIONS

Since non-motorized transportation systems have been promoted and concerned by the government with sustainable development and environment friendly approaches, for developing countries with limited financial capacity arises a need to prioritize road links for the provision of infrastructure facilities. In this condition this model to prioritize pedestrian facilities in an urban environment was developed for the research.

When developing the model the first research question of what are the most appropriate variables for evaluating pedestrian facilities requirements was explored.

Secondly a GIS based model for pedestrian demand was developed as a remedy to the second research question.

Lastly a point scoring frame work was developed for prioritizing road links with an evaluation of existing pedestrian facilities. Within this process the third research question was answered with a criterion to evaluate pedestrian facilities.

The main aim of this research that is to propose a methodology to prioritize pedestrian facilities requirements in an urban area was completed. Walkability measures were utilized for the development of this model which achieved the objectives of the research study as given in Chapter Two. The model estimated and validated in this study could be applied to other developing countries with same socio-economic conditions as given in model application section of this thesis. Since the six selected land uses are characteristically visible in most of the urban areas of these it should be a very rapid and simple process to apply this model and select road links to provide pedestrian facilities requirements or improvements. However, this transferability might be not precise because the model is estimated from data in Sri Lankan context only.

The researcher recognizes several limitations in the application of this model. Although the model developed in this research is more applicable to Sri Lanka if other countries need this model and more precise pedestrian demand, it is recommended to consider the change of variables such as selected land uses, pedestrian trip rates and urban definition or hierarchy for the country.

This is a meso-scale model that does not represent pedestrians individually but may aggregate them into relatively small pedestrian demand nodes using Thiessen polygon method with trip rates of selected land uses. Hence, exact demand at the nodes, delays occur at each road segment due to individual travelling speeds, mode of travel, turning movements at intersections were not incorporated when developing the model. Also during a walking trip, pedestrians not always select the shortest path, rather they will select least congested routes or roads which they are most acquainted or have previously used. However, the model developed here is an unassuming and rapid model that will give impartial results for the purpose of identifying routes to provide pedestrian facilities.

Finally, the model can be applied to a variety of research problems and practical applications. For instance, local governments could benefit from the model developed in this study when they need to select and prioritize the road links when a need arise for pedestrian facilities or improvements of existing pedestrian facilities. In addition, the results from this study could be used for several research topics such as the impact of land development patterns and urban design on travel behavior, connections between built environment, physical activity and public health outcomes, assessment of potential transit markets, and understanding pedestrian risks. For all applications, the sensitivity analysis could be performed to predict the changes in pedestrian demand, connectivity or excising pedestrian facilities.

To conclude this model functionality and user experience can be improved by adding functionality such as scenic, pleasing and safety walking environment etc. In the same way more specified indicators could be applied in the evaluation of pedestrian facilities.

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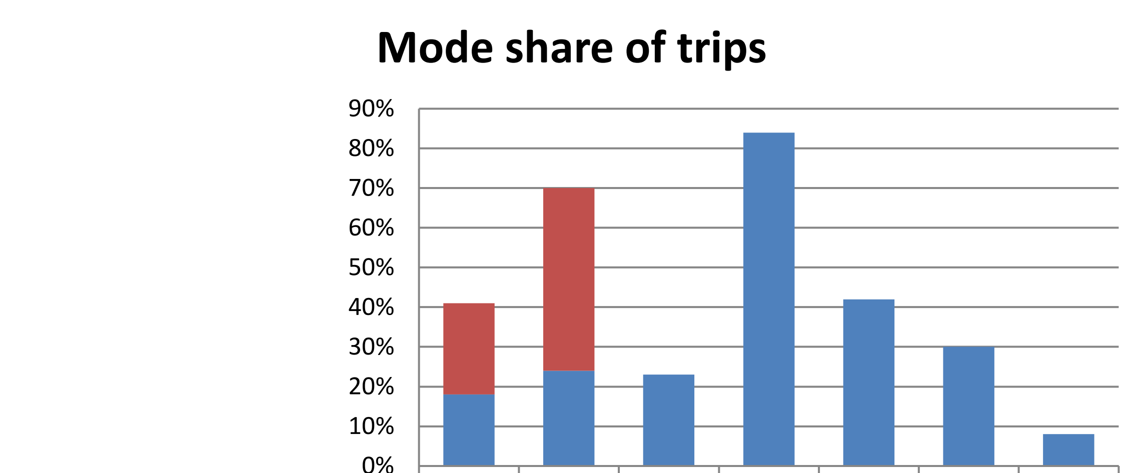
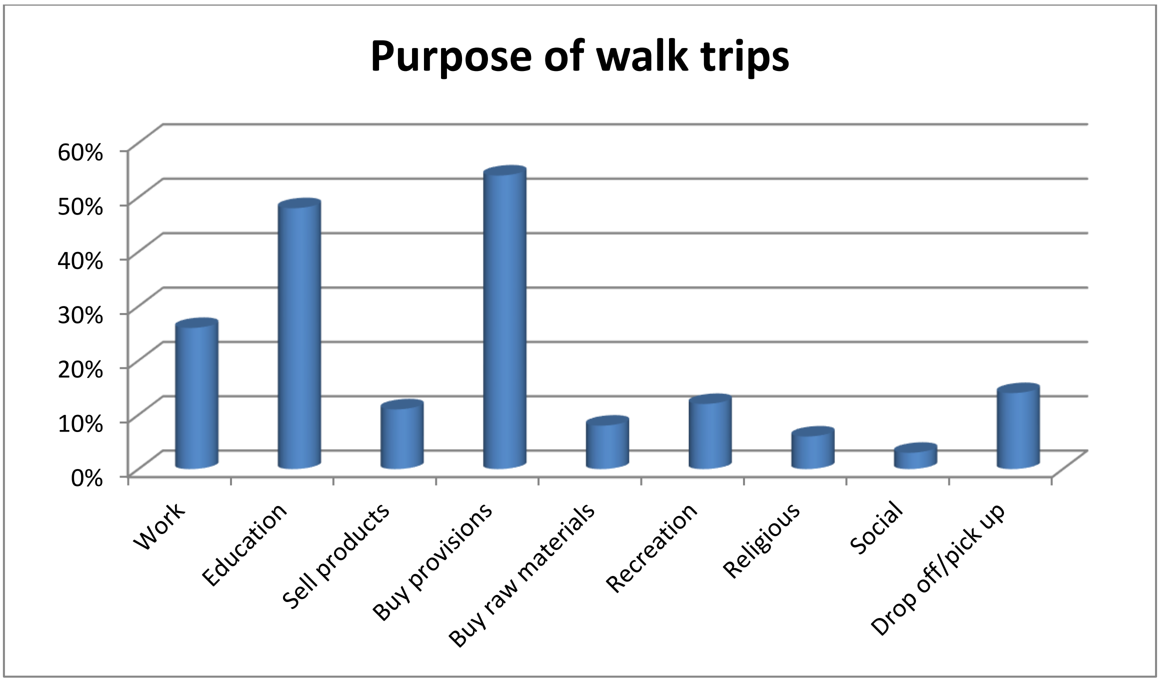
Appendix – A

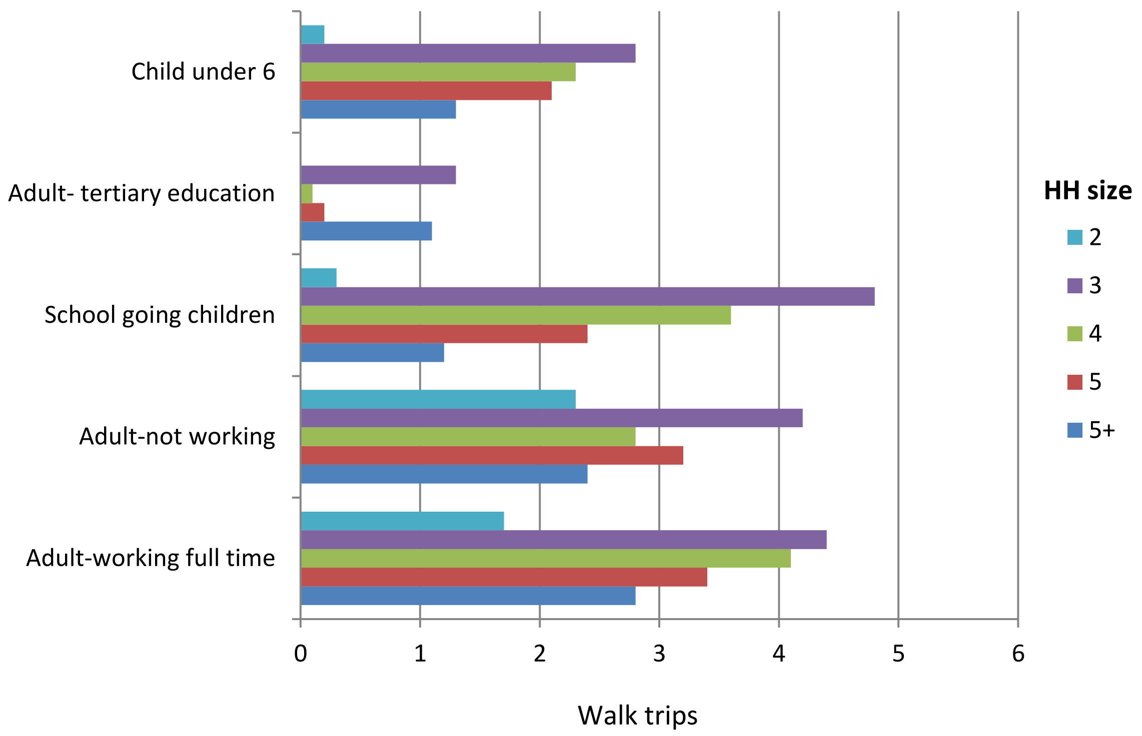
HH travel Survey and trip diary facts

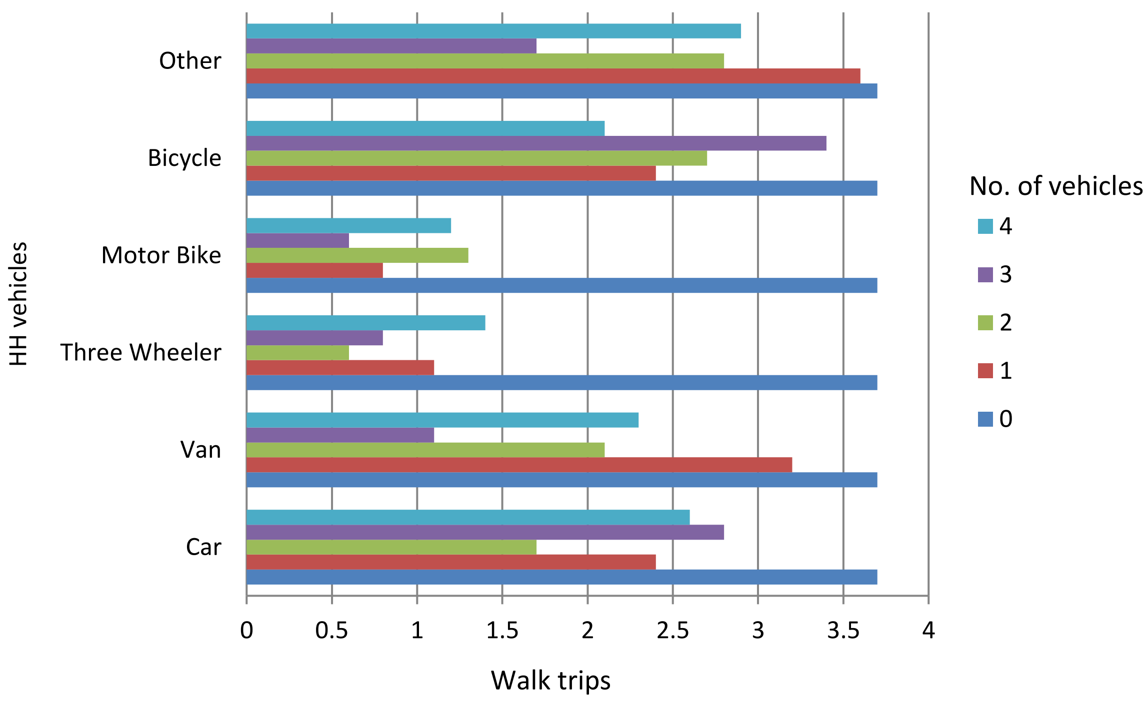
House hold travel survey 2013 – Panadura Urban Council



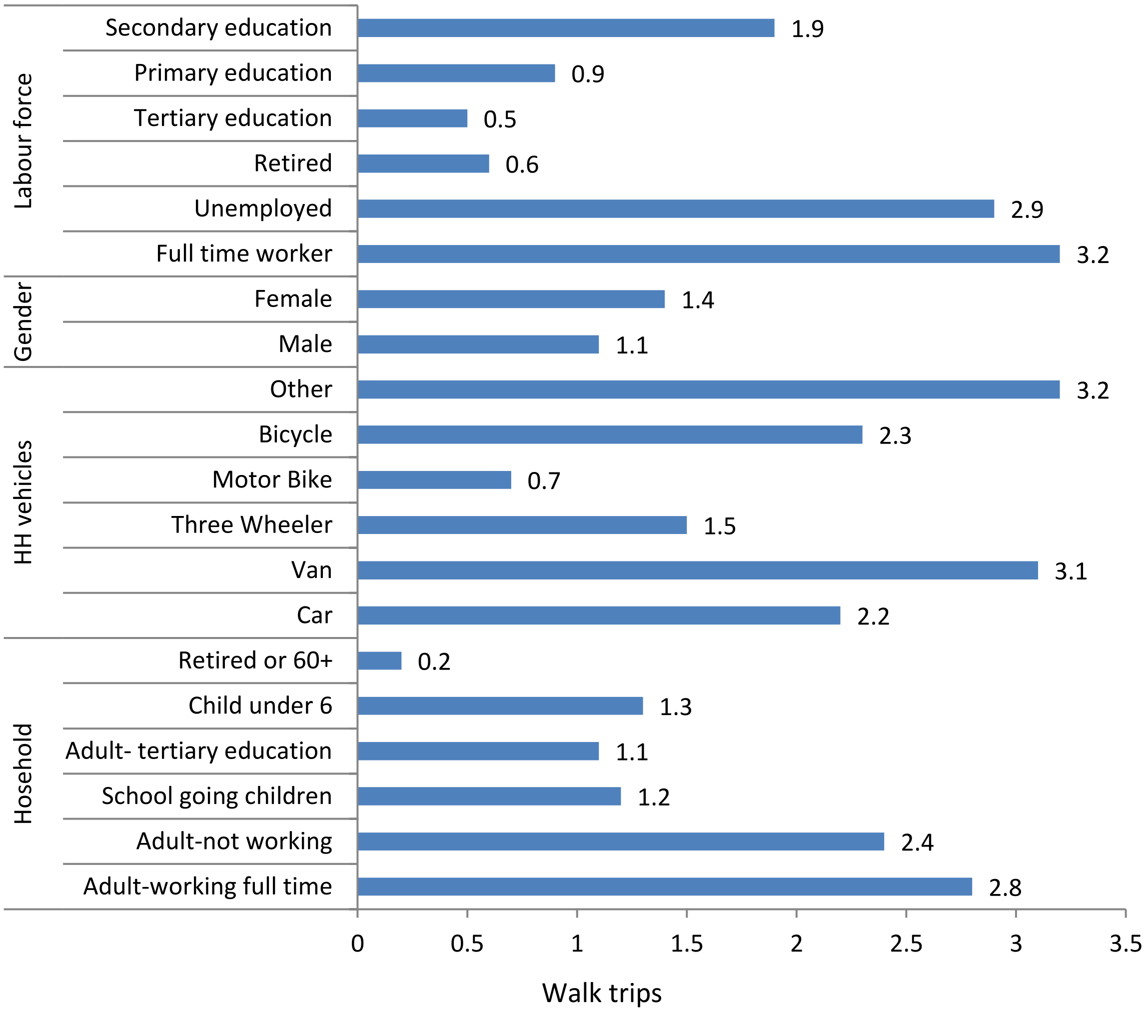
	Vehicle	Walk	Train	Bus	Motor Bike	Three wheel	Other
Passenger/Walk+Any otherther mode	23%	46%					
Driver/Walk only	18%	24%	23%	84%	42%	30%	8%




Child under 6
Adult- tertiary education
School going children
Adult-not working
Adult-working full time
0
1
2
3
4
5
6
Walk trips
HH size
2
3
4
5
5+


HH vehicles
Other
Bicycle
Motor Bike
Three Wheeler
Van
Car
0
0.5
1
1.5
2
2.5
3
3.5
4
Walk trips
No. of vehicles
4
3
2
1
0

Average number of walk trips per person per day by socio-demographic characteristics, Panadura UC



- On average Panadura residents made 0.8 walk trips a day. This includes both walk only trips and walk linked trips.
- There is a clear relationship between the amount of walking and various socio demographic characteristics
- Females walked more than males
- Those who are full time working adults made the most walking trips
- Walk trips are lower in retired or age 60+ people
- Walk trips are remarkably less in households having a motor bike