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**Procedia**  
Social and Behavioral Sciences2<sup>nd</sup> Conference of Transportation Research Group of India (2nd CTRG)**Performance Evaluation of Multimodal Transportation Systems.**P. Phani Kumar<sup>a</sup>, Dr. Manoranjan Parida<sup>b</sup>, Mansha Swami\*<sup>c</sup><sup>a</sup>*M.tech student, Transportation Engineering, IIT-Roorkee, Roorkee-247667, India*<sup>b</sup>*Professor, Civil Engineering Department, IIT-Roorkee, Roorke-247667, India,*<sup>c</sup>*Research Scholar, Civil Engineering Department, IIT-Roorkee, Roorkee-247667, India***Abstract**

Connectivity of more than one mode to a line haul in an urban area constitutes the multimodal transport system of the city. In this paper New Delhi has been taken up as a case study to evaluate performance of multimodal transportation system (MMTS), where metro became main mode in routine public transport trips. Public transport in Delhi carries only about 60% of total vehicular person trips as against 80% of the expected population size of the city. The present bus services, metro rail and IRBT (Integrated Rail-cum-Bus Transit), if implemented as planned together are estimated to carry about 15 million trips per day by 2021. Since, all the public transport trips are multimodal, it is necessary to evaluate the performance of multimodal transportation systems. The study is divided into two phases. In the first phase, the study of travel time elements (access time, transfer time, waiting time, line-haul time, and egress time) is done. Next, the influence of access and egress times on the total travel time is examined. Use is made of a comprehensive commuter travel diary to collect detail travel time estimates. A representative commuter survey, with 460 respondents, is drawn on platform at each station of Red Line and Yellow Line (Kashmiri Gate – Saket) Delhi Metro. Implementing the Second phase of study, performance measures such as Travel Time Ratio, Level of Service, Interconnectivity Ratio, Passenger Waiting Index, and Running Index were evaluated. Interconnectivity ratio (proportion of access and egress time w.r.t total travel time) for various combinations such as Mixed-Metro-Mixed, Walk-Metro-Walk, Walk-Metro-Bus and Walk-Bus-Walk has been observed. Travel Time (defined as the time differential between private transport and public transport) ratio shows much variation with trip direction, time of day, mode used, and distance travelled, etc.,. Level of Service Indicator (Out-of-vehicle Travel Time/In-Vehicle Travel Time) ratio inferred that people spends more time out-of-vehicle as compared to that of in-vehicle. Access time, transfer time, waiting time and egress time are the most important and complex travel time elements that transport systems should consider improving its efficiency and modal share. The results can be used in planning catchment area of public transport. Access and egress (together with waiting and transfer times) appear as factors that affect effectiveness and performance of a multimodal transportation system to a larger extent as unacceptable distances are likely to reduce ridership patronage. At the same time, there are key deciding factors when a trip originates as to whether the commuter shall choose public transit over personal mode of travel.

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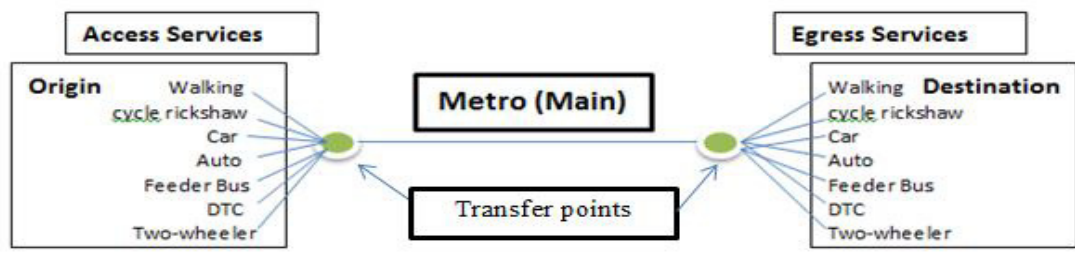
Keywords: Multimodal Public Transport Systems; Access time; Egress time; Performance Measures.

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## 1. Introduction

Urban areas are indeed the primary wealth creators and supporters of economic growth. The primary characteristics governing the qualitative interaction potential of metropolitans or large cities are the land use and transport system taken in combination. The cities currently are facing set of problems around the world which range from loss of agricultural zones due to urban sprawl, public spaces and zones located in such a manner that they are inaccessible, conflicts arising due to pedestrian and vehicles plying on the same section of the road, traffic jams, public transport struggling with overloading and operational inefficiency. Due to the above mentioned factors secondary system failures in terms of lowered potential for interaction as the travel times have increased and costs incurred higher. Accessibility is hampered and when coupled with congestion they together result in the transaction costs getting higher, inept use of resources, loss of monetary competitiveness and an overall distasteful environment.

Multimodal public transportation (MMTS) has been welcomed as a sustainable alternative to car travel which is also environmentally friendly and provides flexible mobility to the citizens. It adds a dimension to the public transport by providing it with ease of travel through its multimodal character. MMTS can be defined as “public, ordinary networks in urban areas, particularly in metropolis where the citizens may utilize the combinations of several modes of transportation such as personal car, taxi, two-wheeler, metro, bus and walking”. Using these networks brings real benefits for citizens by saving their time and cost, and also greatly assists sustainable development of metropolis.



**Fig 1: Schematic Outline of Multimodal Transport System (Metro as Main Mode)**

Clearly, as multimodal transportation place unique space-time limitations on travellers such as long access and egress stages, long trip times, transfers and limited system accessibility, users of the system will be constrained in their activity engagement opportunities. Since, all the public transport trips are multimodal, it is necessary to evaluate the performance of multimodal transportation systems.

## 2. Literature Review

Transport is a critical element of Urban system which in the present scenario us generating a huge pressure on the travel demand and hence, mass transit system is required as effective means for providing better, advanced, efficient and effective mass transit services; However, the efficiency of an effective MRTS shall depend on availability of various modes at city and regional level, location and design of nodes, pedestrian flow at transfer station, network structure, line density, stop density, frequency of services, bus routes etc ( Kumar Pawan et al., 2009).

The importance of measuring customer satisfaction for public transport service is apparent, even beyond the more immediate marketing processes; The overall satisfaction levels for the service and its frequency of use seem not correlated for multimodal travelers; Satisfaction numbers are highest in smaller towns and lower in metropolitan cities (Marco Diana, 2012). Connectivity plays a crucial role in multimodal public transit and defines the level of coordination of the transit routes, coverage, schedule, speed, operational capacity, urban form characteristics and is an influential element of the image of any transit network ( Mishra Sabyasachee et al., 2012). Access and egress determine importantly the availability of public transportation and should travelers face unrealistic access and egress

times public transport trips will be excluded as an alternative compared to unimodal transport alternatives. (Krygsman Stephen et al., 2004).

### **3. Public Transport: Indian Context**

The urban population of India has been projected to 540 million (2021). (source: cited in reference number 14). The ever increasing demographic values have exerted pressure on the transport systems such that many Indian cities have not been able to meet these expected demands of the transportation. Passengers have shifted to personalized modes and intermediate public transport in the wake of deteriorated urban bus services and all this is resulting in traffic gridlocks and poor quality of urban mobility. For public transport to get more commuters it requires increasing its reliability and needs to make it more attractive so the commuter is willingly shifting to public transit and leaves the personalized transit. Therefore the public transit needs to be designed to be integrated and multimodal. Integration amongst public transit modes aids in easy mobility and accessibility, is economical, comfortable, and efficient, reduces congestion on road and is convenient to the commuters. This research focuses on removing barriers to intermodal operations through improved transfers and interchanges between modes thereby promoting a seamless journey from origin to destination. The underlying motivation of all these land use and transport initiatives is to enhance the functional competitiveness of multimodal transport as a substitute for mainly car travel in order to optimistically achieve a better modal split in favour of public transport. In this paper New Delhi has been taken up as a case study to evaluate the performance of the multimodal transportation system (MMTS).

### **4. Multimodal Public Transportation in Delhi**

The Public transit of Delhi has a share of 60% of the total number of vehicular trips as against a desired value of 80%. The Population of Delhi which was 16.7 million (2011) has been expected to grow to 23 million (2021). Also the intracity vehicular trips which were 12.7 million are expected to grow to 24.7 million in the same period. If around 15% intercity trips are taken in addition to the existing then we will get a total of 28.7 million trips per day by the year 2021. That means that till 2021 80% of trips shall have to be catered towards public transport which would be around 24 million trips. The expected passenger turnout from the integration of the metro rail, the existing bus services and the IRBT (Integrated Rail-cum-Bus Transit) is estimated to be around 15 million trips per day by 2021. There is an additional requirement of 9 million by other public transport. Thus it becomes imperative to take steps for optimizing the passenger ridership in public modes.

Different studies conducted so far on Transportation, Planning and Traffic engineering indicates that the per capita trip rate (excluding walk trips) has increased from 0.72 in 1981 to 0.87 in 2001. It is estimated that per capita trip rate may reach to 1.2 by 2021 in Delhi. Delhi Intra-City Motorized trips are expected to increase from 117 lakh in 2007 to 174 lakh in 2021. Inter-city trips will increase from 33.4 lakh per day in 2007 to 79.6 lakh per day in 2021. The total road length (km. lane) was 14316 km in 1981 which increased to 28508 km in 2001 and 31373 km in 2009 in Delhi. However, the number of vehicles increased from 5.62 lakh in 1981 to 34.57 lakh in March 2001 and 64.52 lakh in March 2010.

This situation of fast increase in number of vehicles has created the problem of congestion on Delhi's roads and accordingly slowed down the vehicles movement. The demand forecast and development of public transport network study prepared by RITES and others in October, 2010 recommends that total Metro length within Delhi shall be 330 km., light Metro (LRT) 40.3 km. and BRT Corridors 359 km. in 2021 so as to take care of 255.27 lakh motorized daily trips estimated to be met by Public Transport Network in Delhi in 2021. The modal share of the estimated total daily trips of motorized vehicles will be 23.3% by Car, 18.6% by Two-wheelers, 32.8% by Bus, 20.1% by Metro, 4.6% by Auto and 0.5% by Train.

A major fall out of this has been distortion between infrastructure, transport and land use. To ensure balance in the spatial distribution, the development is supposed to follow the mass movement corridors. This has its own limitations and restraints w.r.t. land use planning, MRTS availability along important transport corridors. This

is definitely going to solve the problems faced by the mass transportation sector but also would be able to generate growth potential for employment. Such an arrangement is exists in Delhi Metro. In this context, the Metro Corridors up to a certain depth would require selective Re-development and Re-densification of the existing land uses based on site conditions.

#### 4.1 Performance Measures:

1. Travel Time Ratio (TTR): The travel time ratio, defined as the travel time by public transport divided by travel by car between the same origin and destination. The ratio fluctuates from 1 to 5 for most trips and generally, the larger the ratio, the less competitive public transport is considered to be (Bovy., et al. (1991).
2. Level of Service: The ratio OVTT/IVTT is frequently used not only as the level-of-service indicator for public transport trips but also to assess demand elasticity. The larger the ratio, the less attractive public transport becomes as an alternative. Estimates of the weight of OVTT compared to IVTT range between 1.2 and 5.
3. Interconnectivity Ratio (IR): The interconnectivity ratio can be defined as the ratio of the combination of access and the egress time to the total trip time. The range of values shall be from 0 to 1, as it makes the comparison easier between the alternatives. For most of the multimodal public transit trips this ratio has values between 0.2 and 0.5
4. The passenger waiting index (PWI) is the ratio of mean passenger waiting time to the frequency of the transport service. The PWI value can be fixed between 0 and 1 provided that the passenger waiting to be boarded should be equal or less than the space available in the transport service. Practically zero value is not possible.
5. Running index (RI) is defined as the ratio of total service time to the total travel time. As RI increases, efficiency of the system decreases. Its value can be fixed between 0 and 1. For passengers' satisfaction, its value can be fixed between 0.15 and 0.75 depending upon the number of passenger boarding and alighting at different hours of the day.

## 5 Study Methodology

Delhi metro in the last 10 years have been the major mode to commute for public transport trips. It comprises of six lines having a total route length of 189.63 Kms consisting of 142 stations out of which five stations are at grade, 35 underground stations and the remaining are elevated stations. As the main objective of study, to evaluate the performance of multimodal transportation systems like Delhi Metro a large and extensive commuter travel data is required. . It can be done with a proper, ease and suitable survey performa. The survey performa carries the following necessary information:

- i. Personal Information of the passenger: Gender, Age, Income, Purpose of Trip, Household size, Vehicle Ownership, etc.;
- ii. Travel Information of the passenger: Origin, Destination, Access mode and Access time, Egress mode and Egress time, Transfer Time and Wait time at each switch point, In-vehicle time;
- iii. Passenger Satisfaction Measures in terms of speed, cost, comfort, reliability and transfer;
- iv. Passenger Suggestions regarding his/her experiences with multimodal transportation.

A total of 460 samples, representing 176 female and 284 male respondents were interviewed. The first phase included extensive study of various travel time elements, is done from the survey data. Data was collected by stated preference commuter survey and demographic data along with the travel time pattern of the commuters were collected in the survey format. The sampling strategy used was random sampling strategy.

The analysis showed that slow modes (i.e. cycle rickshaw and walking) dominate the access and egress stages of multimodal trips. Slow modes, in particular walking, has a strong distance decay function with the result that users drop off substantially after 2.5 kilometers (approximately the maximum walking distance). Fig. 2. shows the areas in which survey was conducted indicating the red and yellow lines of the Delhi metro.

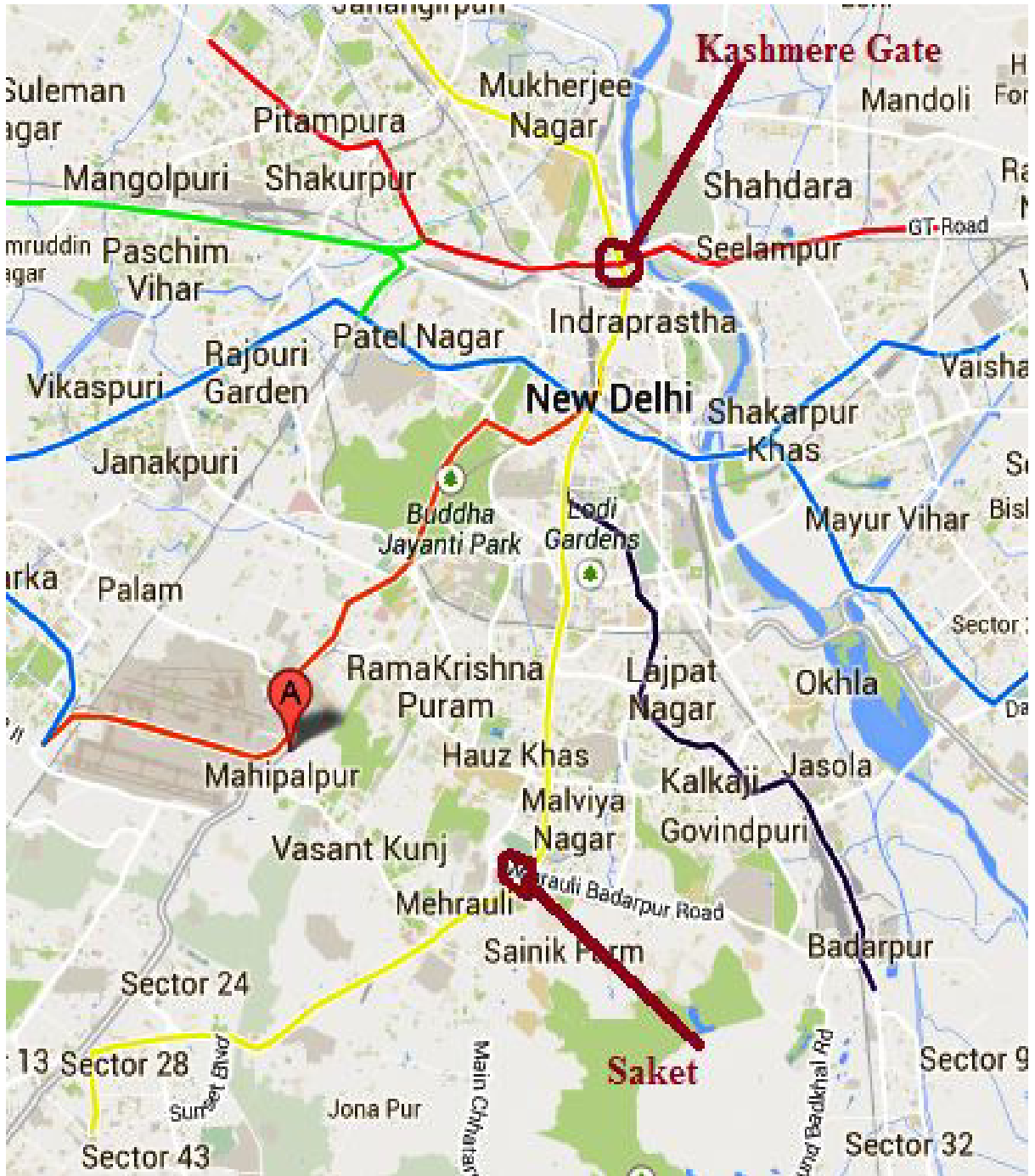


Figure 2. Red and Yellow lines of Delhi Metro.



Fig.3 shows the trip distribution w.r.t purpose of trips. The purpose of trip mainly depends upon the type of trip, trip distance, and number of transfers. Nearly 72% of trips consist of Education, Office and Work Trips indicating that most of the metro users are routine passengers. The remaining are the Leisure trips on non-daily trips.

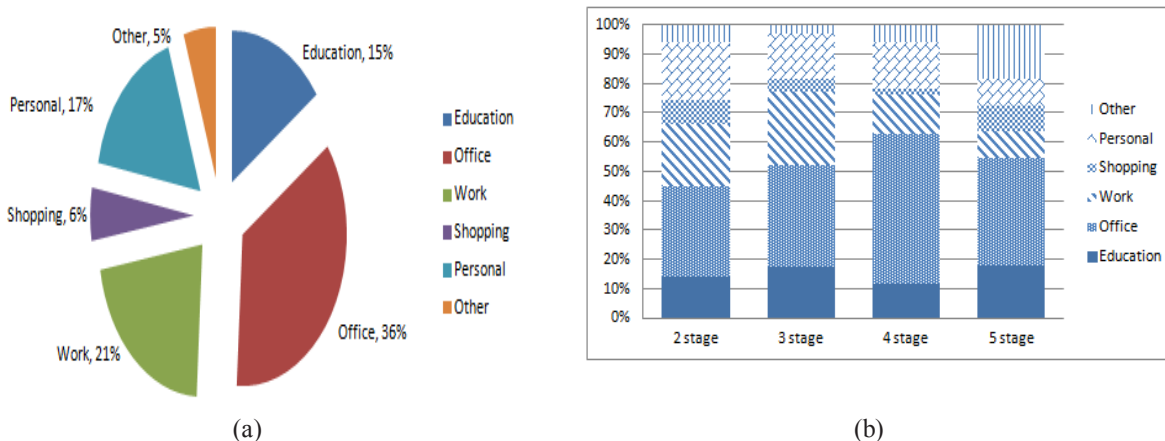


Fig.3. (a) Passenger trip purposes. (b) Trip motives for various number of transfers

On the egress side, the problem of asymmetric mode availability is evident with more users having to rely on walking and public transport to reach their final destinations. When the access and egress exceed an absolute maximum threshold, users will not use the public transport system. When the commuters use walking as the access/egress mode this threshold value is 2.5 Kms beyond which the commuter may not prefer to use public transportation. The combination of longer trip lengths and of seamless transfers is essential to make multimodal transport more attractive than uni-modal transport.

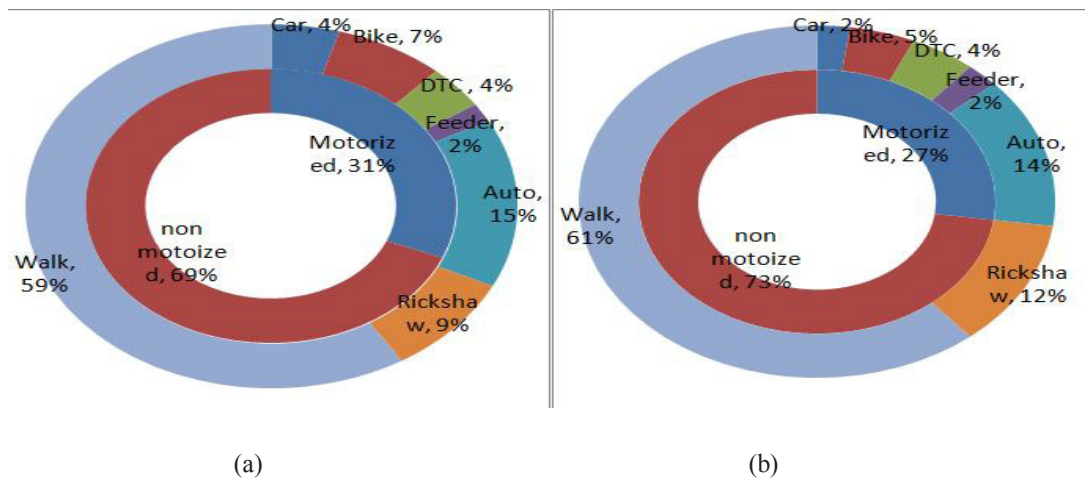


Fig 4. (a) Access mode share. (b) Egress mode share.

From figure 4 we can clearly study the access and egress mode shares. we can interpret that most of the commuters use walking as egress and access modes in the multimodal structure, This clearly implies that the station locations are catering to most crowds from nearby catchment and as for the far off areas of the station location lesser people are taking up public transit option. From figure 5(a) & 5(b) we see the cumulative frequency distributions of the access and egress times of the motorized and non motorized transport.

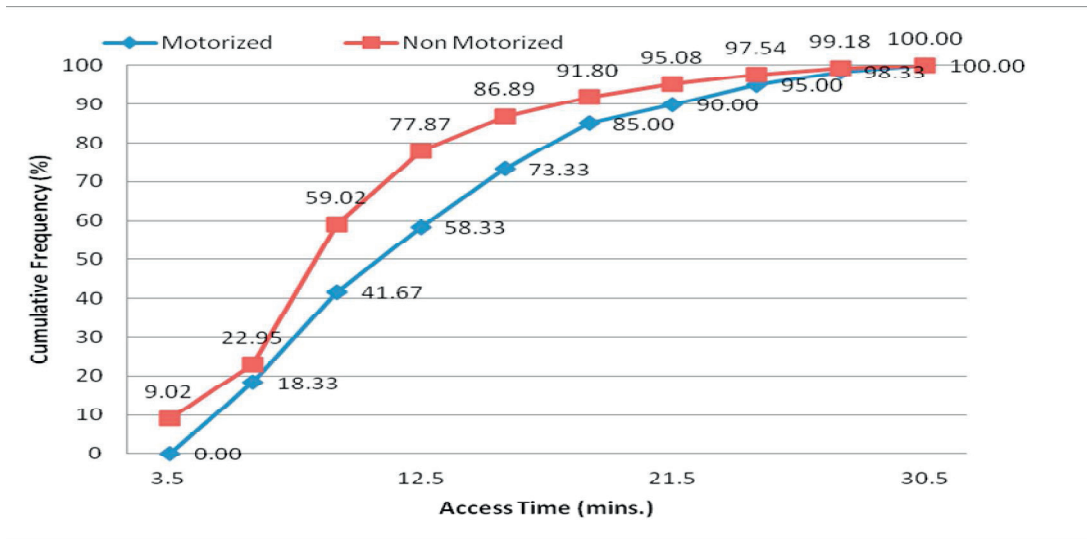


Fig 5(a): Cumulative frequency distribution of the access times of the motorized and non motorized modes

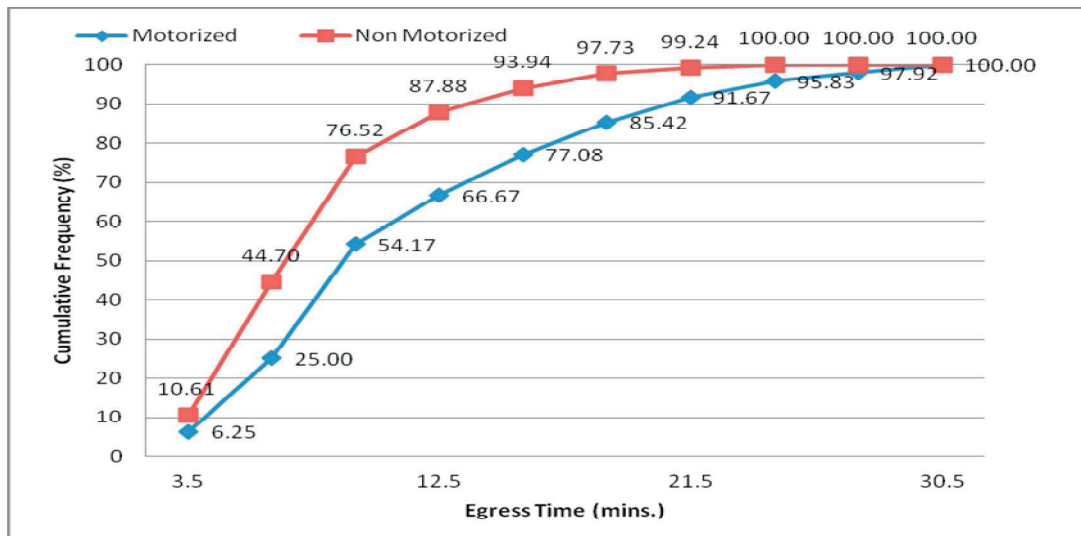


Fig 5(b): Cumulative frequency distribution of the egress times of the motorized and non motorized modes.

Implementing the Second phase of study, performance measures such as Travel Time Ratio, Level of Service, Interconnectivity Ratio, Passenger Waiting Index, and Running Index were evaluated. Interconnectivity ratio for various combinations such as Mixed-Metro-Mixed (MIX), Walk-Metro-Walk (WM), Walk-Metro-Bus (WMB) and Walk-Bus-Walk (WB) has been observed as shown in Fig 6(a).

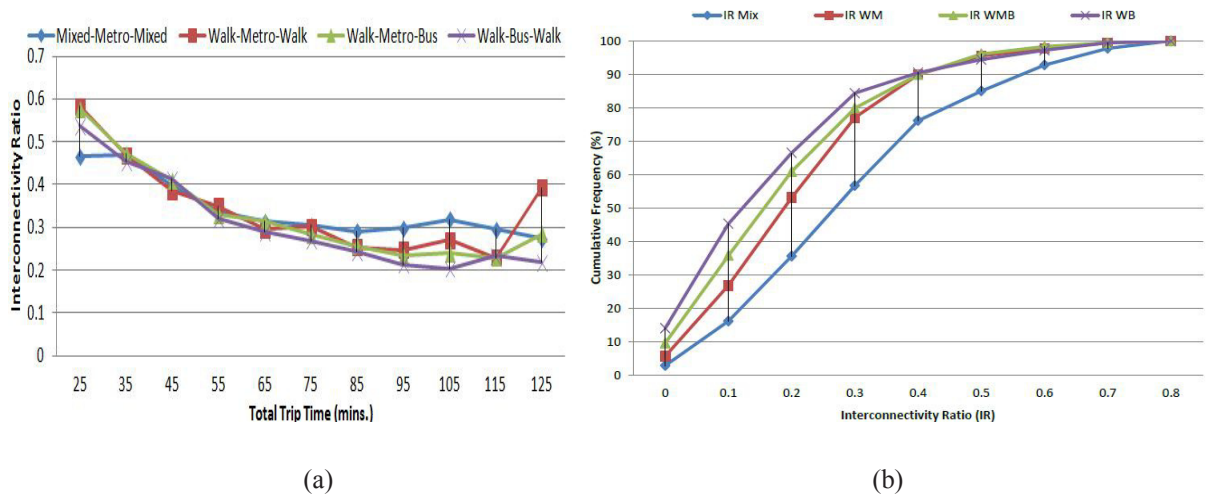


Fig 6: Interconnectivity ratio (a) and its Cumulative Frequency (b) of multimodal chains

### 6 Results and Discussions

Access and egress times increase with increasing trip time, however, the increase is not as strong as line-haul time and as a result the interconnectivity ratio declines as trip time increases. For most multimodal trips, the interconnectivity ratio falls within a modest range of 0.2–0.5. Fig 6(b) illustrates that roughly 10% of the WM, WMB and WB consumers have a ratio in surplus of 0.42 whereas nearly no mixed metro commuters have a ratio of this amount. Bearing in mind the two chains, walk–metro–walk and mixed-metro-mixed, the second is at first larger and also amplifies at a steeper rate evaluated to walk–metro–walk. This may represent that the mixed mode share used for longer access & egress times ensuing in an outsized ratio.

Travel Time ratio shows much variation with trip direction, time of day, mode used, and distance travelled, etc., The closer to 1, the more comparable the travel times for the two alternative modes (metro and car) of transport. Fig 7(a) shows, the TTR trying to reach 1 at higher trip distances and gradually declining to 1.6. This indicates that the public transport is competitive to the car at longer trips. The present study determined that, the mean travel time ratio for the Delhi is around 1.3, implying a very competitive position for public transport.

Level of Service Indicator (Out-of-vehicle Travel Time/In-Vehicle Travel Time) ratio implied that people spends more time out-of-vehicle than in-vehicle. Figure 7(b) shows that the mean OVTT/IVTT is nearly always larger than 1. This implies that people spend more time out-of-vehicle than in-vehicle. This is true even for 4-stage transfers with a longer line haul stage. The longer line haul times are partly offset by the increase in waiting and transfer time. For short trips, OVTT/IVTT ratio is increasing constantly after 2.5 predicting people spend more time out of vehicle than in vehicle. For longer trips, the level of service will be always less, as the line-haul time will be longer.

Running Index (RI) which is the ratio of total service time to the total travel time should be between 0.15 and 0.75 for passengers’ satisfaction. The mean RI value obtained from the study is 0.7681 indicating that measures should be taken to improve passenger satisfaction. As RI value increases, efficiency of the system decreases.



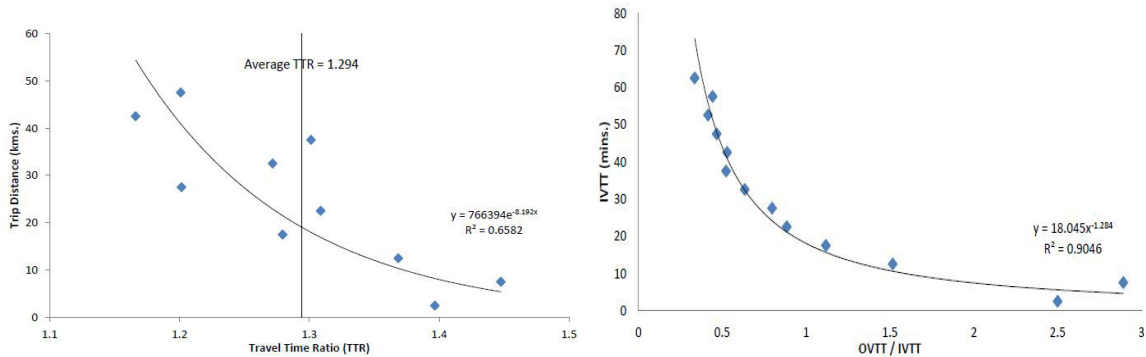


Fig 7 Travel Time Ratio (a) and Level of Service (b)

Passenger Waiting Index as explained as the ratio of mean passenger waiting time to the frequency of the transport service should be between 0 and 1 provided that the passenger waiting to be boarded should be equal or less than the space available in the transport service. The study recommends a value of 0.825 for the Metro transport service. This indicates that mean passenger waiting time is nearly same as the frequency provided by the Metro transport service.

## 7 Conclusions

Analysis of transfer time is also made from 2-5 stage transfer levels. Trip lengths of multimodal trips helped us to quantify the average penalties for various transfers. This is true even for 4-stage transfers with a longer line haul stage. The longer line haul times are partly offset by the increase in waiting and transfer time. The results can be used in planning the catchment area of public transport. Multimodal transport is especially suited to longer distances. If we look at the number of trips, the trip distance should be ranging between 7.5 and 35 kilometers. The most important attribute of a multimodal trip seems to be total travel time.

Multimodal transportation is only an attractive alternative if the access and egress distance is not too large. Access and egress (together with waiting and transfer times) appear as factors that affect the effectiveness and performance of a multimodal transportation system to a larger extent as unacceptable distances are likely to reduce rider-ship patronage. At the same time, there are key deciding factors when a trip originates as to whether the commuter shall willingly choose public transit over personal mode of travel.

OVTT & transfer times can be reduced by improving access & egress facilities, transfer facilities, and providing park & ride facilities, card access at public transit systems. Access, egress & transfer times can be reduced by bringing altogether different modes at one location called interchange which represents an Integrated MMTS. Access & egress times can also be reduced by providing exclusive facilities for pedestrians and bicyclists. Access time, transfer time, waiting time and egress time are the most important and complex travel time elements that transport systems should consider improving its efficiency and modal share.

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