IATSS Research 39 (2016) 164–172

Contents lists available at ScienceDirect

IATSS Research

Research article

Access–egress and other travel characteristics of metro users in Delhi and its satellite cities

Rahul Goel *, Geetam Tiwari

Transportation Research and Injury Prevention Programme, Indian Institute of Technology, Hauz Khas, Delhi, 110016, India

ARTICLE INFO

Article history:
Received 15 April 2015
Received in revised form 29 September 2015
Accepted 14 October 2015
Available online 23 October 2015

Keywords:
Metro system
Public transportation
Access
Trip length
Delhi
Mode choice

ABSTRACT

We present details of access–egress as well as other travel characteristics of metro users in Delhi, and its satellite cities. For this study, we conducted an on-board survey of metro commuters ($n = 1112$) in 2011. Survey respondents reported use of seven different modes to access metro stations, with 55% using non-motorized modes. The alternative modes reported by the respondents indicate that, in the absence of metro, a majority of commuters will use bus, and up to 40% will use private motorized modes. Up to 18% of the respondents may not have made the trips if metro was not available, indicating a significant proportion of induced trips. We used multinomial logistic regression models to understand the factors associated with the choice of access–egress modes, as well as alternative mode, for the current trip. Trip length, vehicle ownership, location of metro station (classified as administrative units within Delhi, and neighbouring cities), and population density around metro station have statistically significant associations with the choice of access/egress modes. Alternative modes of metro trips are found to be dependent on trip length and vehicle ownership. We found that up to 88% of metro trips have an interconnectivity ratio with the range of 0.2 to 0.5, with 0.4 as the mean, corroborating the results of [13] for a European setting. The results indicate that this ratio may be universally applicable, thus making it a robust parameter to assess, or forecast, ridership of public transportation systems.

1. Introduction

Delhi has been experiencing a declining mode share of public transportation (PT) trips. From 1994 to 2008, it reduced from 42% [1] to 29% [2]. Since 1990s, auto ownership of the city increased rapidly. During 1991–2000, on an average, 50,000 cars and 100,000 motorized two-wheelers (2W) were registered every year, which almost doubled in the following decade (2001–2010) to 110,000 and 180,000 per year [3]. However, growing auto-ownership in the city was not accompanied by a robust supply of PT. Though development of bus-based rapid transit network throughout the city could have been achieved much faster, however, policy makers preferred metro system instead. Metro in Delhi started its operation in December 2002, with an 8-km line. Its construction has been carried out in phases. With the completion of Phase I and II by 2011, it had an operational network of 190 km, consisting of elevated, at-grade, and underground lines.

From an international perspective of major cities, city-based rail development in Delhi is recent. For instance, in most cities of the industrialized world, city-based rail systems started in the early 20th century — London (in year 1890), Chicago (1897), Paris (1900), Boston (1901), Berlin (1902), New York City (1904), Madrid (1919) and Tokyo (1927). Thus, unlike Delhi, rail development in these cities preceded the growth of private motorization. Prior to the Delhi metro, metro system in India was constructed in Kolkata city, located in the eastern part of the country. This was the first underground railway project implemented in India. Its expected daily ridership after opening of first phase in 1978 was anticipated to be 1.3 million passengers, and in 1990, 1.7 million. However, the number of passengers on the metro during 1999–2000 could reach only up to ~150,000, which is only one-eleventh of the estimated traffic. The system originally estimated to be constructed at a cost of US Dollars (USD) 31 million, was completed at a cost of USD 355 million [4]. Similarly, ridership forecast for Delhi metro could not come close to actual ridership. After nearly USD 4.2 billion spent in its construction [5], in 2009, Delhi metro was operating at a ridership which was one-fourth of the forecast [6]. While success of Delhi metro as a public transport mode is still questionable, its successful implementation fuelled up the inclination of Indian policymakers towards implementation of metro systems in Indian cities. Currently, more than a dozen cities have them under planning or construction stage [7].

* Corresponding author at: MS-815, Main Building, Transportation Research and Injury Prevention Programme, IIT Delhi, Hauz Khas, Delhi, 110016, India. Tel.: +91 11 2659 6361.

E-mail address: rahulatiitd@gmail.com (R. Goel).

Peer review under responsibility of International Association of Traffic and Safety Sciences.

http://dx.doi.org/10.1016/j.iatssr.2015.10.001

Ridership of metro, or any PT system, is highly dependent on the time people spend during its access and egress parts [8,9], and the level and quality of access [10,11]. Access and egress are the weakest parts of a PT trip since these stages also involve much physical effort ([12] cited in [13]), and occur in an outdoor environment. As a result, with an increase in access and egress time, the usage of public transport decreases [14,15]. Access and egress (distance and time), in turn, depend on the coverage of PT system. The motivation of this study is to understand the access–egress parts of a metro trip in Delhi, and the different factors which influence the choice of access mode. In addition, we have investigated the mode-shift of current metro users. In this study, we present results from an on-board survey of Delhi metro users.

2. Delhi and its satellite cities

Delhi had a population of 16.7 million in 2011 [16], and with a built-up density of ~24,000 persons per square kilometre [17], it is one of the densest cities in the world [18]. Among all the major metropolitan cities in India, it has one of the highest motor-vehicle ownership, and among all states of India, has one of the highest per capita income (Delhi is a city-state) [3]. According to Census 2011, 21% of households own at least one car, 30% at least one motorized two-wheeler (2W), up to 30% own a cycle and 37% households own no vehicle. The ownership categories do not add to 100%, as the categories are not mutually exclusive, and one household can own more than one vehicle type.

In 2008, bus-based PT in Delhi catered to ~27% of the total trips [2], most of which are served by state-run bus system with a fleet of more than 10,000 buses operating on more than 700 routes [19]. Travel demand in Delhi is not only intra-city, but also has a significant share of inter-city travel because of growth of adjoining satellite cities around it. During the last three decades, total population of these cities – Ghaziabad, Faridabad, Gurgaon and Noida (see Fig. 1) – have grown 7 times, reaching 5.3 million in 2011 (Table 1). As a result, this region has become an agglomeration, giving rise to high demand for travel from one of these cities to another.

Table 1
Population and vehicle ownership according to Census 2011.

	Population	Car ownership[a]	2W ownership[b]
Delhi	16,750,000	21%	38%
Noida	650,000	30%	40%
Ghaziabad	2,400,000	18%	39%
Gurgaon	900,000	36%	43%
Faridabad	1,400,000	20%	44%

[a] defined as percent households owning at least one car.
[b] defined as percent households owning at least one 2W.

2.1. Delhi metro system

The network of Delhi metro consists of six lines (named by different colours), and covers not only Delhi, but also reaches some of its contiguous satellite towns — Noida in the east, and Gurgaon in south, just outside Ghaziabad in north-east, and Faridabad in south-east (see Fig. 1). Table 1 shows population and vehicle ownership in Delhi and its satellite cities. In 2011, Delhi metro had a daily ridership of 1.6 million [5]. The trains consisted of both 4 and 6 coaches, which run during off-peak and peak hours, respectively.

2.2. Other forms of public transportation (PT)

A variety of transit and para-transit modes operate in Delhi, which play a vital role in the daily travel of city's population. Para-transit refers

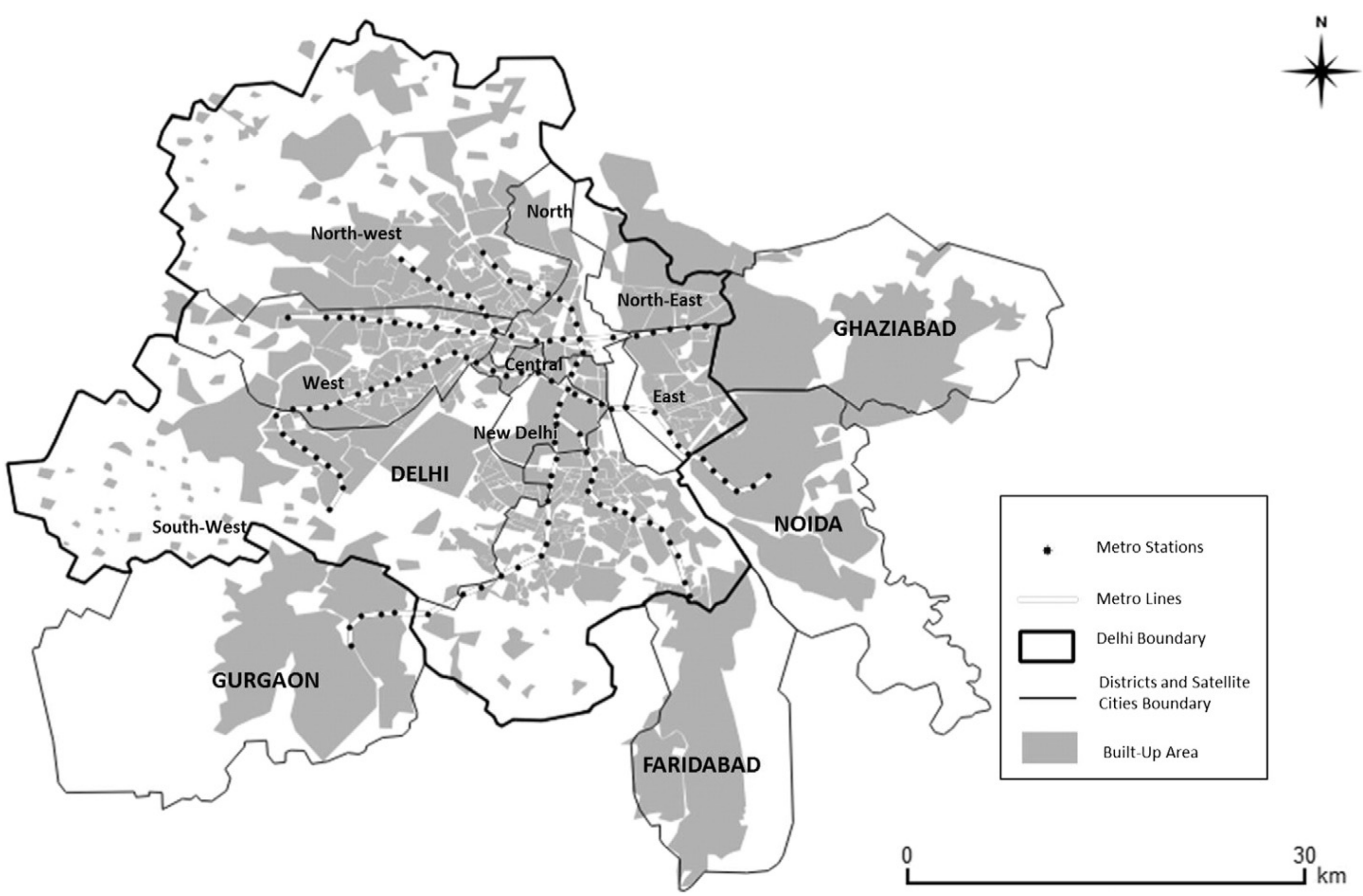

Fig. 1. Delhi metro network, districts of Delhi and surrounding satellite cities.

Table 2
Modal Share and Travel Time (with 95% CI) for access–egress trips.

Mode Used	% Trips (number of access–egress trips)	Time in minutes (number of access–egress trips)
Walk	43.7 (*968*)	5.8 ± 0.4 (950)
Cycle	1.0 (*21*)	12.5 ± 6.9 (*19*)
Cycle rickshaw	9.6 (*213*)	7.9 ± 0.9 (*203*)
Auto rickshaw	21.5 (*475*)	10.9 ± 1.2 (*468*)
Bus	11.0 (*244*)	21.6 ± 5.9 (*244*)
2W	3.5 (*77*)	9.8 ± 2.6 (*76*)
Car	9.4 (*208*)	13.0 ± 2.3 (*207*)

to the travel modes which differ from conventional transit in that they have no fixed schedules and their service is demand responsive. All the para-transit modes plying in Delhi area are privately operated, and are both motorized as well as non-motorized. Among non-motorized para-transit modes are the cycle-rickshaws. These are human powered tri-cycles with a capacity of two persons. They serve short distances, with most of their trips shorter than 2 km.

Among motorized para-transit, there are auto rickshaws and buses. Auto rickshaws are of two types — contract carriage and shared. Contract-carriage auto-rickshaws are three-wheeled scooter rickshaws, which operate like taxis and are equipped with fare metres, and have a capacity of 3–4 persons. Shared auto-rickshaws are both three-wheeled as well as four-wheeled vehicles. Unlike the former, shared auto-rickshaws operate on a fixed route, which is mostly short in length, and have intermediate stops. Depending on the manufacturer and the model of vehicle, their capacity varies from 3 to 4 persons or more.

Buses can be classified in to three categories. First category is the stage-carriage intra-city buses. These operate mostly on arterial roads, and thus have a lesser reach into minor roads of unplanned residential or commercial areas, due to lack of right-of-way required for their movement. They have a standard capacity of up to 55 passengers, but accommodate more than 70 during crush load. While bus system of Delhi, operated by government, is well developed, this is not the case in other satellite towns, which depend mostly on auto rickshaws and cycle rickshaws. Secondly, stage-carriage mini-buses, another mode of para-transit, operate on short fixed-routes (less than 10 km). Third category is the feeder buses started by Delhi metro in order to augment the connectivity of metro stations to their respective catchment areas. The latter two bus types have a seating capacity ranging from 12 to 24. All the above mentioned modes are authorized, and their fares regulated, by government. Also, only cycle rickshaws and contract-carriage auto-rickshaws operate like taxis, and thus have the highest fares among all these modes.

3. Passenger surveys

We conducted an on-board survey of Delhi metro passengers during the month of November 2011. The survey was carried out on the all the operational lines of Delhi metro network. It was conducted during morning and evening rush hours, starting at 8 AM and 6 PM, respectively, by six volunteers, with one volunteer in each coach of a 6-coach train. The volunteers, consisting of five males and one female, interviewed passengers, selected randomly, while travelling in the train. This was done to cater to five general coaches, where both males and female passengers are allowed, and one “women only” coach, where only female passengers are allowed. The total number of survey respondents was 1112.[1] The survey questionnaire consisted of 9 questions, which include questions regarding access and egress modes, origin and destination metro stations, auto ownership, alternative mode, and a question to investigate whether the current trip is induced by metro availability. A short questionnaire reduced the likelihood of non-response, which remained below 5%.

[1] Though, the total number of survey respondents is 1112, however, number of respondents for each question is less than that, since some question were not answered, or found to be ambiguous while cleaning the data.

Table 3
Vehicle ownership of survey respondents.

Vehicle Category	% Respondents (*n*)
No vehicle	44.5 (*436*)
Cycle	1.1 (*11*)
2W	25.3 (*248*)
Car	24.6 (*241*)
2W and car	4.3 (*42*)
2W, car and cycle	0.2 (*2*)

3.1. Access-egress outside metro station

For the purpose of this study, we consider access and egress of a metro trip divided into two segments— a) outside the metro station, which involves the trip from the origin of a passenger to the entry of metro station, or from exiting the metro station to destination, and b) inside the metro station, which involves movement of the passenger from station entry till s/he reaches train platform. While the survey questionnaire involved questions regarding outside the station only, the discussion regarding inside of the station is based on the observations by the survey team.

3.1.1. Modal share

In the survey, we asked respondents their access and egress modes. We did not ask whether the access or egress is at home or non-home end. Therefore, for the purpose of mode share, we do not discriminate access and egress trips, and for each respondent, consider them as two access (or egress) trips. Also, in a round trip, the two are interchanged. According to the survey, an access trip to metro involves seven different modes — walk, cycle, cycle rickshaw, auto rickshaw, 2W, car and bus (Table 2). During the survey, contract carriage auto-rickshaws, as well as shared auto-rickshaws were both recorded as auto rickshaws, with no distinction between the two. However, they differ significantly in terms of fares, with the fare of contract-carriage auto-rickshaws reaching up to 4–6 times that of shared auto-rickshaws, within 2 km.

More than half of trips have been carried out using non-motorized modes (walk–44%, cycle —1% and cycle-rickshaw– 9.6%). Para-transit modes (cycle rickshaw and auto rickshaws) have a combined share of almost one-third (31%) of the access–egress trips; almost three times that of buses (11%). Usage of private motorized modes – 2W and cars – for access–egress also differs significantly. While 2W have been used for less than 4%, cars were used for 9.4% of the access–egress trips. Note that most metro stations have parking facilities for 2W and cars, though the capacity varies from one station to another. Note that cars as access modes include those owned by respondents as well as those provided by employers to shuttle between offices and metro stations.

Table 4
Trip Length Frequency distribution survey respondents.

Trip Length (Km)	% Respondents (n = 1112)
0–2	0.5
2–4	1.9
4–6	4.4
6–8	3.5
8–10	5.1
10–15	17.5
15–20	21.7
20–25	15.0
25–30	12.2
30–35	8.0
>35	10.1

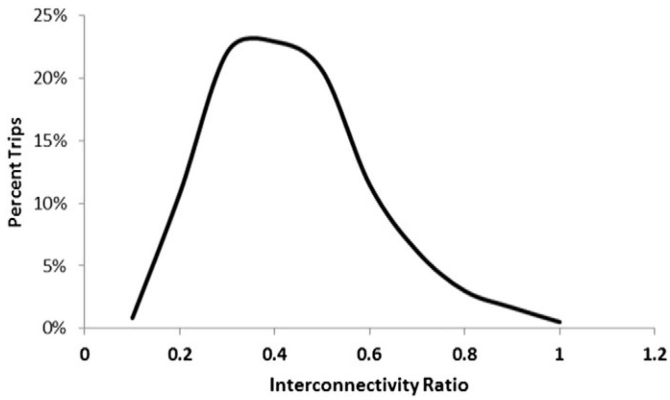

Fig. 2. Distribution of interconnectivity ratio.

3.1.2. Travel time for access–egress

In the survey, respondents reported time to access and egress outside metro station. Table 2 summarizes access–egress time for different modes. Walking has the least, while bus has the highest travel time. In general, motorized travel modes have higher travel time than walking and cycle rickshaw. Among motorized modes, 2W has the lowest average travel time.

3.1.3. Vehicle ownership

In the survey, we asked respondents to mention all types of vehicles owned by them. While ~45% of respondents mentioned owning no vehicle, 2W and cars were owned by almost equal number of respondents (~25% each), and less than 5% owned both 2W and cars (Table 3).

3.1.4. Main-haul trip length

Using origin and destination metro stations for each respondent, we determined main-haul trip length (henceforth referred to as trip length) of survey respondents. The trip length was measured along the length of metro network using a GIS-based network, in which each metro station pair was connected with a link of metro line. The average trip length is 20.3 ± 0.5 km. More than 80% respondents have trip lengths longer than 10 km (Table 4). Using origin and destination metro stations, we determined fares paid by respondents for their current trip, using fare chart available at Delhi metro website. The average fare paid by survey respondents is INR 20.7 ± 0.3. Interestingly, similar value of average fare (INR 19.3) is obtained using total revenue (INR 39 million) and corresponding ridership (2,007,000) for January 9, 2012 reported by Delhi metro [20,21]. This corroborates the results obtained from the study. It is noteworthy that the trip lengths reported here represent only the main-haul segment of a metro trip. Therefore, overall trip length, which includes access and egress, will be even longer.

3.1.5. Alternative mode

We asked respondents to mention the alternative mode for their current trip as it indicates the mode-shift pattern due to metro. Less than 2% respondents mentioned non-motorized modes (walk, cycle, and cycle rickshaw), while a majority (52.5%) mentioned bus as their alternative mode. One-eighth mentioned auto rickshaws, and 15% and 25% mentioned 2W and cars, respectively. Note that the percentages do not add up to 100% because respondents could mention multiple modes.

3.1.6. Induced trips

In order to estimate the number of trips which are induced by the availability of Delhi metro, we also asked respondents if they would still make this trip if metro was not available. Almost 14% respondents mentioned they would not make the trip, and 4% mentioned they may or may not.

3.1.7. Interconnectivity ratio

We calculated interconnectivity ratio for each respondent, as defined by [13], as the ratio of access and egress time to the total trip time—access, egress and in-vehicle travel time (**ation 1**). For calculating interconnectivity ratio for each respondent, we used reported access and egress time, and estimated time of main haul trip using an average travel speed of 32 km/h for metro. We did not include transfer time at interchange stations in the total trip time. We also excluded those respondents who did not mention their egress time. The average interconnectivity ratio is 0.38 ± 0.01. Up to 88% trips have the ratio between 0.2 and 0.5 (Fig. 2).

$$\textit{Interconnectivity Ratio} = \frac{\text{Access Time} + \text{Egress Time}}{\text{Total Travel Time}} \tag{1}$$

3.2. Access-egress inside metro station

Access of a metro commuter does not end with reaching the metro station. Similarly, egress does not end with de-boarding the train. If we consider bus system as a reference, it includes the time taken by a commuter to reach from station entry to the rail platform, and in case of a bus, access time is up to bus stop. Once the passenger reaches the entry of the metro station, s/he has additional access time due to—

a) walk[illegible]p or down the stairs, or using escalators and elevators, since most stations of Delhi metro are underground (depth ~ 20 m), or over ground (height ~ 11 m);
b) waiting time in the queue for buying a token for those with no pre-paid smart cards;

Table 5
Access Mode Choice- Model 1.

	Walk/cycle	Auto-rickshaw	Cycle-rickshaw	Car	Bus	2W
Intercept	–	−1.443***	−2.554***	−2.499***	−1.825***	−3.957***
Trip length	–	0.019**	0.016	0.006	0.027**	−0.005
Vehicle owned − none	–	–	–	–	–	–
Vehicle owned − car	–	0.376*	0.393	1.859***	−0.257	−0.853
Vehicle owned − 2W	–	0.116	0.015	0.359	−0.325	2.449***
Vehicle owned − car & 2W	–	−1.049*	0.672	1.230***	−0.764	2.154***
Delhi	–	–	–	–	–	–
Gurgaon	–	1.2***	0.678	1.606***	0.415	2.118***
Noida	–	0.462	1.251***	0.422	0.340	0.403
−2 Log Likelihood = 2548.746						
Nagelkerke R-squared = 0.202						

***P < 0.1, ** P < 0.05, ***P < 0.01.**

Table 6
Egress Mode Choice- Model 1.

	Walk/cycle	Auto-rickshaw	Cycle-rickshaw	Car	Bus	2W
Intercept	–	−0.778***	−1.585***	−2.943***	−1.530	−5.759
Trip length	–	−0.002	0.015	−0.006	0.005	0.007
Vehicle owned — none	–	–	–	–	–	–
Vehicle owned — car	–	−0.047	0.340	2.082***	−0.340	0.875
Vehicle owned — 2W	–	0.124	−0.359	−0.038	0.198	4.120***
Vehicle owned — car & 2W	–	0.002	0.609	−0.124	0.244	2.624*
Delhi	–	–	–	–	–	–
Gurgaon	–	1.210***	−0.546	1.859***	0.586	1.176*
Noida	–	0.696**	−0.040	1.496***	1.018	−0.107
−2 Log Likelihood = 2624.576						
Nagelkerke R-squared = 0.182						

***P < 0.1, ** P < 0.05, ***P < 0.01.**

c) waiting time in the queue for frisking by the security forces, and baggage checks using scanner machines (similar to the ones at airports); and.
d) time taken through queue build-up while going through the fare gates.

In case of egress, only a) and d) apply. In addition, commuters changing lines at interchange stations within the metro network have an additional disutility during transfers. For instance, transfer from *Yellow line* to *Red line* at *Kashmere Gate* station requires climbing three stairs/escalators, in addition to walking, since Yellow line is underground and Red line is elevated. Among the survey respondents, more than two-thirds (68.5%) made no transfers, a quarter (24.4%) made one transfer, and only 7% made more than one transfer. It needs to be highlighted here that, as opposed to a metro system, components of walking within the station, buying a token, frisking, and baggage scanning are absent from a bus system. Buses have on-board ticketing done by a conductor once the bus leaves bus stops, and have no security checks.

4. Regression models

In this section, we present results of regression models for access and egress modes, alternative mode, and interconnectivity ratio. Predictor variables used for the regression models include trip length, vehicle ownership, location of metro station, and population density.

4.1. Access and egress modes

A multinomial logistic regression model is used in order to investigate the association between access and egress modes on one hand and trip length, vehicle ownership, access–egress location, and population density on the other. Three models have been developed for access modes as well as for egress modes. The model results are shown in Tables 5 through 10, and the variance explained by the models vary from 8% to 20%. A large proportion of unexplained variance is likely because of lack of explanatory variables for the personal characteristics of respondents, as well as trip characteristics.

In the first model — *model-1* (Tables 5 for access mode and Table 6 for egress mode), six categories of access–egress modes (cycle and walk are combined in one as a reference category) are dependent variables, with independent variables including trip length, vehicle ownership (categorized as those owning 2W, those owning cars, and those owning cars as well as 2W), and three categories indicating city of metro station (Delhi, Gurgaon, and Noida).

In the second model — *model-2* (Tables 7 for access mode and Table 8 for egress mode), for location of metro station, Delhi has been reclassified into nine districts, while Gurgaon and Noida remain the same. With more number of location categories, in order to maintain significant number of data points in each category, access and egress modes were reclassified into two broad categories — non-motorized modes (walk, cycle and cycle rickshaw), and motorized modes (auto rickshaw, bus, car and 2W), with the former as a reference category.

In the third model — *model-3* (Tables 9 for access mode and Table 10 for egress mode), we investigated the effect of population density around metro station on the access/egress modes. Initially, we also considered employment density, as well as ridership of the metro stations, to include in this model. We hypothesised ridership to influence availability of para-transit modes. It is observed that stations with high ridership attract a large number of para-transit operators. With large number of passengers, it is also profitable for them to operate. In order to analyse the spatial distribution of population density, we divided Delhi into 1 km × 1 km grids, and calculated population for each grid. Population and employment density were calculated for area within 1.5 km around each metro station. For this, population density for each metro station was estimated as the average of population for the nine grids (central grid containing metro station and eight grids surround it). However, preliminary analysis showed that the three variables were highly correlated, significant at 99% CI. While the correlation of ridership with population density as well as employment density is intuitively understood, correlation between population density and employment density indicates mixed land-use highly prevalent in Delhi [1]. Therefore, in *model-3* we included only one of these three variables — population density. Spatially detailed information for population density was, however, available only for Delhi. Therefore, we considered only those access and egress trips for *model-3* which were located within Delhi— a total of ~80% and 85% of all the access and egress trips, respectively. We considered walk/cycle as the reference category.

4.1.1. Trip length

Model-1 for access mode shows that trip length is a significant variable in the case of bus and auto rickshaw. A positive coefficient indicates

Table 7
Access mode choice — model 2.

	Non-motorized	**Motorized**
Intercept	–	−1.166***
Trip length	–	0.015**
Vehicle owned — none	–	–
Vehicle owned — car	–	0.6***
Vehicle owned — 2W	–	0.226
Vehicle owned — car & 2W	–	0.099
New Delhi	–	–
Central-North Delhi	–	0.823***
Northwest Delhi	–	1.142***
East Delhi	–	1.0418***
West & South-West Delhi	–	0.495*
South Delhi	–	0.937***
Gurgaon	–	1.9***
Noida	–	1.26***
−2 Log Likelihood = 1280.25		
Nagelkerke R-squared = 0.107		

***P < 0.1, ** P < 0.05, ***P < 0.01.**

Table 8
Egress mode choice — model 2.

	Non-motorized	**Motorized**
Intercept	–	−1.142***
Trip length	–	0.003
Vehicle owned — none	–	–
Vehicle owned — car	–	0.394**
Vehicle owned — 2W	–	0.260*
Vehicle owned — car & 2W	–	0.329
New Delhi	–	–
Central-North Delhi	–	1.096***
Northwest Delhi	–	1.334***
East Delhi	–	1.551***
West & South-West Delhi	–	0.674**
South Delhi	–	1.360***
Gurgaon	–	2.008***
Noida	–	1.818***
−2 Log Likelihood = 1300.35		
Nagelkerke R-squared = 0.089		

*P < 0.1, ** P < 0.05, ***P < 0.01.

that likelihood of using these modes for access trip increases with an increase in the trip length. Model-2 also has trip length as a significant variable for motorized access modes. In model-3, which is applicable only for Delhi, trip length is a significant variable only for buses. In the case of egress modes, on the other hand, trip length is not a significant variable in any of the models.

4.1.2. Vehicle ownership

All the models for access as well as egress modes show that car ownership is a significant indicator for use of car to access stations. This is also true for 2W ownership, which has a significant positive influence on the use of 2W, except model-3 for egress trips. Car ownership also has a significant positive effect on the use of auto rickshaws, however, only for access trips, and 2W ownership is non-significant in this aspect. Note that, in this case, auto rickshaws may be referred to the contract-carriage auto-rickshaws, which operate like taxis, and use of which is much more expensive than shared auto rickshaws. The difference between car owners and 2W owners with respect to use of auto rickshaws possibly indicates the difference in the affordability of this mode.

4.1.3. Spatial variation

An important aspect of the three models is to evaluate spatial dependence of access/egress modes. According to model-1, satellite city Gurgaon has a significant coefficient for auto rickshaws, cars, as well as 2W, for access as well as egress modes. The positive signs and magnitudes of coefficients indicate higher likelihood of these modes for access/egress in Gurgaon, as compared to Noida and Delhi. Noida, on the other hand, has no consistency in the significance for access and egress. In model-1 for access modes, cycle rickshaws, and for egress modes, cars have significant coefficient for Noida.

In model-2, all the locations have significant and positive coefficients. In this model, New Delhi district is a reference category. Comparing the sizes of coefficients shows that both the satellite towns – Noida and Gurgaon – have higher likelihood of motorized modes for access/egress than any district in Delhi. Within Delhi also, there are variations, with north-west, east, as well as south districts having higher coefficient values than central, north, west, and south-west districts.

4.1.4. Population density

In model-3 (applicable only for Delhi), population density is a significant variable. The model indicates that the use of auto rickshaws and cars for access mode reduces with increasing population density, with similar results for egress modes. For egress mode model, cars and 2W are combined into one mode category. The results from the models show that areas with higher density of population have lesser use of motorized modes for access and egress trips.

4.2. Alternative mode model

In order to model the relationship between alternative mode and predictor variables, we considered only those responses in which only one alternative mode was mentioned (respondents could mention more than option). These consist of 92.5% of the total responses. The predictor variables are trip length and vehicle ownership. To model alternative modes, we used multinomial logistic regression. The coefficient values (Table 11) show that ownership of car increases the likelihood of using cars, as well as auto rickshaws, as alternative modes. However, ownership of 2W increases only the likelihood of using 2W. Also, the likelihood of a car owner to use the car is 1.5 times higher than the likelihood of a 2W owner to use 2W. Coefficients of trip length indicate that, with increasing trip length, likelihood of using auto rickshaws as well as 2W reduces. In contrast, trip length has no effect on car.

4.3. Interconnectivity ratio

We modelled interconnectivity ratio using linear regression (see Table 12). The predictor variables include dummy variables for walking on access side and walking on egress side. The two dummy variables have significant negative coefficients. It indicates that interconnectivity ratio decreases with walking. Conversely, with any mode other than walking, this ratio increases.

5. Discussions

5.1. Access–egress using non-motorized modes

This study presents one of the first accounts of access–egress and other travel characteristics of Delhi metro users. There are a variety of modes which commuters use to access metro stations, reflecting the heterogeneity of travel modes in Indian cities. A low share of cycling (~1%) in the access trips is expected. This is because cycling in Delhi is used mostly

Table 9
Access mode choice – model 3.

	Walk/cycle	Auto-rickshaw	Cycle-rickshaw	Car	Bus	2W
Intercept	–	−0.774***	−2.134***	−1.816***	−1.720***	−3.677***
Trip length	–	0.009	−0.010	0.001	0.021*	0.015
Vehicle owned — None	–	–	–	–	–	–
Vehicle owned — car	–	0.401*	0.616*	1.733***	−0.379	−0.750
Vehicle owned — 2W	–	0.053	0.163	0.276	−0.275	1.903***
Vehicle owned — car & 2W	–	−0.993	0.376	0.561	−1.047	1.946***
Population density/10,000	–	−2.042***	−0.036	−1.999**	0.017	−1.069
−2 Log Likelihood = 2278.634						
Nagelkerke R-squared = 0.119						

*P < 0.1, ** P < 0.05, ***P < 0.01.

Table 10
Egress mode choice — model 3.

	Walk/cycle	Auto-rickshaw	Cycle-rickshaw	Car/2W	Bus
Intercept	–	−0.421	−1.709***	−2.438***	−1.820***
Trip length	–	−0.002	0.011	0.002	0.013
Vehicle owned — none	–	–	–	–	–
Vehicle owned — car	–	−0.113	0.317	1.996***	−0.552*
Vehicle owned — 2W	–	0.124	−0.363	1.492***	0.188
Vehicle owned — car & 2W	–	0.112	0.766*	0.835	0.267
Population density/10,000	–	−1.598**	0.612	−2.458**	0.541
−2 Log Likelihood = 2338.87					
Nagelkerke R-squared = 0.081					

***P < 0.1, ** P < 0.05, ***P < 0.01.**

by poor for whom even the subsidized fares of bus transportation are cost prohibitive [1]. Therefore, they are even less likely to use metro, which has higher fares than buses. Also, among the survey respondents, not more than 2% (n = 13) even owned a cycle. In addition, use of cycle as an access mode needs support from supply side. For instance, parking facilities needed for cycles are available only in a few stations provided under a bicycle rental programme initiated by Delhi metro. Also, the network of dedicated cycle lanes is limited in Delhi.

Other than walking, cycle rickshaw is the most used non-motorized option for access trips. The significance of availability of cycle rickshaw as para-transit mode has also been highlighted by [22] who estimated 27% to 38% of metro trips as dependent on cycle rickshaws, given different scenarios of road congestion in the city. However, the movement of cycle rickshaws has been restricted by civic authorities and police officials in many areas, and on most major roads in Delhi. Also, a ceiling on the maximum number of rickshaws which could operate in the city reduced their supply even further. However, a judgment of the Supreme Court of India in April 2012 (survey was conducted in 2011) removed restriction on their movement, as well as any limit to their number [23]. This should help increasing their mode share in access trips of metro users. No such restrictions are imposed on cycle rickshaws in satellite cities. Table 13 shows access/egress modes of metro/rail systems for various international settings, with an ascending order of walk mode share. Among all the settings, Delhi has the lowest walking share.

5.2. Access–egress using para-transit modes

Among non-private motorized vehicles, it is observed that para-transit modes (auto rickshaws and cycle rickshaws) have a combined share of 31%, which is almost three times that of buses (11%). There are various factors which could contribute to difference in their shares. Firstly, para-transit, owing to their small vehicle size, have much better access to minor roads of high-density unplanned residential and commercial areas, as compared to stage-carriage buses, which run mostly on major roads. Secondly, even though shared auto-rickshaws and mini buses often run on the same routes as other stage-carriage bus routes, their routes are much shorter, and they operate with higher frequency. Thirdly, satellite cities (Noida and Gurgaon) served by metro do not have a fully developed intra-city bus transportation system similar to that in Delhi, and therefore access by para-transit dominates.

Models also show spatial dependence of access/egress modes. Satellite cities have the highest likelihood of using motorized modes for access and egress trips, with Gurgaon higher than Noida. High use of motorized modes for access and egress trips in Gurgaon and Noida can be partially explained by the extent of metro coverage in these cities. Metro has only a small fraction of its network in these cities: ~11 km and ~7 km in Gurgaon and Noida, respectively (Fig. 1). Due to this, a large proportion of population may have to access metro stations using motorized or other non-walk modes. In addition, car ownership of Gurgaon is 70% higher and that of Noida is 42% higher than Delhi (Table 1). This could also explain higher likelihood of Gurgaon and Noida commuters to use private motorized-modes than those in Delhi.

5.3. Pollution exposure and emissions due to motorized access modes

It is important to minimize the use of motorized modes to access PT, since a higher volume of these modes also has important implications in terms of pollution. With a large number of commuters coming to or leaving from metro stations using motorized modes, a similar magnitude of vehicles idle outside stations, for instance, buses, auto rickshaws, and private vehicles, for drop-off or pick-up. This is a common sight in Delhi that shared auto-rickshaws and mini-buses operated by private owners idle outside metro stations (and other major PT stops) with their engines running until they have enough passengers before they leave. As a result, many commuters are exposed to these idling emissions. Exposure is even higher for those waiting for a pick-up or a bus. In addition, if emissions of motorized vehicles during access trips are taken into account, emission benefits achieved due to a mode shift from motorized vehicles to metro may be reduced to some extent.

5.4. Trip length

The average trip length of a metro trip is ~20 km, and more than 80% respondents have trip lengths longer than 10 km. According to a travel survey conducted by RITES in 2007–08, only 20% of all the trips in Delhi are more than 10 km long [2]. This shows that trips by metro are more likely to be longer in length than other modes of transportation. Few research works from the past have indicated similar results. In a review of methods for rail demand forecast in UK, [24] also reported a positive relationship of distance with inter-city rail use.

5.5. Vehicle ownership

Regression models for access modes indicate that car and 2W ownership have a significant influence on the use of respective modes for access trips. Those owning car as well as 2W have higher likelihood to use 2W, which could be likely because of less parking charges for 2W than cars, and out of the two modes, a commuter is more likely to block a 2W from being used by other members of the household, while the vehicle is parked at the metro station. Chakour and Eluru [25] also found a significant relationship between car ownership and driving a car to commuter rail station in Montreal. Rastogi [26] also discussed that

Table 11
Alternate Mode Model.

	Bus	Auto-rickshaw	Car	2W
Intercept	–	−0.865***	−2.156***	−2.473***
Trip length	–	−0.043***	0	−0.021*
Vehicle owned — none	–	–	–	–
Vehicle owned — car	–	0.768**	3.324***	0.370
Vehicle owned — 2W	–	−0.116	0.4	2.901***
Vehicle owned — car & 2W	–	0.151	2.449***	2.768***
−2 Log Likelihood = 1420.879				
Nagelkerke R-squared = 0.458				

***P < 0.1, ** P < 0.05, ***P < 0.01.**

Table 12
Interconnectivity ratio model.

Constant	0.427***
Access Mode (Walk = 1)	−0.028**
Egress Mode (Walk = 1)	−0.054***
(Adjusted) $R^2 = 0.032$	

***P < 0.1, ** P < 0.05, ***P < 0.01.**

willingness to shift to non-motorized modes to access commuter rail stations in Mumbai was less with high income levels. However, this is in complete contrast with [10] who found no strong effect of car ownership for access trips to railways stations in Netherlands. However, the two settings are very different in terms of car ownership.

5.6. Population density

Population density has a statistically significant negative association with the use of car and auto rickshaws (Tables 9 and 10), which indicates increasing likelihood of using walk (reference mode) for access/egress as population density increases. This association is possible due to various reasons. Firstly, areas with high population density may have more congested roads, and hence access by motorized modes is less efficient than walking. Also, such areas may have household with lower income level and vehicle ownership, thus less likely to have access by cars. The density has no significant association with use of bus and 2W (Table 9). For buses, this is possible because bus service in Delhi is provided by state government, and its availability is less likely to be determined by the profitability of the routes. For 2W, this is likely because of their higher manoeuvrability in congested areas, and households living in high-density areas are more likely to own a 2W as opposed to cars, due to parking constraint. Higher propensity of using walk and PT modes for higher density areas has been shown by various other research work such as [27].

5.7. Alternative modes

Up to 65% respondents mentioned PT modes – buses and auto rickshaws – as their alternative modes. Internationally also, mode shift to new metro rail systems occurred largely from other PT modes. In Athens [28], more than two-thirds of the metro users used PT modes before the metro. In the Madrid subway project, the observed modal shift was 50% from the bus and 26% from private cars. In Croydon, UK, majority of Tramlink passengers (69%) were former bus users. Similarly, in Copenhagen, 60–72% of the metro users were previously bus users [29].

According to the alternative mode choice model, choice of two alternative modes – auto rickshaw and 2W – has a significant negative relationship with trip length. Since bus is a reference mode, the negative coefficients indicate that, with increasing trip distance, the individuals prefer PT over auto rickshaw and 2W. Also, the influence of trip length on choice of auto rickshaw is twice as much as of 2W. Since auto rickshaws operate like taxis, and their cost is linearly related to distance, there is a limit to how much a person is willing to spend, for instance, for their daily commute. In addition, auto rickshaws cannot perform inter-city operations — from Delhi to satellite cities, or vice-versa. Thus, respondents who travel inter-city, and more likely with long trip lengths, would not choose auto rickshaws.

In case of 2W, cost of operation may not be as important as in case of auto rickshaws. Owing to high fuel efficiency (~50 km/l; [30]), per km cost of using 2W is comparable to per km fare of metro, and less than one-sixth that of using an auto rickshaw. The reason for negative association with distance for 2W may be due to exertion from driving, as well as risk of road crashes associated with their use. One quarter of all the fatal accidents in Delhi involve a 2W user [31].

Car as an alternative mode is independent of trip length. Clearly, those who mentioned car as an alternative mode may have little cost concern. In addition, use of car has much less exertion and risk of road accident. Car owners are twice as likely as non-owners to use auto rickshaws, indicating affordability and preference of this mode by car owners. This has important implications in understanding mode-shift behaviour. This shows that car owners do not prefer any PT mode other than metro, irrespective of the trip distance. In the absence of metro, their preferred mode is auto rickshaws and cars. For those not owning cars, use of bus becomes a preferred mode with increasing trip length.

5.8. Induced trips

Up to 18% of respondents are making a trip in metro, the need for which is induced by the availability of metro. Comparing this to international settings, in case of Copenhagen metro, 13–18% trips were induced, Manchester light rail system had 20% induced traffic, and in case of Madrid subway, up to 25% were induced trips [29,32].

5.9. Implications of interconnectivity ratio

The model for interconnectivity ratio indicates that the ratio is the least with walking for access as well as egress. As compared to walking, with a non-walk mode, proportion of access/egress time in the total trip time increases. The distribution of interconnectivity ratio from this study is strikingly similar to the one found by [13]. This indicates that the range of interconnectivity ratio 0.2–0.5 may be universally applicable for multimodal PT trips.

Compared to trips by metro which have an average length of 20 km, bus trips are 10 km long, on an average [2]. We can use interconnectivity ratio to understand the trip length differences among two public transportation modes. In equation-1, using an interconnectivity ratio of 0.4 and a range of values from 0 to 20 min for total access and egress time, we calculated in-vehicle travel time for the two modes. For buses, we used in-vehicle speed of 15 km/h [30], and for metro, we used 32 km/h, and estimated corresponding travel distance (Fig. 3). It can be seen that, for a given value of access–egress time, travel distance of a metro trip is higher than that of bus by a factor of two; same as the ratio of speed of metro to that of bus. Further, the difference between travel distances of the two modes increases as the access–egress time increases. Given that there are up to 6000 bus stops in Delhi compared to 132 metro stations, for a given trip, time spent by an individual for access–egress for bus trip will be much lesser than a metro trip, thus widening the difference between the trip distances even more.

Delhi metro authorities have been providing feeder bus services in order to augment catchment areas of metro stations. However, resulting

Table 13
Access/egress modal share for rail-systems in different international settings.

Setting of metro network	Reference	Access/egress	Walk	Cycle	NMT-para Transit	Bus	Private motorized	**Motorized** para-transit	Others
Delhi, India	**This Study**	Both	44	1	10	11	13	22	–
Mumbai, India	**Rastogi (2010)**	Access	49	6	–	30	4	10	–
Nanjing, China	**Zhao et al. (2013)**	Access	59	3		26	3	3	7
Nanjing, China	**Zhao et al. (2013)**	Egress	76	1	–	17	1	2	4
Manila, Philippines	**Fillone et al. (2008)**	Access	50	–	8	–	–	41	1
Santiago, Chile	**Bianchi et al. (1998)**	Access	47	–	–	31	11	10	2
Athens, Greece	**Tsamboulas et al. (1992)**	Access	62	–	–	18	16	3.5	1

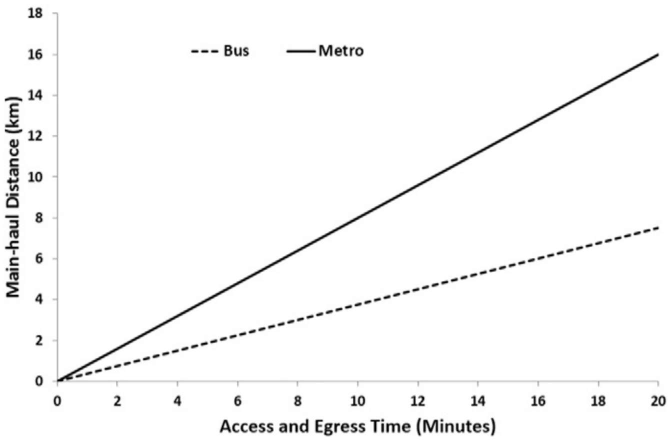

Fig. 3. Main haul distance and access–egress time for bus and metro.

increase in the access time with the use of feeder buses implies higher likelihood of those trips to be longer in lengths. This has also been shown in the logistic model for access modes, in which likelihood of using buses and auto rickshaws has a positive association with trip distance. Note that the average travel time for access or egress trips using buses is 22 min, as opposed to 6 min for walking. Using a bus for access–egress has additional disutility due to walking up to the bus stop, wait-time, bus fare, and transfer inconvenience (changing from bus to metro). Transfers in a multi-modal trip have been recognized to add significant inconvenience in the use of PT. [33] summarized the studies from various countries quantifying the penalty imposed by transfers, according to which, a bus to rail (LRT or suburban) transfer, which occurs outside station area, is equivalent to up to 28 min of in-vehicle travel time.

6. Conclusions

The status of metro systems in a dozen of Indian cities is either under planning or under construction phase [7]. However, being a new system, their effectiveness to cater to daily travel in Indian cities has not been assessed. Despite pedestrians and cyclists contributing to more than 50% of the total road fatalities in Delhi [31], metro systems in India are constructed without taking into account a convenient and safe access of commuters by non-motorized modes. We found that Delhi metro has the lowest share of commuters walking to or from stations, compared to rail systems in other international settings.

Delhi metro has limited coverage in terms of population living within 500 m of metro network [22]. As a result, for a large proportion of population, metro may involve significant efforts during its access and egress. This explains high usage of motorized modes to access metro in Delhi. Using the concept of interconnectivity ratio for bus and metro, we demonstrated that, for a given duration of access and egress, trips in metro will be longer than trips in buses. This is because, on an average, metro travels two times longer distance than bus for a given travel time. Given that access to a metro station in Delhi is much longer than a bus stop owing to differences in their coverage, the trips catered to by metro systems will always be longer, and hence, their share in overall trips will also be small. Since most metropolitan cities in India have well-developed road-based public transportation system – private or government-provided – the coverage of new metro systems in these cities will always be low. As a result, such metro systems will only cater to long trips and will have a limited mode share in overall trips.

Acknowledgements

We would like to thank the team of undergraduate Civil Engineering students at IIT Delhi who helped carrying out the survey for this study. We would also like to thank PURGE programme at the London School of Hygiene and Tropical Medicine (UK) for partial financial support.

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