Proceedings of the Eastern Asia Society for Transportation Studies, Vol.12,2019

How Far People Can Walk to Access Metro? A Study of Access Trip Characteristics of Delhi Metro Users

Akshay GUPTA [a], G.R. BIVINA [b], Manoranjan PARIDA [c]

[a,] AECOM India Pvt. Ltd., DLF Cyber City, Gurgaon, Haryana, 122002, India
[b,c] Indian Institute of Technology Roorkee, Roorkee, Uttarakhand 247667, India
[a] *E-mail: gupta.akshay2011@gmail.com*
[b] *E-mail: biviplna@gmail.com*
[c] *E-mail: mparida@gmail.com*

Abstract: This paper presents access trip characteristics of metro users of Delhi, India with an aim to formulate policy interventions that can enhance access environment of a metro station. Face to face surveys were carried out with metro users accessing metro stations. Access trip characteristics are examined with respect to access mode share, trip length, time and cost. Acceptable walking distances are calculated from cumulative frequency distribution curves of walk trip distances for various groups of metro users based on their gender, age, dependency factor, occupation, household income and vehicle ownership. The study found that significant relationships exist between travel pattern and socioeconomic characteristics of metro users. Quality of pedestrian infrastructural facilities around the metro stations has a strong association with access walking distance and walk mode share. Also, an attempt to identify people's relative priority on various built environmental factors which affect their access to metro stations has been done.

Keywords: Walk, Access, Acceptable Walking Distance, Metro, Delhi

1. INTRODUCTION

Traffic congestion and pollution have become growing issues in metropolitan areas. Hence, the use of non-motorised transport to access public transport has started gaining attention (Martens, 2004; Advani and Tiwari, 2006; Rastogi, 2010). The large population of these metropolitan cities depends upon mass rapid transit systems like metros and buses for their daily travel. In a developing country like India, people use various modes to access metro stations such as walk, bicycle, two-wheeler, electric rickshaw, manual rickshaw, auto-rickshaw, metro feeder bus and car. But utility of each mode is limited only up to a certain range of distance (Khisty and Siraj, 1996; Arasan et al., 1994). The straggling of cities has resulted in an increase in trip length for accessing transit systems that have further increased the share of motorized modes for accessing transit systems. This has resulted in the environmental degradation (Travisi, 2010), social degradation (Hanson, 1993) and economical degradation (Jacob et al., 1981). Therefore, it is a paramount to curtail the aforesaid impacts by the promotion of non-motorised modes such as walking for transit access.

Walking is an important and environmentally efficient mode for transit access (Litman, 2003), having health benefits with its sustainable transport goals (Lee and Moudon, 2004). Therefore, walking should be encouraged in order to attain these goals. In context of developing countries, walking and pedestrians are disregarded in the design of transportation infrastructures leading to the motor vehicle oriented framing of transportation policies among decision makers. The basic reason for this neglect is ascertained as the vagueness in the concept of walk trip characteristics. This incomprehension frequently leads to the disinterest of planners and authorities towards any alteration in the spatial kinetics (Priemus et al., 2001). Also, physical exertion makes walking reasonably just for short distances (Rahul and Verma, 2014). Hence, one first needs to comprehend the trip characteristics, particularly access trip characteristics to promote walking to public transit.

There can be many implications of comprehending the trip characteristics. One amongst them is the clear understanding of distance and catchment area up to where infrastructural facilities are indispensable in order to promote walking and other public transport in the existing transit system. The present study also explains walking distance as acceptable distance that a person can cover and uses it for formulating policy interventions and guidelines for the improvement of pedestrian infrastructures with respect to travel characteristics. The mean and median values of walk trip distances are adopted as acceptable distance by several studies. Koushki (1988) used mean distance as acceptable walking distance and Tjahjati et al. (1991) computed ideal trip length using cruising speed of walking. Some researchers have calculated median and 85th percentile distance in the same context (Burke and Brown, 1988; Johar et al., 2015). A methodology proposed by Seneviratne (1985) for estimating acceptable walking distance used cumulative frequency distribution curves. According to his study, previous literatures have not provided a good explanation for considering mean or median distances as the acceptable walking distance. Thus, many of the studies (Arasan et al., 1994; Rastogi and Rao, 2003; Rahul and Verma, 2014) conducted after 1985 have adopted the methodology developed by Seneviratne (1985) to calculate the acceptable walking distance. Also, there are some studies that found that pedestrian friendly service areas are within 75th percentile walking distance (O'Sullivan and Morrall, 1996; EI-Geneidy et al., 2014). These acceptable walking distance can be increased by providing pedestrian-friendly environment (Rastogi and Rao, 2003; Rahul and Verma, 2014). Access and egress trips to and from transit have a robust impact on commuters' choice to use public transport as their main commute mode. Characteristics of these trips were taken into consideration to understand the present scenario and identify factors that impact people's decision to choose public transport (Givoni and Rietveld, 2007). Apart from distance (proximity), socioeconomic characteristics are also given importance in formulating policies to provide better access to public transport (Murray et al., 1998). Access trips give more importance than egress trips in increasing the rail use (Wardman and Tyler, 2000). Therefore, the present study emphasizes on access trip to metro stations. Moreover, commuters' perception towards access journey trip should be taken into consideration in identifying the barriers in the access environment (Yang et al., 2015).

The level of satisfaction with the quality of environment has been considered as an important factor that affects walking, which can be helpful in the promotion of sustainable modes over motorised modes. But most of the previous studies have focused on non-behavioural aspects of built environment such as walking distance and time and information about psychological aspects such as pedestrian attributes, etc. that may affect the decision to walk, remains limited (Kim et al., 2014). Various built environment factors along with individual characteristics were found to affect commuter's choice of walking (Loutzenheiser, 1997; Kim et al., 2007). Researchers stated that pedestrian environment around transit station is negatively affected by pedestrian-hostile streets (Schlossberg and Brown, 2004). Some studies have emphasized the importance of quality of pedestrian infrastructural facilities around the transit (Cervero et al., 2009).

Microscale walkability assessment is the street level assessment of walking environment that is perceived by pedestrians. Factors such as quality of sidewalks, sidewalk width, presence of crossings, pedestrian amenities, sidewalk encroachment, sidewalk obstruction, sidewalk availability are found supportive for pedestrian access (Evans et al., 1997). Researchers have evaluated the influence of numerous aspects of built environment, such as width of sidewalk and their availability (Gallin, 2001; Parida et al., 2007; Bivina et al., 2019), quality of sidewalk (Parida et al., 2007, Sheikari et al., 2014), and availability of streetlights (Sheikari et al., 2014; Rajendran et al., 2018) on the overall satisfaction with walking. Maintenance of sidewalks and speed limits of traffic have a significant influence on people’s inclination towards walk. All of these factors are correlated with a perception of safety. Interactions between people and urban detractors influence the perceptions and satisfaction of pedestrians (Porta and Renne, 2005). When sidewalks are shaded and impact of traffic is lower, people have more tendency to walk to access transit (Olszewski and Wibowo, 2005, Jiang et al., 2012; Park et al., 2015). Loutzenheiser (1997), Dantas (2005) and Hendricks (2005) explored that walking could be unsafe or inconvenient if there is heavy traffic, no street lights, poor sidewalk conditions. The attractiveness of walking to transit stations can be weakened by encroachments on sidewalk, and parked vehicles as an obstruction on sidewalk (Alfonzo et al., 2014). Factors like traffic control devices, garbage on sidewalk, buffer between road and sidewalk, fence and greenery is considered to assess walking environment around metro stations (Sun et al., 2017). Audirac (2008) discussed the barrier free design for people with disability while accessing transit. Some of the qualitative factors that are subjective in nature, such as cleanliness of sidewalks, security from crime around the station catchment area have an impact on ridership and mode choice to the transit station (Kim et al., 2007). The microscale built environment factors have a significant association with peoples' satisfaction of walking (Kim et al., 2014; Rajendran et al., 2018). Thus, present study emphasizes on considering various qualitative factors of walk environment for accessing metro transit stations by foot by analysing metro users’ perception of satisfaction and importance on each of the qualitative factors.

Delhi being the capital of India has a huge potential for promoting walking and public transport usage. Delhi metro stand out to be as best solution for travel demand problems and it helped in shifting considerable number of motorist users to public transport. A number of researches on egress and access distance to metro stations, metro commuter’s characteristics, and service quality of stations have been conducted. However, studies exploring access travel characteristics, walk trips characteristics, and acceptable walking distance with respect to these metro stations are limited. Access trip characteristics and acceptable walk distance are associated with the area context and presently there is no study that deals with these characteristics of Delhi metro. Thus, the present study fills this gap by interpreting walk access environment and trip characteristics with respect to the access mode share, trip length, time and cost and it also estimates the acceptable walking distances of people accessing metro station. The study also analyses the metro users’ perceptions to access the metro station on the various micro-scale built environment factors. The findings of the study will be helpful for policymakers and local government to understand existing neighbourhood access characteristics and formulate policies for the improvement of walkability around stations. The acceptable walking distance can also be used for transit and land-use planners as a general guideline for aligning the transit route and planning for a pedestrian-friendly service area. Further, it helps in formulating transport demand management (TDM) strategies and promoting the circumstances that favour shifting of private vehicle users to public transport and walk for accessing it.

2. STUDY AREA CHARACTERISTICS

Delhi, officially the National Capital Territory of Delhi or NCT, has been selected as the study area. Being the capital city is the centre of socio-economic, cultural, and political activities of the country, Delhi has a population of 16.75 million and about 97.50 percent of this the population lives in urban areas and 2.50 percent in rural areas (Census of India, 2011). Transport system should meet the mobility requirement for this population. There has been a major improvement in transport infrastructure in recent years in terms of flyovers, road widening, new roads development and development of metro rail corridors along major routes of travel in the city. Delhi has the status of one of the highest road densities cities and also has the highest number of registered vehicles i.e. 8.85 million as of 2016 (Road Transport Year Book, 2015-16). But due to continuous increase in population and employment opportunities, there is a constant increase in demand. Infrastructure has not grown in adequate proportions, making the existing network system function beyond its capacity. This has led to serious traffic problems of congestion, delays, safety, pollution, and system management in the city. To curb this situation, efficient public transport system is needed.

2.1. Public Transportation System in Delhi

Different types of transit and paratransit systems are operated in Delhi. Transit systems serves the intra city as well as inter cities transport demands whereas para-transit serves the intra city demand. Delhi's public transport modes such as metro and bus form a strong network to serve the need of the public

2.2. Delhi Metro

The current major public transit system in the city is metro, operated by Delhi Metro Rail Corporation (DMRC) that provides good commuting facilities with an average daily ridership of 2.76 million in 2017 (DMRC, 2017) and its citywide network comprising of six different metro lines. The six lines are the Red, Green, Blue, Yellow, Orange, and violet, which serve 218.17 kilometers (km) stretch with 164 stations. Modes such as bus, private vehicles, walk, bicycle, auto rickshaws, manual-rickshaws and electric-rickshaws serve as feeder modes to access metro.

2.3. Other Public Transport

Para-transit modes are demand driven unscheduled public transport. Intermediate public transport (IPT) modes both motorised and non-motorised such as auto rickshaws, e-rickshaws, manual rickshaws also play a significant role in commuting people. Auto rickshaws are basically two types i.e. contract carriage and shared basis. Contract carriage auto rickshaw system is similar to a private taxi that has fare based on standard meter charges as per the distance travelled or on the agreeable rates, and having the capacity of 3 persons. Shared auto rickshaws run on a fixed route and have the intermediate stops. They are either three wheeled or four wheeled and having the capacity of 3 to 6 persons. Electric rickshaws are battery operated, three wheeled vehicle. They mostly work as shared basis for shorter routes and having the capacity of 4 persons. Manual rickshaws are pedal powered tricycle; serve for shorter distances and having the capacity of 2 persons.

Bus service in Delhi can be classified into three types. First one is stage carriage intra city buses which operate mostly on arterial roads and they do not serve the local areas. Intra city buses further have three types, in which first two are government buses, one is red bus (AC) and another is green bus (non AC) operated by Delhi Transport Corporation and third one is orange bus (non AC) operated by private entities. They have seating capacity of 50 to 55 persons. Second one is stage carriage mini buses which are serving the local areas and third one is the metro feeder buses operated by DMRC that provide connectivity to persons within the catchment area of metro stations. The capacity of these two types of buses is around 20 persons.

2.4. Metro Station Selection Criteria

Land use type and ridership of metro station, were considered as the criteria for selection of 15 metro stations. Land use characteristics of catchment areas were considered for selection of metro stations. Metro stations having typical land use type such as residential or commercial or industrial or public area or mixed or having a multimodal transportation hub were selected for study. Furthermore, the metro stations selected were from each ridership category, such as lowest daily ridership (below 20,000), average daily ridership (20,000–40,000) and highest daily ridership (above 40,000). Metro station line type, average ridership, land use type, population data and employment data for all selected metro stations are presented in the table 1. Population density map, employment density map and land use map with buffer area of 800 m and 1500 m are presented in the fig. 1.

Table 1: Distribution of ridership, land use type, population and employment

Metro station	Metro Line	Average Ridership	Land use type	Population Within 1500 m buffer	Employment within 1500 m buffer
Rohini west	Red	18844	R+ C+Re+P	220592	65437
Netaji subhash place	Red	14158	R + C+Re+P+I	265366	104373
Shahdara	Red	39952	R+P	257209	95426
Kashmere gate	Yellow	34712	T+R+P+Re	119029	116229
Chandni chowk	Yellow	66355	R+ C+T+Re	231296	169624
Rajiv chowk	Yellow	74667	C+R+P	178285	267308
Central secretariat	Yellow	18324	P+Re	36591	125534
INA	Yellow	26622	R+C	195514	78728
Hauzkhas	Yellow	35898	R+P+Re	137967	45274
Rajouri garden	Blue	21286	R+C	249309	92321
Karol bagh	Blue	45944	R+ P+Re	214285	165398
Laxmi nagar	Blue	42911	R	352659	107995
Karkarduma	Blue	13384	R+P+I+C+T	49231	20477
Kalkaji mandir	Violet	8740	C+Re+R+P+I	171460	85303

Apollo Jasola	Violet	11573	I+C+R	103486	83580
Total		473370		2782286	1623007

Note: C = commercial, I = industrial, P = Public, R = residential, Re = recreational, T = transportation (Bus/ rail terminal except the existing roads)

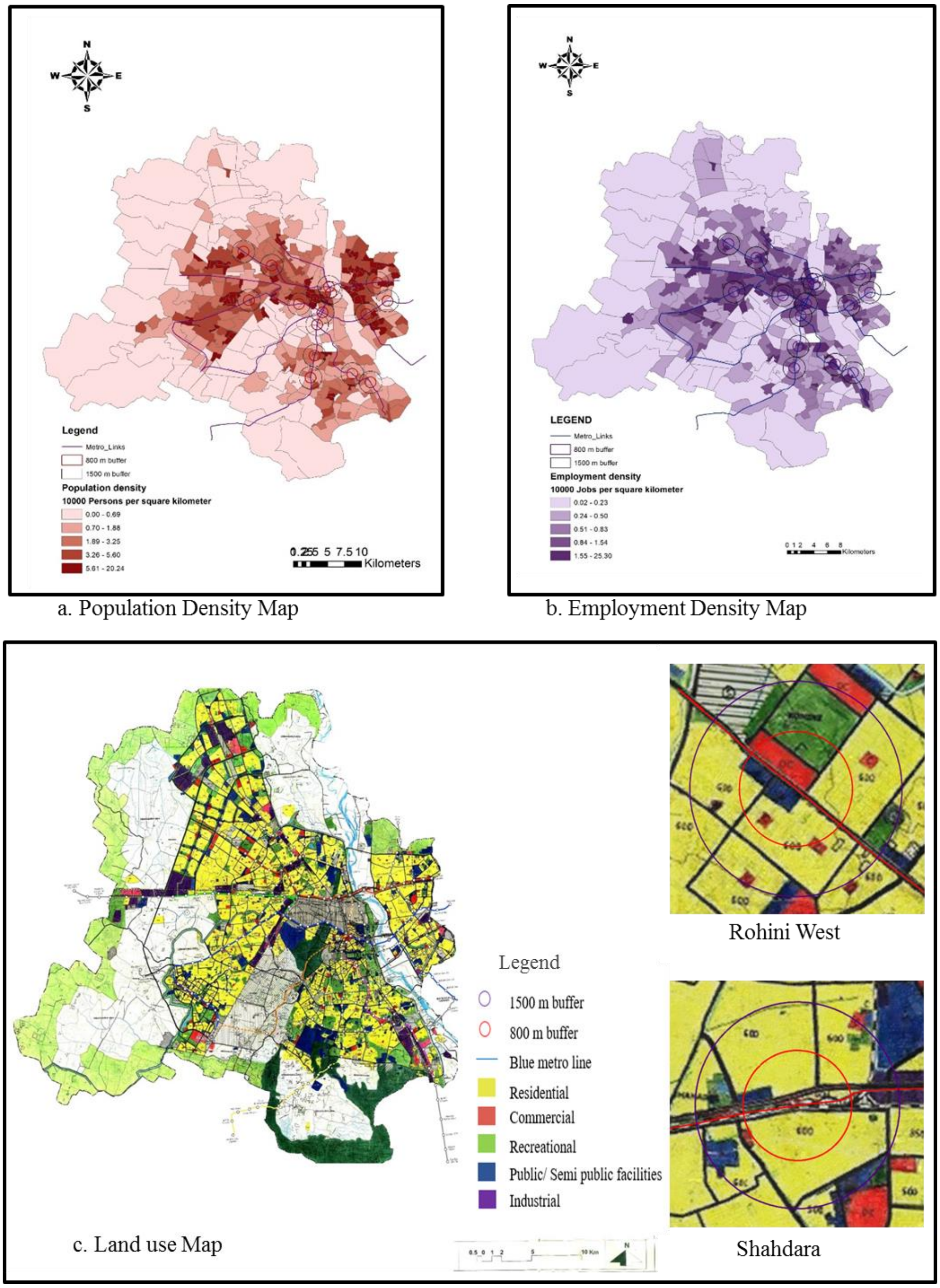


Figure 1: Land use, employment and population characteristics of Delhi

3. DATA COLLECTION

A pilot study was conducted to determine the time taken to conduct the survey and the degree of complexity of questions being asked to respondents. After the pilot study, survey proforma was modified by replacing some factors and changing the pattern of questions on the basis of feedback provided by respondents. The main survey was conducted with the modified questionnaire and responses are collected from metro station platforms, households, offices, and public spaces. Sample size for the final survey was determined from the equation proposed by Krejcie and Morgan (1970) as shown below:

$$\text{Sample Size} = \frac{\chi^2 NP(1-P)}{d^2(N-1)+\chi^2 P(1-P)} \quad (1)$$

Where,
χ^2 = table value of chi-square at degree of freedom =1 for desired confidence level (at 95 % confidence interval χ^2=3.84)
N = population size=16.7 million
P = population proportion (assumed to be = 0.50)
d = degree of accuracy expressed as a proportion (0.05)
For 95% confidence level, 0.5 population proportion and 0.05 degree of accuracy (5% desired margin of error), the minimum sample size required is 384 samples.

Survey has been conducted within 800 meters (m) and 1,500 m (Fig. 2) catchment area around each metro station**.** Six hundred samples were collected based on the population and employment density within the catchment area. The population and employment densities of buffer area of each metro station were calculated using ArcGIS software (as shown in fig. 1) to distribute the sample size proportionately based on population and employment density. Hence, 426 samples were collected within 800 m and 174 samples collected within 800 m to 1500 m. Responses from people who are walking to stations or had previous experience of walking to station were taken. The simple random technique has been adopted to capture the information. This survey was preferred over on-board survey because built environment characteristics around a particular metro station can be better known by the people who live or work around the stations. Each question in the survey proforma was explicated to respondents and their response was marked.

Weighting method was adopted to ensure the sample representativeness. Variables such as age and gender were used for carrying out weighting method. In this method, an adjustment weight is assigned to each respondent. Respondents who are underrepresented obtain a weight less than 1 and overrepresented obtain weights greater than 1. The variables are measured from field data and their corresponding population distribution is obtained from the secondary data of National Statistical Institutes. The results of weighting method conclude that all data highly represented population data except for the female respondents. Female population is slightly underrepresented in the sample. The reason for the higher percentage of males in the survey is that the majority of working populations are males in the context of Delhi and a majority of the metro users are males. According to Delhi's Census (2011), the male working population is 27% and female working population is 4.4%.

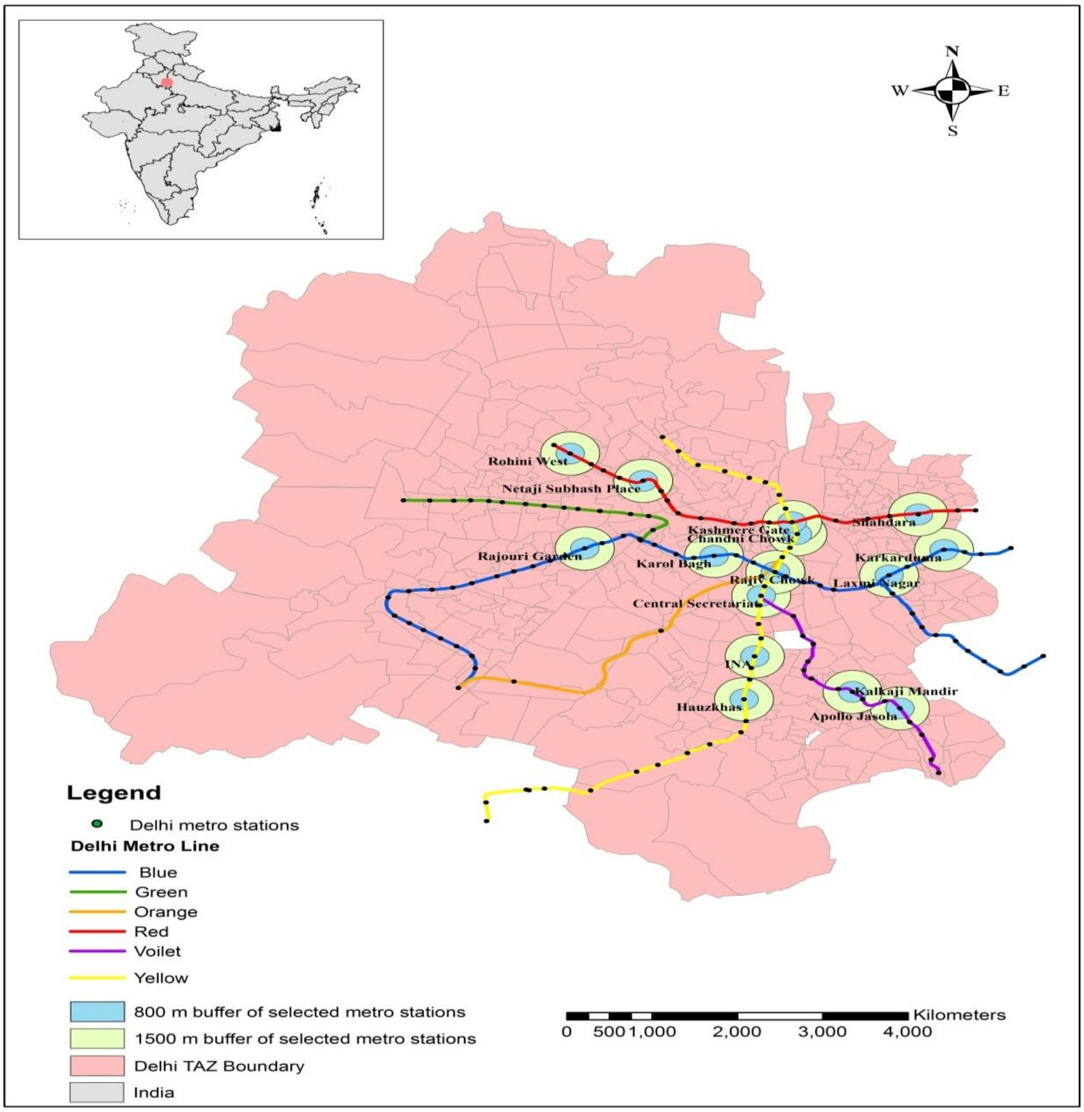


Figure 2: Delhi metro network and location of selected sites for study

Questionnaire proforma was structured in four main sections. The first two sections included demographics and socioeconomic characteristics which collected personal information (e.g. Age, gender, driving license availability, education, occupation, monthly income, and monthly expenditure on transport) and household information (e.g. Household size, number of working members, household income, and household vehicle ownership). The third section was oriented towards travel information which collected trip information such as trip purpose, distance, mode, travel time, waiting time, cost etc. The fourth section was more oriented to a user's perception of built environment factors that affect the walking environment. Metro users specifically were asked to rate 19 built environment factors defined under mobility, safety, security and comfort based on their satisfaction and importance. The rating scale for satisfaction followed Likert scale from 1 to 5 where 1 represented worst and 5 for excellent and rating scale for importance was also from 1 to 5, where 1 represented not important and 5 represented for very important.

4. RESULTS

4.1. Descriptive Analysis

Descriptive analysis of survey data collected from study area is presented in Table 2. About 66.77% of respondents are males and about 40.51% are in the age group of 31 to 45 years old. Average household size and average monthly individual income are found to be 4.61 and Rupees (Rs.) 27,919 respectively. Around 59% of metro users lie within the income slab of Rs. 15,000 to Rs. 70,000. Most of the respondents (77%) are in the middle age group, i.e. 16-45 years with two third of them being male. Nearly half of them are graduated and employed. It is observed that most of the trips (63%) are work trips. Dependency factor (number of members supported by working members in the household) is found out to be 2.83 and average monthly expenditure on transportation is found to be Rs. 2,474.

Table 2: Data descriptive of the study area

Category	**Sub-category**	**Values**
Age group	0-15 year	3.39 %
	16-30 year	37.12 %
	31-45 year	40.51 %
	46-60 year	15.42%
	>60 year	3.56 %
Gender	Male	66.77 %
	Female	33.22 %
Driving License	Yes	60.75 %
	No	39.25 %
Occupation	Unemployed	0.51 %
	Employed	56.10 %
	Self-employed	16.95 %
	Student	17.29 %
	Retired	2.88 %
	Housewife	6.27 %
Education	Illiterate	0.17 %
	Up to 5th	3.05 %
	Secondary	12.54 %
	Higher secondary	22.20 %
	Graduate	50.17 %
	Postgraduate/above	11.86 %
Individual monthly income	< Rs. 15000	34.91 %
	Rs. 15,000 to Rs. 40,000	40.16 %
	Rs. 40,000 to Rs. 70,000	19.32 %
	Rs. 70,000 to Rs. 1,00,000	4.40 %
	Rs. 1,00,000 to Rs. 1,50,000	0.67 %
	>Rs. 1,50,000	0.50 %
Purpose of Trip	Work	63.73 %
	Education	13.05 %
	Shopping	7.63 %
	Recreational	5.42 %
	Social	7.46 %
	Other	2.71 %
Household monthly income	< Rs. 15000	3,89 %
	Rs. 15,000 to Rs. 40,000	28.30 %
	Rs. 40,000 to Rs. 70,000	30.00 %
	Rs. 70,000 to Rs. 1,00,000	23.55%

	Rs. 1,00,000 to Rs. 1,50,000	7.96 %
	>Rs. 1,50,000	6.27 %
Household Vehicle Ownership	None or bicycle	20.84 %
	Motorised	80.16 %
Average individual monthly income		Rs. 27,919
Average monthly expenditure on transport		Rs. 2,474
Average size of household		4.61 (1.221)
Dependency factor		2.83 (1.11)
Detour Distance		779.71 m (336.05)
Sample Size		590

4.2. Characteristics of Access Trips

In survey, respondents were asked about their access modes to metro station. Access travel characteristics are presented in Table 3. It is found that access trip involves eleven modes - walk, bicycle, two-wheeler, manual rickshaw, electric rickshaw, auto rickshaw, shared auto rickshaw, bus, metro feeder bus, car and other modes. More than half of access trips have been completed using non-motorised modes (walk-49%, bicycle-0.3% and manual rickshaw-8.8%) and average distance for walk mode is found to be 590 m. Motorised IPT modes (electric rickshaw, auto rickshaw, shared auto) consist a combined share of almost 29% and buses shares around 4% of access trips. While 9% of access trips have been completed by private modes (two wheeler-8% and car-1%). Average distances for all modes have been comprised in the Table 3. Walking has the least average access distance and metro feeder bus has the highest average access distance among all the modes.

Table 3 also summarises the average access time and average cost for each mode. Bicycle has the least, while bus has the highest travel time. In motorised vehicles, two-wheeler has the least travel time. Walking does not include any cost. Bicycle consist the minimal parking cost i.e. Rs. 3 to Rs. 5 which varies based on the duration of parking. In motorised modes, car has the highest travel cost as operating cost and parking cost of cars are very high. It was also found during survey that people avoid to park their two wheelers and cars in designated parking spaces provided by DMRC due to high parking cost and parked them at vacant spaces or at off street near the metro stations. Average waiting time and average distance of mode availability is also discussed in table shown below. For all modes other than buses, average waiting time and average distance of mode availability are found to be less than 1 minute and less than 100 m respectively. The most preferred mode among the non-walk modes is E-rickshaw. The reasons behind this are their low fare, availability and travel time. Although the travel cost for manual rickshaw and shared auto rickshaw are same as E-rickshaw but comfort and distance of mode availability are the deterrence for these modes respectively. When E-rickshaw is compared to auto rickshaw, the cost is found the major discouragement for auto-rickshaw (Rs. 25 for first 2 km and Rs. 8 for every additional kilometer).

After combining all access modes, average values of metro-access trip characteristics to metro station such as detour distance, time, cost, waiting time and mode availability distance are also discussed. The average access trip length is found to be 779 m which take 8.5 minutes at an average travel time to reach metro. The average waiting time for various modes (exclude walk and private mode) is 0.68 minute and average cost of access trip is estimated to be Rs. 12.5 excluding walk mode.

Table 3: Characteristics of access leg trips

Mode	Mode share	Average Distance (m)	Average Time (min)	Average Cost per trip (Rs.)	Average Waiting time (min)	Average distance to access given mode (m)
Walk	48.8%	589.68	7.73	-	-	-
Bicycle	0.3%	650	5	3	-	-
Two wheeler	8.0%	859.8	6.04	15.67	-	-
Manual Rickshaw	8.8%	854.54	10.65	11.18	0.41	53.09
Electric Rickshaw	19.3%	984.6	9.27	10.1	0.51	75.47
Auto Rickshaw	5.3%	990	9.58	24.23	0.5	64.6
Shared Auto rickshaw	3.9%	1059	10.04	10.22	0.95	102.2
DTC bus	2.2%	1125	13	6.25	2.33	160.8
Metro feeder bus	2.0%	1204.5	11.63	5	2.09	131.8
Car	1.0%	960	6.8	29	-	-
Other	0.3%	1100	11.5	10	0.5	85
Overall	100.0%	779	8.53	12.55[a]	0.68 [b]	78 [b]
Standard Deviation	-	336	3.55	6.16	1.22	56

Note: [a]Excludes walk mode. [b]Excludes walk and private modes.

The share of access mode within 800 m catchment area and outside 800 m catchment area are illustrated in Fig. 3. It is found that from 49% of walk access trips, around 85.7% of walk trips are within 800 m. This result shows that most of the metro users who walk to access metro station are within this distance, beyond that the share of walk mode becoming very small. It can be observed from the fig. 3 that most of the metro users who choose feeder modes are from outside the 800 m distance form metro station.

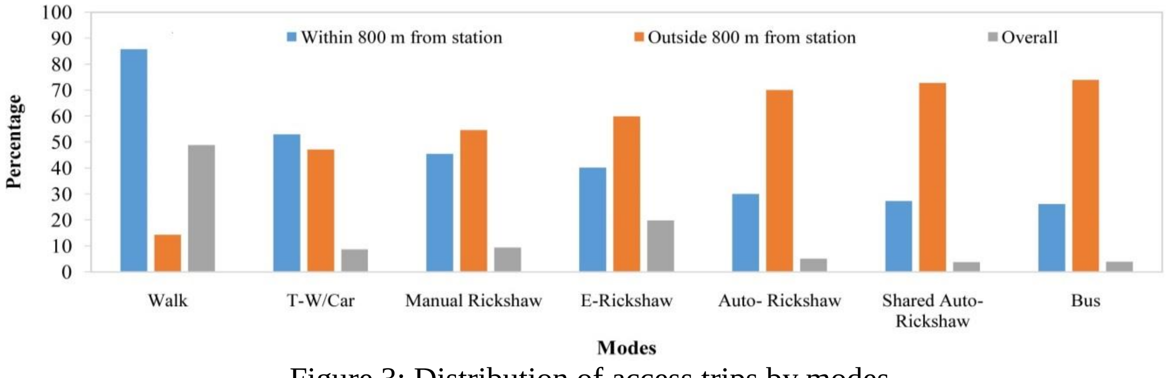


Figure 3: Distribution of access trips by modes

Distribution of access trips for different modes based on trip distances is illustrated in Fig.4. It is understood that the people prefer to walk to station if the distance is short up to 600 m and after 600 m, walk share reduces. In between 600 to 800 m of access distance, this competition is between manual rickshaw, e-rickshaw (electric rickshaw) and two-wheeler/car. Electric rickshaw (E-rickshaw) has the highest share among non-walk modes. After 1400 m, the share of bus has increased. People who walk greater distances are mostly from lower income group with monthly income less than Rs. 15,000. Most of these people are residing far from transit stations. This may happen because of higher land values near transit stations as these areas are the potential choice of higher income groups and business outlets (Cervero and Duncan 2002). Buses run by DTC (Delhi Transport Corporation) are found to be affordable with a minimum fare of Rs. 5 upto 4 km and Rs. 15 on 10 km onwards. Hence, they are used by low-income categories of metro riders for a distance greater than 1200 m. The smallest trip length of metro users using e-rickshaw is found to be 400 m. The share of e-rickshaw increases as the trip length increases and its cumulative value is always greater than other para transit modes within 1.5 km.

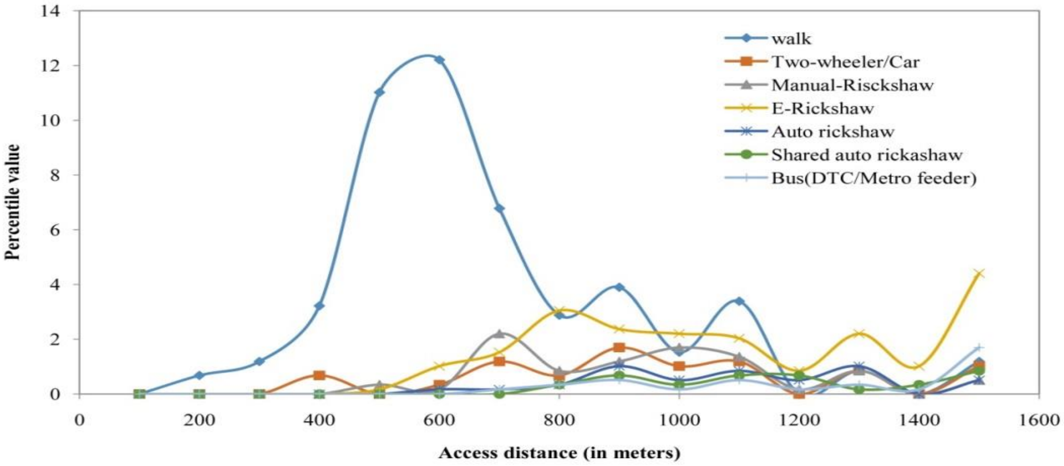


Figure 4: Distribution of access trip distances for different modes

Distribution of access trip cost for different modes is illustrated in Fig. 5. It is observed that around half of the access trips have no cost as it included walk trips also and nearly one-third of total access trips costs Rs. 10 for an individual. As e-rickshaw has a fixed cost of Rs. 10 for

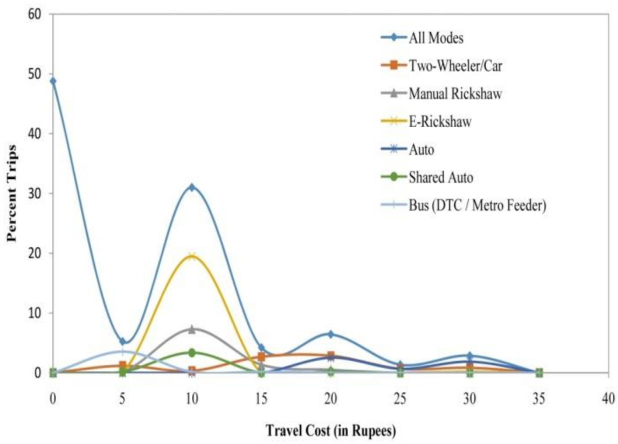


Figure 5: Distribution of access trip cost for different modes

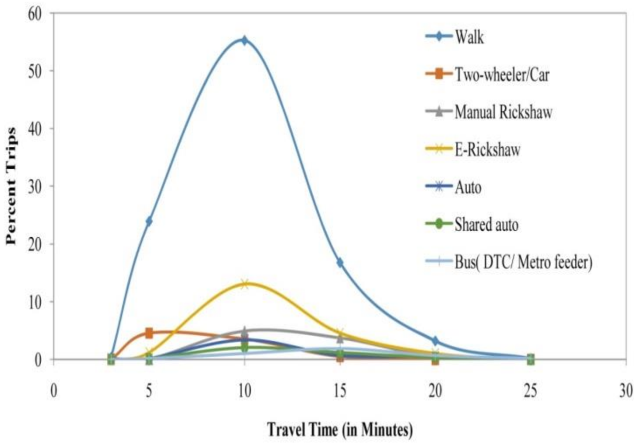


Figure 6: Distribution of access trip time for different modes

access distance within 1.5 km on shared basis. Manual rickshaw cost may vary from Rs. 10 to Rs. 15 based on distance and location. Auto rickshaw is found out to be the costliest mode (Rs. 20 to Rs. 30) to access metro stations. There are other modes, like Grameen Seva (shared by seven or eight passengers) and shared auto-rickshaw (shared by two or three persons), which cost between Rs. 5 to Rs. 10 based on trip distance. Even though bus has the minimum cost (Rs. 5) among the non-walk modes, it attracts comparably fewer trips. Amongst private vehicle users, two wheeler and car users access metro stations within a cost of Rs. 20. The tail end of the distribution is due to the car or two-wheeler use that costs around 3.5 times higher than e-rickshaw and 1.15 to 1.75 times higher than auto rickshaw. The use of car or two-wheeler is mostly limited to a high-income group.

Distribution of the time spent for a mode to access metro station is plotted in Fig 6. Distribution curves of access trips time follow similar trends for a walk, manual rickshaw, E-rickshaw, auto and shared auto. Buses have higher access trip time due to longer and fixed routes, the shorter spacing of bus stops and traffic delays. Distribution of travel time of two-wheelers is within the range of 5 to 15 minutes. Nearly 90% of walk trips have travel time less than or equal to 10 minutes. As walk is a slow mode and it has a significant reduction in travel time greater than 10 minutes. But there are few metro users who walk up to 1.5 km to reach the station those results in the long tail of the distribution of travel time. Average speed of walking is also computed based on walk distance and travel time, meanwhile, it is also compared with the values reported in other literature at the end of the paper

4.3. Built Environment

The built environment variables are generally measured in three scales: (1) Regional, (2) Neighbourhood and (3) Street level. The regional and neighbourhood scale is not applied in this study. Previous studies have tried to estimate micro-scale factors of walking in the form of audits tools, models and indices such as Pedestrian Level of Service (Sarkar, 1994; Dixon, 1996; Dowling, 2008), SPACES (Systematic Pedestrian and Cycling Environmental Scan) by Pikora et al., (2002), etc. Four main factors selected for the study are comfort, mobility, safety, and security. Under this main qualitative factors, several sub attributes are defined such as shaded sidewalks, pedestrian amenities, roadside greenery, presence of obstructions width of sidewalk, quality of sidewalk, continuity of sidewalks, encroachment along sidewalks, infrastructure for people with disability, cleanliness, presence of CCTV cameras, police patrolling, street lighting, traffic volume, traffic speed, guard rails, presence of buffer, raised sidewalk, presence of crossing and presence of traffic signal and signs. The attributes considered in the survey were identified by critically reviewing various literatures, IRC: 103-2012, sidewalk assessment tools, etc.

4.3.1. Metro users' attitude towards the built environment

To understand the present access environment of metro stations and identify factors to be improved for providing a better walking experience for accessing station, there is need to know metro users' perception of satisfaction and importance on each of the built environment factors. Satisfaction and importance ratings for various attributes of walking environment are given by respondents in 5 points Likert scale. Average satisfaction ratings of walking environment (comfort, mobility, safety, and security) are illustrated under radar charts in fig. 7. Comfort parameter of walking environment consists of four sub-factors; shaded sidewalk, pedestrian amenities, cleanliness of sidewalk and presence of obstructions is presented in Fig. 7 (a). It is noted that curves are following the similar trends for all sub-factors of comfort in all stations. People are more satisfied with the Central Secretariat and INA metro station environment with an average rating of 4.78 and 4.0 respectively and less satisfied with Shahdara and Laxmi-Nagar metro station with an average rating of 1.58 and 1.68 respectively for comfort sub-factors. Mobility consists of five sub-factors; quality of sidewalk surface, the width of the sidewalk, continuity of sidewalk, encroachment on footpath and facilities for physically disabled. Satisfaction rating for mobility is illustrated in Fig. 7 (b). Average ratings of mobility parameter for Central Secretariat and INA are 4.40 and 4.09 respectively, which are higher than other stations and on the other hand, Shahdara and Chandni-chowk received lower values of 1.41 and 1.98 respectively. Safety parameter entails seven sub-factors; raised sidewalk, traffic speed, provision of the guard-rail, the presence of buffer, the presence of crossing, traffic volume and traffic signal and signs. The satisfaction rating for safety parameter attained in each metro station is presented in Fig. 7 (c). Average safety parameter ratings for the Central Secretariat, INA and Rajiv Chowk are 4.02, 3.38 and 3.29 respectively, which are higher than other metro stations. Similarly, satisfaction ratings for security sub-factors; street lighting, CCTV (Closed Circuit Television) surveillance and police patrolling are presented in Fig. 7 (d). Respondents are highly dissatisfied with CCTV surveillance for all the stations except Central secretariat and Chandni-Chowk metro stations.

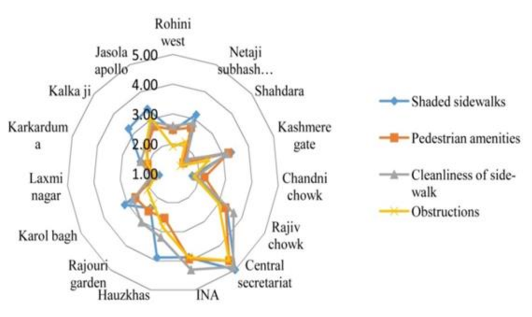


Figure 7 (a): Satisfaction ratings for the walking environment (comfort)

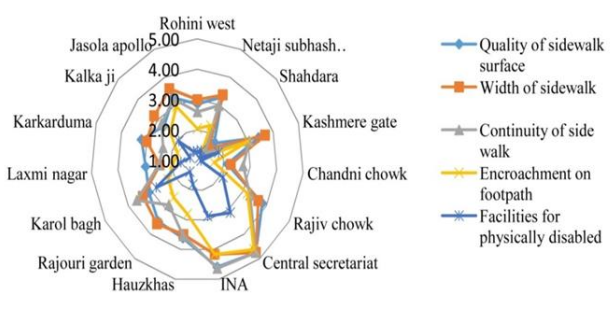


Figure 7 (b): Satisfaction ratings for the walking environment (mobility)

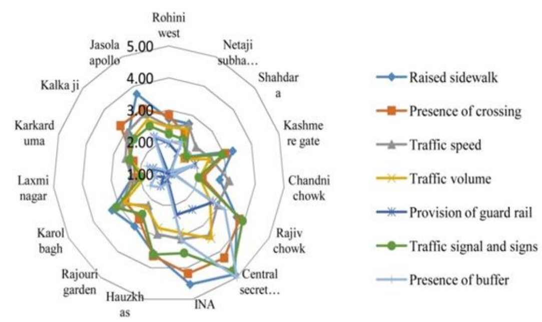


Figure 7 (c): Satisfaction ratings for walking environment (Safety)

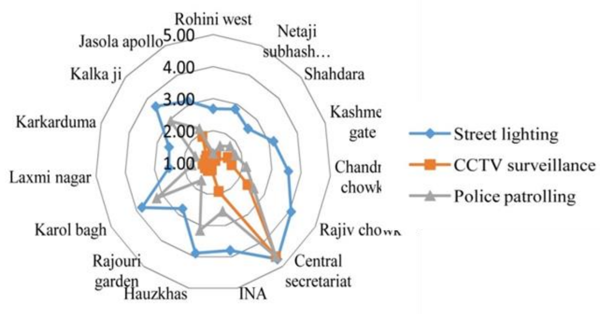


Figure 7 (d): Satisfaction ratings for walking environment (Security)

Figure 7: Satisfaction rating for walking environment

Metro users' average importance and average satisfaction ratings of walking environment attributes are presented in Table 3. Shaded sidewalk, cleanliness of sidewalk, quality of sidewalks and width of sidewalks turned out to be most important factors with average ratings that are 4.7, 4.6, 4.4 and 4.3 respectively. Facilities for persons with disability and presence of buffer are considered to be the least important factors with average ratings of 1.89 and 2.12 respectively. A paired t-test was performed in SPSS and results of paired t-test showed that there is a significance difference in mean values of satisfaction and importance ratings of each attribute as shown in Table 3. Factors such as shaded sidewalk, police patrolling, cleanliness of sidewalk and CCTV surveillance are showing greater difference in means of importance ratings and satisfaction ratings of people. Greater differences in ratings indicate that there is need to improvise the facilities which are important but are not employed properly according to people's perceptions.

Table 4: Paired sample t-test for average satisfaction and importance rating

Attributes	Notation	Importance (I)	Satisfaction (S)	I-S	Std. deviation	t	Sig. (2-tailed)
Quality of sidewalk	W1	4.44	3.19	1.24	1.22	-22.32	0.000

surface							
Width of sidewalk	W2	4.36	3.11	1.25	1.27	-19.91	0.000
Continuity of side walk	W3	3.91	2.96	0.94	1.42	-13.23	0.000
Encroachment on footpath	W4	3.47	2.43	1.04	1.55	-13.02	0.000
Facilities for physically disabled	W5	1.88	1.71	0.17	1.06	-2.94	0.000
Shaded sidewalks	W6	4.74	2.70	2.04	1.31	-29.88	0.000
Pedestrian amenities	W7	4.00	2.55	1.45	1.22	-23.47	0.000
Cleanliness of side-walk	W8	4.67	2.75	1.92	1.26	-29.82	0.000
Obstructions	W9	3.45	2.33	1.12	1.49	-14.54	0.000
Raised sidewalk	W10	4.10	3.01	1.09	1.26	-17.14	0.000
Presence of crossing	W11	4.29	2.82	1.48	1.36	-21.20	0.000
Traffic speed	W12	4.28	2.65	1.63	1.16	-15.86	0.000
Traffic volume	W13	3.56	2.38	1.18	1.18	-20.41	0.000
Provision of guard rail	W14	2.28	1.65	0.63	1.25	-10.11	0.000
Provision of Traffic signal and signs	W15	3.00	2.60	0.40	1.48	-4.64	0.000
Presence of buffer	W16	2.13	1.89	0.24	1.35	-3.64	0.000
Street lighting	W17	3.41	3.12	0.29	1.51	-3.84	0.000
CCTV surveillance	W18	3.34	1.50	1.84	1.26	-6.24	0.000
Police patrolling	W19	4.09	2.08	2.01	1.32	-30.58	0.000

4.4. Acceptable Walking Distance

Acceptable walking distance is the distance that commuter is willing to walk to transit station (Rastogi & Rao, 2003). To promote walkability around transit station and to encourage socially affordable modes to access transit stations, an analysis was conducted to recognize the utility of walk mode among metro users with respect to acceptable walking distance. A graph was plotted between distance travelled by foot and corresponding cumulative frequency of metro users. Walk distance and number of metro users obtained from survey data were used for plotting graphs. Thus, cumulative frequency value at any distance of distribution curve will provide the number of users who stop walking once their walk trip distance crosses that distance.

Various frequency distribution curves are plotted for different groups of users those were classified according to their gender, age group, dependency factor, occupation, household income and vehicle occupancy. The acceptable walking distance is estimated based on statistical analysis. Cumulative frequency curve for walking distance of gender group is illustrated in Fig. 9. Males are likely to walk a greater distance than females. This result is supported by the analysis conducted by Census of India (2011) in which average distance travelled by women is lower than that of the men in many metro cities of India. According to the NCRB (National Crimes Record Bureau, 2016), Delhi is one of the most unsafe cities in India, especially for women and children. It accounted for the highest crime rate of 182.1 compared to the national average of 77.2 amongst the metropolitan cities during 2016. Nearly 40% of cases reported were rape cases. Thus, this may be a possible reason for the difference in distance walked by women and men in Delhi.

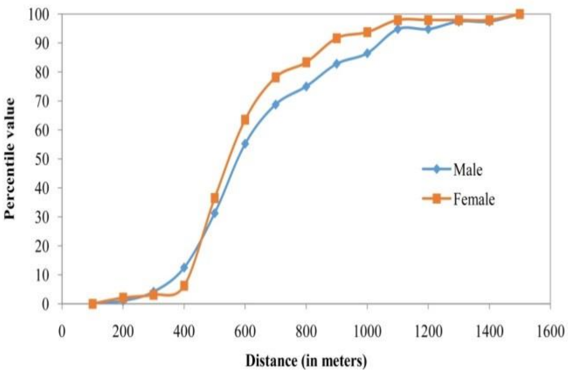


Figure 8: Cumulative frequency curve for walk by gender

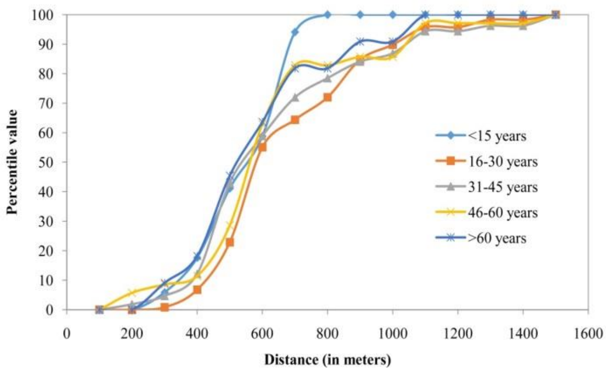
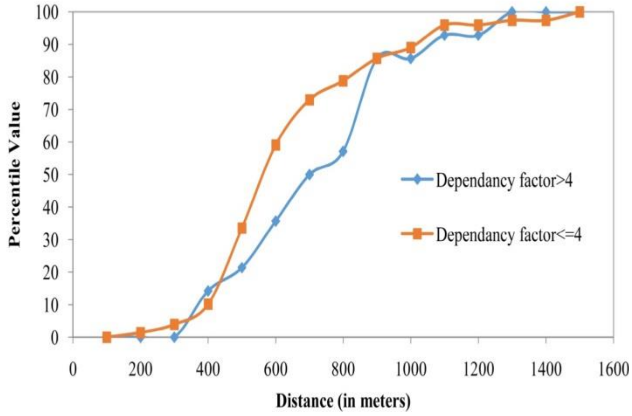


Figure 9: Cumulative frequency curve for walk by age group

Age group is classified into 5 groups, namely, 0-15 years, 16-30 years, 31-45 years, 46-60 years and over 60 years as shown in Fig. 10. It can be inferred from the figure that the walk distance is highest for metro users with age group of 16 to 30 years. Higher walk distance for an age group of 16-30 years can be explained as younger group takes more steps towards transit (Morency et al., 2011). The walk distance is the lowest for age group of 1to15 years.

Trip length frequency distribution by dependency factor is presented in Fig. 10. Basically, dependency factor is a measure of members supported by working member in the household. Value 4 is taken as a reference for dependency factor based on average size of household. It can be noted that there is a significant difference in both groups (dependency factor >4 and dependency factor $\leq$ 4) up to 80th percentile value. Subgroup of dependency factor greater than 4, walks greater distance to access metro station. People who are earning and supporting more number of members in their household may prefer to walk greater distance to minimize their expenses.

Occupational group is categorized into four subgroups, namely, employed, self-employed, student and other. The subgroup 'other' consists of unemployed, retired and house-wife. Since access trip characteristics of these subgroups are similar, they are combined together. It can be inferred from Fig. 11 that trends of subgroups are found similar between 10th to 60th percentile values except for self- employed subgroup. Trip length is found to be maximum for 'employed' subgroup and least for 'others' subgroup. This finding is in accordance with Census report of India that Indian cities walk for works (The Hindu, April, 2016).



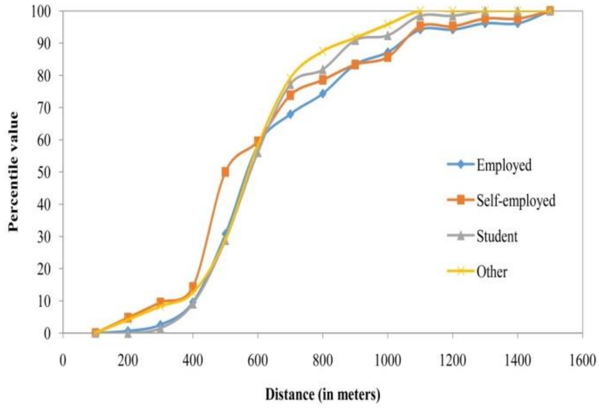
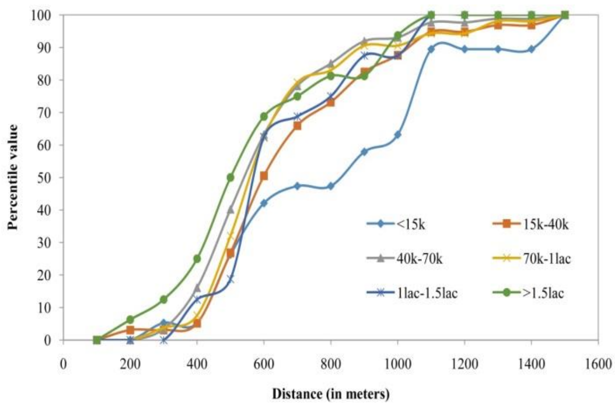


Figure 10: Cumulative frequency curve for walk by dependency factor

Figure 11: Cumulative frequency curve for walk by occupation

The metro users are also segmented into six subgroups by monthly income of household, namely, less than Rs. 15,000 (<15k), Rs. 15,000 to Rs. 40,000 (15k -40k), Rs. 40,000 to 70,000 (40k to 70k), Rs. 70,000 to Rs. 1,00,000 (70k to 1 lac), Rs. 1,00,000 to Rs. 1,50,000 (1 lac to 1.5 lac) and above Rs. 1,50,000 (>1.5 lac). Frequency distribution curve for monthly household income is presented in Fig. 12. It can be inferred from this curve that lower income group (<15k) shows highest walk trip lengths and higher income group (>1.5 lac) has lowest walk trip lengths. The results are compiled with the fact that higher income group prefers smaller walking distance.

Grouping is also done based on the vehicle ownership namely; non-motorised vehicle group and motorized vehicle group. It is observed that people who own motorized vehicle are walking for smaller distance than people who do not have the motorized vehicle, as people with low income do not have any option other than walking to access metro station (Fig. 13).



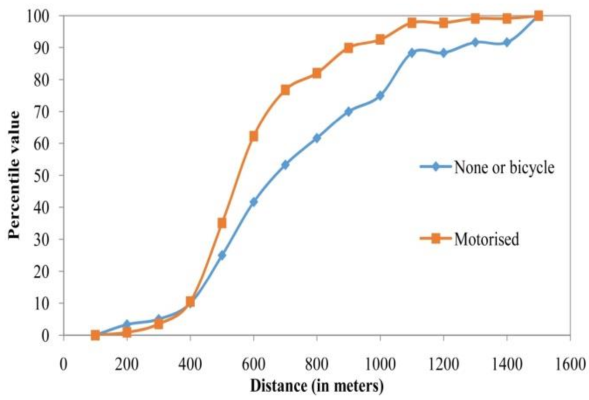


Figure 12: Cumulative frequency curve for walk by household income

Figure 13: Cumulative frequency curve for walk by vehicle ownership

The methodology proposed by Arasan et al. (1994) is adopted in this study to compute acceptable walking distance. If the observed data follow a standard probability distribution then the critical distance can be found easily by directly using simple calculus. Therefore, field data is fitted with various types of distributions like normal and gamma distribution, which are generally suitable for walk distances data fitting. To find suitable distribution for fitting data set, a goodness of fit Chi-Square test is done. A primary analysis showed that field data was following gamma distribution. After identifying the suitable distribution, a point is located at which, rate of change of slope of cumulative distribution curve is negatively maximum, termed as acceptable walking distance. Acceptable walking distance in case of gamma distribution is computed as follows;

The slope of cumulative distribution F(x) is

$$\frac{dF(x)}{dx} = \frac{\beta^{\alpha} x^{\alpha-1} e^{(-\beta x)}}{\Gamma(\alpha)} \tag{2}$$

Where x = trip distance, α = shape parameter and β = inverse scale parameter. Since we have to compute the maximum rate of change of slope, the second derivative of $F(x)$ must be evaluated.

$$\frac{d^2F(x)}{dx^2} = \frac{\beta^{\alpha}\{(\alpha-1)x^{\alpha-2}e^{-\beta x} - \beta e^{-\beta x}x^{\alpha-1}\}}{\Gamma(\alpha)} \tag{3}$$

Hence, Eq. (3) has to be maximized in order to obtain the value of x, therefore, the third derivative was worked out and equated it to zero, and value of x was obtained as

$$x_{critical} = \frac{(\alpha-1) \pm \sqrt{(\alpha-1)}}{\beta} \tag{4}$$

Acceptable walking distances and their percentile values which are computed from fitted distribution curves for various categories and comparison with their mean values are illustrated in Table 5. It can be inferred from results that female respondents, respondents having dependency factor ≤ 4 and respondents owing motorized vehicles have lower acceptable walking distance than their respective counterpart subgroups. It is seen that respondents of employed group, respondents within age group of 16 to 45 years and respondents with low income (< Rs.15,000) have higher acceptable walking distance in their respective categories.

Table 5: Walk access distance characteristics for different categories

Categories	**Subgroup**	**Mean (m)**	**Standard deviation (m)**	**Acceptable distance (m)**	**percentile value**	**Sample size**
Gender	Male	605	271	726	73	192
	Female	557	216	672	78	96
Age Group	0-15 years	501	141	595	78	17
	16-30 years	622	241	750	74	118
	31-45 years	584	282	693	72	107
	46-60 years	561	252	673	74	35
	>60 years	523	225	628	73	11
Dependency factor	*DF* <=4.0	585	254	703	75	274
	DF >4.0	667	255	805	74	14
Occupation	Employed	611	273	732	74	156
	Self-employed	564	289	663	72	42
	Student	574	196	690	77	66
	Other	537	177	648	74	24
Household Income	<Rs. 15,000	726	374	853	70	19
	Rs. 15,000-40,000	623	256	751	74	97
	Rs. 40,000-70,000	545	221	657	73	87
	Rs. 70,000-1,00,000	576	242	693	74	53

	Rs. 1,00,000-1,50,000	590	211	711	75	16
	>Rs. 1,50,000	506	256	596	70	16
Vehicle Occupancy	None or bicycle	701	333	874	75	60
	Motorised	560	220	676	74	228

Mean walking distance, acceptable walking distance and percentage share of walking with respect to 15 metro stations are discussed in Table 6. It is noticed that Apollo Jasola and Rajiv Chowk metro stations are having greater mean walking distances than other metro stations. As per the results, mean walking distance for Shahdara metro station is higher than the average value but,the share of the walking mode is the lowest (27.2%). Walk percentage share is low because of the lack of walk friendly environment near the metro station. But walk distance is found to be higher as the users from the lower socio-economic background are residing far from the metro station and they prefer to opt walk mode to access metro as part of their savings. Kalkaji and Rohini west metro stations are having low mean walking distance as well as low walk share because of the higher socio-economic profile of area. It is found that higher income group prefer to walk shorter distances and choose faster modes over walk mode to access transit stations.

Table 6: Distribution of walking distances and walk mode share

Station name	**Metro line**	**Mean walking distance (m)**	**Std. deviation**	**Acceptable walking distance**	**Percentage share of walk mode (%)**
Rohini west	Red	525	200.3	629	36
Netaji Subhash place	Red	630	214.3	758	57.8
Shahdara	Red	633	341.6	749	27.2
Kashmere gate	Yellow	591	277.8	684	50
Chandni Chowk	Yellow	573	265.2	687	42.9
Rajiv Chowk	Yellow	683	209.2	813	42.8
Central Secretariat	Yellow	550	341.6	551	57.1
INA	Yellow	626	222.8	752	69.2
Hauzkhas	Yellow	515	211.2	623	47.8
Rajouri garden	Blue	502	243.1	605	48.1
Karol Bagh	Blue	608	215.2	733	51.1
Laxmi Nagar	Blue	591	261.7	711	54.6
Karkar duma	Blue	535	233.4	645	58.8
Kalkaji Mandir	Violet	484	128.1	570	43.3
Apollo Jasola	Violet	840	445.4	986	52.3

5. SALIENT FINDINGS AND IMPLICATION OF THE STUDY

Access trips' characteristics are analysed to understand the present scenario which will be beneficial to identify policies for promoting green modes to access metro stations. Findings are discussed here:

- Average household size, average individual income, average expenditure on transport are found to be 4.61, Rs. 27,919 and Rs. 2,474 respectively. Since more than half of the metro users are graduates, most of the trips are work trips (63.73%) and maximum share of metro users lie in age group of 16 to45 years old (77.63%) and males are the dominant users (66.77%).

- Analysis revealed that certain relationships exist between access travel pattern and the socio-economic characteristics of metro users. It is noted that lower income group prefers to walk longer distance than higher income group. Vehicle ownership and economic status are also related to each other. Hence, motorized vehicle ownership is found to be increasing with increase in economic status of household and vice-versa. Proportion of lower income household increases with an increase in access distance.
- There is a considerable representation of walk mode share in total access mode share. About 49% of trips are walking trips and among walk trips 86% trips cover equal or less than 800 m trip distance. Highest share of walking is found for INA metro station and lowest for Shahdara metro station. Study analysed relation between percentage of walk share and metro users' satisfaction with walking environment for each station and found that they are related to each other. Thus, walk mode share can be increased by providing pedestrian-friendly environment. Sidewalk availability is the basic need of pedestrians. Sidewalk width, quality, cleanliness, and protection from the weather in the form of trees, are factors found to be more important to pedestrians for choosing walk mode as access mode. Respondents rated walk access environment of Shahdara, Chandni-Chowk and Laxmi Nagar as below satisfaction. Hence, these stations should be given priority for improving walk access environment by planning authorities.
- Two tailed paired t-test results indicate that there is significant difference in satisfaction and importance ratings of respondents. Attributes like shaded sidewalk, police patrolling, cleanliness of sidewalk and CCTV surveillance have greater inconsistencies in satisfaction and importance ratings. Policies should be deployed to fill out these differences so that perception towards walking environment as well as access walk mode share can be increased.
- Distribution of access trip with time shows that 91% walk trips have a travel time of less than 10 minutes. One can interpret that activities should be located within 10 minutes walking distance from metro stations.
- Acceptable walking distance is estimated from frequency distribution curve of walk distance of different subgroups based on rate of change of slope and it is estimated to be 74th percentile value for Delhi metro users which differs from percentile value suggested by Arasan et al. (1994) and Rastogi and Rao (2003), but it is quite similar to percentile reported by O'Sullivan and Morrall (1996).
- The acceptable walking distance for females is found to be shorter than males. Security is the main concern for females as most of the respondents rated below average satisfaction score for security parameter while accessing metro station by foot. Incidences of crime deter walking for females as mentioned in Kim et al. (2007). So there is need to improve security around metro stations with certain measures such as police patrolling at night, video surveillance by CCTV, proper street lighting etc. (Kumar et al., 2011; Rajendran et al., 2017). One of the other major reasons for low acceptance for females is that females prefer closer location for doing their activities. Finding is found to be consistent with the study conducted by Srinivasan and Rgers (2005).
- Acceptable walking distance for subgroup having a motorised vehicle is found to be shorter than non-motorised subgroup. Higher income group also has shorter walking distance than lower income group as higher vehicle ownership is associated with higher income group (Rastogi and Rao 2003). Town planners can use this acceptable

distance for planning sustainable communities by deciding the settlement location according to income characteristics. Neighbourhood facilities could also be developed based on the acceptable distance of particular income group, so that group like higher income group can shift from private vehicle to non-motorised vehicle and public transport.

- The comparison of mean walking distances and mean walking speeds of various cities across the world is presented in Table 7. The mean walking distance for the present study is found to be 590 m and it is comparable with mean walking distances reported for Sydney and Singapore and mean walking speed is comparable with Beijing. Mean walking speed value is similar to the value of the study conducted for Delhi by Chandra and Bharti (2013).

Table 7: Comparison of mean walking distances and mean walking speeds

City/ Country	Author	Mean Walking Distance(m)	Mean walking speed (m/min)
Calgary, Canada	Seneviratne (1985)	335	-
New York, United States	Seneviratne (1985)	523	-
Riyadh, Saudi Arabia	Koushki (1988)	859	65
Indonesia	Tjahjati et al. (1991)	400	58-83
Tiruchirapalli, India	Arasan et al. (1994)	1700	-
Calgary, Canada	O'Sullivan and Morrall (1996)	326-649	-
Netherlands	Rietveld (2000)	1200	-
Mumbai, India	Rastogi and Rao (2003)	910	-
Singapore	Olszewski and Wibowo (2005)	608	-
Brisbane, Australia	Burke and Brown (2007)	760	-
United States	Agarwal, Schlossberg and Irvin (2008)	928	-
Sydney, Australia	Daniels and Mulley (2011)	573	-
Jinan, China	Jiang et al. (2012)	475-1392	-
Beijing, China	Yang, Yan, Xiong and Liu (2013)	472	75
Montreal, Canada	El- Geneidy et al. (2014)	564	-
Bangalore, India	Rahul and Verma (2014)	511	69
Delhi (DTC), India	Johar et al. (2015)	647	-
Delhi (MRTS), India	Present study	590	76

6. CONCLUSIONS AND DISCUSSION

The study endeavours to analyse the present access trip characteristics of metro users, their satisfaction with the existing walking environment and how the acceptable walking distance differ among various groups of metro users for accessing metro stations in Delhi. The certain relationship was identified between travel patterns and socio-economic characteristics of trip makers. The results conclude that the access walking distance and walk mode share are positively associated with good infrastructural facilities around metro stations. The study conducted by Rahul and Verma (2014) supports these results in which acceptable walking distance will increase with good pedestrian facilities and higher acceptable walking distance will encourage people to shift towards non-motorised transport options. The present study also tries to enlighten the influence and importance of various built environmental parameters for selecting walk as an access mode and also shows the inadequacies of the existing walking environment. Thus, by addressing the shortcomings of walking facilities and other qualitative factors through policy implications, one can effectively improve the percentage of walk mode share for accessing metro station. The acceptable walking distance increases with the upgrade of infrastructural facilities. As the acceptable walking distance increases, more people will shift to walking. This shifting of people to walk mode would reduce the number of motorized vehicle usage that will further lead to a healthy society. The estimation of acceptable walking distance may be useful to locate various activities, to estimate distance up to which infrastructure can be improved and to align the metro service.

These results may be helpful for policymakers to understand the present travel patterns of metro users and their needs while accessing metro station. Thus, it helps to formulate strategies for improving walk accessibility to Delhi metro stations. The results of the present study have several policy and design implications. Delhi Government is falling behind in respect of providing pedestrian friendly infrastructure due to lackadaisical approach towards pedestrians. Presently there is no study available in the context of Delhi regarding the acceptable walking distances. Therefore, this study aims to bridge this gap to identify the pedestrian friendly catchment area and safety concerns. The outcomes of this study can be supportive to frame transport policies for the improvement of microscale built environment factor that are reasonably easy and practical than mesoscale factors such as diversity, density, etc., that requires huge alteration of the urban structure. Modal shift towards public transport as well as walk to access it could be possible by improving the micro scale built environment factors,. Relevant policy measures for pedestrians should be framed to achieve both long-term and short-term strategies. Based on the present study, various strategies for pedestrians have been recommended as follows:

- To improve crossing facilities at city level by installing pedestrian traffic signals.
- To improve the quality of sidewalks by implementing measures to increase quality (with anti-skid and resilient surface), continuity (minimising the change in levels), safety, cleanliness and provide more space to ease walkability.
- To provide lightning for better visibility in night, weather protection through trees and sunshades.
- To avoid conflict with traffic, segregated sidewalks (either by guardrails or provision of raised sidewalk), foot over bridges, subways, zebra crossings etc.
- To ensure police patrolling along the streets to warrant psychological security.
- To restrict two- wheeler entry and car parking on footpaths, enforcing traffic rules, and speed limits.
- To adopt traffic calming strategies such as lane narrowing, speed humps, speed tables, speed cushions, or making shared streets.

The implementation of these suggestive recommendations depends on the government initiatives along with the appropriate budget allocation. Actions taken along this line will surely encourage people to choose walking as well as public transport.

With regard to the limitations, the present study is limited geographically to Delhi context. The acceptable walking distance computed for an area cannot be imposed on another area as it depends on socioeconomic characteristics, demographic characteristics and transport facility features in a city. Results of the study can be applied to metro cities in Asia that are similar to Delhi. Further study can be conducted by employing analytical methods to examine the perception of non-metro users on access environment around transit station. The willingness to shift from motorised modes to non-motorised modes can be studied in future by stated preference survey with comparison between present and improve access environment.

ACKNOWLEDGMENT

This research was done while the author was a master’s student at IIT Roorkee and was supported by the scholarship awarded from Ministry of Human Resources and Development (MHRD), India.

REFERENCES

Advani, M. and Tiwari, G. (2006), March. Bicycle–As a feeder mode for bus service. In Velo Mondial conference: third global cycling planning conference, Cape Town.

Alfonzo, M., Guo, Z., Lin, L. and Day, K., (2014). Walking, obesity and urban design in Chinese neighborhoods. Preventive medicine, 69, pp.S79-S85.

Arasan, V. Thamizh, V. R. Rengaraju, and KV Krishna Rao (1994) Characteristics of trips by foot and bicycle modes in Indian city. *Journal of transportation engineering,* 120 (2), 283-294.

Asadi-Shekari, Z., Moeinaddini, M., Shah, M.Z., 2014. A pedestrian level of service method for evaluating and promoting walking facilities on campus streets. Land Use Policy 38, 175–193.

Audirac, I., (2008). Accessing transit as universal design. Journal of Planning Literature, 23(1), pp.4-16.

Bivina, G. R., Gupta, A., & Parida, M. (2019). Influence of microscale environmental factors on perceived walk accessibility to metro stations. Transportation Research Part D: Transport and Environment, 67, 142-155.

Burke, Matthew, and A. L. Brown (2007) Distances people walk for transport. *Road & Transport Research: A Journal of Australian and New Zealand Research and Practice* 16 (3), 16.

Census-India, Census of India 2011 (2012) The Government of India, New Delhi, India.

Cervero, Robert, and Michael Duncan (2002). Transit's value-added effects: light and commuter rail services and commercial land values. *Transportation Research Record: Journal of the Transportation Research Board* 1805: 8-15.

Cervero, Robert, Olga L. Sarmiento, Enrique Jacoby, Luis Fernando Gomez, and Andrea Neiman (2009) Influences of built environments on walking and cycling: lessons from Bogotá. *International Journal of Sustainable Transportation* 3 (4), 203-226.

Chandra, Satish, and Anish Kumar Bharti (2013) Speed distribution curves for pedestrians during walking and crossing. *Procedia-Social and Behavioral Sciences* 104, 660-667.

Daniels, Rhonda, and Corinne Mulley (2013) Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use* 6 (2), 5-20.

Dantas, (2005). Improving Pedestrian and Bicyclists Access to Selected Transit Stations. Massachusetts Highway Department, Boston

Dixon, Linda (1996) Bicycle and pedestrian level-of-service performance measures and standards for congestion management systems. *Transportation Research Record: Journal of the Transportation Research Board* 1538: 1-9.

DMRC, (2017) Delhi Metro Rail Corporation. *Delhi Metro's Cumulative Ridership for the financial year 2016-2017 crosses one billion.* Retrieved July, 15, from http://www.delhimetrorail.com/press_reldetails.aspx?id=ZlXC4jMrU00lld

Dowling, Richard, Aimee Flannery, Bruce Landis, Theo Petritsch, Nagui Rouphail, and Paul Ryus (2008) Multimodal level of service for urban streets. *Transportation Research Record: Journal of the Transportation Research Board* 2071: 1-7.

El-Geneidy, Ahmed, Michael Grimsrud, Rania Wasfi, Paul Tétreault, and Julien Surprenant-Legault (2014) New evidence on walking distances to transit stops: identifying redundancies and gaps using variable service areas. *Transportation* 41 (1): 193-210.

Evans IV, J., Perincherry, V., and Douglas III, G. (1997). Transit friendliness factor: approach to quantifying transit access environment in a transportation planning model. Transportation Research Record: Journal of the Transportation Research Board, (1604), 32-39.

Gallin, N. (2001). Quantifying pedestrian friendliness--guidelines for assessing pedestrian level of service. Road & Transport Research, 10(1), 47.

Givoni, Moshe, and Piet Rietveld (2007) The access journey to the railway station and its role in passengers' satisfaction with rail travel. *Transport Policy* 14 (5): 357-365.

Hanson, M. E (1993) Economic incentives and mode choice. Transp. Res. Rec. 1396, Transportation Research Board, Washington, D.C., 61–68.

Hendricks, S. J., Fleury, E. S., Flynn, J., & Goodwill, J. (2005). Impacts of transit oriented development on public transportation ridership (No. BD549-05). National Center for Transit Research, University of South Florida.

IRC: 103-2012, (2012) *Guidelines for pedestrian Facilities.* Indian Roads Congress, Delhi, India.

Jacobs, G. D., D. A. C. Maunder, and P. R. Fouracre (1981). Transport problems of the urban poor in developing countries. In *Transport Research for Social and Economic Progress. Proceedings of the Second World Conference on Transport Research United Kingdom Government Organisation for Economic Cooperation and Development European Conference of Ministers of Transport*.

Jiang, Yang, P. Christopher Zegras, and Shomik Mehndiratta (2012) Walk the line: station context, corridor type and bus rapid transit walk access in Jinan, China. *Journal of Transport Geography* 20 (1), 1-14.

Johar, Amita, S. Jain, P. Garg, and P. Gundaliya (2015) A study for Commuter Walk Distance from Bus Stops to Different Destination along Routes in Delhi. *Eur. Transp.*

Khisty, C., and P. Sriraj (1996) Use of scenario-building transportation model for developing countries. *Transportation Research Record: Journal of the Transportation Research Board* 1563, 16-25.

Kim, Saehoon, Sungjin Park, and Jae Seung Lee (2014) Meso-or micro-scale? Environmental factors influencing pedestrian satisfaction. *Transportation Research Part D: Transport and Environment* 30, 10-20.

Kim, Sungyop, Gudmundur F. Ulfarsson, and J. Todd Hennessy (2007) Analysis of light rail rider travel behavior: impacts of individual, built environment, and crime characteristics on transit access. *Transportation Research Part A: Policy and Practice* 41 (6), 511-522.

Koushki, Parviz Amir (1988) Walking characteristics in central riydah, Saudi Arabia. *Journal of Transportation Engineering*114 (6), 735-744.

Krejcie, R.V. and Morgan, D.W. (1970) Determining sample size for research activities. Educational and psychological measurement, 30(3), pp.607-610.

Kumar, Pawan, S. Y. Kulkarni, and M. Parida (2011). Security perceptions of Delhi commuters at Metro-bus interchange in multi modal perspective. *Journal of transportation security* 4 (4), 295-307.

Lee, Chanam, and Anne Vernez Moudon (2004) Physical activity and environment research in the health field: Implications for urban and transportation planning practice and research. *Journal of planning literature* 19 (2): 147-181.

Loutzenheiser, David (1997) Pedestrian access to transit: model of walk trips and their design and urban form determinants around Bay area rapid transit stations. *Transportation Research Record: Journal of the Transportation Research Board* 1604: 40-49.

Litman, Todd (2003) Economic value of walkability. *Transportation Research Record: Journal of the Transportation Research Board* 1828: 3-11.

Martens, K. (2004). The bicycle as a feedering mode: experiences from three European countries. Transportation Research Part D: Transport and Environment, 9(4), pp.281-294.

Mitra-Sarkar, S (1994) A method for evaluation of urban pedestrian spaces. Ph.D. diss., University of Pennsylvania.

Morency, Catherine, Martin Trépanier, and Marie Demers (2011) Walking to transit: an unexpected source of physical activity." *Transport Policy* 18 (6): 800-806.

Murray, Alan T., Rex Davis, Robert J. Stimson, and Luis Ferreira (1998) Public transportation access. *Transportation Research Part D: Transport and Environment* 3 (5): 319-328.

NCRB (2016) *National Crime Record Board*, *Report*, Urban Transport, Ministry of Home Affairs. Retrieved Dec. 22, 17, from http://ncrb.gov.in/StatPublications/CII/CII2016/pdfs/NEWPDFs/Crime%20in%20India%20-%202016%20Complete%20PDF%20291117.pdf

O'Sullivan, Sean, and John Morrall(1996) Walking distances to and from light-rail transit stations. *Transportation research record: journal of the transportation research board* 1538: 19-26.

Olszewski, Piotr, and Sony Wibowo (2005) Using equivalent walking distance to assess pedestrian accessibility to transit stations in Singapore. *Transportation Research Record: Journal of the Transportation Research Board* 1927: 38-45.

Parida, P.M., Najamuddin, Parida, M., 2007. Planning, design & operation of sidewalk facilities in Delhi. Highway research bulletin, Indian Roads Congress, Delhi, No.77m 81–95.

Park, S., Choi, K., & Lee, J. S. (2015). To walk or not to walk: Testing the effect of path walkability on transit users' access mode choices to the station. International Journal of Sustainable Transportation, 9(8), 529-541.

Porta, S., Renne, J.L., 2005. Linking urban design to sustainability: formal indicators of social urban sustainability field research in Perth, Western Australia. Urban Des. Int. 10 (1), 51–64.

Priemus, Hugo, Peter Nijkamp, and David Banister (2001) Mobility and spatial dynamics: an uneasy relationship. *Journal of transport geography* 9 (3): 167-171.

Pikora, Terri J., Fiona CL Bull, Konrad Jamrozik, Matthew Knuiman, Billie Giles-Corti, and Rob J. Donovan(2002) Developing a reliable audit instrument to measure the physical environment for physical activity. *American journal of preventive medicine* 23 (3): 187-194.

Rahul, T. M., and Ashish Verma (2014) A study of acceptable trip distances using walking and cycling in Bangalore. *Journal of Transport Geography* 38: 106-113.

Rajendran, B. G., Parida, M., & Sapnani, S (2018) Modeling Perceived Pedestrian Level of Service of Sidewalks: An Application of Structural Equation Modeling. Paper

presented at the Transportation Research Board 97th Annual Meeting: (No. 18-00815), Washington D.C., January 2018.
Rastogi, Rajat, and K. V. Krishna Rao (2003) Travel characteristics of commuters accessing transit: Case study. *Journal of Transportation Engineering* 129 (6): 684-694.
Rastogi, R., (2010). Willingness to shift to walking or bicycling to access suburban rail: Case study of Mumbai, India. Journal of urban planning and development, 136(1), pp.3-10.
Rietveld, Piet (2000) The accessibility of railway stations: the role of the bicycle in The Netherlands. *Transportation Research Part D: Transport and Environment* 5 (1): 71-75.
Rodríguez, Daniel A., and Joonwon Joo (2004) The relationship between non-motorized mode choice and the local physical environment. *Transportation Research Part D: Transport and Environment* 9 (2): 151-173.
Schlossberg, Marc, and Nathaniel Brown (2004) Comparing transit-oriented development sites by walkability indicators. *Transportation Research Record: Journal of the transportation research board* 1887: 34-42.
Seneviratne, Prianka N (1985) Acceptable walking distances in central areas. *Journal of Transportation Engineering* 111 (4): 365-376.
Sun, G., Webster, C. and Chiaradia, A., (2017). Objective assessment of station approach routes: Development and reliability of an audit for walking environments around metro stations in China. Journal of Transport & Health, 4, pp.191-207.
Tjahjati, BuDHY, S. Soegijoko, and S. I. Horthy (1991) Role of Non-Motorized Transport Modes in Indonesian Cities. *Transportation Research Record* 1294: 16-25.
Srinivasan, Sumeeta, and Peter Rogers (2005) Travel behavior of low-income residents: studying two contrasting locations in the city of Chennai, India. *Journal of Transport Geography* 13 (3): 265-274.
The Hindu, *India walk to work: Census*. Retrieved Dec. 24, (2017), from http://www.thehindu.com/data/india-walks-to-work-census/article7874521.ece.
Travisi, Chiara M., Roberto Camagni, and Peter Nijkamp (2010) Impacts of urban sprawl and commuting: a modelling study for Italy. *Journal of Transport Geography* 18 (3): 382-392.
Wardman, Mark, and Jonathan Tyler (2000) Rail network accessibility and the demand for inter-urban rail travel. *Transport Reviews* 20 (1): 3-24.
Weinstein Agrawal, Asha, Marc Schlossberg, and Katja Irvin (2008) How far, by which route and why? A spatial analysis of pedestrian preference. *Journal of urban design* 13 (1): 81-98.
Yang, Min, Jingyao Zhao, Wei Wang, Zhiyuan Liu, and Zhibin Li (2015) Metro commuters' satisfaction in multi-type access and egress transferring groups. *Transportation Research Part D: Transport and Environment* 34: 179-194.
Yang, Rongrong, Hai Yan, Wen Xiong, and Tao Liu (2013) The Study of Pedestrian Accessibility to Rail Transit Stations Based on KLP Model. *Procedia-Social and Behavioral Sciences* 96: 714-722.