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Diagnostic Evaluation of Multimodal Urban Transport System Operation in Delhi

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Abstract

Delhi, the capital of India had planned its MRTS corridor in 1980's and rolled it out in 2002. With the materialization of Delhi Metro the city got a transit lifeline in terms of connectivity. The existing multimodal public transportation of Delhi urban agglomerate offers a plethora of modes, but the issues are their lack of uniform presence, organized routes, demand responsive presence as well as lack of physical infrastructure to support a seamless multimodal trip. This paper aims to study the existing condition of the operational dimension of multimodality with emphasis on temporal, operational and service quality performance indicators. Some of the indicators included for analysis in this paper are the interconnectivity ratio, level of service, service time ratio,interconnectivity convenience, passenger waiting index, commuter perception index, etc.A commuter travel survey was done and responses from 1328 passengers was taken into account for the analysis. The result reveals the importance of the transfer and proximity related segments of travel. Recommendations to improve multimodal operation have also been discussed.

Keywords: Multimodal Transportation, Performance indicators, access, egress, Transfer, Waiting time.

1. Motivation

Public transport is an integral component of an urban area. In developing countries like India the growth of economic, social, and infrastructural fiber of a city very directly depends upon the condition of its urban transport system.In a study done by Martin Turcotte(2006), impact of the total travel time on perception of commuter was observed. A significant rise in the dislike attitude towards transit was seen when total travel time exceeded one hour (Litman 2015) as shown in Figure 1.

Seco&Goncalves (2007), studied the quality of public transport in which they identified importance of different performance indicators like reliability, comfort, cleanliness, safety, trip price (fare), security, trip environment, transfers necessity and customer service. Comfort during travel includes cleanliness, safety and trip environment. Convenience includes travel time, information parameters, transfer necessity and waiting times.

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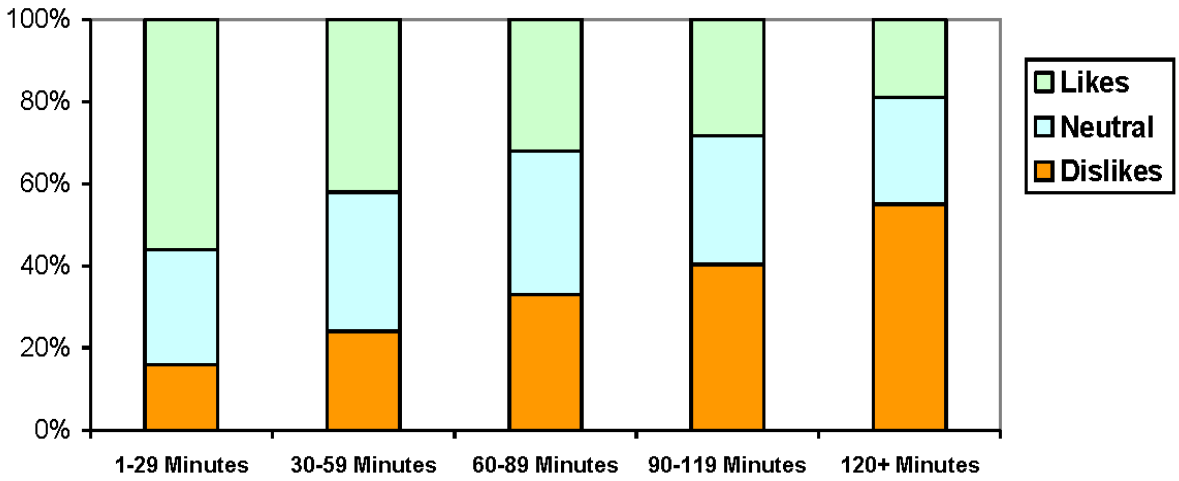


Figure 1. Passenger perception on commute duration. (Source: Turcotte, 2006).

Comfort and convenience are very important characteristics of importance to any public transport entity. Convenience is defined here as how simple the Public Transport service is to use and how well it adds to one's ease of mobility.

A multimodal transport environment has to essentially coordinate between several parameters of importance at the planning, design, operation and maintenance stage of a public transit system.For transit agencies, higher levels of customer satisfaction are associated witha better public image, customer loyalty and, consequently, customerretention and increased ridership (TCRP Report 88, 2003). A study was carried out in order to compare the distance travelled in twin scenario of a fixed route alternative and a demand responsive alternative both having competent transit attributes. The study revealed that demand responsive, especially when in a ring-radial network are more effective than the fixed route travel alternative. This was observed in the case when demand density wasn't very high and a LOS upgrade was sought after (Marco Diana, 2009). In order to ensure public spending is utilized in the best possible manner the transit stops and route performance can be evaluated with respect to connectivity (Sabyasachee Mishra *et al.* 2015). In the case of central Delhi the ring radial network exists, but the demand for travel is high. A comprehensive study on the comparison between the two alternatives for the Delhi Scenario is recommended.

In case of Delhi, development of mass transit system has been done in 2002, much before the actual projections of vehicular increase and change in the scenario was witnessed. The unexpected growth in motor vehicles and rapid transformation of economic policies have brought about a drastic change in the land use pattern of the city. Aljoufie, M. *et al.*(2011), examined the relationship between urban growth and transport for Jeddah city in Saudi Arabia. GIS tool was used to develop several indices related to spatial expansion, land use change, population density, transport infrastructure expansion, road density, road area density and urban trips density. A spatial proximity analysis was then carried out to conceptualize two major types of urban growth, outward expansion and sprawl development, both of which had a significant influence on the transport infrastructure. Multimodal Transport System (MMTS) relates to a single trip consisting of combinations of modes i.e. vehicle modes (bus,

metro, car, cycle rickshaw, etc.) or service modes (private/public) between which the travelers have to transfer. The main aim of MMTS is to promote public transport in urban areas. A coordinated integration of different modes brings about reduced congestion on the road, greater convenience for commuters, efficiency and cost effectiveness. In Delhi also, the urban sprawl in the last two decades has increased the transport demand manifolds. The demand for mobility has risen from 20 million trips per day to the projected value of 29 million trips per day in 2021 (RITES, 2005). Though an operational MMTS exists, but the scenario is still far away from reaching the ideal ridership of 80%.

Marco Diana (2012), studied the commuter satisfaction for public transport services in terms of service frequency, punctuality, possibility of finding sitting place, the speed of the service, cleanliness of the vehicles, comfort while walking at bus stops, connectivity with other municipalities, convenience of schedules, cost of the ticket, the municipality where the household is located and frequency of the use of urban public transport in Italy.The metro network along with its stations should be seen as an opportunity space, which is properly developed can transform the image of a city into vibrant, dynamic, well connected and comfortable space for commuters. Spring C. Hsu, (2010), formulated a model to represent the transfer waiting time for connecting service at multi-modal stations, simulation results suggest that multi-modal operations, transfer waiting time cannot be improved without operational coordination with the feeder service. Multimodal Transportation is an attractive alternative only if the access and egress distances are not too large (Krygsman &Djist 2001). When the access or egress distances go beyond a certain threshold value the affinity to travel in a public transport mode decays.

2. Multimodal Public Transport in Delhi

Delhi is located in northern India and also is the capital of India. Delhi is the fourth most polluted city in the world and urban transportation is the most dominant factors of increment in urban pollution (Das. & Parikh 2004). Delhi has always boasted of a good public transport system in terms of connectivity. However, with the arrival of metro services in Delhi, the scenario of public transportation changed forever. Naveen Eluru*et al.*(2012) did a study on the travel mode choice and transit route choice and a negative propensity towards travel time on bus was observed as compared to metro or rail modes. Delhi, earlier used to move in DTC buses or personal modes on a big scale. After metro came into operation a large number of people started moving through the metro, which eased the traffic to an extent and also eased pressure on the bus system of Delhi. Even though Delhi Metro has been a boon to the public transport scenario of Delhi, it is also true that the population of the city has increased many folds thereby increasing the pressure on the transportation infrastructure yet again.

Rising incomes, flexible door to door service of personalized transportation modes, privacy and use as a status symbol has led to increase inthe number of privately owned vehicles causing a state of chaos and congestion on Delhi roads. Delhi has a high number of vehicle owners and even then around 50% of its population do not possess a four wheeler or a motorized two wheeler. This means that there is a huge scope of growth for vehicle ownership in the city (Sahai& Bishop 2010, RITES Ltd and TERI 2010). This congestion

also hampers the speedy operation of the bus services and causes a lot of time delay.Despite implementation of MRTS, about 8.85 million vehicles are expected to roll on Delhi roads in 2020. The share of motorized travel demand met by personal mode of transport is expected to increase in Delhi from 40% in 1997 to 48% in 2020 (Das. & Parikh 2004).The number of trips commuted daily has increased. Also the share of public transport in Delhi has reduced from 60% in 2001, to less than 45% in 2008 (Jain Suresh *et al*. 2014).Public transport in Delhi carries only about 60% of total vehicularperson trips as against 80% of the expected population size of the city (Kumar P.*et al.* 2013).Delhi is a city of historical grandeur and the tourism footfall in the city is high. There has been limited research into the experiences of visitors with the public transportation system of a city. The urban area tourism of any city constitutes in the package of numerous goods and services, a vital experience in terms of public transport facilities (Thompson & Schofield, 2007).

Delhi has a multimodal transportation system operational with a combination of personal modes (cars, jeeps, SUVs, two wheelers, cycles, etc.) and various public transport modes (minibuses, DTC buses, JnNURM buses, high capacity buses, ring railway, Delhi metro rail, upcoming monorail & Intermediate paratransit modes or IPTs like auto rickshaws, battery operated rickshaws, etc.).Connectivity is likely to aid as a performance measure in a large scale urban multimodal transit network comprising metro, local DTC buses, JnNURM buses, local light rail, regional light rail, ring railway bus rapid transit, and other Intermediate Paratransit (IPT) based transit services, where such services are provided by multiple public and private agencies with little coordination (Sabyasachee Mishra *et al.* 2015).The spatial spread of the city is such that all these modes can be combined, if completely efficient in all respects cater to the demands of the citizens. However, there are certain issues regarding travel time delay, connectivity and accessibility in the operational framework and inadequate amenities that are preventing it from becoming a seamless and self-sufficient urban public transportation system.

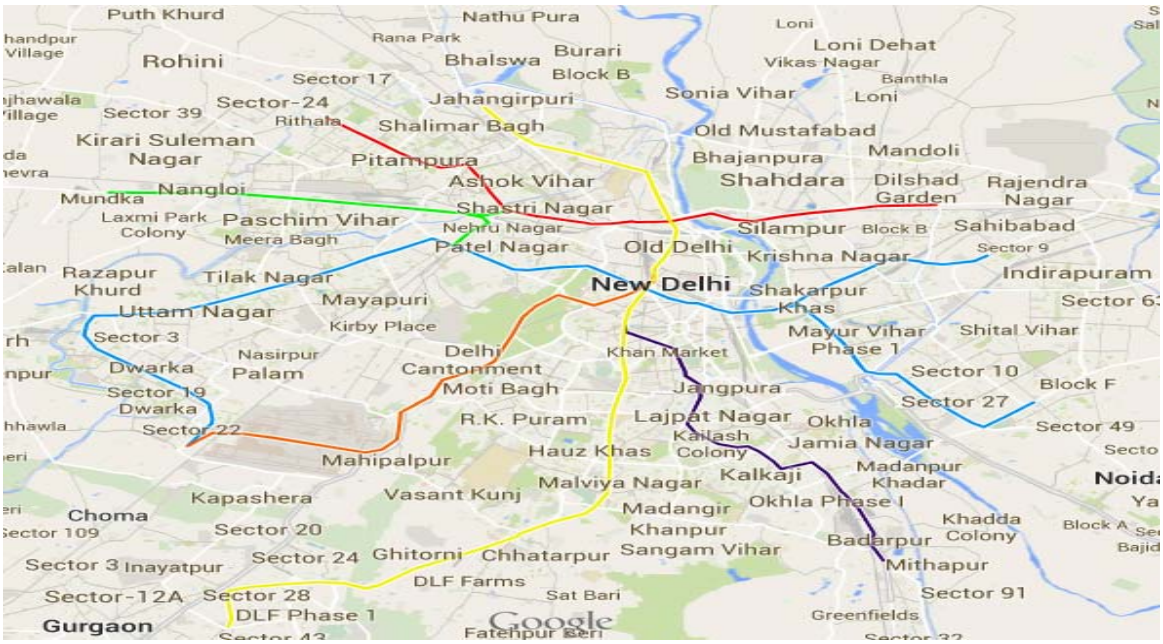


Figure 2. Delhi map showing Metro lines (Yellow, Red, Blue, Green, Violet& Orange).

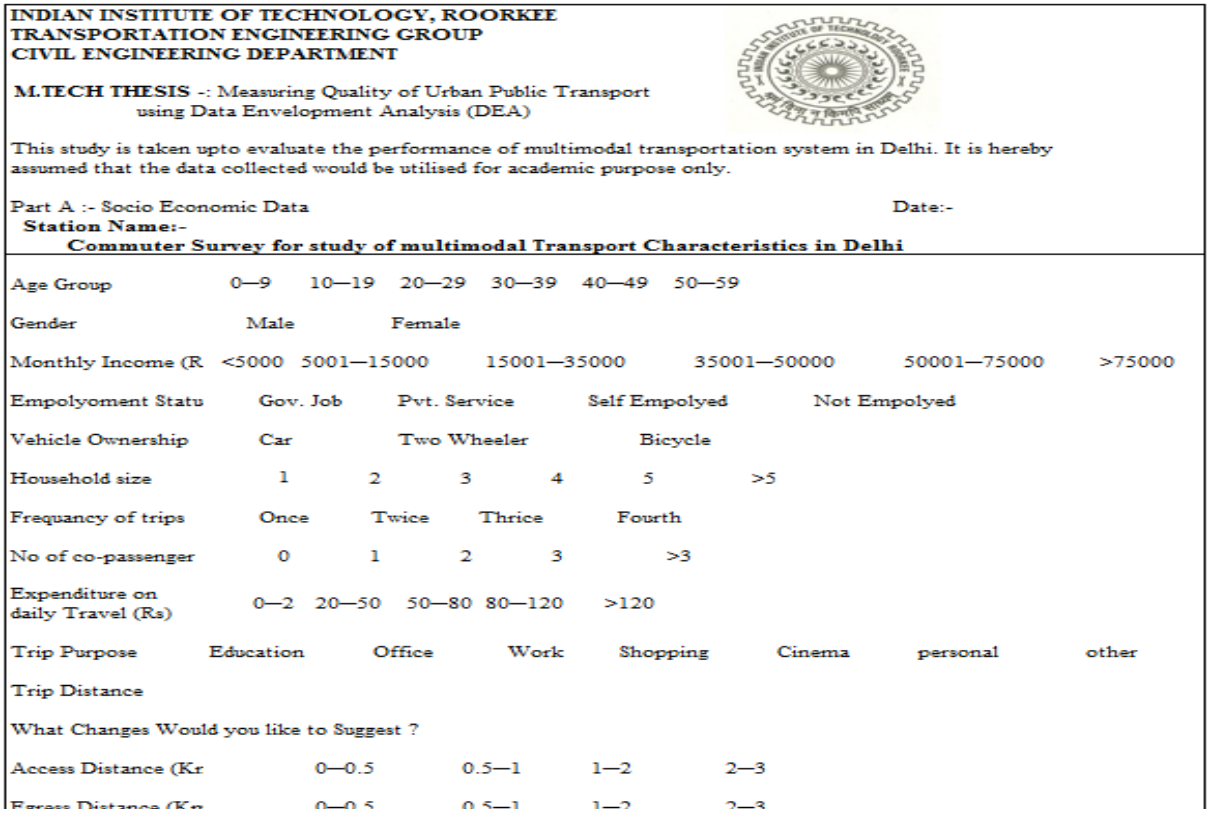
The technique used for data collection should be thoroughly checked in order to see if the data collection instrument is suitable for the purpose (Rastogi & Rao, 2002). The data was collected in activity based format which has emerged as a better substitute to the conventional trip-based models (Subbarao& Rao, 2014).The choice of customer perception was done as customers have the right elements for aptly evaluating the used service as they are the direct users (Eboli&Mazzulla 2014).Service quality is all about how a transit system is perceived by its users (Marsden and Bonsall 2006, TRB 2010, Dhingi 2011, Litman 2008, 2011 & 2014). Amongst the plethora of perspectives considered are 5 A's of Availability, Accessibility, Aesthetics, Amenity and Affordability. The other factors are speed of travel, frequency, reliability, integration between modes, information, physical design ease, comfort, convenience, payment options, seamless travel scenario, baggage handling infrastructure, security infrastructure etc.

Customer perception survey questionnaire was also filled during the data collection. It contained several questions on the various aspects of a public transport station. According to the TCQSM the two issues that cause concern to the customers are the service availability and if the service is available then the comfort and convenience it offers. The factors that are of importance in the customer's mind are Spatial Availability, Temporal availability. Information availability and capacity availability (TCRP Report 88, 2003). In a previous analysis on activity based data the activities were broadly segmented in 3 categories namely work, employment, business or education based and the other two categories were split in daily maintenance works and leisure based recreational activities (Subbarao& Rao, 2014).

3. Data Collection

The Population of Delhi, which was 16.8 million (2011) as per census of India, has been expected to grow to 23 million by 2021. Also the intracity vehicular trips which were 12.7 million are expected to grow to 24.7 million in the sameperiod. 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 (Kumar P.*et al.* 2013).

For this purpose a pilot survey was carried out first for 50 respondents and then the main survey was done. The data for analysis was collected from 1450 commuters in a travel response questionnaire which included questions on socio-demographic, temporal parameters and commuter preference on the quality and service aspects of the multimodal transit system. Further the responses were filtered and 1328 responses were finally recorded in spreadsheets to be analyzed.



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M.TECH THESIS -: Measuring Quality of Urban Public Transport using Data Envelopment Analysis (DEA)

This study is taken upto evaluate the performance of multimodal transportation system in Delhi. It is hereby assumed that the data collected would be utilised for academic purpose only.

Part A :- Socio Economic Data Date:-

Station Name:-

Commuter Survey for study of multimodal Transport Characteristics in Delhi

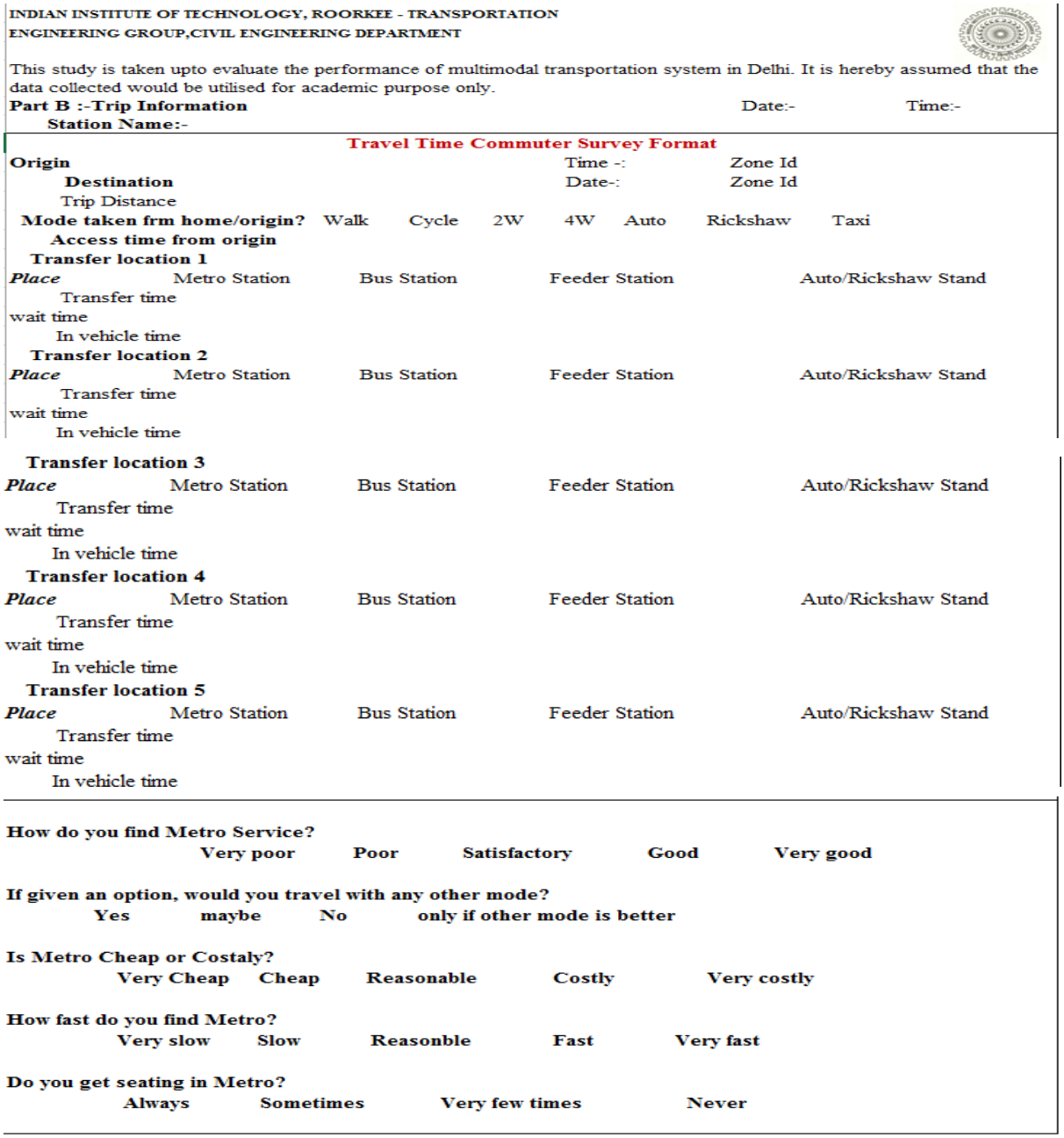
Age Group	0—9	10—19	20—29	30—39	40—49	50—59	
Gender	Male	Female					
Monthly Income (R	<5000	5001—15000	15001—35000	35001—50000	50001—75000	>75000	
Empolyoment Statu	Gov. Job	Pvt. Service	Self Empolyed	Not Empolyed			
Vehicle Ownership	Car	Two Wheeler	Bicycle				
Household size	1	2	3	4	5	>5	
Frequancy of trips	Once	Twice	Thrice	Fourth			
No of co-passenger	0	1	2	3	>3		
Expenditure on daily Travel (Rs)	0—2	20—50	50—80	80—120	>120		
Trip Purpose	Education	Office	Work	Shopping	Cinema	personal	other
Trip Distance							

What Changes Would you like to Suggest ?

Access Distance (Kr	0—0.5	0.5—1	1—2	2—3
Egress Distance (Kr	0—0.5	0.5—1	1—2	2—3

Figure 3(a)Survey questionnaire format.

The data were collected for the yellow and red lines of Delhi metro as shown in Figure 2. Metro was taken as the major mode of travel or the line haul mode in the multimodal trip in this study. (RITES 2010) conducted a study which revealed that Delhi Metro has been successfully able to attract the personal mode user and that the current number of metro users have 45% passengers who own a personal vehicle. This is due to the fact that Delhi Metro has provided better services to the users in the terms of safety, reliability and comfort. It also indicates an attitude of acceptance from the passengers. This attitude if tapped properly may aid in reaching the ideal patronage. The survey formats are as shown in Figure 3.



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This study is taken upto evaluate the performance of multimodal transportation system in Delhi. It is hereby assumed that the data collected would be utilised for academic purpose only.

Part B :-Trip Information Date:- Time:-

Station Name:-

Travel Time Commuter Survey Format

Origin Time -: Zone Id

Destination Date-: Zone Id

Trip Distance

Mode taken frm home/origin? Walk Cycle 2W 4W Auto Rickshaw Taxi

Access time from origin

Transfer location 1

Place Metro Station Bus Station Feeder Station Auto/Rickshaw Stand

Transfer time

wait time

In vehicle time

Transfer location 2

Place Metro Station Bus Station Feeder Station Auto/Rickshaw Stand

Transfer time

wait time

In vehicle time

Transfer location 3

Place Metro Station Bus Station Feeder Station Auto/Rickshaw Stand

Transfer time

wait time

In vehicle time

Transfer location 4

Place Metro Station Bus Station Feeder Station Auto/Rickshaw Stand

Transfer time

wait time

In vehicle time

Transfer location 5

Place Metro Station Bus Station Feeder Station Auto/Rickshaw Stand

Transfer time

wait time

In vehicle time

How do you find Metro Service?

Very poor Poor Satisfactory Good Very good

If given an option, would you travel with any other mode?

Yes maybe No only if other mode is better

Is Metro Cheap or Costaly?

Very Cheap Cheap Reasonable Costly Very costly

How fast do you find Metro?

Very slow Slow Reasonble Fast Very fast

Do you get seating in Metro?

Always Sometimes Very few times Never

Figure 3(b) & 3(c) Survey questionnaire format.

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Part C :- **Commuter Inventory** Date:- Time:-
Station Name:-

Commuter Satisfaction Survey Format for Station Inventory

Condition	yes	No		Remarks
This station/stop area is clean ?				
There are enough places to sit?				
There are places to buy food and beverage nearby				
There is enough shelter from sun and rain				
The information signs here are helpful				
Its easy to find routes and travel				
It is a convenient and comfortable way to travel				
Do you feel safe in the day ?				
Do you feel safe in the night ?				
Do you know where to contact in case of an				
Is the station lighting adequte?				
Are there enough security Personnel?	Always	Sometimes		Not at all Present
Is this an easy place to transfer for bus or another mode of transport	Somewhat	Easy		Not easy at all
What suggestion would you like to give to develop this station into a better multimodal hub to ease the travel for passengers				
Do u find that your time is wasted in transfers and				
Do you prefer to travel with this system?	Yes	Not at all	Only if no alternative present	strongly
The system is better than road travel	Yes	No	Only in rush hours I travel from Public transit to avoid traffic	
How good is the Access and Egress facilities at the station	Not good	satisfactory	good	very good
are there good restrooms in the station premises	not available	available but not	good	very good

Figure 3(d). Survey questionnaire format

4. Data Analysis Results

Socio demographic data were collected through direct interactions with the commuters. The results are presented in figure 4. Which reveal that more males travel in the MMTS system than the females. Majority of people travelling in the system were in the age group (20-40) years. In the present study they have been classified as education based, work based and recreation based which includes maintenance, shopping, social and leisure based activities. Also, the trip purpose for most of the trips were either education or work. The consistency of these travels towards metro patronage is considered more than those who are travelling for recreational purposes. Also, 65% people travelling in public transport are possessing private vehicles.

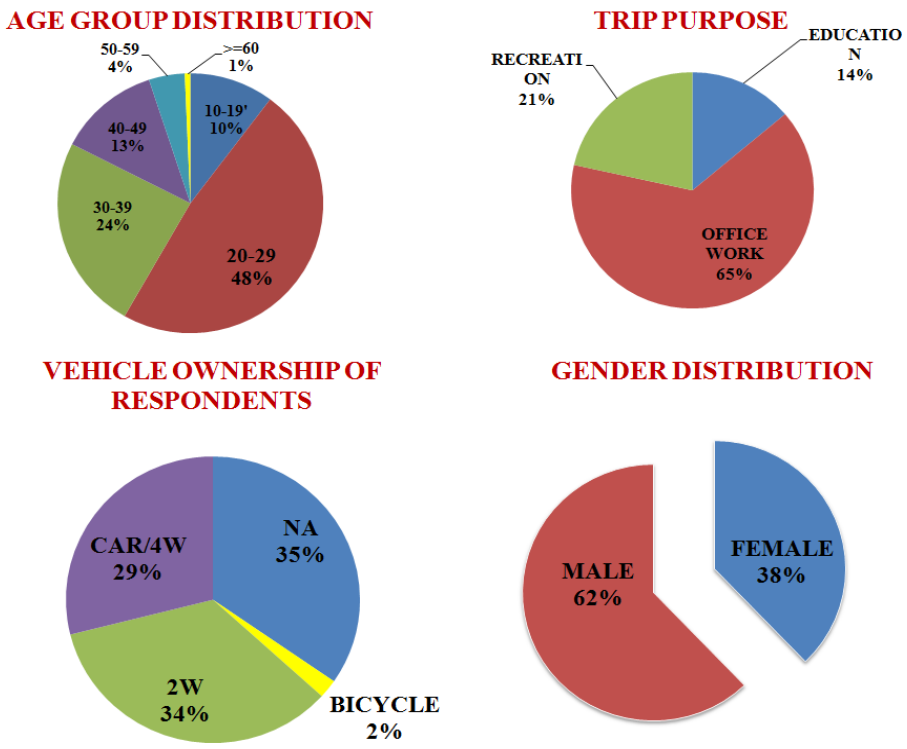

Figure 4. Demographic characteristics of the commuters.

Responses collected were then analyzed and are shown in Table 1. Customer perception values were divided on basis of the domain of facility or service and further response values were developed for the same. These response values are on the scale of 1 to 10. And are tabulated in Table 2. As we can see that the cleanliness of station premises, shelter availability, lighting, information signs, and availability of food and beverage in the Delhi Metro stations is up to the mark. However, the facilities that are related to the access and egress facilities or the transfer related concourse facilities do not seem to have a very good response as per the commuter's perception.

According to a study by RITES (2010) around 75% of access and egress trips to the Metro Stations are traversed through non-motorized modes (RITES Ltd and TERI 2010, Sahai& Bishop 2010). Access, egress and transfers all contribute to the major part of time lags while travelling in a multimodal system. This is where a private mode traveler saves time.

Table 1. The customer perception responses of the Delhi Metro System (red & yellowline).

CONDITION	*YES (%)*	*NO (%)*	
This station/stop area is clean?	**98.27**	**1.73**	
There are enough places to sit?	**54.71**	**45.29**	
There are places to buy food and beverage nearby	**87.43**	**12.57**	
There is enough shelter from sun and rain	**97.56**	**2.44**	
The information signs here are helpful	**96.75**	**3.25**	
Its easy to find routes and travel	**96.14**	**3.86**	
It is a convenient and comfortable way to travel	**96.25**	**3.75**	
Do you feel safe in the day?	**97.87**	**2.13**	
Do you feel safe in the night?	**81.66**	**18.34**	
Do you know where to contact in case of an emergency?	**47.11**	**52.89**	
Is the station lighting adequate?	**98.78**	**1.22**	
Are there enough security Personnel?	*Always %*	*Sometimes %*	*Not at all Present %*
	61.19	**38.19**	**0.006**
Is this an easy place to transfer for bus or another mode of transport	*Somewhat %*	*Easy %*	*Not easy at all %*
	64.94	**17.79**	**17.26**
Do you find that your time is wasted in transfers and waiting?	*YES %*	*NO %*	
	9.84	**90.15**	
IF YES, HOW MUCH TIME?	*(0-20) RANGE %*	*(20-40) RANGE %*	
	96.37	**3.63**	
Do you prefer to travel with this system?	*YES %*	*NO %*	
	97.76	**2.24**	
The system is better than road travel	*YES %*	*NO %*	
	98.07	**1.93**	
How good is the Access and Egress facilities at the station	*Not Good %*	*Satisfactory %*	*Good %*
	13.61	**33.73**	**52.64**
Are there good restrooms in the station premises	*Not Available %*	*Available but not good %*	*Good %*
	0.059	**41.86**	**52.13**

These time lags eventually are a reason for the private vehicle users to not shift their mode choice from private mode to public mode. So, these are crucial segments of travel which require to be studied in detail and opportunities of improvement in these aspects are an essential prerequisite to upgrade the ridership of public transit system. Factors such as service delivery, travel time, safety and security and maintenance are falling directly under the

purview of the transit agency (TCRP Report 88, 2003). Similar observation can be made from the response values of the customer perception analysis also.

Table 2. The customer perception response values of the Delhi Metro System (red & yellow line).

INFRASRUCTUTRE AND FACILITIES AT THE STATION PREMISE	**RESPONSE VALUE**
This station/stop area is clean?	**7.8**
There are enough places to sit?	
There are places to buy food and beverage nearby	
There is enough shelter from sun and rain	
are there good restrooms in the station premises	
INFORMATION ADEQUACY RESPONSE	**RESPONSE VALUE**
The informative signs here are helpful	**8.4**
Itis easy to find routes and travel	
It is a convenient and comfortable way to travel	
Do you know where to contact in case of an emergency?	
SECURITY AND SAFETY RESPONSE	**RESPONSE VALUE**
Do you feel safe in the day?	**7.1**
Do you feel safe in the night?	
Do you know where to contact in case of an emergency?	
Is the station lighting adequate?	
Are there enough security Personnel?	
ACCESS - EGRESS AND EASE OF TRANSFER RESPONSE	**RESPONSE VALUE**
Is this an easy place to transfer for bus or another mode of transport	**4.02**
Do you find that your time is wasted in transfers and waiting?	
Do you prefer to travel with this system?	
How good is the Access and Egress facilities at the station	
If given an option, would you travel with any other mode?	
RESPONSE TO ENTIRE METRO SYSTEM	**RESPONSE VALUE**
The system is better than road travel	**4.9**
Do you get seating in Metro?	
How fast do you find Metro?	
Is Metro Cheap or Costly?	
If given an option, would you travel with any other mode?	
How do you find Metro Service?	

Table 1. &2.Show the customer perception, values for the entire system, i.e. red and yellow lines of Delhi Metro considered together. However, for a better understanding of which station lacks in which specific domain it is required to have the customer perception values for individual stations. The station specific details are presented in Table 3. Here, the positive response was taken as 1 and negative response as 0. As we can see in the customer perception

response values for the individual stations there are several stations which are performing better like GTB Nagar, Vishwavidyalaya, Chawri Bazaar, Rajiv Chowk, Patel Chowk, Race Course, etc. in yellow line and Kohat Enclave, NSP, Seelampur, etc. in red line.

A Special Multimodal Transport security regulatory authority has been suggested for the Delhi multimodal system (Pawan Kumar *et al.* 2011). Since the concourse area design, information signage, security installments and personnel for almost all station areas in DMRC are similarly operated, the difference in the response values for the better and worse stations is attributed to the ease of travel and ease of transfer facilities in these individual stations.

Table 3. Station specific customer perception response values.

Individual Stations	Customer PerceptionResponse Values	Individual Stations	Customer PerceptionResponse Values
JAHANGIRPURI	0.735	RITHALA	0.806
ADARSH NAGAR	0.777	ROHINI WEST	0.800
AZADPUR	0.717	ROHINI EAST	0.715
MODEL TOWN	0.700	PITAMPURA	0.812
GTB NAGAR	0.813	KOHAT ENCLAVE	0.850
VISHWAVIDYALAYA	0.835	NETAJI SUBHASH PLACE	0.838
VIDHAN SABHA	0.760	KESHAV PURAM	0.792
CIVIL LINES	0.835	KANHAIYA NAGAR	0.791
KASHMERE GATE	0.757	INDERLOK	0.778
CHANDNI CHOWK	0.774	SHASTRI NAGAR	0.793
CHAWRI BAZAAR	0.893	PRATAP NAGAR	0.644
NDLS	0.805	PULBANGASH	0.785
RAJIV CHOWK	0.830	TIS HAZARI	0.813
PATEL CHOWK	0.844	KASHMERE GATE	0.757
CENTRAL SECRETARIAT	0.819	SHASTRI PARK	0.762
UDYOG BHAWAN	0.800	SEELAMPUR	0.800
RACE COURSE	0.894	WELCOME	0.793
JOR BAGH	0.817	SHAHADRA	0.756
INA	0.796	MANSAROVAR PARK	0.600
AIIMS	0.866	JHILMIL	0.735
GREEN PARK	0.800	DILSHAD GARDEN	0.684
HAUZ KHAS	0.819		
MALVIYA NAGAR	0.835		
SAKET	0.821		
QUTAB MINAR	0.847		
CHATTARPUR	0.811		
SULTANPUR	0.808		
GHITORINI	0.779		
ARJANGARH	0.820		
GURU DRONACHARYA	0.827		
SIKANDARPUR	0.825		
MG ROAD	0.828		
IFFCO CHOWK	0.820		
HUDA CITY CENTRE	0.813		

The percentage of transfers based trips from the total trips is an important observation when transport integration is considered (Katarzyna& Zak, 2014).

The Interconnectivity ratio is the ratio of Access and egress time taken together to the total trip travel time. For most multimodal trips the IR range is from 0.2 to 0.5. The value receivedfor I_R in this analysis is 0.3. Service Time Ratio is the ratio of the penalty time (wait time + transfer time) to the Total Travel Time (TTT). For Most Trips It Is Between (0 - 0.5). The value obtained for STR in this analysis is 0.234.

Interconnectivity Convenience is the percentage of IVTT that is spent in the Access and Egress together. It is expressed in %. A value of more than 0.4 shall be undesirable as that would mean that a person has spent more than 40% of his IVTT time in access and egress. Value received in the current study is 0.665 which is very much higher than 0.4. This indicates a dire need to reconsider the access and egress legs of the multimodal trip.

Time delays in the access and egress part is a deterrent to modal shift in favor of public transport.In a study done in 1980's in USA, they used multinomial logit model to predict transit ridership in 3 predefined scenarios and they considered the quality of transit being represented by an additive function of IVTT, OVTT and the travel fare or cost (Frank S. Koppelman 1983).

$$Ic= \frac{(ACCESS+EGRESS)}{IVTT}*100$$

TCQSM has defined six measures of LOS having two broad categories of service availability which includes service frequency, service coverage and service span and a second category of service quality which includes service reliability, passenger loading and transit-auto travel time difference. In this study LOS has been taken out in the temporal context (Fu & Xin, 2007). A service quality index was also developed in which MNL was further used to estimate the weights of the important attributes (Hensher *et al*. 2003). In the recommendation for further work on transit LOS a previous study done in Switzerland suggested a comparison of transit LOS with automobile LOS (Hermann Orth *et al*. 2011). This paper studies the travel time component in both the modes to evaluate LOS of a multimodal system.Level of service is the ratio of out-vehicle travel time to the in-vehicle travel time. It estimates the weight of OVTT compared to IVTT. The larger the ratio less attractive is the public transport. In the present analysis the ratio obtained is 0.680.

Passenger Waiting Index is the ratio of mean passenger waiting time to the frequency of the transport service. Practically 0 is not possible. PWI value can be fixed between 0 and 1.The value received from our analysis is 1.867 which is way higher that the upper range 1. The gap here is due to the waiting time for the access mode as well as the egress mode.

Table 4. Mean values for the performance indicators of the Delhi Metro corridors.

	INTERCONNECT-IVITY RATIO (I_R)	*SERVICE TIME RATIO (STR)*	*INTERCO-NNECTIVITY CONVENIENCE (I_C)*	LEVEL OF SERVICE (LOS)	PASSENGER WAITING INDEX (PWI)
JAHANGIRPURI TO KASHMERE GATE	0.301	0.221	0.663	0.713	2.011
CHANDNI CHOWK TO CENTRAL SECRETARIAT	0.321	0.243	0.722	0.699	1.829
UDYOG BHAWAN TO SAKET	0.297	0.22	0.628	0.644	2.062
QUTUB MINAR TO HUDA CITY CENTRE	0.269	0.190	0.514	0.545	2.178
RITHALA TO KANHAIYA NAGAR	0.273	0.238	0.570	0.587	1.712
INDERLOK TO KASHMERE GATE	0.318	0.269	0.781	0.795	1.601
SHASTRI PARK TO DILSHAD GARDEN	0.323	0.259	0.776	0.775	1.675
Mean values	**0.300**	**0.234**	**0.665**	**0.680**	**1.867**

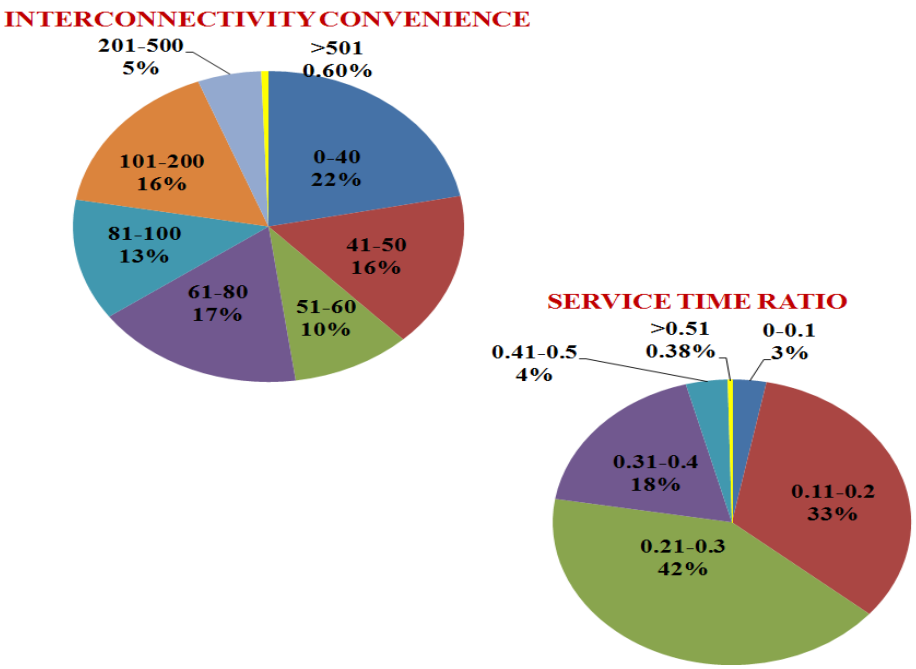

Figure 5. Percentage split of the Interconnectivity Convenience IC and the Service Time Ratio STR for the red and yellow line stations of Delhi Metro.

The results indicate towards a weak coordination in the non line haul parts of the multimodal journey. Thepercentage split of the interconnectivity convenience value as seen in figure 5. Shows that apart from 22% people the rest 78% people are spending more than 40% of their IVTT times in the access, egress, wait and transfers. That is, the actual time for a public transport mode to connect them to origin to destination is taking lesser time as compared to the fringe timings wasted in OVTT due to improper coordination between the four legs of multimodal transportation viz. Access leg, Egress leg, Line-haul leg and the transfer leg. Also, the service time distribution shows that upto 30% time of majority of commuters is lost in penalty time (wait time and transfer time) when compared to the total trip time. The transit agencies in their design stages may opt for providing 'planned' transfers in order to attract commuters who are regular in using the interchange terminals as the provision of planned or unplanned transfers may allow the transit agencies to pre-plan for increasing the ease of travel, reduction in travel times and making the image of the transit provider as more reliable (Subeh Chowdhury *et al*. 2013). The minimum distance of travel for coming forward to use rapid transit mode such as metro in most cases is a distance above 10Kms (Vuchic 2005: 32). So a planned transfer here may help to reduce the total time spent on a travel distance greater than 10 Kms. Since transit modes which have smaller walking times are the preferable choice (Naveen Eluru*et al*. 2012), it implies that the proximal catchment area of the transit mode should be shorter enough to be easily walkable.

5. Conclusions and Recommendations

The existing conditions of the Delhi Metro stations are studied for the role played by the yellow and the red line in the multimodal fabric of the trip of commuters. The Delhi Metro has done a commendable task in being able to bring forward a large number of commuters to shift their mode of preference in the favor of MRTS system. However, a lot of improvements can still be done to enhance the performance of the system which would eventually reward DMRC in the form of increment in the ridership. The major insights drawn from the study are:

1. The Delhi Metro stations are clean, well informed, provide good security within the station premises, are well designed to prevent from climate and are well equipped in terms of comfort and station environment for the commuters. This has positively impacted the image of DMRC and has also brought forward people to travel in DMRC.

2. DMRC is the line haul mode for most multimodal trips in Delhi. The temporal analysis done on various performance indicators reveal that as far as the metro rail frequency, speed and IVTT times are considered the DMRC is operating in a satisfactory manner. But, the problem lies out of the metro rail and unless and until this is given its due attention, it is unlikely that the commuters will further come forward to use the metro system. The interconnectivity convenience values are more than 0.4 % for most trips. The Access and egress facilities are poorly designed with most stations having no organized or formal parking areas for IPT modes or feeder bus facility. This causes the commuter to wait for the access and egress modes for a long time, a major adherence to embrace the MMTS system.

3. The transfer area concourses and turnpikes can also be redesigned to save the time of the passenger in the peak hours as the Service time ratio shows that a lot of time is wasted in waiting and transfer areas. Various measures can be adopted like a common mobility card, multiple turnpikes for specific hours, design alterations to reduce concourse area for potential transfers in order to reduce time lag in this leg of public transport travel.

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