

**IMPROVING PEDESTRIAN MOVEMENTS AT
CONGESTED URBAN AREA: CASE STUDY
RATHNAPURA TOWN**

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Degree of Master of Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

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Thesis submitted in partial fulfilment of the requirements for the Master of
Engineering in Highway and Traffic

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Declaration of the Candidate and Supervisor

I declare that this is my own work, and this dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or institute of higher learning and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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IMPROVING PEDESTRIAN MOVEMENTS AT CONGESTED URBAN AREA: CASE STUDY RATHNAPURA TOWN

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Abstract: Pedestrians are one of the main components of urban traffic environment. Improved corridor for vehicle movements, but lack of pedestrian facilities are indifferent identifications of conventional urban environment. Now transport planners considered about pedestrian friendly city environment to achieve sustainable development and encourage green patronage.

Unplanned and uncontrolled pedestrian movements result in delays and safety risk at town center. Individual facility development without proper traffic impact study may cause delays to pedestrians and motor vehicles and increase in safety risks. Often, there are lots of public requests for proper network of pedestrian pathways including amenity development. However, it is very difficult to plan and design an efficient pedestrian network without understanding pedestrian movement behavior at such vicinity. This study is focused on developing a methodology to identify pedestrian movement behavior, critical areas and make necessary adoptions to develop such facilities to encourage walkable city environment.

Rathnapura town is the capital city of Sabaragamuwa Province, where having different terrain condition throughout the city area. One of the main arterials of the country connecting southeastern parts with the capital, induce a lot of vehicular movements in the city. Less the development of pedestrian amenities is reflected heavy complexity in the behavior of pedestrian movements, and it guided to a congested city environment.

Pedestrian movement has a high degree of freedom in selecting origin - destination pair than any mode of transportation. Household or occupational purpose utility related trips are commonly identified in such urban environment and it directly relates with land use pattern of a town area. This study identifies specific land use that are trip generators or attractors, generated pedestrian trips and possible pedestrian paths within the urban territory. Collecting vehicle speed data using Google maps to identify the congested crosswalks, data verification using field survey and development of a GIS based land use model with pedestrian paths is also under the framework of study.

Shortest path origin destination matrix development for pedestrian network is one objective of this study. According to the OD matrix, frequency of sidewalk or crosswalk usage in each OD pair is counted and ranked. Prioritized list is pre-pared according to the Rank and level of interacting traffic.

Keywords: Pedestrian trips, connectivity, land use, prioritization of pedestrian amenity

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List of Abbreviations

OD Origin – Destination

GIS Geographical Information System

ADB Asian Development Bank

1 INTRODUCTION

1.1 General

“Walkers are 'practitioners of the city,' for the city is made to be walked. A city is a language, a repository of possibilities, and walking is the act of speaking that language, of selecting from those possibilities. Just as language limits what can be said, architecture limits where one can walk, but the walker invents other ways to go.”

- **Rebecca Solnit, Wanderlust: A History of Walking**

The town center is the core area of a city which is associated with many commercial and retail activities. Urban development in a city is interpreting a number of human factors and physical factors. “Economic growth” is the simple explanation for these human and physical factors for urbanization.(Black & Henderson, 1999). Wegener (2004) has introduced nine types of major urban sub systems, perhaps transportation system is most critical ones deciding urban frame and structure within the long term. According to his study, Urban land-use transport models join the foremost fundamental processes in spatial development including all types of land uses. Distribution of land use is determined by human activities such as education, employment, leisure, shopping, etc. Those human activities create banks, schools, shopping areas, government institutes in the spatial space in an urban area. These activities require a spatial interaction or trips. Distribution of transportation system feed that demand and that opportunity can be measured as accessibility.(Wegener, 2004) The result would be the complex transport network, and diversified land use area over urban space.

There was less interference of the physical planning institution or regulating body at the beginning of this evolution in countries like Sri Lanka. So, it allows for cities to grow in unplanned natural ways. Present condition of major cities in Sri Lanka shows similar characteristic due to this natural growth. The following can be considered as the main characteristics in the typical Sri Lankan city.

1. Main schools are in the middle or near to city center,
2. Commercial activity and related financial institution or branches are located within the city limits.
3. Government institutions are in the town center.
4. The bus terminal is located within the city.

Many researchers have worked on developing models for traffic movement in a city. Lowry introduced how interrelates the land use and transportation in a city. (Lowry, 1964). This is a computer-based model which described the spatial organization of human activities in the metropolitan area. After Lowry, Goldner (1971), Putman (1983, 1991) and Mackett (1983), Boyce et al. (1981) have introduced modifications to this land use, transportation feedback cycle in urban area. Growth of trips at town center, results the traffic congestion and safety risk. City planners proposed new concept where move out some trip attraction points outside the city as a solution. New town development, administrative complex buildings outside the city limit are practical examples of those solutions in Sri Lanka. With the population growth, those separations would be difficult.

Even most of the administrative activities are stripped from town centers, commercial activity, schools, and other key micro level business requires space. Pedestrians are the main component of that kind of activities. So, improving pedestrian movement is a necessary activity to optimize traffic movement in a city environment.

Individual facility improvement without analyzing entire study area may impact another part of the city and it could create delays and safety risks. Often, there are lots of public requests for proper network of pedestrian pathways including amenity development. However, it is very difficult to plan and design an efficient pedestrian network without understanding pedestrian movement behavior at such vicinity. (Zheng et al., 2016)

Rathnapura town is the capital city of Sabaragamuwa province, where having different terrain condition throughout the city area. As it is located along one of the main arterial of the country connecting southeastern parts with the capital city of the island, it induces a lot of vehicular movements in the city. Underdeveloped pedestrian amenities are reflected an uncontrolled pedestrian movement, and it guided to a congestion at city environment. Pedestrian facility improvement is also a worldwide trend in urban development. Workability, Pedestrian facility are the key words that searched rapidly among researchers worldwide in recent time. So, Sri Lanka also requires more studies regarding this field when country tends to reach sustainable approach in transport development.

Ivan Blečić et al (2020), who studied about workability analytical tools, have conducted a survey regarding pedestrian and workability keyword search in academic field. (Table 1.1).

	Walkability	“Walkability” + “Measure”	“Walkability” + “Planning Support”	“Walkability” + “Evaluation”
Scopus				
(2000–2005)	26	9	-	4
(2006–2010)	193	92	-	19
(2011–2016)	739	347	5	54
(2017–2019)	555	247	4	36
Web of Science				
(2000–2005)	20	8	2	3
(2006–2010)	182	93	7	11
(2011–2016)	810	393	42	37
(2017–2019)	561	274	43	36
Google Scholar				
(2000–2005)	1070	746	9	540
(2006–2010)	4570	2750	46	2410
(2011–2016)	14,700	11,700	254	8340
(2017–2019)	9500	5210	141	4790

Table 1.1 Number of papers for keyword walkability and related search (Blečić et al 2020)

According to that study (Blečić et al., 2020) , walkability and relate search have become a trending topic among researchers.

So, studying on pedestrian development and suggesting improvement on urban vicinity is essential study for our country to reach sustainable goals.

1.2 Research Problem

One of the main parts of the urban traffic environment is pedestrian. There are trip generation points and trip attraction points in town. Pedestrian paths can be identified between trip Origin and Destination. The pedestrian path network is conflicting with vehicle path network mainly at pedestrian crossing locations, and it creates delays, safety risk and congestion at urban environment. If the pedestrian crossings are not located at appropriate locations unsafe pedestrian-vehicle conflicts can be increased.

Analyzing the pedestrian network, identifying optimum pedestrian paths, and necessary improvements, and correct positioning of pedestrian crossing locations, are the primary methods of traffic improvement in the urban environment. In many parts of the world main cities have inadequate facilities for pedestrians. Methodology to identify the network conflicts and improvements for pedestrian environment is mostly required matter at present in urban traffic optimization. The study is focused on this problem, and solutions will be proposed to optimize critical pedestrian amenities for the reduction of traffic conflicts and related congestion at town center.

1.3 Research Objective

The main goal of this study is to develop a methodology to identify the most used pedestrian amenity at a specific urban center. The specific objectives are,

- Identify the pedestrian behavior and walking pattern in a town center.
- Develop a methodology to identify the locations of traffic conflicts and congestion due to Pedestrian movement.
- Propose a methodology to prioritize existing sidewalk links for improvements, identify the best locations for crossings to optimize pedestrian movement and traffic flow.

2 LITERATURE REVIEW

2.1 Walkability

Walking is a basic requirement of mobility, and it promotes a healthy lifestyle and social interactions. Overall, walking is sustainable, environmentally friendly transport mode and it increases the quality of life in society. Generally 95% of trips below 100m are completed on foot.(Dörrzapf et al., 2019)

Walkability defines in many ways at town centre. Basically, walkability forces on pedestrian comfortability for walking at urban environment. Walkability describes about the quality of pedestrian facilities, roadway conditions, land use patterns, community support, security, and comfort of walking in an area.

Workability index project explain in 4 types of basic scene: the safety, security, economy, and convenience of traveling by foot. A healthier worksite initiative described walkability as a measurement of the transportation and recreation opportunities for pedestrians, while considering safety, convenience, and route aesthetic for pedestrians.(Hewawasam et al., 2013)

2.2 Element of Walkability

Many researchers have focused on the components of walkability from distinctive aspects.

Shay et al 2013 introduced some facts which are affecting workability at the pedestrian moving environment. Those are,

1. Accessibility, convenience (proximity to destinations within walking distance)
2. Mixed land use
3. Density (residential or employment)
4. Pedestrian facilities (walking tracks, sidewalks, crosswalks)
5. Aesthetics (Green surrounding, architectural features, trees, landscaping)
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 (crime safety, clean paths, no beggars, freedom from obstacles, crime safety, access for special populations) (Shay et al., 2003)

Infrastructure, Destination, Journey and Environment are four key elements which address all aspects of walkability evaluation criteria. Physical properties of sidewalks, crossing and other amenities address under Infrastructure. Land use distribution and trip pedestrian attraction is

described under destination. Pedestrian flow, connectivity and network properties represent the journey. Environment means aesthetic and safety in road vicinity. Table 2.1 illustrates those elements in detail manner.

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)

Table 2.1: Element of walkability (Hewawasam et al., 2013)

Fitzsimons in 2013 has done the prominent work in his publication “A multidisciplinary examination of walkability: Its concept, appraisal and applicability”. According to his work, two fundamental bunches have been identified. Those are.

- Functional environment
- Street scape (Fitzsimons D’Arcy & Lorraine, 2013)

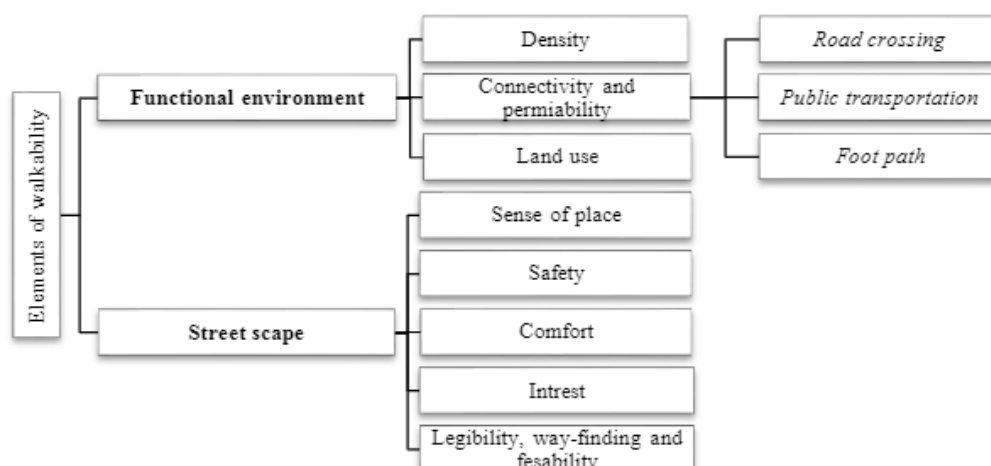


Figure 2.1:Element of walkability and built environment. (D’Arcy, F., & Lorraine., 2013).

2.2.1 Functional environment

Functional environment is consisting of roads, footpaths, buildings, and other physical structures related to pedestrians. These key functional, environmental elements are interconnected with density, connectivity, and land use.

1. Density - Density is simplified as population of each land block. It is varied with the characteristic of each unit section. High densities with less provision of parking lots, nearby destinations would increase the number of walking trips on particular origin.(Fitzsimons D’Arcy & Lorraine, 2013)
2. Connectivity and permeability – Connectivity is simplified as a road or footpath network of that area. This is the main skeleton of pedestrian moving path, including alleyways, steps, identified shortcuts in 3-dimensional space. According to Fitzsimons’s readings, even some identified paths are connecting two different places, some connecting paths have less permeability due to environmental psychology. “Physical barriers may include the absence of footpaths and social barriers may include a perception of an area being unsafe”(Fitzsimons D’Arcy & Lorraine, 2013). Geographical, physical barriers are cut shortening the connectivity. But social reasons may improve the popularity, or abundant the path vice versa.
3. Land use – Different kind of usage in physical space is identified as Land use. This includes residential, office, retail/ commercial, and public space. This kind of different land use attracts pedestrian groups in different characteristics.

2.2.2 Street scape

Street scape is identified as visual surrounding of a road. This includes adjacent buildings, green area, protection, aesthetic pleasing, architecture and level of service. These are other nonphysical, qualitative factors which are directly impacted for intention of walking.

Street scape has five key elements as a qualitative measurement in workability. Those are sense of place, safety, comfort, interest, legibility, way-finding and feasibility.(Rafie Manzelat et al., 2017).

More recent literature such as GabrieleD'Orso (2020) has illustrated, detailed walkability indices which can measure practically to get values for analysis.

Factors	Indicators	Lower /Upper limit	Description	
Practicability	Sidewalk slope	0	Steep slope for elderly people and wheelchair users (>5%)	
		1	Manageable slope (< 5%)	
	Pedestrian LOS	0	High pedestrian flows, small pavement width, obstacles (LOS D, E, F)	
		1	Low pedestrian flows, adequate sidewalk width or absence of obstacles (LOS A, B, C)	
	Surface degradation	0	Presence of holes or dips, degraded sidewalk	
		1	Absence of holes or dips, pavement in a good state	
Pleasantness	Street furniture	0	Absence of baskets, benches, and other elements of street furniture	
		1	Presence of baskets, benches, and other elements of street furniture	
	Shelter for rain and sun	0	No shelter from sun or rain	
		1	Presence of shelters from sun or rain	
	Green spaces	0	Absence of flower beds or green areas	
		1	Presence of flower beds or green areas	
	Shops	0	Absence of shops	
		1	Presence of shop windows	
	Building context, land use mix, and urban design	0	Degraded urban landscape (presence of damage to urban furniture, lack of cleanliness, presence of graffiti and abusive posters in buildings, presence of buildings with a degraded facade, presence of industrial buildings)	
		1	Nice urban landscape (perfect functionality of urban furniture, adequate cleaning, presence of well- maintained buildings)	
	Safety	Streetlight	0	Poor lighting according to the Uni standard (UNI 11248) or lack of streetlights
			1	Proper and efficient streetlights according to the Uni standard (UNI 11248)
Traffic volume and vehicle speed		0	High traffic volumes (> 1000 vph) or high speed (> 50kms)	
		1	In other cases,	
		2	Free flow (< 300 vph) and low speed (30 km/h)	
Barriers for pedestrian protection from vehicles		0	Absence of protection elements	
		1	Presence of barriers for pedestrian protection from vehicles Absence of traffic control signal at the intersection	
Traffic control signal at intersections		0	Traffic control signal at the intersection but presence of conflicts between different traffic components Traffic control signal that eliminates conflict points between vehicles and pedestrians	
		1	Traffic control signal at the intersection but presence of conflicts between different traffic components	
		2	Traffic control signal that eliminates conflict points between vehicles and pedestrians	
Driveway		0	Absence of driveways along the way	
		1	Presence of one or more driveways	

Table 2.2: Walkability indices (D'Orso & Migliore, 2020)

Table 2.3 illustrates the details of indices, and it reflects the same points which highlighted in previous literature of Hewawasam (2013) and Fitzsimons D'Arcy (2013). Gabriel D'Orso's work clearly indicates the upper and lower limits of each qualitative indicators to measure the walkability. This workability indices gives clear reference to measure the walkability in typical

urban environment. Both qualitative and quantitative measurements vary from 0-1 range except traffic volume/speed indices and traffic control signal at intersection.

2.3 Acceptable Walking Distance

Critical walking distance is identified as the distance from any kind of transportation facility (Railway station, Bus terminal, Parking lot) at commercial capital or town center to main trip generators (Seneviratne, 1985). In the Sri Lankan context, office premises, schools, tuition classes, banks and other government institutions, commercial areas such as market, shops are the main trip generators.

According to Seneviratne (1985) this kind of trips at town center would depend on some external factors such as type of trip, purpose of trip, type of day. It may directly influence to walking distance. Utility related walking trips may indirectly influence some factors such as congestion, parking fee, one-way road, parking availability, etc. Even there is no parking fee or subjectively low cost on town center, people including workers are willing to walk up to 610 m. Threshold limit of walking distance at town center is identified as 610m in this study.(Seneviratne, 1985)

Walking distance is depending on trip purpose mainly. However, a threshold value for average walking distance is required to identify. Another study has been proposed a mean and maiden values for walking trip in a day. (Yang & Diez-Roux, 2012). According to that 60% of respondents had at least one daily walking trip. Mean value of walking distance is 1120m and the median value is 804m. Their purpose varies with income category. Relatively lower income population walks longer distance to work and shorter for recreation. But higher household income population walks longer distance for recreation and shorter to work.(Yang & Diez-Roux, 2012)

Marc F. Roddin's work regarding to determine the benefits of separating pedestrian and vehicles, stated the general statement about pedestrian walking length. Most of time pedestrian route length is less than 3,000 ft (915 m) in length. (Roddin, 1981) Highway capacity manual Chapter 13 quotes, Rodin's method to calculate total travel time in pedestrian network.

Total travel time = Number of pedestrian x ((Route length / Walking speed) + Signal Delay)

In here, Rodin introduced maximum possible walking route length at city < 915m. In addition, ideal pedestrian route length < 1.2 x straight line distance between trip origin and destination. This assumption is important to avoid long distance alternative routes which reduced the complexity of OD matrix.(Roddin, 1981)

Recent medical study of Murtagh et al (2021) reveals that walking outdoors at a usual pace was an average speed of 1.31 m/s, a cadence of 116.65 steps/min. (Murtagh et al., 2021) This value is important to use as an assumption for walking speed on above Rodin's equation.

There are several studies regarding threshold value for walking at an urban center. Rongrong Yang et al (2013) introduced threshold value for pedestrian at transit station china as 400m to 800m according to Krishi's logit Price Sensitivity Model. Another study conducted in Spain regarding the threshold distance to walk from home to school by Carlos Rodríguez-López (2016) and it was 875 m for young people's community.

Average acceptable walking distance for the study of typical city in Sri Lanka is selected as 750 m by considering literatures.

2.4 Pedestrian route identification

Proper data collection method should be identified to find the possible pedestrian routes.

A broad range of methods for data collection was found in the literature. Rafor (Rafor et al., 2005) developed a method, respondents can draw their route on paper. But it would be very difficult on urban context. Snizek (Snizek et al., 2013), developed a criterion regarding web-based questionnaire. This method is quite advanced, with connected to web API, google maps and open street maps. Application of web-based methodology would be difficult in the Sri Lankan city because most of pedestrian categories have a low level of computer literacy. It would result to omit the majority in pedestrian categories from the survey.

A hybrid data collection, including web-based method and personal interviews are covered all categories of pedestrians.

2.4.1 Shared space.

Shared space concept of designing roads and junctions has been very popular in recent years and it forced to discourage car domination model on road space. Many researchers, including Baillie, Frosch, Hammam have published their studied regarding the shared space concept at many cities around the world. In the modern cities in Europe, where promoting non-motorized transport and focusing on sustainable approach, adopt the shared space concept for their town plans. (Kaparias & Wang, 2020) (Baillie, 2008)

At the shared space concept, there are no curb, pedestrian crossing, sidewalks. In Sri Lanka, unplanned shared road space used by pedestrians but there are no planned and designed shared spaces except for very limited locations. Less traffic condition of roads leads pedestrians to use the road carriage way as their space. Hard shoulder, or soft shoulder also used when there is no

proper sidewalks or pedestrian amenity exist. Shared space concept is essential to consider when proposing improvement for pedestrian amenities.

2.5 Pedestrian Route Choice

There are many studies about pedestrian route choice. Pedestrians are enjoying a high degree of freedom of movement in a congested city environment with comparison to other travel modes.

Hill (Hill, 1982) found important factors regarding pedestrian route choice according to four different attributes: ages, gender, trip purposes, and environments. Across from all factors, responders were considered minimization of distance at first place while selecting a route. Only 1 out of 211 observations deviated from shortest distance on his study.(Hill, 1982)

Another study in Sweden town center, private vehicle users who parked their vehicle in the central parking area, attempt to go most distance location first and then gradually walking back to the vehicle over the course of their visit. Nearly 70% of shoppers attempt to minimize the distance while on their trip.(Gärling & Gärling, 1988). Another research in UK urban context, 616 of the 820 sample pedestrians took the shortest route. It was 75% of records and majority trips on the other 25% were slightly longer than the shortest route.(Verlander, 1997)

Cities in Germany and USA where there are more pedestrian friendly environments, Zielstra's study (2012) aims to research about smart device usage among pedestrians. Those kinds of smart device such as a tablet, smart phones led into an increase of popularity of pedestrian related routing application on such environments. Non recreational and multimodal trip pedestrians have used that kind of application because pedestrians typically aim to reduce their walking distance. Pedestrian network shortest path algorithm programme is really helping to find the shortest way and thus to avoid unnecessary detours.(Zielstra & Hochmair, 2012)

2.5.1 Shortest path

Shortest path generally saves time, cost, and energy. Many empirical research proves that pedestrians are choosing the shortest path to avoid unnecessary detours on utility-based trips most of the time. (Hill, 1982), (Verlander, 1997). There are some other considerations for pedestrian route choice. There would be a low walk score in shortest path, due to the poor condition of walkability measures which described in literature such as (Hewawasam et al., 2013), and (D'Orso & Migliore, 2020). If the walk score is low in shortest path, the probability of selecting a next available connectivity path, would be high for many categories of pedestrians.

Even there is less probability of using the shortest path, it is considered in the spatial explicit model.

2.5.2 Application of Dijkstra's Algorithm.

Dijkstra's Algorithm is a fundamental shortest path algorithm which gives the optimum route on network by counting method. It computes shortest distance from one node to every other node. Hence it is used in many researches and very efficient in shortest distance problem, Dijkstra algorithm is used to find the list of the shortest routes in the O-D pair list. At the end of iteration process each node is consist with (x, y) values. "y" value at Destination node (x, y), represent the shortest distance from Origin node.

If y value > Threshold value of walking distance (750 m), the probability of occurrence of the trip using pedestrian mode in particular O-D pair is very less.

ArcGIS network analysis solver in shortest distance and Origin Destination cost matrix represent the Dijkstra algorithm. ArcGIS gives both time-based, and distance-based optimum route. In this model, shortest distance method used to build up the minimum cost OD matrix.

2.5.3 Long walking trips.

Straight line distance between the destination and city center will correspond to the Rayleigh distribution.(Bunke, 1969). Rayleigh distribution function as follows.

$$F(x) = 1 - e^{-\frac{x^2}{2\sigma^2}}$$

Where;

x - Straight line distance between destination and city center

σ - Rayleigh distribution parameter concerning the variable x (Bunke, 1969)

This distribution is implied to find the probability of trips for long distance O-D paths.

2.6 Pedestrian Trips in Sri Lanka

When it comes to Sri Lankan context, Hewawasam's study (2013) regarding the pedestrian route choice, key identification in pedestrians during utility related trips was that most of the time pedestrians were reaching their destination by the shortest route. Planning stages to focus on sustainable development in a city, developers should consider about improving workability at urban spaces. In order to improve walkability in cities, professionals, planners should provide shortest, less time-consuming connectivity paths between trip generators and attractors.(Hewawasam et al., 2013)

As a developing stage of cities in Sri Lanka, most of cities have evolve with time in a natural pattern. ADB study regarding Walkability and Pedestrian facilities in Asian Cities reflected the

worst stage in pedestrians in Colombo city. Other provincial capitals in Sri Lanka would show the same pattern because they are also becoming an unplanned and evolved city.

according to figure 2.2, Public transport and pedestrian mode share in selected Asian cities, shows that Sri Lanka has lowest mode share of walking with respect to other Asian cities.

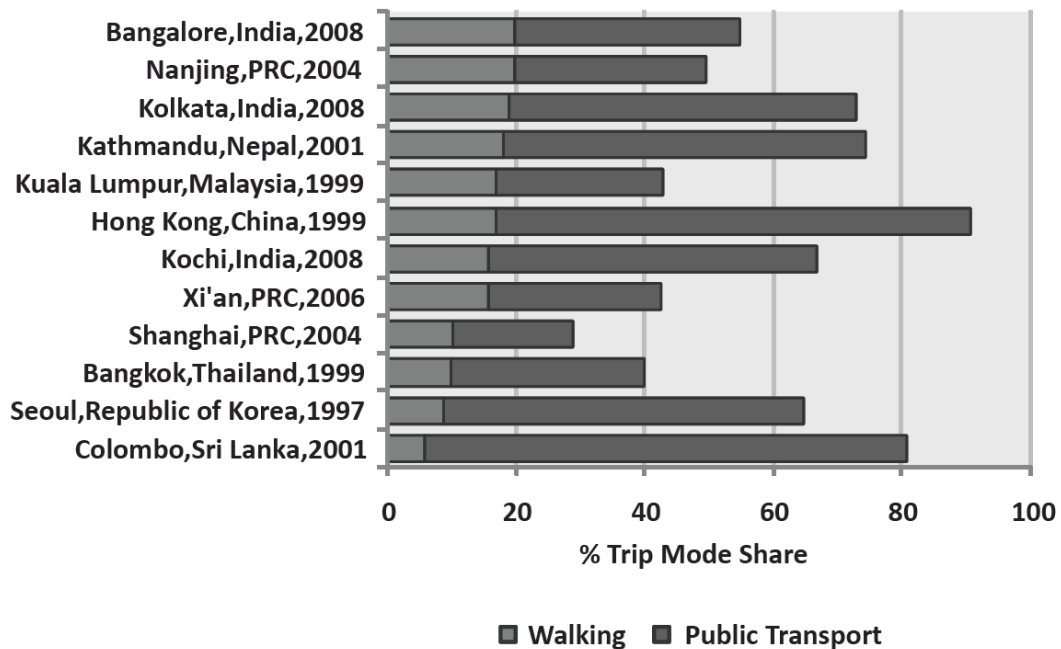


Figure 2.2: Public Transport and Pedestrian mode share in selected Asian Cities

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

The total number of vehicles in Sri Lanka is increasing annually. In 2007, total population of vehicle was 3 million and it increased from up to 8 million in 2019.

Huge growth of vehicle population leads more complex and riskier environment at city center. That riskier environment is directly affected to pedestrians on city. Fig.2.3 shows the vehicle population growth from 2007 to 2019. It shows, there was a significant increase in motorcycles, three wheelers and motor car population.

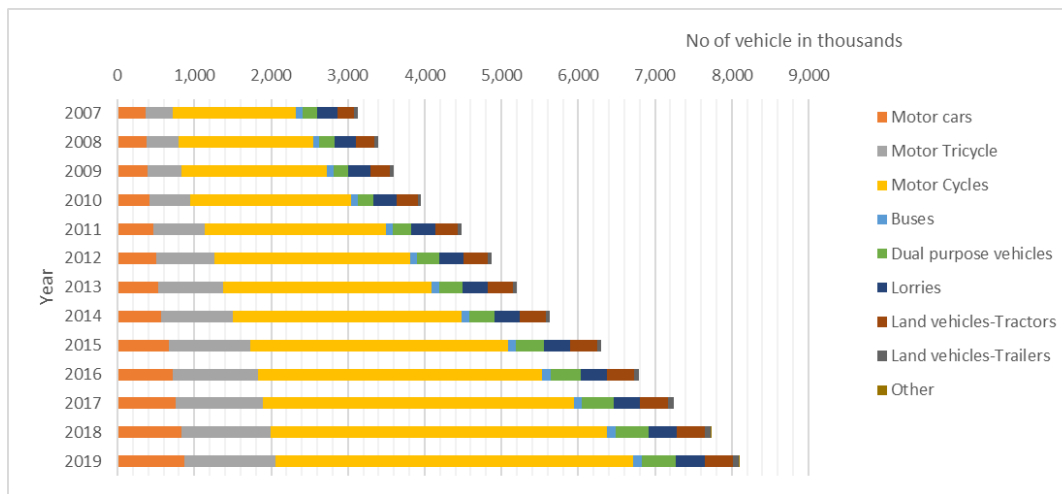


Figure 2.3: Vehicle population in Sri Lanka (2007-2019)

Source: Department of motor traffic Sri Lanka, Ministry of transport Sri Lanka

2.7 Pedestrian Demand at Medium Size City in Sri Lanka

What is important in pedestrian planning process is predicted of pedestrian moving pattern and functional movement of network. Unlike in vehicle traffic demand, pedestrian traffic demand is very difficult to estimate. In this methodology, the first step is to understand pedestrian trip origin nodes.

According to the report on “state of Srilankan cities” by SoSLC, Srilankan cities have been expanding rapidly during the last few decades. Expansion of Srilankan cities shows the characteristics of sprawl.(www.SoSLC.lk, 2018) Urban sprawl is defined by Bhatta 2010 as low-density city expansion in unplanned and/or uncontrolled way with rapid land consumption. This change transforms rural space into urban land use.(Bhatta, 2010)

Commercial activities and business are concentrated along the road link and around the railway stations in typical Sri Lankan cities. It can be identified as ribbon development. Ribbon development guides the sprawl, which consumes low density urban land use.(www.SoSLC.lk, 2018) This characteristic is very important to identify typical Srilankan urban space land use utilization.

Fig 2.4 shows 50% of people entering into the city in Srilanka by public transport. That means public transport terminal, bus stops are main pedestrian trip generators in the city centre.

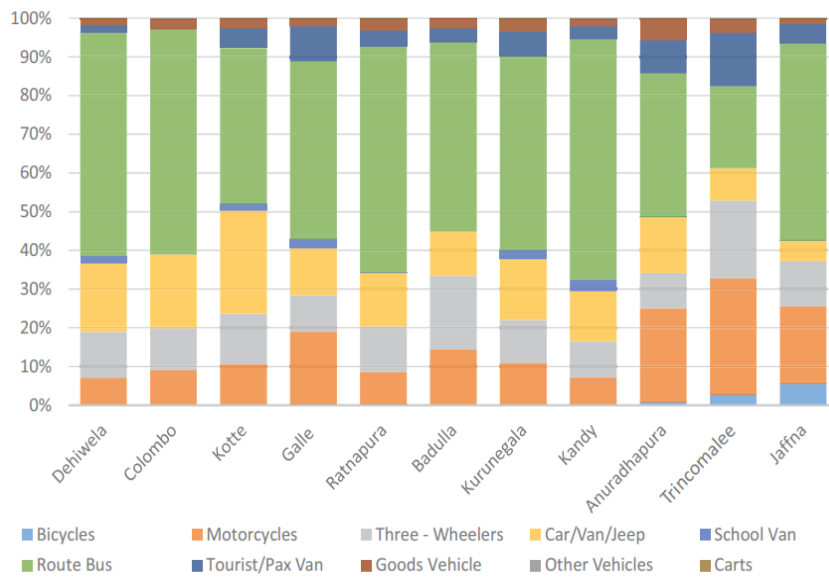


Figure 2.4: mode share by passenger volume in main urban areas in Sri Lanka

Source: State of Srilankan cities 2018 report.

When we consider motorcycle, three-wheel, taxi, school van, users connect destination by itself. Due to the congestion on city centre, private vehicles, car, van users must walk from parking place as the last mode of transportation. When it comes to study, public bus terminals, central parking areas are main pedestrian trip generators at urban centre.

Moulden's study in 1997 describes apartments and grocery stores create a high number of pedestrian trips in urban area. It means that the apartments and residential units generate pedestrian trips in general. (Moudon et al., 1997) But this study focuses on pedestrian traffic at the central area of town where, residential units are somewhat limited. Fig.2.5 shows trends in urban population growth in South Asian region. It clearly shows, Srilankan urban residents tend to move away from urban centre to nearby residential spaces by showing the lowest growth rate in South Asian region.

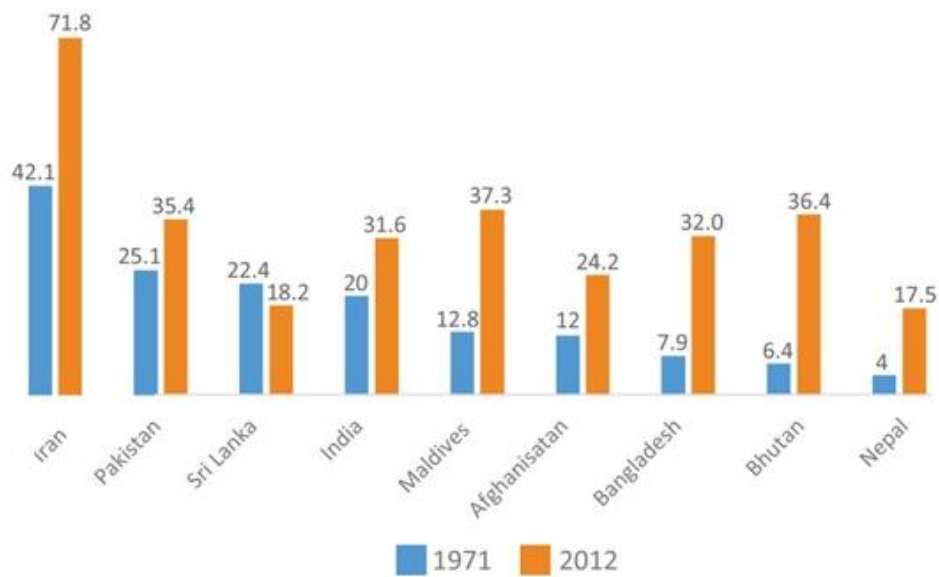


Figure 2.5: South Asian urban population growth trends in 1971 and 2012

Source: World Urbanization Prospects: The 2018 Revision, United Nations

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Considering literature, methodology of pedestrian demand in urban town center described in following key points.

- Bus station, bus stop and train station are main nodes of pedestrian trip generators.
- Central parking lots, parking area secondary pedestrian trip generation nodes.
- Residential area such as flats, apartments at urban vicinity are secondary trip generation nodes.
- Trip generation nodes are acting as trip attractors on the return trip.

Land use distribution in the typical Srilankan city can be categorized into 6 different types.

- Residential (apartment and flat)
- Commercial (supermarket, fair, retail shop)
- Institutional (educational, financial, medical, and other public office)

- Religious (temple, kovil, church, mosque)
- Recreational (cinema, park, playground, beach park)
- Transportation facilities (bus/train station, parking)

These 6 types can be identified when analyzing land use distribution in urban space. According to a study in Panadura MC area, commercial land use category supermarket generates lesser trip rate than fair and retail shops. Secondary schools that are located within the walking distance from the bus stand and railway station produce more pedestrian trips. (Hewawasam et al., 2014)

Table 2.3 shows that urban school attracts almost 30% walking children and 13.1% bus/train passengers. Bus/train passengers last mile connectivity to school is always a walking trip. That means around 40% of school population use walking as their last mile connectivity mode in urban space. It is also reported that 35% of 15-17 age group school children use bus/train as a transport mode to school and it was highest among other modes and 12-14 age group is also showing 26% of second-best mode to travel as bus/train.

Sector, Gender, Age group	Mode of travel							Total
	Walking	Bicycle	Motor cycle Threewheeler	Bus/Train	School van	Car	Other	
Sri Lanka	33.9	9.4	19.1	19.1	2.2	16.1	0.2	100
Sector								
Urban	29.9	7.3	26.6	13.1	6.5	16.3	0.3	100
Rural	32.4	10.4	18.3	20.5	1.5	16.8	0.2	100
Estate	67.4	1.4	6.7	19.1	0.1	5.3	0.0	100
Gender								
Boys	33.4	11.1	18.1	20.3	2.2	14.6	0.2	100
Girls	34.4	7.6	20.0	17.9	2.3	17.7	0.1	100
Age group								
5-11	34.6	8.4	24.4	12.5	2.5	17.4	0.2	100
12-14	33.4	11.1	12.0	26.0	1.7	15.7	0.2	100
15-17	31.8	10.5	9.3	35.0	1.9	11.4	0.2	100

Table 2.3: Distribution of school attending by mode of travel

Source: Child Activity Survey Srilanka 2016. Department of Census and Statistic

Table 2.4 shows that 46.7% of employees at Srilanka use the bus and train as the mode of transport to reach their workplaces.

Major mode of transport	All sectors		Central government public sector		Provincial public sector		Semi government sector	
	Total	%	No.	%	No.	%	No.	%
All employees	1,109,475	100.0	485,471	100.0	380,198	100.0	243,806	100.0
Walking	62,893	5.7	23,240	4.8	26,641	7.0	13,012	5.3
Bus	471,172	42.5	192,509	39.7	169,811	44.7	108,852	44.6
Train	46,773	4.2	28,667	5.9	4,614	1.2	13,492	5.5
Assigned official vehicle	6,174	0.6	2,661	0.5	813	0.2	2,700	1.1
Official group transport	12,807	1.2	1,752	0.4	519	0.1	10,536	4.3
Private motor vehicle	42,548	3.8	16,309	3.4	14,131	3.7	12,108	5.0
Staff service	11,395	1.0	3,589	0.7	3,055	0.8	4,751	1.9
Taxi	42,926	3.9	11,647	2.4	26,038	6.8	5,241	2.1
Motor cycle	266,919	24.1	125,399	25.8	96,449	25.4	45,071	18.5
Foot bicycle	32,004	2.9	15,636	3.2	11,035	2.9	5,333	2.2
Other	5,943	0.5	2,092	0.4	2,816	0.7	1,035	0.4
Not specified	107,921	9.7	61,970	12.8	24,276	6.4	21,675	8.9

Table 2.4: Distribution of employees by major mode of transport and sector of employment Sri Lanka

Source: Department of census and statistics 2016

Public transport users create mandatory pedestrian trips between urban centre and working places. Last mile connectivity mode of transportation from bus stop or train station to their working places. Almost 50% employees in Sri Lanka create walking trips according to this survey. These trips create during on weekdays at morning time and evening times.

3 METHODOLOGY

3.1 Framework Development

Walkability is vital important factor to develop in a pedestrian friendly environment. Available pedestrian amenities are essential part to attract people to use pedestrian mode. Improving walkability at available pedestrian amenities are the main approach towards pedestrian friendly city. Utilization of public funds in walkability improvement projects require the prioritization with the limitation of available cost allocation. OD matrix development is a micro level attempt for prioritizing work on pedestrian facility requirement at urban environment. Unlike Other pedestrian demand analysis models in residential or mixed land use area, urban center consists of many non-recreational trips. In order to develop an OD matrix model, it is required to identify the pedestrian route network and travel behavior in that area. Pedestrian demand estimation is a quite challenging task on this process. There is no any convenient method other than, pedestrian count survey, video survey to establish the estimation of pedestrian flow. Hence, Initial models have been run by assuming uniform demand at each generation node. Geographical information system (GIS) based methodology is proposed to generate the initial network model. GIS network analyst tool is used to find the connecting OD links and rank the pedestrian amenities according to the usage is conducted after developing the OD matrix. After establishing an initial model, data verification method is conducted. After that modification tools are introduced to obtain accurate results. Following steps describe the descriptive methodology of OD matrix development.

Step 1

Identify the trip generation nodes for medium size city urban center, assess the threshold limit of average walking distance set the boundary using buffer area of trip origins. Threshold walking distance is used to determine the buffer radius. In addition to that, terrain barriers and built environment barriers to be considered to set the spatial limits for pedestrian movement. Study area is assumed as close polygon and trip generators are assumed as nodes in the initial model.

Step 2

GIS base methodology is developed based on pedestrian movement network. The best connectivity path between a trip origin node and destination node is considered. Best connectivity path is the minimum cost path that consumes less energy to reach destination. It would be a shortest distance path with minimum number of road crossings in an urban network.

A minimum cost path is made from series of sidewalk segments and crosswalk segments. O-D path matrix is developed by manipulating sequence of each origin and destination connectivity paths.

Step 3

Elements of O-D path matrix consist the set of sidewalk and crosswalk segments. Each segment's frequency at urban network O-D matrix is counted and ranked according to descending order. Higher rank means that particular crosswalk or sidewalk belongs to the many numbers of pedestrian O-D paths. So, Priority list in pedestrian amenities is developed according to that ranked list. Pedestrian amenities are ranked based on the usage of the network. Frequently used sidewalks and crosswalks are selected and compared the walkability aspects of selected items. Those high rank amenities are selected for walkability improvement projects.

Step 4

Road segment wise Google traffic speed data is extracted from the town area. Continues series of low-speed segments represent the vehicle queue at junctions or at pedestrian crossing locations. Data collection is done through the Google sheet script and it allowed to extract each segment's speed data in 10 min interval automatically. After collecting data, spatio temporal graph that represent average speed data matrix, is developed according to location vs. time. This data analysis was conducted to identify congested locations, and normal traffic behaviour on city environment.

Step 5

Pedestrian counts are conducted at selected links to compare the O-D matrix results. Selected path should include a mix of higher and lower ranked sidewalk and crossing locations to verify the pattern of pedestrian variation with the model result vs real world scenario Manual pedestrian spot counts for 15 minutes during a selected peak time is basic survey method to collect the data. Pedestrian count using birds eye view video from drone camera is highly effective in this kind of verification

O-D matrix results and pedestrian count results are plotted on XY graph according to the rank and compare R^2 value in linear regression to validate the model results. Prioritize Road segments can be short listed as per budget constraint and proceed with improvement projects as better utilization of public funds.

Study area identification and methodology implementation were done as a case study to identify the prioritized pedestrian amenities at Rathnapura town. Municipal council of Rathnapura, Sri Lanka was allocated funds for development of pedestrian facilities at town center to improve the pedestrian movement in town area.

3.2 Study Area Identification

If we focus on pedestrian behavior at a city center, where they exist less residential land use lots, main pedestrian generators are public transport stops and terminals. In addition, public parking areas can be considered as pedestrian trip generators.

Walkable distance is the main influencing factor in pedestrian mode choice. Based on the literature a 750 m is selected as convenient distance for walking. Walkable distance is the main factor to be considered in selection Origin-Destination locations. Pedestrians will not choose a walking mode for longer distances, especially in urban centers where commuter bus, three wheelers, and taxi are available. Study area should not extend beyond the city center because pedestrian trip does not occur between those O-Ds.

Geographical barriers are another influencing factor for pedestrian trips between O-D pairs. This has plus and minus points. Natural barriers like streams, marshy land, etc. limit the walking trips between a O-D pair. But terrain condition like hilly environment with steps may encourage walking mode than vehicles because steps with high gradient cut shorter the distance than vehicular route even for motor cycles. This is another important factor to be considered to in selecting the study area.

Economic status of population category also influences to the pedestrian trips at a town center. Low-income population, school children use walking mode without using three wheels or taxi for short trips.

3.3 Application of geographical information system (GIS)

3.3.1 Pedestrian Network

A Transport network consists of nodes and links. Pedestrian network is consisting of trip origin points and destinations, which are identified as nodes. In addition to the main nodes, pedestrian crossings and road intersection considered as intermediate nodes. A link connects to any of two nodes. Pedestrian path, steps, crosswalks, alleyways are example for links at an urban network. Combination of links creates a network at an urban center.

Unlike other urban network, urban pedestrian network considers sidewalks either side of a main road section as two links. Gates, outlet of buildings, act as origin or destination nodes. (Fig 3.1)

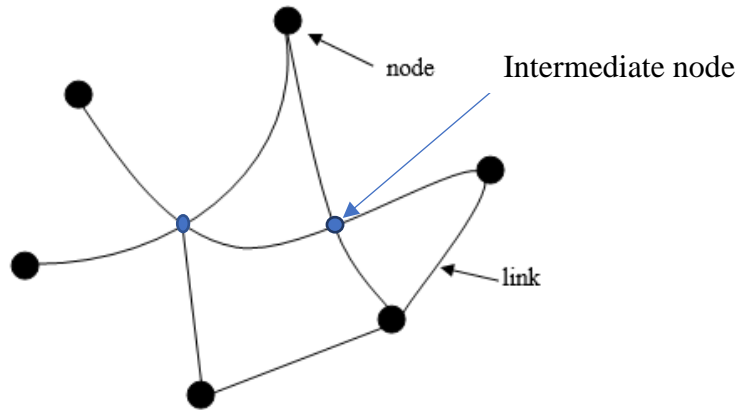


Figure 3.1:Representation of network (compiled by author)

3.3.2 Study area identification using GIS.

Following nodes are considered as trip generation nodes

- Main bus stand
- Train station
- Bus stops
- Parking outlets
- Apartment / Flats exit gates

Acceptable walking distance from trip origin point is considered as 750 m at town center. It means the probability of trip length more than 750m is very rare for pedestrians at the urban environment.

Rodin (Roddin, 1981) introduced ideal pedestrian route length $\leq 1.2 \times$ straight line distance. Hence a 625m (750 m /1.2) will be considered as the maximum radius in the pedestrian trip zone, for a generating node. After identifying all trip generating nodes, a collection of 500 m radius buffer defines the most probable pedestrian zone for each origin node. This pedestrian movement zone is restricted from geographical barriers such as rivers, water stream without a bridge or any other cross path, physical, environmental barriers, marshy land, etc. Those geographical features are extracted as a geographical boundary layer to fine tune the pedestrian movement zone. Close polygon is created by connecting boundaries of barriers and it is named

as barrier a polygon layer. After identifying environmental barriers, polygon created as barrier polygon.

The study area is extracted after merging those geographical barrier layer and pedestrian movement buffer layer. Fig 3.2 illustrates the step breakdown of study area layer identification.

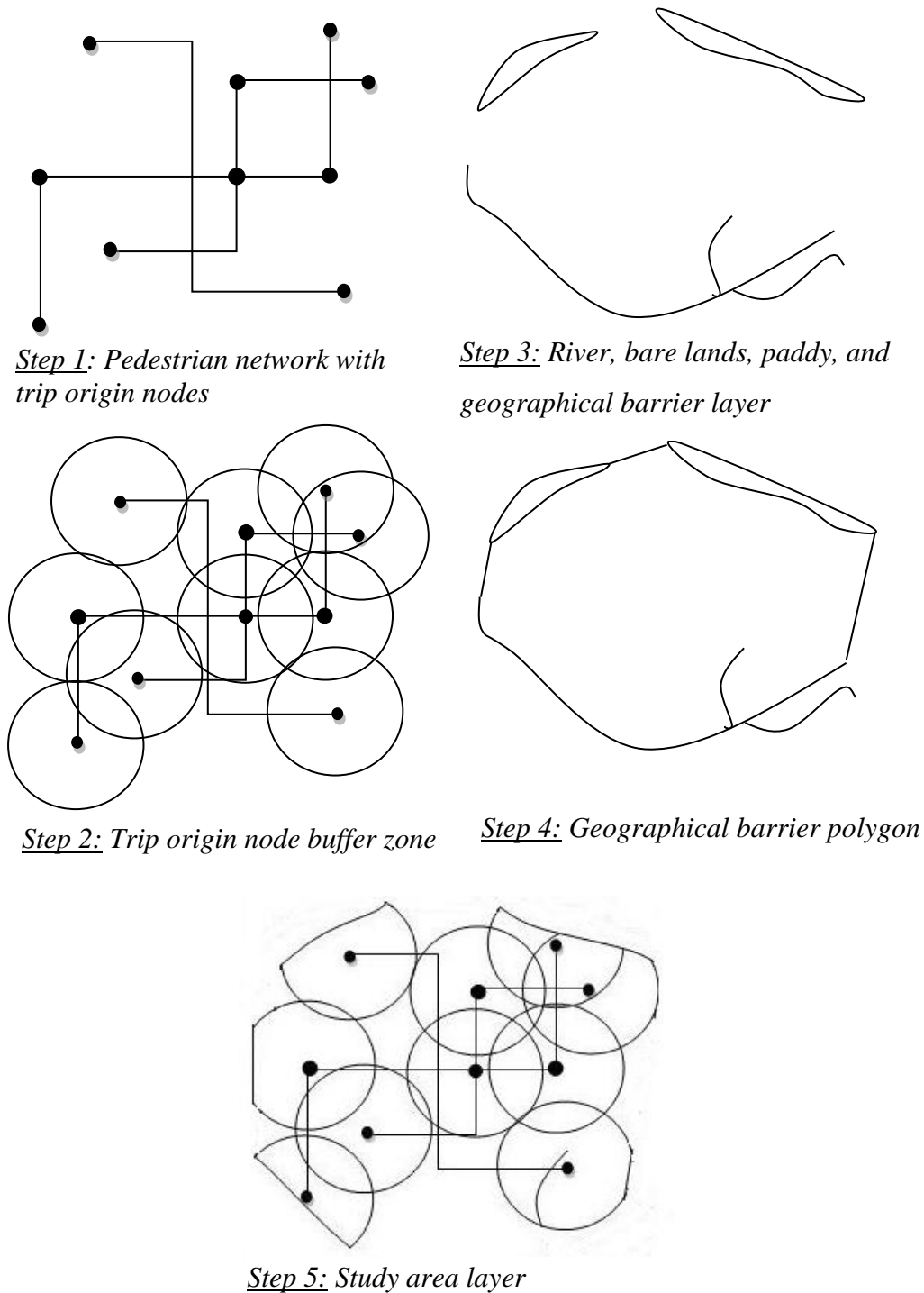


Figure 3.2: Step breakdown for study area identification (Compiled by author)

3.4 Pedestrian Route Choice

Route is required to connect Origin and Destination pair of the network. Route choice is mainly depending on shortest distance. It is not only a deciding factor in an urban environment. According to Ariffin and Zahari (Ariffin & Zahari, 2013) , it takes few factors other than shortest distance. Roadway traffic condition, nearby land use utilization, security and comfort are other influencing factors in route choice.(Rodríguez-López et al., 2017)

Sidewalks and crosswalks are two main physical components in the typical urban pedestrian network. Next step is the identification of possible pedestrian routes which connects all origins and destinations in the town center.

As discussed in Literature review, the hybrid data collection method was carried out to identify the possible pedestrian routes. Open street maps, Google satellite maps used to identify the possible pedestrian paths. Pedestrian paths on both sides of roads, crosswalks, steps, and footpath were identified as an initial step. Pedestrian interview at trip origin locations and site visit on study area to verify the pedestrian routes, and preferred other routes in the urban network were carried out.

Some urban road section in Sri Lanka is acting as shared space with pedestrian and vehicle fleet due to the high-capacity pedestrian flow with the unavailability of pedestrian amenities. As discussed in the literature, shared space concept is also important to suggest improvement for the pedestrian flow.

Considering all above identification methods, possible pedestrian routes are identified and transfer into GIS model as line attributes. (Fig 3.3).

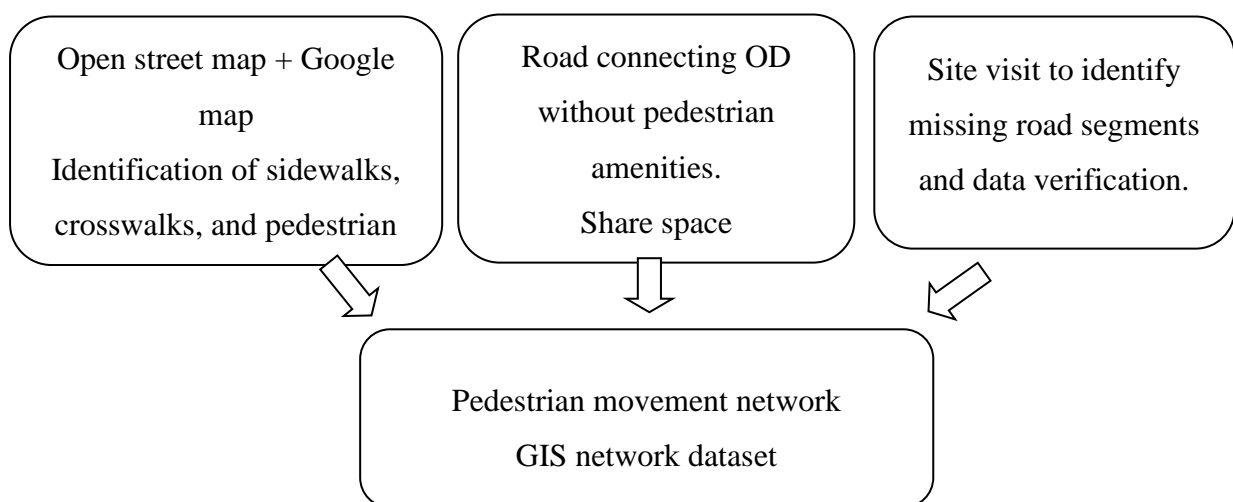


Figure 3.3: Pedestrian network dataset development

3.5 Shortest Pedestrian Path

According to the literature, probability of choosing a minimum cost path is very high.

Each pedestrian path is consisting of two types of conspicuous road furniture; sidewalks and crosswalks. Each sidewalk segment and crosswalks were listed out as follows:

Sidewalk segments = $a_1, a_2, \dots, a_n, a_{n+1}, \dots, a_{n+i}$

Crosswalk sections = $b_1, b_2, \dots, b_n, b_{n+1}, \dots, b_{n+i}$

Origin node and destination node on matrix can be denoted as follows.

Origin = $n_1, n_2, n_3, \dots, n_n$

Destination = $n_1, n_2, n_3, \dots, n_n$

In a two-way trip, Origin is also acting as Destination of return journey unless exit only/ enter only locations. One-way flow, exit/entrance only location on the urban pedestrian network is very rare. But the presence of such location should identify during the site visit. That means almost all elements of Origin node set includes in Destination node set.

3.5.1 Application of Dijkstra's algorithm

As discussed in the literature review, Dijkstra's Algorithm is a fundamental shortest path algorithm which gives the optimum route by counting method. It computes shortest distance from one node to every other node. Hence it is used in many research and very efficient in shortest distance problem, Dijkstra algorithm is used to find the list of the shortest routes in O-D pair list. Figure 3.4 illustrates the application of Dijkstra algorithm in shortest distance problem on sample network.

Assume in fig 3.5,

n_1 is Origin and n_2 and n_3 are Destinations.

Lengths in links $l_{12} = 3, l_{13} = 7, l_{23} = 3$

$$(1, d_{12}); d_{12} = 0 + l_{12} = 3$$

$$(1, d_{13}); d_{13} = 0 + l_{13} = 7$$

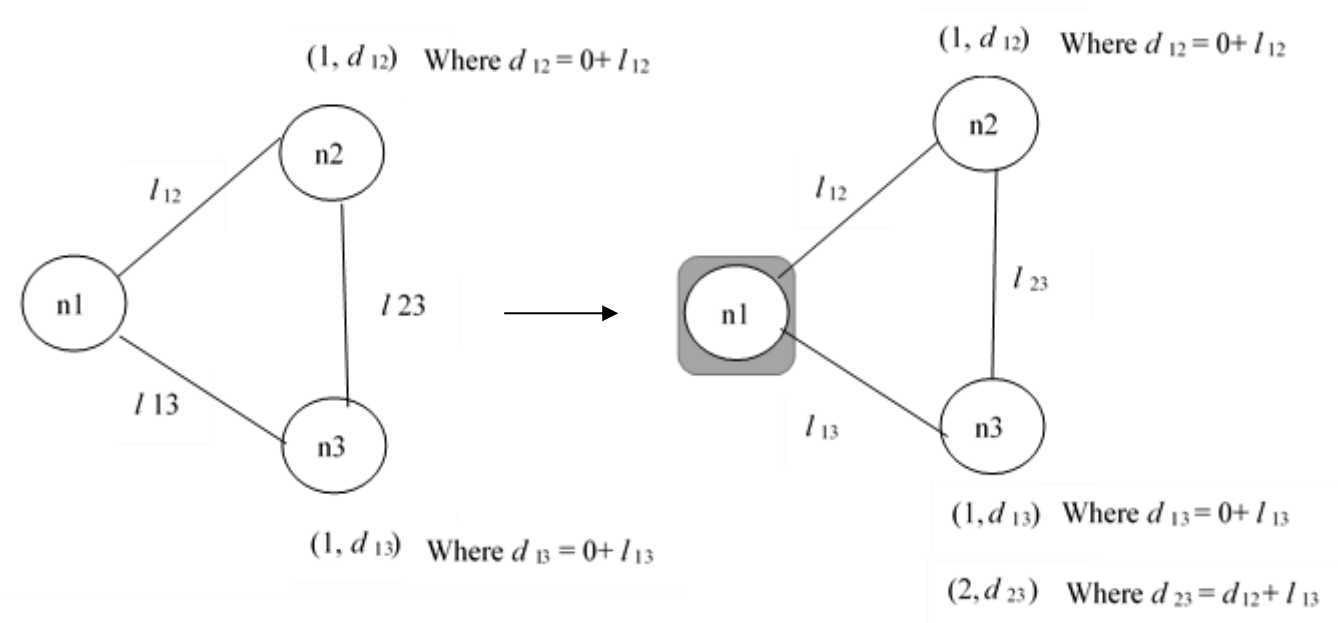
n_1 node is fixed according to the n_2 node, consider n_3 node.

$$(1, d_{13}) = 7$$

$$(2, d_{23}) = 3 + 3 = 6$$

According to the algorithm, d_{ai} value in predecessor node is the minimum value of comparative values.

So, d_{ai} value at n_3 is $(2, d_{23}) = 3+3 = 6$



Step 1: immediate predecessor node n_1 and calculate temporary values at close nodes.

Step 2: n_1 is fixed. Consider lowest d_{1i} node n_2

Figure 3.4: Illustration of Dijkstra algorithm- sample network (Compiled by author)

At the end of iteration process each node is consist with (x, y) values. “y” value at Destination node (x, y) , represent the shortest distance from Origin node.

If y value > Threshold value of walking distance (750 m), the probability of occurrence of trip using pedestrian mode in particular O-D pair is very less.

ArcGIS network analysis solver in shortest distance and Origin Detitanation cost matrix represent the Dijkstra algorithm. ArcGIS gives both time-based, and distance-based optimum route. In this model, shortest distance method used to build up the minimum cost OD matrix.

3.6 Origin Destination Matrix Development

Shortest distance results for all O-D pairs in the network, are extracted from Arc GIS OD matrix solver. Each O-D pair has a distance value and it consist with series of sidewalk lengths and crosswalk lengths.

Arc GIS solver works in two ways. Reduce distance and reduce time for journey. In the Pedestrian network, time factor affects only at major road crossings. There would be some waiting time at main road cross walks. So the additional length modification applies at such crosswalks as follows.

Average walking speed for pedestrian is 1.3 m/s (Murtagh et al., 2021). This average value is applicable up to 5% grade walking paths. According to HCM 2016, section 24-28, walking speed drops as the advancement of the grade. Walking speed on 12% grade is 30% slower than travel on a level surface.(Board, 2016)

If average waiting time at a crosswalk location is t .

Length correction at the crosswalk location = $1.3 t$ in meters. (Up to 5% grade section)

Representation of the sample network illustrated in figure 3.6 and results of shortest distance in O-D matrix tabulated in table 3.1.

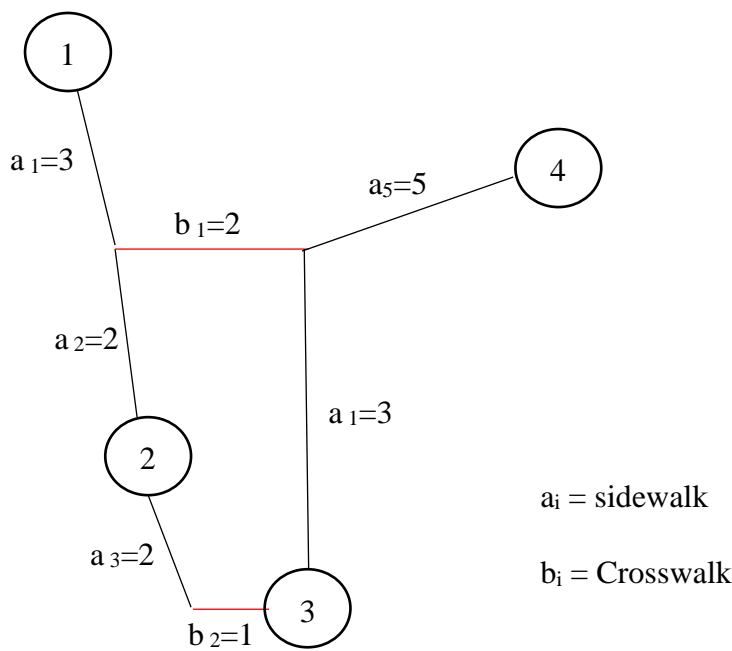


Figure 3.5: Sample pedestrian network

Table 3.1: Shortest path and shortest distance for each OD pair

Origin	Destination	Shortest path	Distance
1	2	a1-a2	5
1	3	a1-a2-a3-b2	8
1	4	a1-b1-a5	10
2	3	a3-b2	3
2	4	a2-b1-a5	9
3	4	a4-a5	10

After finding shortest paths between all pairs of nodes, add each origin – destination pair to the O-D matrix. Origin destination pair of shortest paths consists of the series of sidewalk and crosswalk sections. O-D pair i-j, shortest path l, side walk section a_x , crosswalk section c_x ;

$$l(i,j)=\{a_1,a_2\dots a_n,c_1,c_2,..c_n\} \text{ where } n \in \mathbb{N}$$

Origin-destination matrix (in tens of components of shortest path);

$$[l(i,j)] = \begin{bmatrix} l(1,1) & l(1,2) & \dots & l(1,j) \\ l(2,1) & l(2,2) & \dots & l(2,j) \\ \vdots & \vdots & \vdots & \vdots \\ l(i,1) & l(i,2) & \dots & l(i,j) \end{bmatrix}$$

O-D path matrix can be obtained from above data in a network for the shortest distance in each O-D pair. If the shortest distance for an O-D pair is greater than the threshold value of convenient walking distance, pedestrian trip generation probability would be very small, pedestrians would move into another mode such as taxi or commuter bus in those occasions unless there is a special reason to walk between that O-D pair. According to the literature, probability of longer walking trip occurrence can be obtained from Rayleigh distribution.

Table 3.2 shows the example of cost O-D matrix for the sample network in figure 3.6. All 4 nodes on network act as trip origins and trip destinations in the network. Destination nodes are represented in columns and origin nodes are represented rows.

Road element notations such as sidewalk segments and crosswalk segments are denoted as matrix elements. Hence there are 4 nodes, each node has 3 destination routes. e.g.: for origin node 1, routes are 1-2, 1-3, 1-4.

Table 3.2: OD matrix for shortest distance

O \ D	1		2		3		4	
1	-		a1	a2	a1	a2	a1	b1
					a3	b2	a5	
2	a1	a2	-		a3	b2	a2	b1
							a5	
3	a1	a2	a3	b2	-		a4	a5
	a3	b2						
4	a1	b1	a2	b1	a4	a5	-	
	a5		a5					

3.7 Analysis of Model and Results

Two sets of amenities can be extracted from the O-D matrix. Sidewalk segment set and crosswalk segment set are separate sets of elements on the network. Sidewalks set includes frequent occurrence of

a_n ; where $n \in \mathbb{N}$

$\text{Max } |a_n|$ gives most repetitive element in the network. The most repetitive crosswalk section also identified by the same counting method.

b_n ; where $n \in \mathbb{N}$, $\text{max } |b_n|$ gives the most repetitive crosswalk segment.

Table 3.3 illustrated the frequency of usage of both sidewalks and crosswalks in the network. This kind of frequency table helps to identify the priority elements in a network, and it reinforced the optimum utilization of public funds in development projects. According to this example, a1, a2, a5 segments are frequently used in the network. Developing walkability of those elements would improve the overall efficiency of the network.

Table 3.3: frequencies of pedestrian amenities usage on network

segment	frequency
a1	6
a2	6
a3	4
a4	2
a5	6
b1	4
b2	4

3.8 Application of Google Speed Data Analysis

Google application gathers crowdsource data, such as location from smart devices and process those location displacements with time as traffic data on roads. This algorithm denoted as the distance matrix API, which provides travel distance and travel time from Origin to Destination on google maps. Movement of smart devices have been used to predict the traffic behaviour on the road. Urban centre where there are lots of smart device's movement, predict quite accurate results for the actual traffic behaviour.

Crosswalk locations act as main interruptions for vehicular flow at a town centre. This interruption is one of the root causes for traffic congestion and safety risk at urban centres. OD matrix analysis reflects the frequent usage of crosswalks. Google speed data is available on most of the main road links at study area. In a two-lane road, if vehicle speed data show a

reduction towards a crosswalk, and after a crosswalk vehicle speed data shows average speed, that scenario reflects the impact of the crosswalk on the vehicular flow. Speed variation length along the road reflects the magnitude of impact due to the crosswalk. Google speed data reflects the network peak operation time as well.

3.8.1 Google map travel time and distance data extraction to google sheet.

Google Directional finder class on Google app script allows to find the direction from Origin location to Destination. On the direction data, this class returns travel time between OD, and distance between OD.

Google Directional finder required to follow basic input to run the script.

Origin: coordinates of location

Destination: coordinates of location

Waypoint: coordinates of detour location and intermediate stops

Once it uploads to the script, it returns the distance and expected time, according to real-time traffic condition. The Google sheet script editor allows us to automate this basic process in specific time intervals.

Study of traffic behaviour near the crosswalk requires some modification on this basic process.

It described in the following steps.

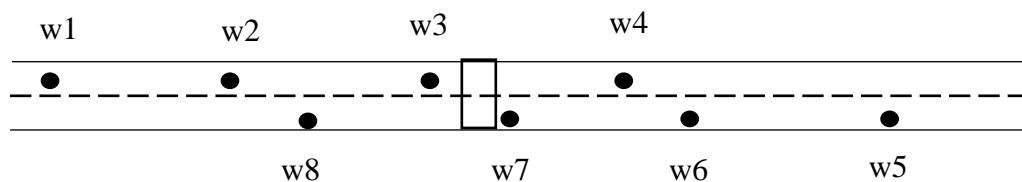


Figure 3.6: way point arrangement near crosswalk

North and East coordinates of each waypoint are extracted from Google map. Location before and after crosswalk are selected to check the speed variation as illustrated in Figure 3.4. Point coordinate required some modification to trigger the script in google sheet script. Point file upload as Origin coordinate and Destination coordinate file as illustrated in Table 3.4.

Table 3.4: sample input table for google sheet script.

Section ID	Origin coordinate	Destination coordinate
w1-w2	6.68226500, 80.4030610	6.68250500, 80.4026820
w2-w3	6.68250500, 80.4026820	6.68257200, 80.4024330
w3-w4	6.68257200, 80.4024330	6.68279500, 80.4019960
w5-w6	6.68279500, 80.4019960	6.68259100, 80.4015740
w6-w7	6.68259100, 80.4015740	6.68228200, 80.4011260
w7-w8	6.68228200, 80.4011260	6.68219900, 80.4010020

Script is set up to trigger at every 10-minute interval on Google sheet, and output file contain estimated duration, trip length, date, and time. This raw output file modified as separate attributes of the date, time, speed (length/time), section ID. From that 4-four attributes, simple pivot table generated with y-axis time, and x axis section ID s. speed data variation can be identified from the graph as denoted in table 3.4. This pivot table is spatio-temporal graph and speed variation illustrates the congestion at the crosswalk. Logic of speed data analysis at a crosswalk as follows.

- If a section before the crosswalk shows red and show green after the section that indicate congestion at the crosswalk location.
- If sections before and after shows red means heavy congestion on the network despite of crosswalk location
- Green in each side means no congestion on the network.

Table 3.5 shows a sample spatio temporal graph and it shows the colour variation according to vehicle speed.

Table 3.5: spacio-temporalaral graph sample

time	Section ID					
	w1-w2	w2-w3	w3-w4	w5-w6	w6-w7	w7-w8
6:10	38.00	20.00	36.00	32.00	25.71	50.00
6:20	38.00	15.78	21.20	20.00	18.00	50.00
6:30	38.00	15.78	21.20	18.60	14.00	50.00
6:40	38.00	13.68	15.90	15.94	18.00	50.00
6:50	38.00	13.68	15.90	15.94	18.00	50.00
7:00	38.00	13.68	15.90	15.94	18.00	50.00
7:10	32.00	12.00	21.20	15.00	12.00	50.00
7:20	32.00	12.00	21.20	15.00	12.00	30.00
7:30	32.00	12.00	21.20	15.00	12.00	30.00
7:40	32.00	12.00	23.85	15.94	12.00	30.00
7:50	32.00	15.78	23.85	15.94	12.00	30.00
8:00	38.00	15.78	23.85	15.94	12.00	30.00
8:10	38.00	17.10	23.85	22.32	12.00	30.00
8:20	38.00	17.10	23.85	22.32	12.00	27.00
8:30	38.00	17.10	23.85	22.32	12.00	27.00
8:40	38.00	15.78	23.85	22.32	12.00	27.00
8:50	38.00	15.78	23.85	22.32	20.00	50.00
9:00	38.00	15.78	23.85	22.32	20.00	50.00

3.9 Results Validation

Site visit and spot pedestrian counts are required to validate the O-D matrix results. Pedestrian movement behaviour at the congested crosswalk location is also monitored and possible countermeasures to avoid conflict between vehicular traffic and pedestrian flow.

Pedestrian route, including sidewalks and crosswalk segments is selected to test the validity of O-D matrix results. The sample route section would contain the mix of higher rank and lower rank pedestrian amenities.

Simultaneous 15 min pedestrian counts at all pedestrian amenities on selected routes and comparison with O-D matrix results is the basic method of data validation. Birds eye view video from drone camera is very cheap and practical application to capture simultaneous pedestrian counts on specific routes.

O-D matrix results and pedestrian count results are plotted on XY graph according to the rank of segment and compare R^2 value in linear regression to validate O-D matrix results and actual values.

Google traffic speed data analysis results required to validate on site. Vehicle queue length in peak and off-peak time can be identified from the site visit. Compare the actual vehicle queue length with the results of spatio-temporal graph is validated both results. If vehicle queue details have complied with the actual conditions, those congested locations can be investigated further to optimize the pedestrian flow, Optimized location for pedestrian crossings is proposed according to the results of the spatio-temporal graph of the network, these analysed results and methods are explained in section 4.3

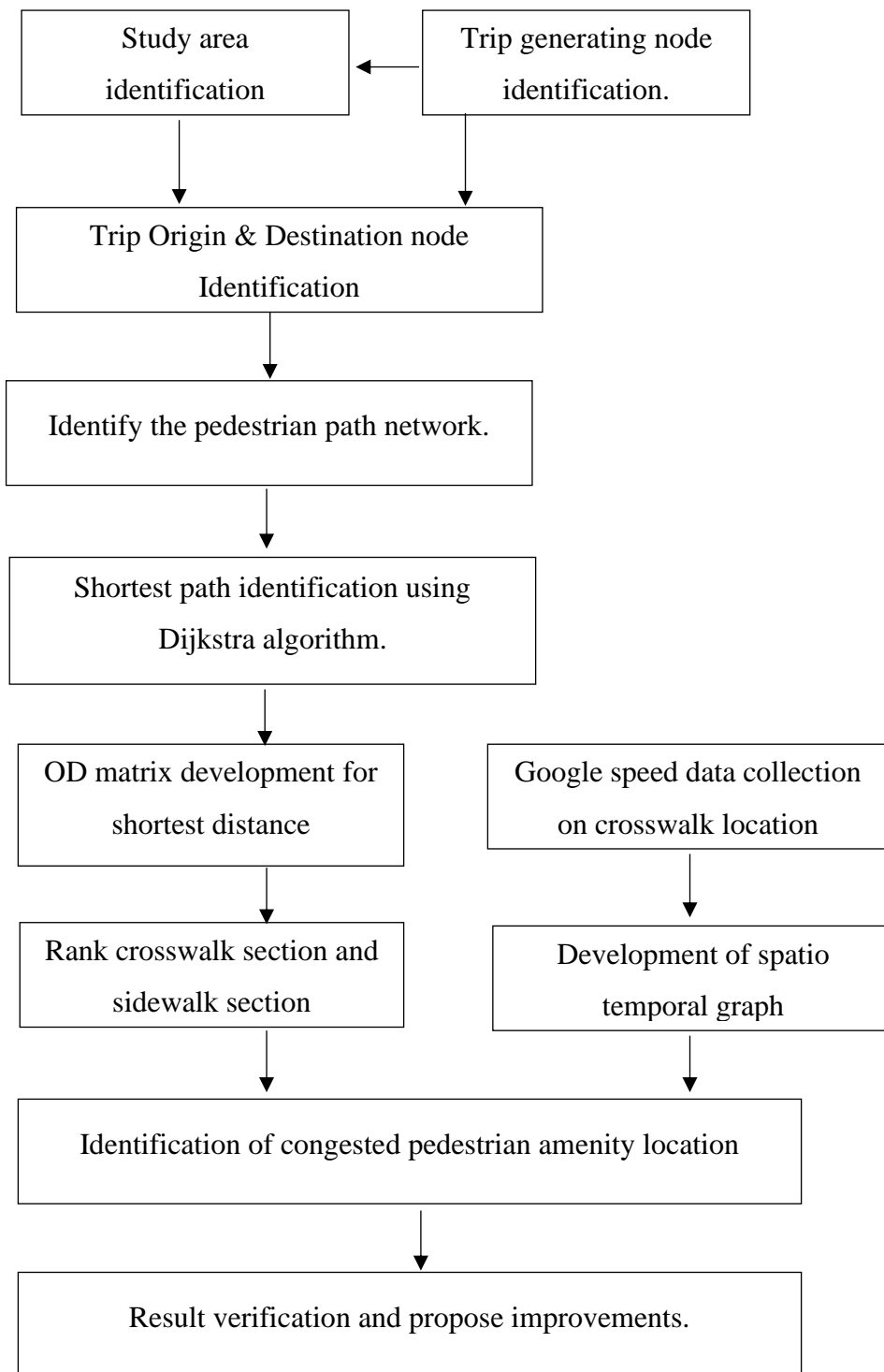


Figure 3.7: Flow Chart of methodology

4 CASE STUDY: RATHNAPURA CITY AREA

4.1 Identification of Study Area

Rathnapura city area is restricted to Kalu river in the south, Pompa kele forest reserved area in northern side and jem mining paddy lands around east and west. According to Rathnapura municipal council area land use distribution, many of residential, agricultural land distributed around the city centre. (fig.4.1).

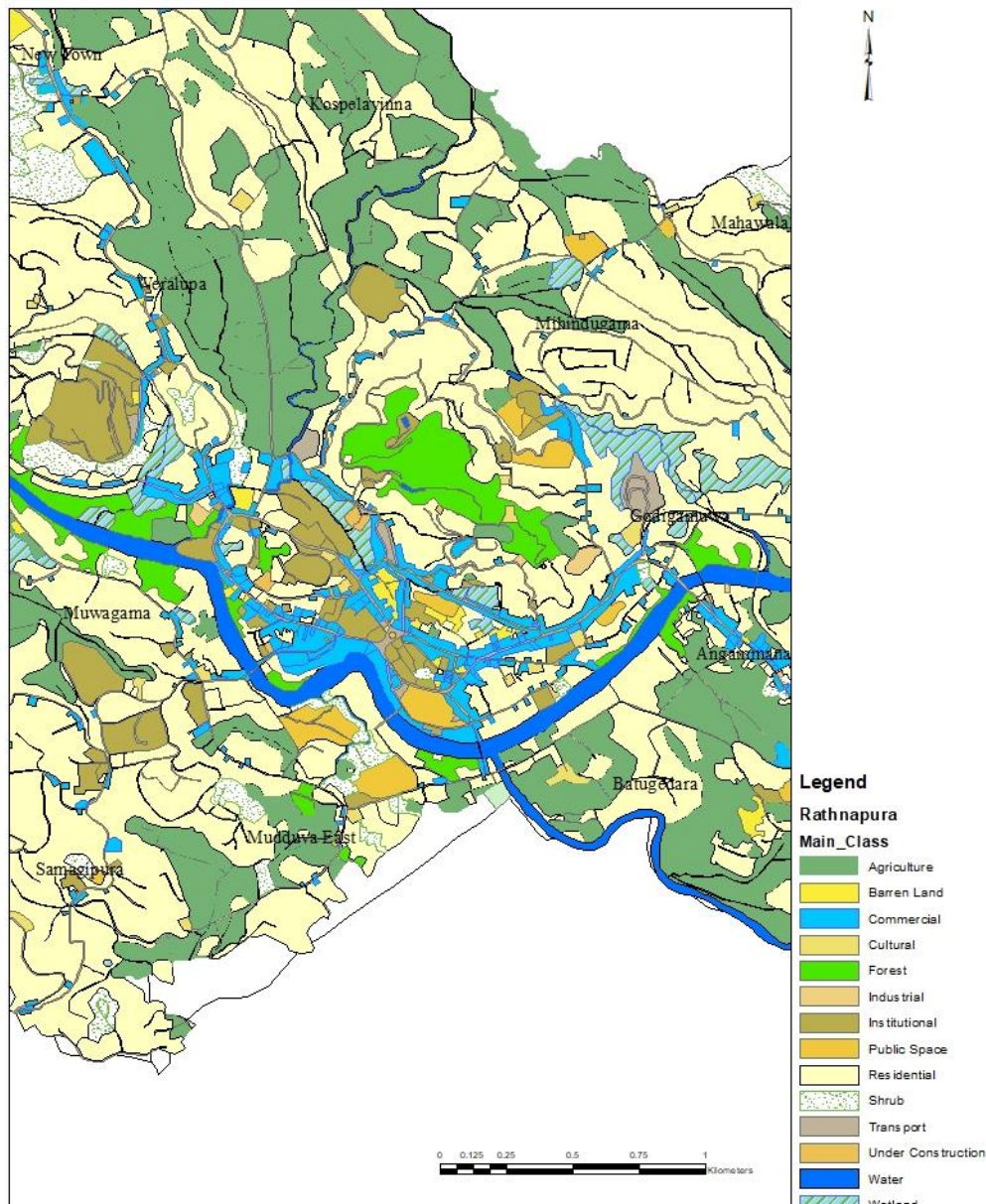
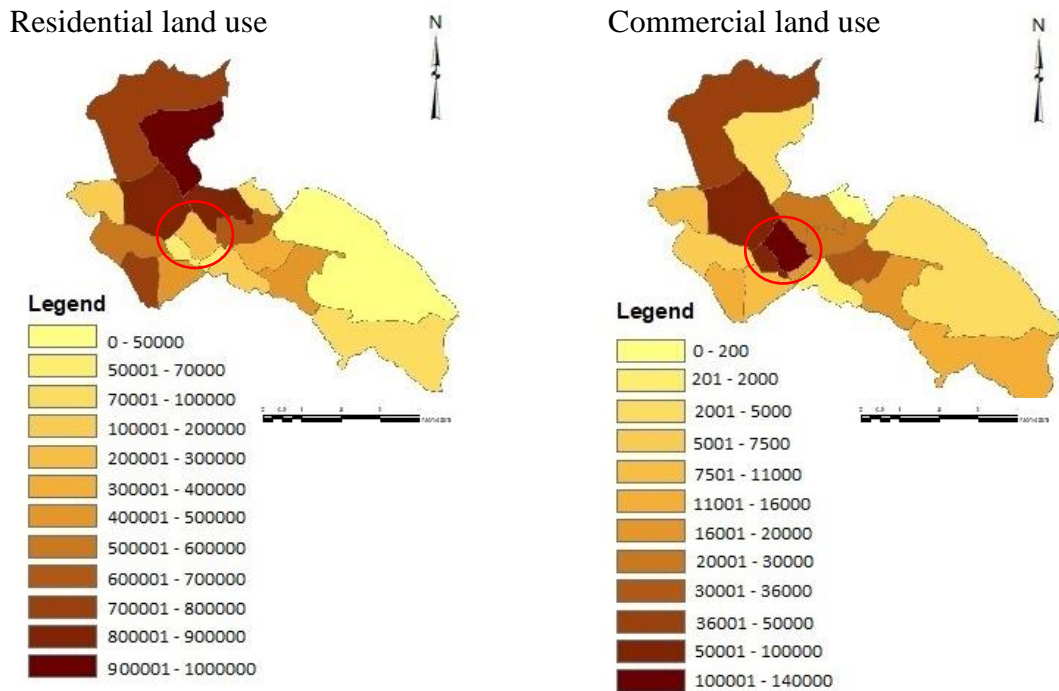


Figure 4.1: Rathnapura city centre map. part of MC area

Source: survey department

City area with the majority of commercial land use can be identified in the land use map. Land use variation of MC according to GN division is evidence to conclude the decision.

Land use layer intersects with a GN division layer, results the variation in the residential land use distribution and institutional / commercial land use distribution over the city. (Fig 4.2). As an initial step to sort list the spatial context, city area is identified according to land use distribution. Three GN Divisions such as Rathnapura town, Rathnapura Town north, Rathnapura town west identified as main city area. (fig.4.2)



Comparison of land use at Rathnapura MC

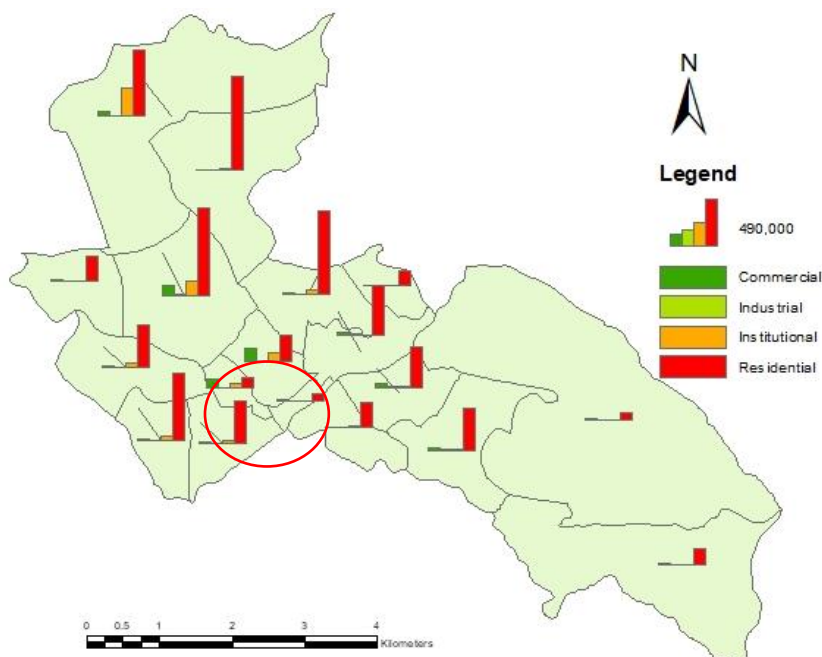


Figure 4.2: Land use distribution in Rathnapura MC area (Compiled by author)

As we consider main pedestrian trip generators, main bus stand, long distance bus stops, public parking identified as trip attracting point. There are no apartment or flats near city limit and there are not much residential units in city area. So, trips from residential units are not considered in this study.

According to literature, maximum walking distance is 750m and convenient straight distance of 625m from origin to destination for pedestrian trip is considered. It means, each pedestrian trip origin node creates 625m length trip zone around the node. So, buffer radius taken as 625 m and all buffers taken as dissolved type to get as separate layer. Dissolved type in ArcGIS is combined all buffer zone as one layer. Figure 4.3 illustrate the threshold limits for each trip origin pairs and geographical barriers for pedestrian movement.

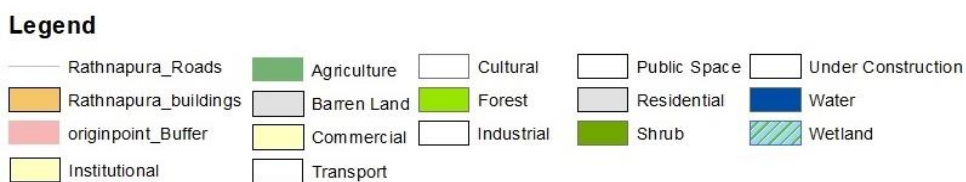
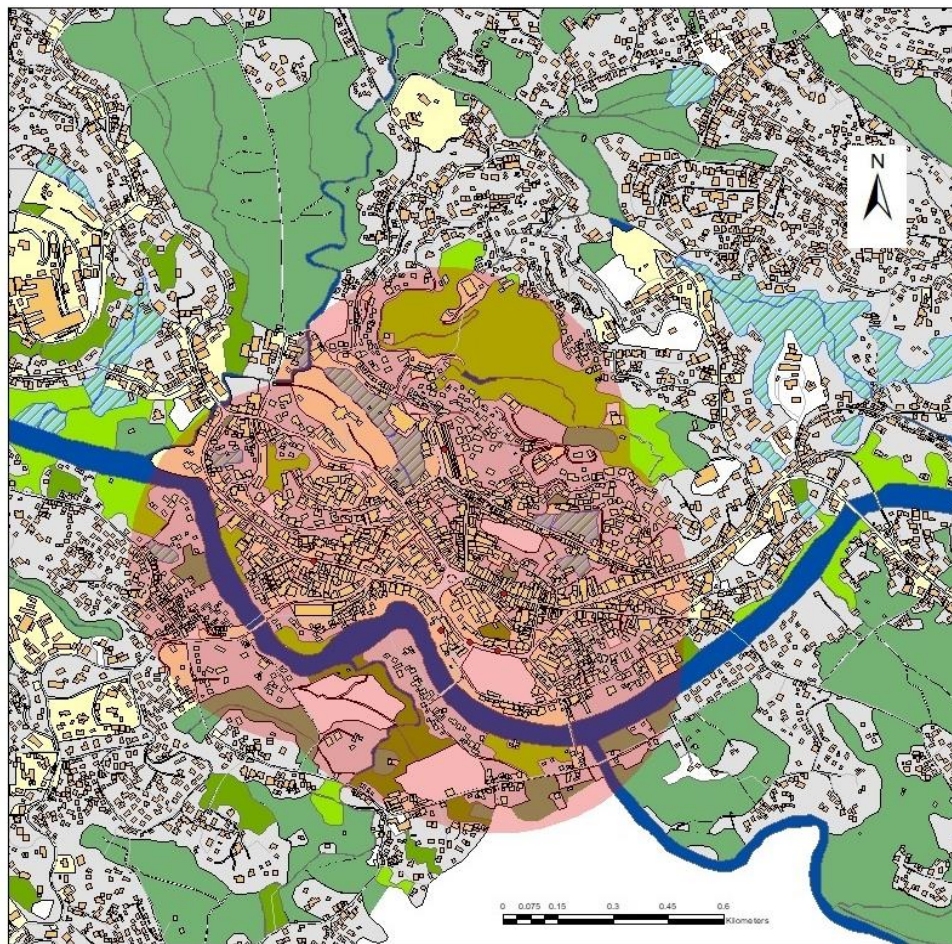


Figure 4.3: threshold limits for pedestrian trips from trip origin points

Non-built-up area such as agriculture land, barren land, forest, shrubs, water, wetland are selected by attribute and separated into another layer as non_builtup. Non_builtup layer clipped with trip_origin_buffer creates a layer with natural barriers within pedestrian trip threshold limit.

With considering footpaths, and other pedestrian moving pattern on those locations, boundary polygon was created for study area. Land use, road, building layer are clipped from boundary polygon while considering land use, road, building layers as input features and boundary polygon as clip feature.

Study area is finalized with considering all factors. Rathnapura town is surrounded from Kalu river, agricultural and bare land where gem mining work progressing and forest area. So, town centre is clearly identified on built environment map. (Fig 4.4)

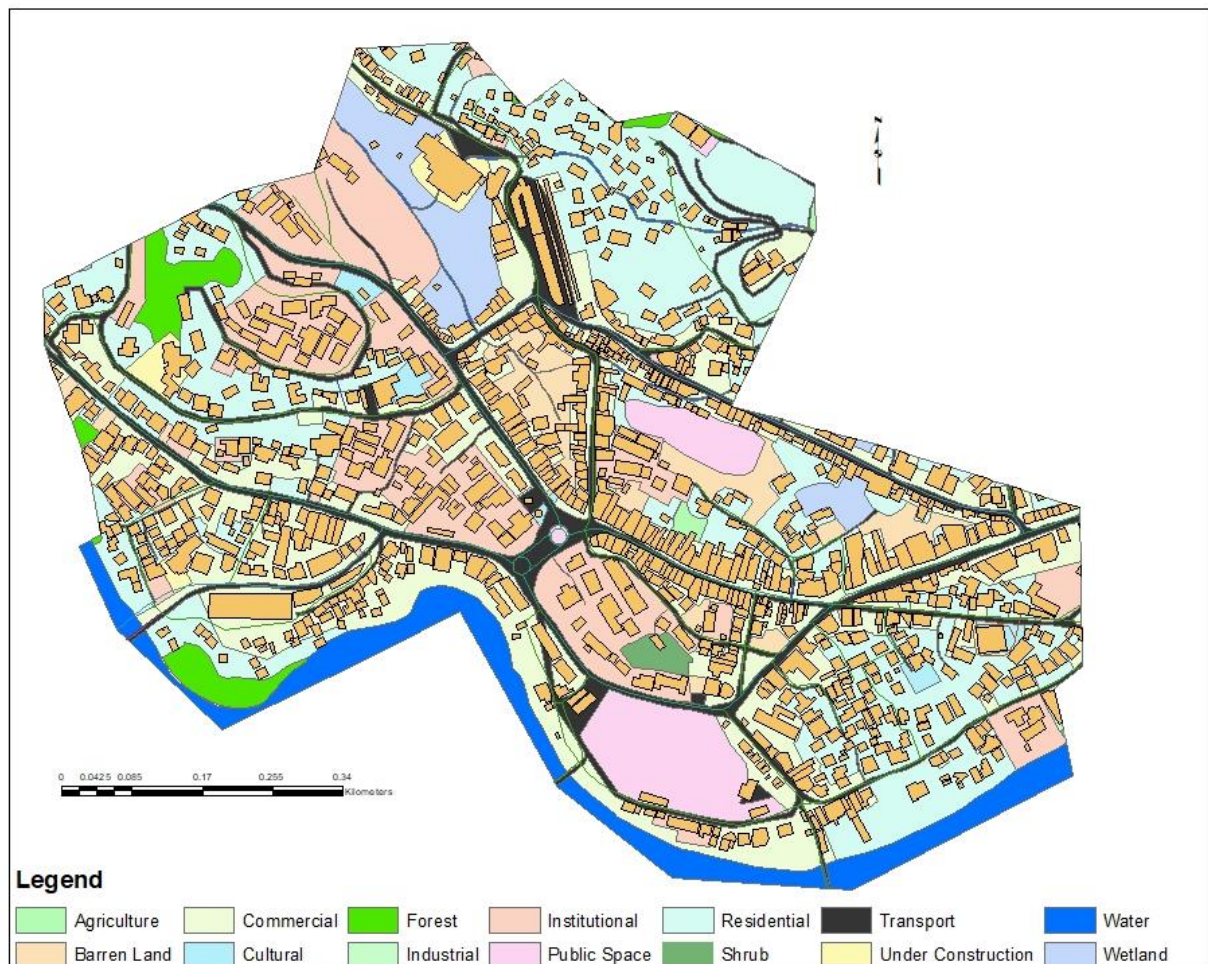


Figure 4.4: Study area map

4.2 Identification of Pedestrian Trip Origin and Destinations

Trip origin node identification on study area is the next step of the study. According to the literature, main trip attractors are,

- Residential (apartment and flat)
- Commercial (supermarket, fair, retail shop)
- Institutional (educational, financial, medical, and other public office)
- Religious (temple, kovil, church, mosque)
- Recreational (cinema, park, playground, beach park)
- Transportation facilities (bus/train station, parking)

By considering the land use at study area, 20 trip attraction points can be identified. Bus stand, Ferguson college, fish market and Ambagahayata gem market, have more than one exit/ entry points. So those exit points considered as a separate destination node to calculate the shortest distance. Selected node list on study area is tabulated in table 4.1.

Table 4.1: Pedestrian Trip attractors on Rathnapura city centre

ID	Name	Type of attractor
1	Long distance Bus halt (Embilipitiya/Badulla)	Public transport infrastructure
2	Bus stand exit 2	Public transport infrastructure
2	Bus stand main exit	Public transport infrastructure
2	Bus stand exit 3	Public transport infrastructure
3	Tuition class + School (Convent of Child Jesus)	Educational institute
4	Mihidu Vidyalaya	Educational institute
5	Ferguson college gate 1	Educational institute
5	Ferguson college gate 2	Educational institute
6	St. Luke college	Educational institute
7	Commercial bank + Sampath bank	Bank
8	Tuition class 2 + Jothi cinema	Educational institute / leisure
9	Long dist. Bus halt 2 (Colombo)	Public transport infrastructure
10	Bus halt (palawela/karavita)	Public transport infrastructure
11	Rathnapura Market	Retail
12	Post office + RDA + SLT	Govt office / bank
13	Police+ Library + Gem market (main street)	Govt office / Gem market
14	Fish market gate 1	Retail
14	Fish market gate 2	Retail

ID	Name	Type of attractor
15	Long dist. Bus halt 1 (Colombo)	Public transport infrastructure
16	Gem business 2 - council Avenue	Gem market
17	Gem business 3 Ambagahayata exit 1	Gem market
17	Gem business 3 Ambagahayata exit 2	Gem market
18	St. Allocious college	Educational institute
19	Bazaar entry point 1	Retail
19	Bazaar entry point 2	Retail
19	Bazaar entry point 3	Retail
20	Peoples bank / NSB Bank	Bank

Public transport terminal, is a key point of pedestrian trip origin. People coming from public transport divided into two categories.

1. Transfer-transit passengers who are seeking another bus, or taxi to reach their destination.
2. Pedestrian who are walking to their destination.

Bus station, long distance bus stop is taken as main trip origin point. Schools and tuition classes are main pedestrian attractors because majority of the students use public transport as main mode of transportation. This condition would change with primary school level. Privet vehicles are the main mode of transportation for majority of primary class students. Tuition class and elementary level schools are identified as a pedestrian trip destination on city limit. (Department of Census and Statistic, 2016)

According to the survey report on employment sector Sri Lanka (Department of census and statistics, 2016), majority of employment sectors use public transport as a mode of transportation. It means, office premises attract trips from public transport infrastructure. Banks and other institution which are away more than 625 m from town centre was not considered Because pedestrian trips were rarely happening between urban centre and those destinations. Public Market, Gem market is also identified as main trip attraction point, because majority of users end their trip as a pedestrian from vehicle park or public bus stop.

4.3 Development of Network Model

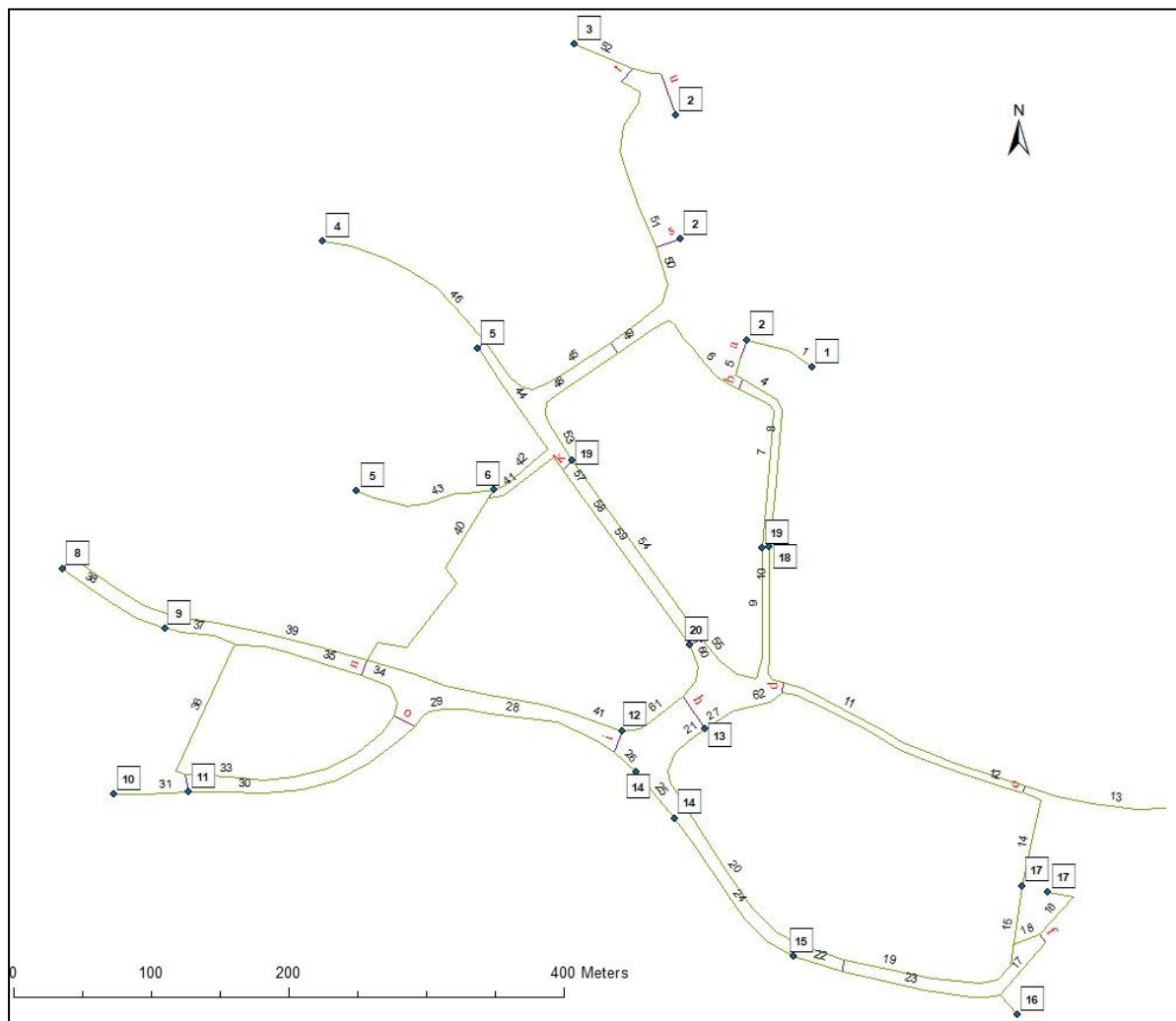


Figure 4.5: Network model (Compiled by author)

Connectivity consists of paved foot paths, gravel shoulders, steps, overhead bridges, pedestrian underpasses, alleyways, and crosswalks, etc. Pedestrian amenities are identified as arcs and junctions are identified as nodes of pedestrian network. The planner network data set was prepared for Rathnapura Town centre using ArcGIS network analysis tool. Pedestrian amenity such as sidewalks were included as an attribute in ID no. crosswalks were attributed as ID letters. Identified network is illustrated in figure 4.5.

4.4 Origin Destination connectivity

According to literature pedestrians are always willing choose the shortest route on utility-based trips. When an alternative longer route has more safety, shading, aesthetic appearance or special reason, the probability of choosing that route would be high. If the shortest route fulfils those considerations in satisfied level, it will be the best option for pedestrians.

Network Analysis is facilitated to develop OD matrix according to shortest distance in a given Origin Destination set. In addition to that, ArcGIS facilitate shortest distance between two locations.

First, pedestrian paths were denoted on GIS as shape file and lines were featured to develop a network data set.

Pedestrian network data set was developed to perform network analysis extension in ArcGIS. OD cost matrix was generated from the network dataset and shortlisted the data from simple SQL formula.

[OriginID] <> [DestinationID] AND [Total_Length] <= 750 This formula rejects all long-distance OD pairs which longer than acceptable walking distance and OD trip between same nodes.

ObjectID	Shape	Name	OriginID	DestinationID	Total_Length
1406	Polyline	bazzar 3 - St.Allocious	53	50	5.74
1325	Polyline	St.Allocious - bazzar 3	50	53	5.74
1352	Polyline	bazzar 1 - peoples bank	51	54	9.43
1433	Polyline	peoples bank - bazzar 1	54	51	9.43
974	Polyline	Com bank - Tution/jothi	37	38	11.05
1001	Polyline	Tution/jothi - Com bank	38	37	11.05
1109	Polyline	RDA/Post - Fish 2	42	45	38.13
1190	Polyline	Fish 2 - RDA/Post	45	42	38.13
1163	Polyline	Fish1 - Fish 2	44	45	43.9
1191	Polyline	Fish 2 - Fish1	45	44	43.9
731	Polyline	EMB/BAD halt - Busstand 2	28	29	52.54
758	Polyline	Busstand 2 - EMB/BAD halt	29	28	52.54
1055	Polyline	karavita halt - Market	40	41	53.92
1082	Polyline	Market - karavita halt	41	40	53.92
1136	Polyline	Police/gem - peoples bank	43	54	70.33
1434	Polyline	peoples bank - Police/gem	54	43	70.33
1137	Polyline	Police/gem - bazzar 1	43	51	79.76
1353	Polyline	bazzar 1 - Police/gem	51	43	79.76
1110	Polyline	RDA/Post - Police/gem	42	43	81.18
1138	Polyline	Police/gem - RDA/Post	43	42	81.18
1111	Polyline	RDA/Post - Fish1	42	44	82.03
1164	Polyline	Fish1 - RDA/Post	44	42	82.03
947	Polyline	St.luke - bazzar 2	36	52	85.84
1379	Polyline	bazzar 2 - St.luke	52	36	85.84
1002	Polyline	Tution/jothi - CMB halt	38	39	86.81
1028	Polyline	CMB halt - Tution/jothi	39	38	86.81
1112	Polyline	RDA/Post - peoples bank	42	54	93.4
1435	Polyline	peoples bank - RDA/Post	54	42	93.4
975	Polyline	Com bank - CMB halt	37	39	97.86
1029	Polyline	CMB halt - Com bank	39	37	97.86
812	Polyline	Bus stand 3 - convert	31	32	98.53
839	Polyline	convert - Bus stand 3	32	31	98.53
1113	Polyline	RDA/Post - bazzar 1	42	51	102.83
1354	Polyline	bazzar 1 - RDA/Post	51	42	102.83
920	Polyline	furgusion2 - St.luke	35	36	103.17
948	Polyline	St.luke - furgusion2	36	35	103.17
1298	Polyline	Ambagahayata2 - Ambagahayat	49	48	118.78
1271	Polyline	Ambagahayata1 - Ambagahayat	48	49	118.78
1139	Polyline	Police/gem - Fish 2	43	45	119.3
1192	Polyline	Fish 2 - Police/gem	45	43	119.3
1193	Polyline	Fish 2 - peoples bank	45	54	131.53
1436	Polyline	peoples bank - Fish 2	54	45	131.53
1244	Polyline	Gem lane - Ambagahayata1	47	48	132.3
1272	Polyline	Ambagahayata1 - Gem lane	48	47	132.3
1165	Polyline	Fish1 - CMBhalt 2	44	46	134.52
1217	Polyline	CMBhalt 2 - Fish1	46	44	134.52

Figure 4.6: OD matrix for pedestrian network at Rathnapura city area

Shortest distance between Origin and destination, were considered in this OD matrix. Even there is less probability of choosing shortest path, after improving deficiencies on weak pedestrian amenities, shortest path would use effectively to reduce time and cost.

Figure 4.7 shows one example, in the shortest path analysis, between node 13 Rathnapura police station to node 9 Colombo bus halt. Shortest distance on the network is 433 m and crosswalks, sidewalk sections are 60-41-35-36-h-n.

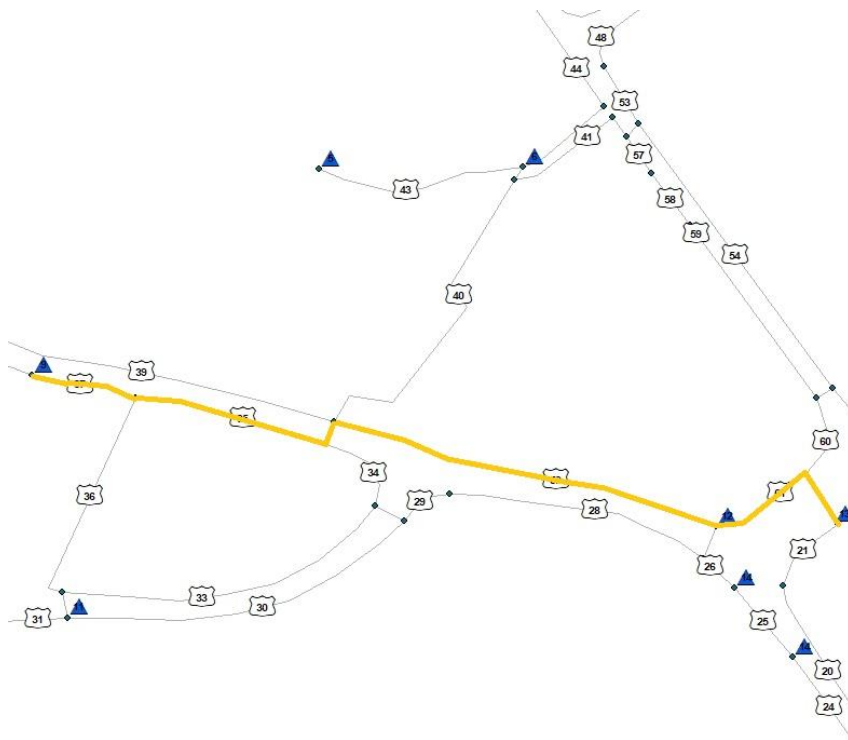


Figure 4.7: Example of shortest distance between two nodes (Compiled by author)

4.5 OD Matrix Development

Shortest path is consisting of sidewalks and crosswalk segments. It calls links in network dataset. But there are some exceptional OD cases, probability of pedestrian trip is less due to several reasons. After an initial site visit, following reasons were identified where there are fewer pedestrian trips between such OD pairs.

1. Node 9 and node 15 are long distance bus stops to Colombo side. If the destination “x” is close to bus stop no 2 (node 9), there would be a trip from bus stop no 2 to destination “x”. Pedestrian trip would not be occurred from bus stop no 1 (node 15) to the destination “x,
2. Less probability on pedestrian trips between bus stop no 1 (node 9) and bus stop no 2 (node 15)

Table 4.3: Results of OD matrix for 20 nos of O-D pairs in Rathnapura town area

Sidewalk segments			Crosswalk segments		
ID	frequency	Location	ID	frequency	Location
61	65	Near post office	d	57	roundabout
55	48	roundabout-mosque	i	52	In front of RDA
60	48	post office peoples bank	h	51	clock tower
5	47	steps cathedral rd to bus stand	a	47	bus stand
8	46	step to Aloysius gate	c	46	cathedral rd
26	42	CIB building police roundabout	j	38	peoples bank
41	42	In front of RDA	r	35	near BoC
10	41	cathedral rd mosque	k	32	In front of Sarasvati
4	40	cathedral rd start	l	29	bus stand rd
9	38	cathedral rd mosque	n	24	near IOC shed

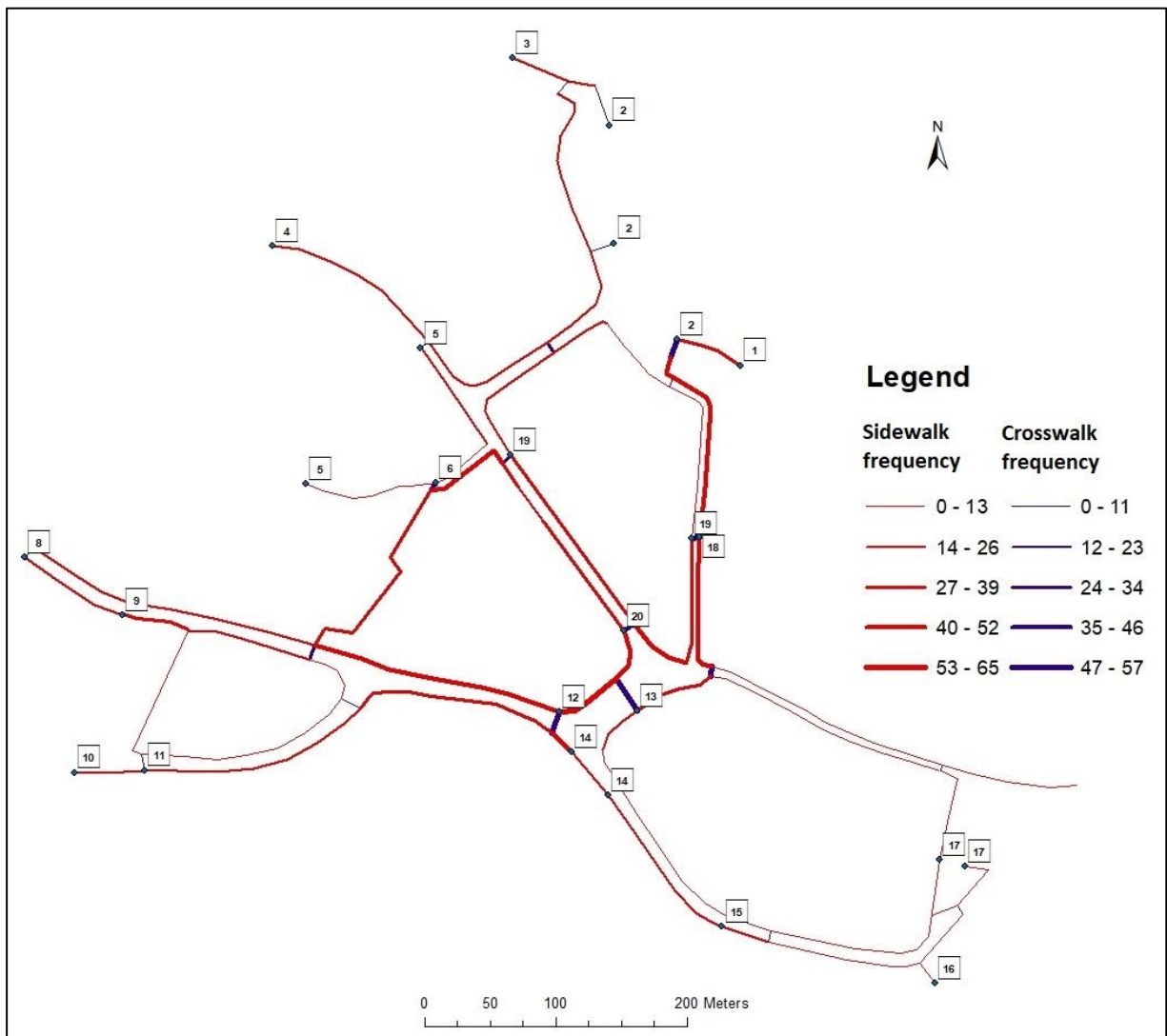


Figure 4.9: Frequency of pedestrian amenity usage (Compiled by author)

4.7 Google Traffic Speed Data Collection

Google traffic speed data collection was done at major road sections in Rathnapura city centre. 5 road sections (table 4.4) were identified according to the result that obtains in OD matrix analysis and locations are shown in figure 4.10.



Figure 4.10: Google traffic data waypoint map in Rathnapura town area.

Table 4.4: Main Road sections in Rathnapura town

Road section	Road name	Number of segments
w1 – w16	Bus stand-St. Luke junction -Clock tower- Police roundabout	15
w17 – w23	Main street [clock tower – KFC junction]	6
w24-w43	AB14 [Dharmapala Mawatha, KFC junction – Jothi cinema]	19
w44-w52	A4 [Moragahayata junction – St Luke junction]	8
w52-w57	St. Luke junction – Bus stand	5

Google data has been extracted from 2020 November until 2021 April. This period, City environment is behaving normal pattern without only school traffic. Raw data extracted and processed to build-up temporal-spatio graph. After processing extracted data, sample data table

is shown in table 4.5. From temporal-spatio graph, several sections were identified as congested crosswalk location. Figure 4.11 shows the sample of spatio temporal graph.

Table 4.5: Google Traffic data table sample

Route	Speed (km/h)	Date	10minTime	Day
w10-w11	35.20	2020-12-01	6:10	Tuesday
w10-w11	35.20	2020-12-01	6:20	Tuesday
w10-w11	26.40	2020-12-01	6:30	Tuesday
w10-w11	26.40	2020-12-01	6:40	Tuesday
w10-w11	26.40	2020-12-01	6:50	Tuesday
w10-w11	21.12	2020-12-01	7:00	Tuesday
w10-w11	22.63	2020-12-01	7:10	Tuesday
w10-w11	22.63	2020-12-01	7:20	Tuesday
w10-w11	24.37	2020-12-01	7:30	Tuesday
w10-w11	24.37	2020-12-01	7:40	Tuesday
w10-w11	24.37	2020-12-01	7:50	Tuesday
w10-w11	24.37	2020-12-01	8:00	Tuesday

Route	bus st	randiya	sarasav	peopl	clock	m.st	m.st	kfc	Agaha																	
mon 7:00	16.44	19.68	15.86	16.25	16.11	18.24	26.90	28.68	26.87	26.35	29.42	25.20	24.81	15.46	21.35	25.20	30.04	29.38	29.49	29.93	33.88	36.60	45.55	36.70	35.60	36.70
mon 7:10	16.44	19.68	15.86	16.25	16.11	18.24	25.97	27.16	25.49	24.68	27.83	25.20	24.81	15.46	21.35	25.20	29.76	28.85	29.22	27.10	33.04	35.70	40.80	36.05	34.29	35.40
mon 7:20	16.44	19.68	15.86	16.25	16.11	18.24	25.97	27.16	25.49	24.68	27.83	25.20	24.81	15.46	21.35	25.20	29.76	28.85	29.22	27.10	33.04	35.70	40.80	36.05	34.29	35.40
mon 7:30	16.44	19.68	15.86	16.25	16.11	18.24	27.48	28.43	24.79	23.98	27.48	25.20	23.84	13.85	21.82	25.20	27.96	28.86	28.12	26.43	33.04	32.23	32.40	32.13	32.62	32.40
mon 7:40	16.49	19.63	15.90	16.28	16.14	18.36	29.91	29.57	26.05	25.07	27.94	25.20	23.99	13.92	21.99	24.80	27.92	28.25	27.16	26.10	32.26	29.18	31.20	29.79	30.70	31.20
mon 7:50	16.38	19.72	15.83	16.23	16.09	18.05	29.62	29.45	26.01	24.92	27.69	25.20	24.23	13.85	21.68	24.42	27.85	28.18	27.55	26.10	31.62	29.11	31.20	29.60	30.47	31.20
mon 8:00	16.32	19.68	15.86	16.25	16.11	18.24	29.33	30.97	26.10	24.91	27.97	25.20	24.04	13.38	20.08	22.10	26.64	25.84	25.81	25.90	29.63	26.99	30.30	27.38	27.65	29.40
mon 8:10	16.32	19.68	15.86	16.25	16.11	18.24	28.26	29.45	24.91	24.28	26.17	25.20	24.04	13.38	20.08	21.52	26.18	25.43	25.28	24.69	28.35	25.53	29.10	26.55	27.06	29.40
mon 8:20	16.12	19.12	15.86	16.25	16.11	18.24	28.26	29.45	25.19	24.28	26.17	25.20	24.04	13.38	20.08	21.52	26.18	25.43	25.44	24.69	28.35	25.53	29.10	26.55	27.06	29.40
mon 8:30	16.24	19.68	15.91	16.25	16.11	18.24	27.90	26.40	24.77	23.81	26.17	24.23	22.87	13.27	19.94	19.77	22.85	22.15	22.18	21.88	26.80	23.28	25.20	26.00	25.77	28.40
mon 8:40	16.69	19.68	15.91	16.25	16.11	18.24	27.47	26.40	23.61	22.84	26.79	24.23	22.87	13.27	19.94	19.90	23.15	22.46	21.77	20.88	25.36	22.34	23.70	24.33	25.27	27.40
mon 8:50	16.65	19.68	15.91	16.25	16.11	18.24	27.47	26.40	23.78	22.84	26.79	24.23	22.87	13.27	19.94	19.90	23.15	22.46	22.12	20.88	25.36	22.34	23.70	24.33	25.27	27.40
mon 9:00	17.03	19.74	15.91	16.25	16.11	18.24	25.97	25.89	20.99	21.20	21.88	21.74	21.05	11.29	17.81	18.33	21.16	20.27	20.91	20.11	22.66	21.51	23.40	24.75	24.84	26.40
mon 9:10	16.48	19.72	15.76	16.42	16.27	19.31	23.12	24.88	19.94	20.24	21.60	22.40	20.16	12.00	17.40	20.16	19.23	18.61	18.83	18.13	20.50	18.68	20.64	20.32	20.88	22.40
mon 9:20	16.48	19.60	15.99	16.30	16.15	18.49	23.02	23.86	20.00	19.84	21.60	23.10	21.84	11.00	18.56	17.58	19.23	18.61	18.83	18.13	20.50	18.68	20.64	20.32	20.88	22.40
mon 9:30	17.06	20.78	15.52	16.47	16.10	17.85	22.72	20.82	18.99	19.22	21.60	16.80	20.16	12.00	17.40	17.58	19.23	18.61	18.83	18.13	20.50	18.68	20.64	20.32	20.88	22.40
mon 9:40	17.21	19.82	15.73	16.48	16.09	18.36	22.32	20.31	20.13	17.60	18.00	16.80	16.80	12.00	16.66	17.58	19.23	18.61	18.83	18.13	20.50	18.68	20.64	20.32	20.88	22.40
mon 9:50	17.17	20.36	15.95	16.22	16.08	18.17	22.32	19.80	17.36	17.14	18.00	16.80	20.16	11.48	16.66	17.58	19.23	18.61	18.83	18.13	20.50	18.68	20.64	20.32	20.88	22.40
mon 10:00	17.26	19.45	15.83	16.43	16.11	18.24	21.89	19.80	17.51	17.21	18.14	16.64	16.38	10.96	15.92	15.00	17.31	16.94	16.75	16.16	18.34	15.84	17.88	15.89	16.92	18.40
mon 10:10	17.25	20.05	15.78	16.43	16.11	18.24	21.18	19.80	17.13	17.10	17.87	16.64	16.38	10.96	15.92	14.77	17.19	16.91	16.97	16.16	18.36	14.51	15.46	14.25	15.28	17.40
mon 10:20	17.06	19.81	15.95	16.28	16.14	18.36	21.13	19.80	16.90	17.01	17.76	16.63	16.36	10.56	15.78	14.62	17.22	16.93	15.78	16.03	18.38	14.48	14.80	14.15	14.42	16.40
mon 10:30	16.72	19.50	15.83	16.23	16.09	18.13	20.67	19.65	16.60	16.68	17.71	16.33	16.59	10.00	13.84	15.31	16.73	16.46	15.57	15.56	17.70	12.80	13.54	12.60	13.48	15.40
mon 10:40	17.01	19.54	15.86	16.25	16.11	18.24	19.83	19.19	16.72	16.22	16.91	16.80	16.58	10.04	13.97	15.60	16.90	16.63	15.55	15.58	17.80	11.12	12.13	11.82	12.36	14.40

Figure 4.11: Spatio temporal graph sample

Analysing average speed data on a daily basis, following assumption can be obtained. This period, school were closed or partially open. It reflects, in the graph also. At 7:30 and 1:30 traffic behaviour on the city has no significant drops. Other commercial activity conducted normal and, results comply with model results.

Crosswalk near RDA, which shows high frequency on model, show congestion at the crosswalk after that vehicle were speedup. Figure 4.12 shows that crosswalk near the roundabout, and crosswalk near RDA shows some drops in speed.

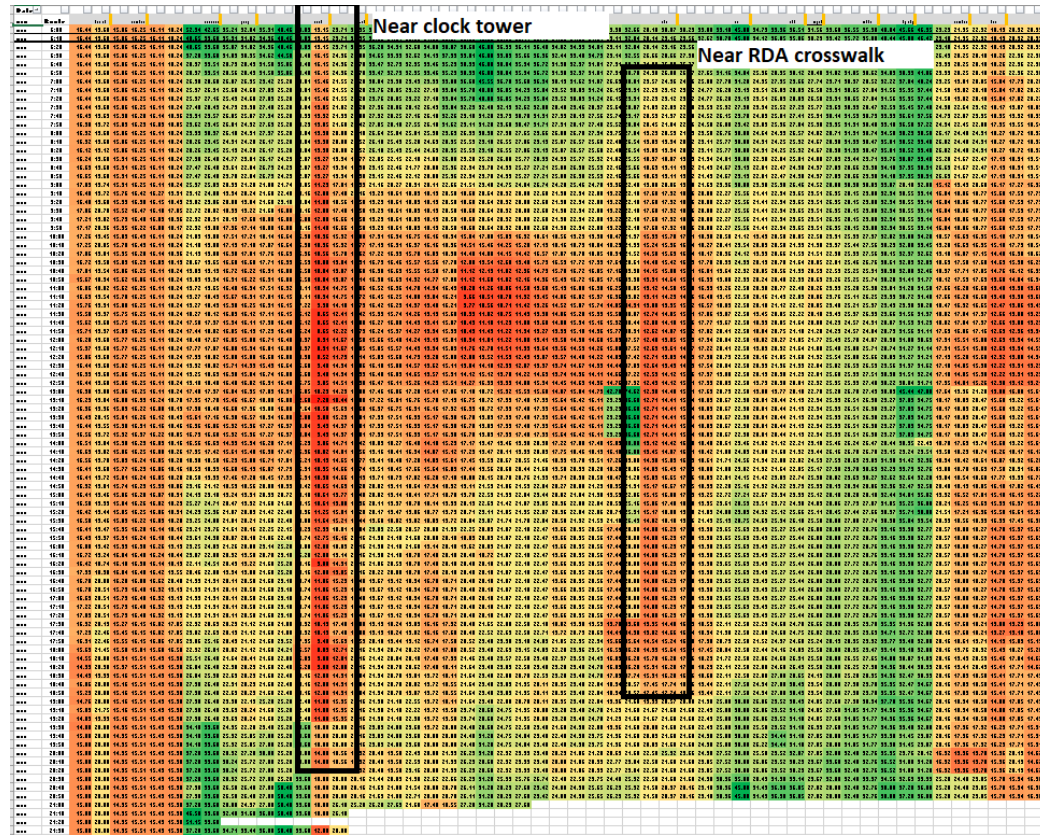


Figure 4.12: Average vehicle speed variation on Monday

4.8 Analysis of Results and Recommendation

Actual pedestrian behaviour shows some similarities with model results and sometimes it deviated with the output. Crosswalk ID “h”, and “i” are high frequency in crosswalk at Rathnapura town area. Google traffic data, verify that results by showing congestion on those locations.

But Crosswalk “d” that is located on the main street entrance, did not show much traffic. Observation on site visit proved that pedestrian did not use crosswalk that is located far away. Pedestrian cut short the distance by crossing congested clock tower area. Fig 4.13 explains the condition of pedestrian behaviour.

According to the literature, pedestrians are always trying to minimize the walking distance. This concept is used unintentionally by a pedestrian at a few locations in the city centre and it shows significant congestion.



Figure 4.14: Pedestrian use shorter distance without using pedestrian path near Clock tower Rathnapura.

In Figure 4.14. Red line shows predicted proper Pedestrian paths for trip generation points of the city. But Pedestrian did not follow that path most of time and cross the main road by using yellow crossing line to reduce the distance on their trip.

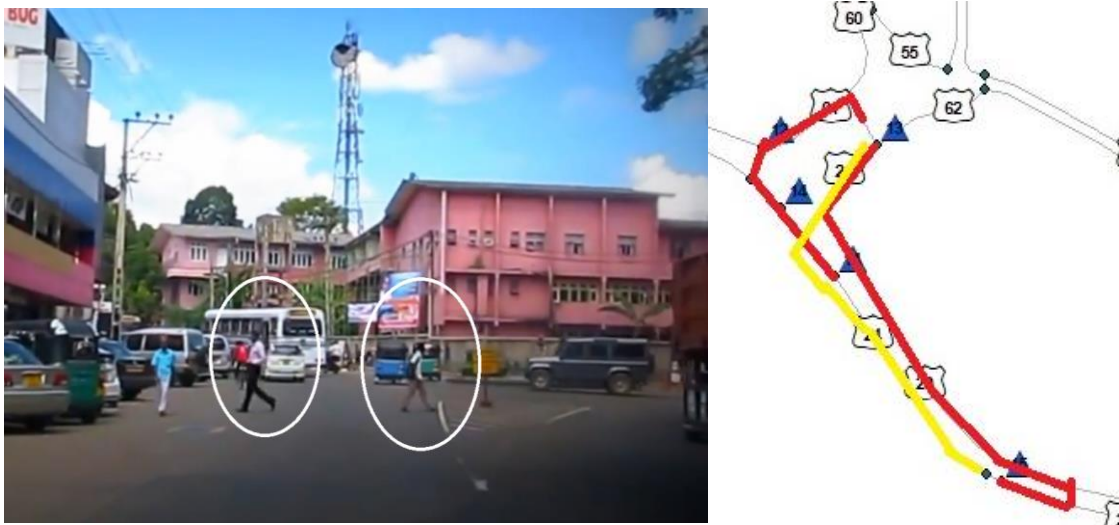


Figure 4.13: Pedestrian crossing near Police roundabout. use the shortest path.

Google speed data shows that vehicles are running near the bus stand area at slower speed. According to the site observation, majority of running vehicles are public transport and those are running at very slow speed with the movement of pedestrians. Privet vehicle count is also very low on that road section.

Model result shows cathedral road sidewalk and sidewalk near post office/ clock tower area are heavily congested. Bird's-eye view photograph (figure 4.15) on typical daytime, prove that

the model results also. Red circle shows pedestrian use shortcut without using the crosswalk “d”.

Blue circle areas shown high pedestrian locations and it complies with the model results in Cathedral Road sidewalks and Clock tower sidewalks.

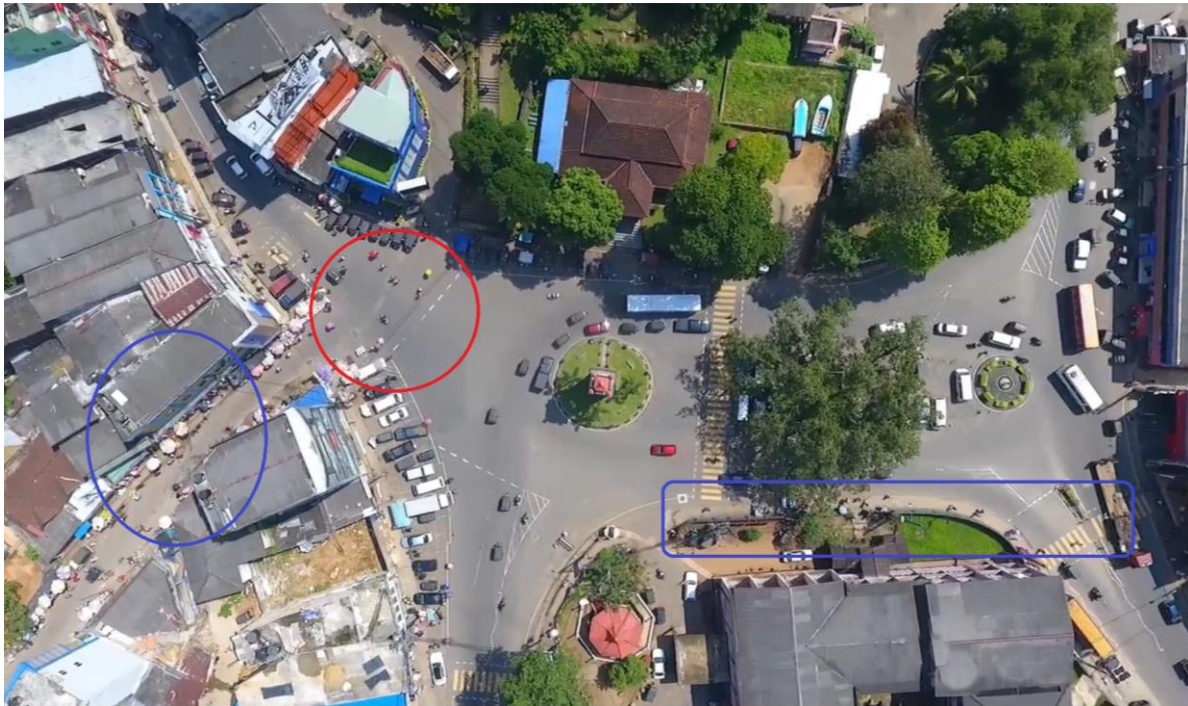


Figure 4.15: Bird eye view of city centre.

O-D matrix model result shows, crosswalk on Cathedral Road is a location with heavy congestion. But the actual condition of the Cathedral Road crosswalk is shown in figure 4.16 below. Pedestrians use shared road space with vehicles on this road. Crosswalks did not function in that area. Sidewalks are occupied by street vendors and people walking freely on the road. Vehicle speed is very slow on that street. But significant pedestrian movement is shown on that location with respect to other sidewalks on this street.



Figure 4.16: Cathedral rd. people share the road with vehicles.

After considering actual condition and model results, following recommendations can propose to improve the efficiency of city traffic, pedestrian movement.

- Cathedral road should improve as vehicle- pedestrian shared space. According to the literature, sidewalk space, kerb space would not be on shared space. Same level space would facilitate proper 45° or 60° one side parking. If proper marking and regulating by the person would improve space utilization. Speed reduction humps at the entrance of road for safety of pedestrian and discourage vehicle entering to the road.
- Privet vehicle should discourage to enter the bus stand area. That zone should prioritize for Pedestrians and public transport users. Speed reduction hump is recommended for reduction of vehicle speed and improve the safety on that area.
- Crosswalk location change is recommended to improve the vehicle flow on city centre as stated in figure 4.17. This arrangement facilitates to change heavy congested pedestrian location and support shorter pedestrian distance.

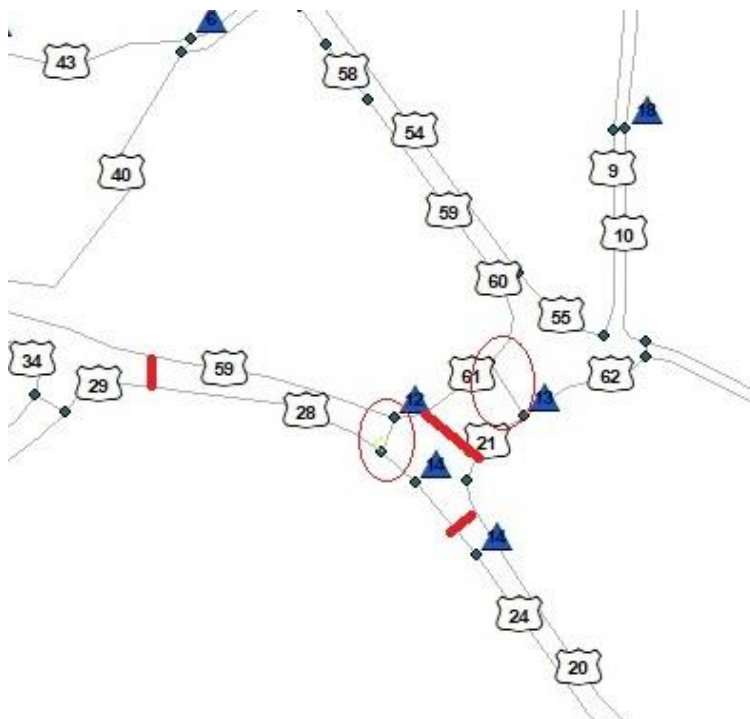


Figure 4.17: Crosswalk location change for achieve shorter walking distance and improve the capacity of vehicle accumulation on roundabout.

- According to OD matrix analysis, sidewalk 20, crosswalk g shows less frequency than sidewalk 24. Main reason for that, pedestrian trips which are starting from a express bus stop, never use crosswalk. figure 4.18 show high frequent path in yellow colour and black colour path with longer distance. So, improvement of segment 24 and new crosswalk near

roundabout may attract more pedestrians and it would improve the safety of pedestrian as well.

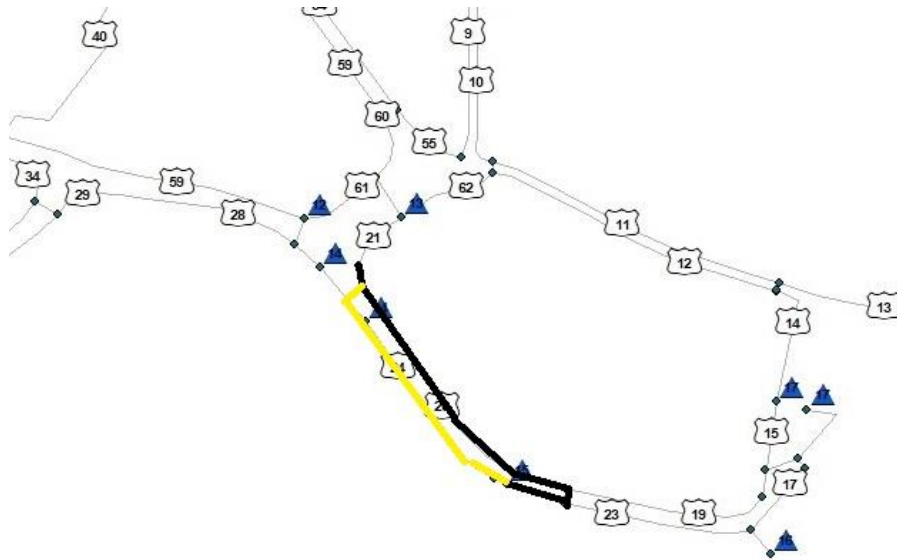


Figure 4.18: facilitate the high frequent path to optimize the pedestrian flow near MC building Rathnapura

5 CONCLUSION

Pedestrian amenity development project is required to identify, prioritize segments at urban centre. Identification of pedestrian paths and Origin Destination connectivity is important in this process. Origin Destination shortest path matrix is a powerful tool to identify the most repetitive homogeneous segment order at urban centre. Improving walkability on those segments is good observation when utilizing public funds for development of city environment in an efficient manner.

This model is validated for medium size city centres which do not have much residential land use. Commercial, institutional, and public transport land use creates pedestrian trips without significant variation of trip generation. Actual city behaviour validates the model result and it describes the pedestrian behaviour well on city environment.

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7 APPENDIX

7.1 Google Sheet App Script for Extract Google Traffic Data

```
//CREATING CUSTOM MENU
```

```
function onOpen() {  
  var ui = SpreadsheetApp.getUi();  
  
  ui.createMenu("Google Travel Time")  
    .addItem("Run", "getDistance")  
    .addItem("Set Triggers", "createEveryMinutesTrigger")  
    .addItem("Delete Triggers", "deleteTrigger")  
    .addToUi();  
}
```

```
// GET TRAVEL TIME AND DISTANCE FOR EACH ORIGIN AND DESTINATION
```

```
function getDistance() {  
  
  var ss = SpreadsheetApp.getActiveSpreadsheet();  
  var inputSheet = ss.getSheetByName("Inputs");  
  var range = inputSheet.getRange("B2:I");  
  var inputs = range.getValues();  
  var outputSheet = ss.getSheetByName("Outputs");  
  var recordcount = outputSheet.getLastRow();  
  var timeZone = "GMT+5:30";  
  var now = new Date();  
  var rDate = Utilities.formatDate(now, timeZone, "MM/dd/yyyy");  
  var rTime = Utilities.formatDate(now, timeZone, "HH:mm:ss");  
  var numberOfRoutes = inputSheet.getLastRow()-1;  
  
  for(i=0;i<numberOfRoutes;i++){  
    var setDirections = Maps.newDirectionFinder() //https://www.thetopsites.net/article/51638880.shtml  
      .setOrigin(inputs[i][1])  
      .setDestination(inputs[i][2])  
      .setDepart(now)
```

```

.setMode(Maps.DirectionFinder.Mode["DRIVING"]); //https://developers.google.com/apps-script/reference/maps/direction-finder

var wayCount = inputs[i][7];

for(j=0;j<wayCount;j++){
  setDirections.addWaypoint("via:"+inputs[i][3+j]);
}

var directions = setDirections.getDirections();

var traveltime = directions.routes[0].legs[0].duration_in_traffic.value;
var distance = directions.routes[0].legs[0].distance.value;
var route = inputs[i][0];

outputSheet.getRange(i+1+recordcount,1).setValue(route);
outputSheet.getRange(i+1+recordcount,2).setValue(now);
outputSheet.getRange(i+1+recordcount,3).setValue(secToMin(traveltime));
outputSheet.getRange(i+1+recordcount,4).setValue(distance/1000);
outputSheet.getRange(i+1+recordcount,5).setValue((distance/traveltime)*(3600/1000));
outputSheet.getRange(i+1+recordcount,6).setValue(traveltime);
outputSheet.getRange(i+1+recordcount,7).setValue(rDate);
outputSheet.getRange(i+1+recordcount,8).setValue(rTime);
}
}

///RUN FUNCTION EVERY n MINUTES BETWEEN GIVEN TIME DURATION
function runGetDistance() {
  var date = new Date();
  var day = date.getDay();
  var hrs = date.getHours();
  var min = date.getMinutes();

  var ss = SpreadsheetApp.getActiveSpreadsheet();
  var inputSheet = ss.getSheetByName("SetTriggers");
  var startHour = inputSheet.getRange("B1").getValue();

```

```

var endHour = inputSheet.getRange("B2").getValue();

if ((hrs >= startHour) && (hrs <= endHour) && (min >= 0) && (min <= 59 )) { //https://stackoverflow.com/a/39903751
  getDistance();
}
}

//CREATE TRIGGER
function createEveryMinutesTrigger(){
  var ss = SpreadsheetApp.getActiveSpreadsheet();
  var inputSheet = ss.getSheetByName("SetTriggers");
  var runningInterval = inputSheet.getRange("B6").getValue();

  ScriptApp.newTrigger("runGetDistance")
    .timeBased()
    .everyMinutes(runningInterval)
    .create();
}

//DELETE TRIGGER
function deleteTrigger() {

  // Loop over all triggers and delete them
  var allTriggers = ScriptApp.getProjectTriggers();

  for (var i = 0; i < allTriggers.length; i++) {
    ScriptApp.deleteTrigger(allTriggers[i]);
  }
}

function secToMin(duration){
  var minutes = parseInt((duration/60));
  var seconds = parseInt(duration%60);
}

```

```
return "00:"+minutes+": "+seconds;  
}
```

Source URL: <https://www.bpwebs.com/get-google-map-travel-time-and-distance/>

7.2 OD Matrix for Road Segments

Destination	Origine																				
	emb/bad halt	busstand exit	convert	mihidu	furgusion1	st.luke	com bank	jothi	cmb halt 1	karavita halt	market	RDA	police	Fish1	cmb halt2	gem lane	ambagahayata	alosyus	bazar	peoples bank	
emb/bad halt	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	NA	NA	NA	NA	NA	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	
busstand exit	1	1	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	N/A	N/A	N/A	N/A	N/A	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	
convert	52 1 t	52 1 t	52 1 t	52 1 t	52 1 t	52 1 t	N/A	N/A	N/A	N/A	N/A	52 k 51 57 50 58 48 60 53 61	52 k 51 57 50 58 48 60 53 61	52 k 51 57 50 58 48 60 53 61	52 k 51 57 50 58 48 60 53 61	N/A	N/A	52 c s 51	52 c s 51	52 c s 51	52 c s 51
mihidu	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	N/A	N/A	N/A	N/A	N/A	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	1 d a 62 5 27 4 h 8 61 10	
furgusion1	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
st.luke	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
com bank	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
jothi	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
cmb halt 1	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
karavita halt	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
market	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
RDA	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
police	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
fish	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
cmb halt 2	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
gem lane	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
ambagahayata	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
alosyus	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
bazar	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c
peoples bank	1 a 5 4 8 10	1 a 5 4 8 10	52 1 t	1 a 45 5 6 49	1 a 45 5 6 49	1 a 48 5 6 49	43	43 38	43	N/A	40	59 60 61	59 60 61	59 60 61	N/A	N/A	N/A	44 c	44 c	44 c	44 c

7.3 Frequently Used Road Sections

ID	Frequency	ID	Frequency	ID	Frequency
26	52	52	24	42	6
56	52	57	24	54	4
37	50	58	24	55	4
61	50	60	24	18	2
5	46	25	22	2	0
59	46	46	22	3	0
35	44	6	18	7	0
10	42	23	18	13	0
40	40	36	18	32	0
41	38	44	20	33	0
48	36	49	18	34	0
53	36	51	18	47	0
1	34	39	18		
8	32	17	14		
50	32	45	14		
4	30	14	12		
38	30	16	12		
62	30	11	8		
24	29	15	8		
27	29	21	8		
28	26	43	8		
29	26	19	6		
30	26	20	6		
31	26	9	4		
22	24	12	4		

Table: Frequently used sidewalk segments

7.4 Frequently Used Crosswalk Sections

ID	Crosswalk location	Nos
I	Roundabout near RDA	50
H	Infront of police station gate	48
A	Bus stand	46
N	AB14 puligupitiya junction	44
D	Main street near roundabout	43
K	St .luke college	40
R	Infront of boc	36
L	Bus stand road	22
m	Furgusion school steps	18
b	Cathedral rd 1	16
f	Ambagahayata	14
s	Near bus stand	16
p	Near market	9
e	Main street Sampath bank	8
q	AB14 jothi cinema	9
c	Cathedral rd st. Aloysius school	6
g	Infront of Rathnapura mc	6
t	Near bus stand 3 rd exit	6
j	Near peoples bank	0
o	Karawita rd puligupitiya roundabout	0

