Improving Pedestrian Movements in Congested Urban Areas

C. S. Punchihewa and J. M. S. J. Bandara

Abstract Pedestrians are one of the main components of the urban traffic environment. Improved corridors for vehicle movements, but the lack of pedestrian facilities are indifferent identifications of a conventional urban setting. Unplanned and uncontrolled pedestrian movements result in delays and safety risks at town centers. Often, there are lots of public requests for a 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 in such a vicinity. This study is focused on developing a methodology to identify pedestrian movement behavior in critical areas and make necessary adoptions to develop such facilities to encourage a walkable 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 to the land use pattern of a town area. This study identifies specific land uses that serve as trip generators or attractors, generated pedestrian trips, and potential pedestrian paths within an urban territory. Collecting vehicle speed data using Google Maps to identify the heavy use crosswalks, data verification using field surveys, and developing a GIS-based land use model with pedestrian paths are also under the framework of the study. Shortest path Origin–Destination matrix development for pedestrian networks is one objective of this study. According to the OD matrix, the frequency of sidewalk or crosswalk usage in each OD pair is counted and ranked. A prioritized list is prepared according to the rank and level of interacting traffic.

Keywords Pedestrian trips · Connectivity · Land use · Prioritization of pedestrian amenities

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1 Introduction

1.1 General

The town center is the core area of a city associated with various commercial and retail activities. Urban development in a city is interpreting number of human factors and physical factors. "Economic growth" is a simple explanation for these human and physical factors for urbanization [1].

Distribution of land use is determined by human activities such as education, employment, leisure, shopping, etc. Those human activities create banks, schools, shopping areas, and government institutes in the spatial space in an urban area. These activities require spatial interaction or trips. The distribution of transportation systems feeds that demand and that opportunity can be measured as accessibility [2]. The result would be the complex transport network and diversified land use area over urban space.

Pedestrians are a main component of different kinds of land use activities in urban spaces. So, improving pedestrian movement is a necessary action to optimize traffic movement in a city environment.

Individual facility improvement without analyzing the 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 a 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 in such a vicinity [3].

1.2 Research Problem

The analysis of the pedestrian network, the identification of optimum walking paths, and the correct positioning of pedestrian crossings are primary methods for improving traffic flow in the urban environment. In many parts of the world, main cities have inadequate facilities for pedestrians. Urban traffic optimization requires a methodology to identify network conflicts and improvements for the pedestrian environment. The study is focusing on this problem, and it proposes a method to optimize critical pedestrian amenities for the reduction of traffic conflicts and related congestion in the 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, and 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 increases the quality of life in society. Generally, 95% of trips below 100 m are completed by foot [4].

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

The walkability index project explains four types of basic scenes: the safety, security, economy, and convenience of traveling by foot. 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 [5].

2.2 Acceptable Walking Distance

Critical walking distance is identified as the distance from any kind of transportation facility (Railway station, Bus terminal, Parking lot) at a commercial capital or a town center to main trip generators [6]. In the South Asian context, office premises, schools, tuition classes, banks and other government institutions, and commercial areas such as markets and shops are the main trip generators.

According to Seneviratne [6], these kinds of trips in a town center would depend on some external factors such as the type of trip, the purpose of trip, and the type of day. It may directly influence walking distance. Utility-related walking trips may indirectly influence some factors such as congestion, parking fee, one-way roads, parking availability, etc. Even if there is no parking fee or subjectively low cost in the town center, people including workers are willing to walk up to 610 m. The threshold limit of walking distance in a town center is identified as 610 m in this study [6].

Walking distance depends mainly on the trip's purpose. However, a threshold value for average walking distance is required to identify the study area. According to another study, the mean value of walking distance is 1120 m and the median value is 804 m. Their purpose varies with the income category. Relatively lower income population walks longer distances to work and shorter for recreation. But higher household income population walks longer distances for recreation and shorter to work [7].

Roddin's work regarding determining the benefits of separating pedestrians and vehicles stated the general statement about pedestrian walking length. Most of the time, pedestrian route length is less than 3,000 ft (915 m) in length [8]. Highway capacity manual Chap. 13 quotes Rodin's method [8] to calculate total travel time in pedestrian networks.

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

In here, Rodin introduced a maximum walking route length is less than 915 m. Furthermore, an ideal pedestrian route length is defined as less than 1.2 times the straight-line distance between the trip origin and destination. This assumption is important to avoid long-distance alternative routes which reduced the complexity of the OD matrix [8].

2010 and 2016 editions of the Highway Capacity Manual mention the threshold length of walking as 3000 ft (912 m) in Chap. 23 in 2010 and Chap. 24 in 2016 versions. A recent medical study [9] reveals that walking outdoors at a usual pace was an average speed of 1.31 m/s, a cadence of 116.65 steps/min [9]. This value is important to use as an assumption for walking speed on the above equation proposed by Rodin.

There are several studies regarding the threshold value for walking in an urban center. Rongrong Yang [7] introduced the threshold value for pedestrians at transit stations in China as 400 m to 800 m according to Krishi's logit Price Sensitivity Model [7]. Another study was conducted in Spain regarding the threshold distance to walk from home to school by Carlos Rodríguez-López [10] and it was 875 m for young people's community.

The average acceptable walking distance for the study of a typical city in Sri Lanka is selected as 750 m by considering the literature.

2.3 Pedestrian Route Identification

Proper data collection methods should be identified to find possible pedestrian routes. A broad range of methods for data collection were found in the literature. Raford et al. [17] proposed a method where respondents can draw their route on paper, but this approach would be difficult in an urban context. Snizek et al. [18] developed a criterion regarding web-based questionnaires. This method is quite advanced; connected to web API, Google Maps, and Open StreetMaps. Application of web-based methodology would be difficult in the Sri Lankan city because most of the pedestrian categories have low levels of computer literacy. It would result to omit the majority of pedestrian categories from the survey.

A Hybrid data collection including web-based methods and personal interviews have covered all categories of pedestrians.

2.4 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 in comparison to other travel modes.

Hill [11] found important factors regarding pedestrian route choice according to four different attributes: age, gender, trip purpose, and environment. Across all factors, responders considered minimization of distance in the first place while selecting a route. Only 1 out of 211 observations deviated from the shortest distance [11].

In another study conducted in a town center in Sweden, private vehicle users who parked their vehicles in the central parking area were observed to typically visit the most distant location first and then gradually walk back to their vehicle over the course of their visit. Nearly 70% of shoppers attempt to minimize the distance while on their trip [12]. In another research conducted in a UK urban context, out of the 820 sampled pedestrians, 616 (75% of the total) chose the shortest route. The remaining 25% of trips were slightly longer than the shortest route [13].

Zielstra's study [14], conducted in more pedestrian-friendly environment in the USA and Germany, examined the usage of smart devices among pedestrians. The study found that the popularity of pedestrian-related routing applications has increased due to the widespread use of smart devices such as tablets and smartphones in such environments. Nonrecreational and multimodal trip pedestrians have used that kind of application because pedestrians typically aim to reduce their walking distance. Pedestrian network shortest path algorithm program is really helping to find the shortest way and thus to avoid unnecessary detours [14].

2.5 Shortest Path

The shortest path generally saves time, cost, and energy. Pedestrians are choosing the shortest path to avoid unnecessary detours on utility-based trips most of the time [11, 13]. There are some other considerations for pedestrian route choice. There would be a low walk score in the shortest path, due to the poor condition of walkability measures, the probability of selecting the next available connectivity path would be high for many categories of pedestrians [5, 21].

2.6 Application of Dijkstra's Algorithm

Dijkstra's Algorithm is the fundamental shortest path algorithm that gives the optimum route on the network by counting method. It computes the shortest distance from one node to every other node. Hence, it is used in many researches and is very efficient in shortest-distance problems. Dijkstra algorithm is used to find the list of shortest routes in the OD pair list. At the end of the iteration process, each node consists of (x, y) values. y value at the destination node (x, y), represents the shortest distance from the origin node.

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

2.7 Long Walking Trips

Straight line distance between the destination and city center will correspond to the Rayleigh distribution [23]. Rayleigh distribution functions as follows:

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

where

x—Straight line distance between destination and city center.

σ—Rayleigh distribution parameter concerning the variable x [24]

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

2.8 Pedestrian Demand in Medium Size City

Unlike vehicle traffic demand, pedestrian traffic demand is very difficult to estimate. In this methodology, the first step is to understand pedestrian trip origin nodes.

Moulden's study in 1997 describes apartments and grocery stores creating high number of pedestrian trips in the urban area. It means that the apartments and residential units generate pedestrian trips in general [15].

Based on the literature, the following key points highlight the assessment of pedestrian demand in urban town centers:

- Bus stations, bus stops, and train stations are the main nodes of pedestrian trip generators.
- Vehicle parking area serve as the secondary nodes for pedestrian trip generation.
- Residential areas such as flats and apartments in the urban vicinity are secondary trip generation nodes.
- Trip generation nodes are acting as trip attractors on the return trip.

3 Methodology

3.1 Framework Development

– Step 1

  The first step in understanding pedestrian activities in a medium-sized city's urban center is to identify trip origin nodes including the threshold limit of average walking distance and setting boundaries using a buffer area around trip origins. Threshold walking distance is used to determine the buffer radius. In addition to that, geographical barriers and built environment barriers are to be considered to set the spatial limits for pedestrian movement.

– Step 2

  GIS-based methodology is developed based on pedestrian movement network. The best connectivity path between a trip origin node and the destination node is considered. The best connectivity path is the minimum cost path that consumes less energy to reach the destination. It would be the shortest distance path with a minimum number of road crossings in an urban network. The minimum cost path is made from a series of sidewalk segments and crosswalk segments. OD path matrix is developed by manipulating the sequence of each origin and destination connectivity path.

– Step 3

  Elements of OD path matrix consist of a set of sidewalk and crosswalk segments. Each segment's frequency at the urban network OD matrix is counted and ranked according to descending order. Higher rank means that a particular crosswalk or sidewalk belongs to many numbers of pedestrian OD paths. So, the priority list for pedestrian amenities is developed according to that ranked list.

– Step 4

  Road segment-wise Google traffic speed data is extracted using Google script. Continuous series of low-speed segments represent the vehicle queue at junctions or at pedestrian crossing locations. Data collection is performed using a Google sheets script, enabling the automatic extraction of speed data for each segment at 10-minute intervals. After collecting data, spatio-temporal graph, which represents the average speed data matrix, is developed according to location vs time. This data analysis was conducted to identify congested locations and normal traffic behavior in the city environment.

– Step 5

  Pedestrian counts are conducted at selected links to compare the OD matrix results. The 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 scenarios. Conducting manual pedestrian spot counts for 15 minutes during a selected peak time is a simple and straightforward survey method. Pedestrian count using bird eye view video from a drone camera is highly effective in this kind of verification.

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

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

3.2 Study Area Identification

Walkable distance is the main influencing factor in pedestrian mode choice. Based on the literature, a 750 m is selected as the convenient distance for walking. Walkable distance is the main factor to be considered in the selection of Origin–Destination locations. Pedestrians will not choose walking as their mode for longer distances, especially in urban centers where commuter buses, three-wheelers, and taxis are available. Hence, the 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 OD pairs. This has plus and minus points. Natural barriers like streams, marshy land, etc., limit the walking trips between a OD pair. In hilly environments with steps may encourage walking as a mode of transportation over vehicles. This is because steps with high gradients can shorten the distance compared to vehicular routes, even for motorcycles. This is another important factor to be considered in selecting the study area.

The economic status of the population category also influences pedestrian trips to a town center. Low-income population, school children use walking mode without using three-wheelers or taxis for short trips.

3.3 Study Area Identification Using ArcGIS

The following nodes are considered trip generation nodes:

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

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

According to Rodin [8], 625 m (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 streams without a bridge or any other cross path, physical barriers, environmental barriers, marshy land, etc. Those geographical features are extracted as a geographical boundary layer to fine-tune the pedestrian movement zone. A close polygon is created by connecting boundaries of barriers and it is named a barrier polygon layer. After identifying environmental barriers, a polygon is created as a barrier polygon.

The study area is extracted after merging those geographical barrier layers and the node pedestrian movement buffer zone layer.

3.4 Pedestrian Route Choice

A route is required to connect an Origin and Destination pair of the network.

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

As discussed in the literature review, the hybrid data collection method was carried out to identify the possible pedestrian routes. Open street maps and Google satellite maps are used to identify possible pedestrian paths. Pedestrian paths on both sides of roads, crosswalks, steps, and footpaths were identified as an initial step. Pedestrian interviews were conducted at trip origin locations, and site visits to the study area were undertaken to verify pedestrian routes and identify preferred alternative routes within the urban network.

3.5 Origin–Destination Matrix Development

The shortest distance results for all of OD pairs in the network are extracted from the Arc GIS OD matrix solver. Each OD pair has a distance value and it consists of a series of sidewalk lengths and crosswalk lengths.

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

The average walking speed for pedestrians is 1.3 m/s [9]. Correction should be added to the graded crossing locations as mentioned in the literature [22].

If the average waiting time at a crosswalk location is t.

Then, the length correction at the crosswalk location = 1.3 t in meters (Up to 5% grade section).

Representation of the sample network illustrated in Fig. 1 and results of the shortest distance in OD matrix are tabulated in Table 1.

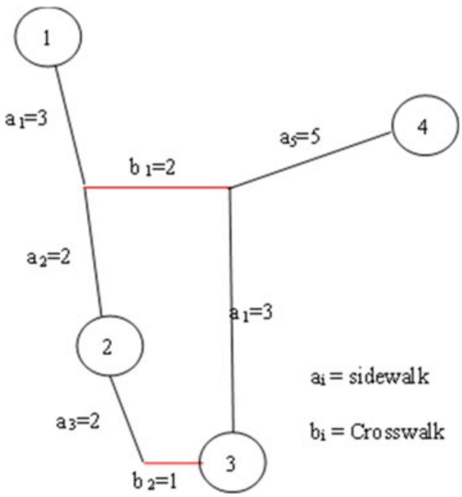

Fig. 1 Sample pedestrian network

Table 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 the shortest paths between all pairs of nodes, add each Origin–Destination pair to the OD matrix. Origin–Destination pair of shortest paths consists of a sidewalk section and crosswalk section series. OD pair i-j, shortest path *l*, sidewalk section a, crosswalk section c;

$$l(i,j)=\{a_1,a_2\ldots a_n,c_1,c_2,..c_n\} \text{ where } n \in \mathbb{N} \quad (2)$$

Origin–Destination matrix (in tens of components of shortest path);

$$[l(I, j)] = \begin{bmatrix} l(1,1) & l(1,2) & \ldots & l(1,j) \\ l(2,1) & l(2,2) & \ldots & l(2,j) \\ \vdots & \vdots & \vdots & \vdots \\ l(i,1) & l(i,2) & \ldots & l(i,j) \end{bmatrix} \quad (3)$$

OD path matrix can be obtained from the above data for the shortest distance between each OD pair. If the shortest distance for an OD 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 a taxi or commuter bus on those occasions unless there is a special reason to walk between that OD pair. According to the literature, the probability of longer walking trip occurrence can be obtained from the Rayleigh distribution.

Table 2 shows the example of the cost OD matrix for the sample network in Fig. 1. All 4 nodes on the network act as trip origins and trip destinations in the network. Destination nodes are represented in columns and origin nodes are represented in 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, and 1–4.

Table 2 OD matrix for the shortest distance

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

Table 3 Frequencies of pedestrian amenities usage on the network

Segment	Frequency
a1	6
a2	6
a3	4
a4	2
a5	6
b1	4
b2	4

3.6 Analysis of the Model and Results

Two sets of amenities can be extracted from the OD matrix. The sidewalk segment set and crosswalk segment set are separate sets of elements on the network. Sidewalk set includes the frequent occurrence of

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

max $|a_n|$ gives the most repetitive element in the network. The most repetitive crosswalk section was also identified by the same counting method.

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

Table 3 illustrates 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, and a5 segments are frequently used in the network. Developing the walkability of those elements would improve the overall efficiency of the network.

4 Application of Google Speed Data Analysis

Google application gathers crowdsource data, such as location from smart devices, and processes those location displacements with time as traffic data on roads. This algorithm is denoted as the distance matrix API, which provides travel distance and travel time from Origin to Destination on Google Maps.

4.1 Google Map Travel Time and Distance Data Extraction to Google Sheet

Google directional finder class on the Google app script allows finding the direction from the Origin location to the Destination. On the direction data, this class returns travel time between OD, and distance between OD according to real-time traffic

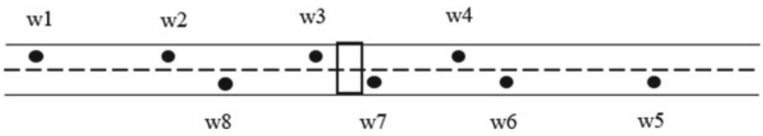

Fig. 2 Way point arrangement near the crosswalk

conditions. Google sheet script editor allows us to automate this basic process in specific time intervals.

Traffic behavior study near the crosswalk requires some modification on this basic process. The latitude and longitude of each waypoint were extracted from Google Maps to check the speed variation as illustrated in Fig. 2.

Google script is set up to trigger every 10 min and it collects the live duration to pass the segment. The duration output file contains the estimated duration, trip length, date, and time. This raw output file is modified as separate attributes of the date, time, speed (length/time), and section ID. From that four attributes, a simple pivot table is generated with y-axis as time, and x-axis as section IDs. Speed data variation can be identified from the graph as denoted in Table 4.

This pivot table is spatio-temporal graph and speed variation illustrates the congestion at any crosswalk.

The logic of speed data analysis at a crosswalk is as follows:

- If the road section before the crosswalk displays a red, and the section after the crosswalk displays a green, it indicates a congested crosswalk.
- If sections before and after show red means heavy congestion on the network despite of crosswalk location
- Green on each side means no congestion on the network.

4.2 Results Validation

Site visits and spot pedestrian counts are required to validate the OD matrix results. The pedestrian movement behavior at the congested crosswalk location is also monitored to identify possible countermeasures for avoiding conflicts between vehicular traffic and pedestrian flow.

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

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

OD matrix results and pedestrian count results are plotted on XY graph according to the rank of the segment and compared R2 value in linear regression to validate OD

Table 4 Spacio-temporal 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	15.94	12.00	50.00
7:20	32.00	12.00	21.20	15.94	12.00	30.00
7:30	32.00	12.00	21.20	15.94	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

matrix results and actual values. Figure 3 represent the flow chart of the methodology which is described in the above section.

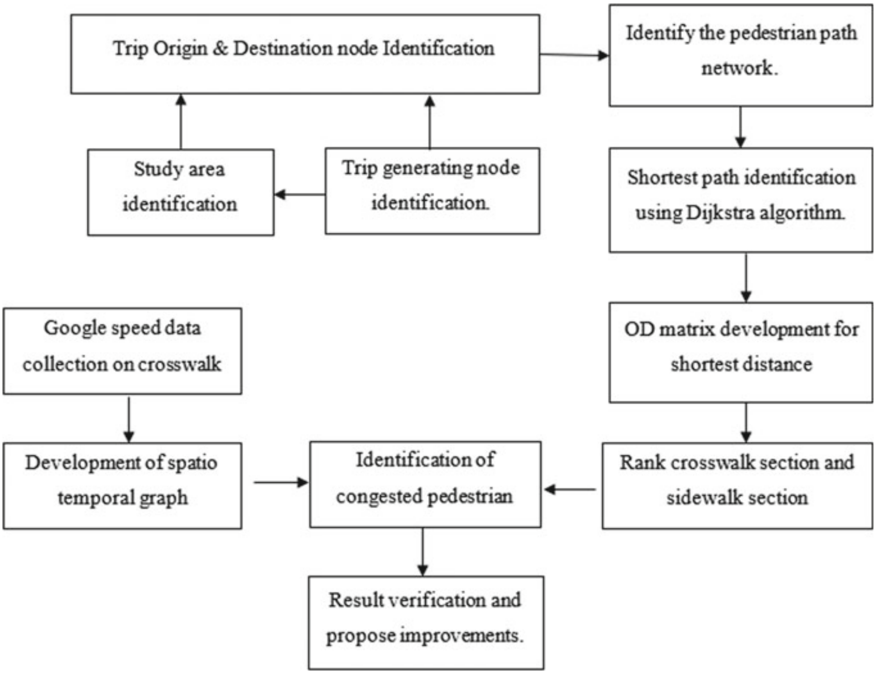

Fig. 3 Flow chart of methodology

5 Conclusion

Pedestrian amenity development project is required to identify and prioritize the order of segments at urban center. Identification of pedestrian paths and Origin–Destination connectivity is important in this process. OD matrix, considering the shortest path, is a powerful tool for identifying frequently used homogeneous segments in the urban pedestrian network. Improving walkability in those segments is a good observation when utilizing public funds for the development of the city environment in an efficient manner.

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