

# MACRO-SIMULATION BASED PASSENGER ASSIGNMENT OF DELHI METRO

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**Abstract:** Metro is the most efficient and sustainable mode of transport in Delhi. Delhi metro helps in transferring a large volume of commuters in an efficient manner. With a growing population and development of infrastructure in Delhi, need for metro is increasing in all the regions of the city. Thus, Delhi Metro Corporation planned and executed further metro expansion from phase II to phase III. This paper studies the metro passenger assignment using Time table based approach in macroscopic simulation software VISUM. This study has been carried out to analyze the effect of increase in ridership and to deduce the factors which are responsible for the change in traffic assignment in the current metro network (2018). The objectives of this study are to compare the Phase II metro network with phase III, and to study the effects due to the extension and addition of metro lines under Phase III. From the study, it was observed that with the implementation of phase III metro plan, both 'journey time' and 'in vehicle travel time' are reduced and 'average speed' of journey through metro is increased. Further, 'passenger kilometer travel' and 'boarding and alighting' have increased tremendously.

**Keywords:** metro, macro simulation, boarding, alighting, passenger assignment.

## 1. Introduction

Transportation is the movement of people or goods from one point to other point, this movement can be done by different modes such as car, auto rickshaw, two wheeler, walk, bus, metro, etc. To make this movement more flexible and efficient, proper planning has to be done, thus transfer of people and goods using different modes in a flexible and efficient way with a proper planning form a system called as transportation system. Transport planning is the process of defining

future policies, goals, investment and to design the system so that people and goods can move from origin to destination in more flexible and efficient way. Transportation consist of transport by land, water and air. Public transport in India remain the primary mode and most heavily used in the world (World Bank, 2007). Proper planning is required to make public transport efficient and lucrative mode. India going to be in the list of fastest growing country in the world (Harvard University, 2018), growing in almost all the sectors like education,

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industries, commerce etc. The demand in transport has also increased accordingly across India, but there is a lag in transport infrastructure, road network and transport planning. As economic growth of the country is directly proportional to road network thus it is important to have good road network and transport infrastructure for increase in economic growth. Transportation is the backbone to the development of urban area (Chattaraj, 2003), as transport development is directly proportional to economy, increase in economy leads to development in country. It is important to maintain growth momentum in a sustainable manner to improve overall standard of living and reduce poverty. For work, education, business, people need to move from one place to other and if there is proper connectivity in modes of transport then this will reduce travel time, this reduction in travel time helps in increasing work time and reduction in fatigue of people that ultimate leads to increase in earning thus help country to increase economic growth and productivity. For this Delhi Metro Corporation is playing important role by making the radial development of metro system, increasing connectivity from end to end in Delhi region.

As the population in India increasing, traffic condition is becoming worse which leads to traffic congestion. With people preferring their own personal vehicles (car, two wheeler) has further worsened the road condition. From residential place people go to office, factories, school, etc. in morning hours and return in evening using their private vehicle leads to congestion. This traffic congestion causes slow movement of traffic, increase in travel time and environmental pollution. If planners want commuters to shift to public transport (metro), then it is important to

provide good connectivity and frequency with less access and egress time.

Delhi is going to be most populous city in the world by 2028 (UN DESA, 2018). NCR Delhi population is estimated to be 28,513,682 in 2018, with a growth rate of 3.3% since 2013. To deal with the rapid growth in NCR Delhi and with the increase in transport demand proper public transport planning is required. For this government is prioritizing transport infra development with increased budget allocation by 20%-30% in the field of transport infrastructure since last 3-4 years. They aim to set efficient and modern transport system by 75th independence (RITES, 2017).

## 2. Literature

### 2.1. General

In last few decades' number of models were developed for traffic assignment. These techniques are used to assign traffic efficiently. In the early research, base models of traffic assignment were developed namely: All or Nothing (AON), Deterministic User Equilibrium (DUE), Stochastic User Equilibrium (SUE), Incremental method, based on the Wardrop's equilibrium principle theory, Frank Wolfe algorithm etc. With the help of these models as base model, further improvement is going on by using different algorithm, by restricting link capacity, using weighted graph, etc. Some of the models are explained briefly in the review section.

### 2.2. Literature Review

(Meng *et al.*, 2007) developed SUE model considering link capacity constraint. Model was developed in terms of path flow. The

main purpose of model was to involve path specific delay function. As a result, they developed SUE model with capacity constraint and developed global convergent Lagrangian dual method in which step size is predetermined. Researchers like (Toroslu and Üçoluk, 2007) used incremental assignment problem, Hungarian algorithm and weighted bipartite graph. In this paper they used matching algorithm by adding pair of vertices and edges to the weighted bipartite graph whose maximum weight matching is already known and new maximum weight matching is to be find out. As a result, they found that use of this model of incremental assignment is more efficient as compare to other assignment methods.

(Watling, 2006) developed a model using user equilibrium (UE) traffic assignment method, considered stochastic travel time and late arrival penalty. He used two travel time model, first is multivariate normal arc travel time and second is mixture distribution of multivariate normal. The model he developed called as late arrival penalized user equilibrium (LAPUE). Result shows that solution from LAPUE is good for mild extension but non additive path disutility was the limitation of the algorithm.

(Dial, 2006) developed a path based user equilibrium algorithm called as algorithm B. This paper presents the space and time efficient UE algorithm. The limitation of Frank Wolfe is overcome by algorithm B. This simple and easy approach is intuitive, time and space efficient and satisfactorily converges.

(Levin *et al.*, 2015) compare the solution of equilibrium assignment for simulation based dynamic traffic problem. They have

done comparison between MSA (method of successive average), partial demand loading scheme and gradient based technique. as a result they suggested that partial loading demand scheme converges more and leads to rapid gap stabilization as in early iteration it reduces congestion.

(Bar-Gera *et al.*, 2012) have used UE with condition of proportionality and compared the results of three assignment algorithm, Link based, route based and pair of alternative segments. As a result, found that link based does not satisfy the condition of proportionality perfectly, route choice algorithm satisfy the proportionality up to certain limit and hindrance occur due to PIRSC (proportionality implied route set consistency). The limitation in link based and route based is overcome by pair of alternative based assignment. It was suggested that as level of convergence increases PIRSC adherence may be improved.

(Boyce *et al.*, 2004) have used user equilibrium assignment with Origin Based Assignment (OBA) algorithm. OBA algorithm was developed by (Bar-Gera, 2002), this assignment technique gives highly convergent result as this method uses intermediate way to assign that is between link flow and route flow algorithm. They made comparison of OBA with Frank Wolfe algorithm by seeing that how many iteration is required for the level of convergence achieved by OBA.

Chang and Dresser (1990) compared five assignment methods: AON, stochastic multipath, incremental, iterative and equilibrium for the existing network. As a result, they found that there is not much difference in macro level between the

assignment in the network but as compare to other in micro level measure incremental assignment method gives the best result and equilibrium method gave good results as compared to other methods. (Lo *et al.*, 2005) developed reliability based user equilibrium (RUE) method. In RUE method instead of using expected travel time for optimum path search they used travel time budget.

(Hong *et al.*, 2017) developed a passenger assignment in metro network model based on Automatic Fare Collection (AFC) and realized time table. With the help of AFC and realized time table observed travel time can be known which is directly related to origin destination (OD) pairs. Novel clustering algorithm is used between OD pair to calculate passenger assignment. By taking example of shanghai metro network for OD pairs found that this algorithm is accurate and work well.

(Jin *et al.*, 2017) developed a route choice behavior model based on discrete choice theory for metro passengers using Logit model by considering number of transfer, transfer time, in vehicle time, level of service, path size factor and perceived transfer threshold (transfer time penalty) as utility function. By taking transfer time penalty in consideration, explanatory abilities of model were improved.

(Zhang *et al.*, 2017) developed a Constrained Multinomial Probit model for route choice with three different set of utility function, compensatory considering in vehicle time, transfer time, number of transfer, revised angular cost and congestion level, non-compensatory involve impacts of routes and error part which is based on multivariate normal distribution. Model gives good forecasting and reliable result.

From above literatures we can conclude that a lot of work has been done in the traffic assignment area for road network but for passenger assignment in metro there is need to develop model as development in metro network is taking place, gives public more alternative routes to choose and yet not much study is done in sector of passenger assignment in metro network which gives scope of research in this sector.

### 3. Study Areas and Data Collection

Delhi NCR has been selected as the study area, with metro transport system for the study of traffic assignment in various lines of metro in current scenario (2018) and phase II metro system (2013). Delhi NCR region is divided into 368 zones and data is collected for all the zones by CRRI Delhi. Household survey is conducted by CRRI in all the 368 zones, around 3100 samples are collected from South Delhi and around 2000 samples obtained from North, East, South-West and West Delhi. Delhi Metro data is taken from DMRC site.

### 4. Model Development

#### 4.1. General

Travel demand model is the decision making system which predict the travel behavior of the people. Decision of people includes destination choice, mode choice, and route choice. Typical travel demand model has four stages: trip generation, trip distribution, modal choice and trip assignment. There are many methods to develop travel demand model, in this paper we have use simulation software VISUM to do traffic assignment in metro rail network fourth step in four stage modelling for the study area NCR Delhi.

For this NCR Delhi is divided into 368 zones whose household survey data is already done by CRRI. With the help of survey data trip attraction and production is calculated by using regression method. Further steps are done in VISUM software as discussed briefly in below section.

## 4.2. Modelling in VISUM

VISUM is a macroscopic simulation software used for modelling transport demand. This study uses standard four step model for travel demand modelling of metro network. Two scenarios were compared, i) after completion of phase II in Delhi metro rail (2013) (Fig. 2) and ii) the current addition and extension of phase III in Delhi metro (2018) (Fig. 1).

Phase II metro rail network in Delhi consisted of six lines: Blue, Green, Red, Yellow, Violet and Orange (Airport express line). Metro network had 143 stations with a total length of 189.63km. Metro train consist of 6 to 8 coaches, earlier it was six but with increasing demand in some of the train 8 coaches were added. Delhi metro rail generally starts at 5:30 AM and the last train runs at 11:30 PM with interval of 2-3 minutes at peak period and 5-6 minutes off peak period. For our study we have taken 4-minute time interval.

In Phase III of Delhi metro rail network two more lines, Magenta & Pink were added. Magenta line runs from Botanical Garden to Janakpuri West and Pink line runs from Majlis Park to Shiv Vihar. Three metro lines were extended. Yellow line is extended up to Samaypur Badli from Janhangirpuri, Green line is extended from Mundka to

Bahadurgarh City Park and Violet line is extended from Badarpur Border to Escorts Mujesar. Currently metro rail network has eight lines with a total length of 314km, serving 229 stations, with average daily ridership 2.76 million passengers. Delhi metro rail became 9th longest and 16th largest in ridership (TIMES OF INDIA, 2018).

The metro network is created in VISUM as shown in fig.1, with the help of nodes and links. Stop points, lines and line route were defined for the metro line network. Traffic assignment for PuT in VISUM can be done in three different ways: a) transport system based, b) time table based and c) headway based.

Transport system based procedure, based on AON assignment method. It gives an overview of demand structure. This method of assignment gives the fastest/ ideal route to choose. Time table based procedure is generally used for the rail network, not suitable for bus network in urban area. When coordination is important for the transfer then this method is used. Headway based method is ideal for urban network for long term planning and whose timetable is unknown. This procedure is generally used for bus network as headway of bus lines are short.

In this paper we have used time table based traffic assignment method with 4-minute interval for all the metro lines with starting time 5:30 AM and last train time 11:30PM except for Airport line starting time is 4:45AM.



**Fig. 1.**  
*Metro Network Lines Digested in VISUM (2018)*

## 5. Results and Discussion

In the current scenario of Delhi metro most of the phase III lines are open. Some of the lines were extended: Green (up to City park from Mundka and from Ashok park to Inderlok), Violet (from Badarpur Border to Escorts Mujesar) and Yellow (from Jahangirpuri to Samaypur Badli) and two new lines were introduced: Pink (Majlis Park to Shiv Vihar) and Magenta (Botanical Garden to Janakpuri West).

Timetable based assignment is done for phase II metro network and for current metro

network (2018). From the analysis of result, it was found that passenger/day has increased for current metro network as can be observed in Fig. 2 and Fig. 3. The thickness of blue bars indicates the volume of traffic on the lines and stops showing the passenger boarding volume with different color.

There is a clear increment in the current traffic when compared to phase II. This increment in passenger/day is due to addition/ extension of phase III metro lines which has increased the reach of metro to areas which were unconnected to metro system before.

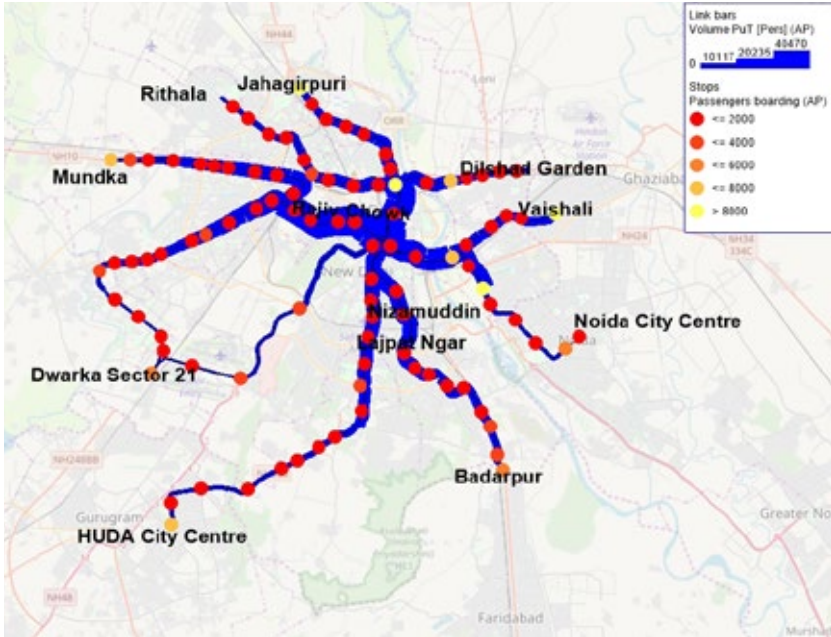


Fig. 2. Metro Trip Assignment for Phase II (2013)



Fig. 3. Metro Trip Assignment for Current Scenario (2018)

Table 1 and Table 2 summarizes the number of passengers boarding and alighting at few of the major and terminal stations for phase II and current scenarios respectively. It can be seen that the boarding and alighting of passengers from major stations have changed

tremendously as ridership is increased from 2013 to 2018 as metro phase III is introduced. In all the stations generally boarding and alighting of passengers are increasing but in Mundka station it is reduced. Reason might be due to the extension of Green line.

**Table 1**

*List of Boarding and Alighting Passengers for Phase II*

Station name	Boarding passengers/day	Alighting passengers/ day
Jahangirpuri	8414	8321
kashmere Gate	52082	52199
Dilshad Garden	5399	5058
Vaishali	8051	12577
Noida City Centre	691	408
Badarpur Border	4621	8995
Huda city centre	6145	4550
Dwaraka Sector 21	5873	5926
Janakpuri West	1958	2259
Mundka	6033	5301
Rithala	3834	4463
Lajpat Nagar	890	1121
Rajiv Chowk	62991	62669

**Table 2**

*List of Boarding and Alighting Passengers for Current Period (2018)*

Station name	Boarding passengers/day	Alighting passengers/ day
Jahangirpuri	21489	29333
kashmere Gate	231508	232427
Dilshad Garden	86123	44073
Vaishali	99955	182003
Noida City Centre	8797	5086
Badarpur Border	17861	13546
Huda city centre	86502	62294
Dwaraka Sector 21	24223	25123
Janakpuri West	8341	10786
Mundka	3466	4137
Rithala	34902	23955
Lajpat Nagar	231957	232551
Rajiv Chowk	227523	225619

Table 3 and Table 4 summarizes the passenger kilometer travel from the two scenarios for the metro lines. From Table 3 and Table 4 it can be seen that the Passenger

kilometer is increased tremendously in 2018 as compared to Phase II (2013), it is due to the addition of new metro lines, extension of metro lines and increase in ridership as well.



From table 4 it can be seen that ‘Mean journey time PuT’ and ‘Mean In vehicle time PuT’ is reduced form earlier and ‘Mean In vehicle speed’ is increased. The reason

behind this might be the introduction of phase III metro, as connectivity and access of the metro system is improved, efficiency of metro increased.

**Table 3**

*Passenger Kilometer in Analysis Period*

Line route	Phase II (2013) Passenger kilometer travel	Current (2018) Passenger kilometer travel
Blue (Noida city Centre to Dwarka sector 21)	796610	7233863
BlueI (Vaishali to Dwarka sector 21)	827214	6614576
Green (Kirti nagar to City Park)	407309	2776511
GreenI (Inderlok to City Park)	-	4197745
Magenta (Botanical Garden to Janakpuri West)	-	3546435
Orange (New Delhi to Dwarka sector 21)	246743	1187486
Pink (Lajpat Nagar to Majlis Park)	-	12740970
Red (Dilshad Garden to Rithala)	510423	4822385
Violet (Escorts Mujesar to Kashmere Gate)	579091	6725879
Yellow (HUDA City Centre to Samaypur Badli)	1165297	10354750

**Table 4**

*PuT Assignment Statistics*

Parameter	Phase II (2013)	Current (2018)
Total passenger kilometer travel	4532457km	60200598km
Mean journey time PuT	2h33min29s	2h7min59s
Mean In vehicle time PuT	46min9s	38min28s
Mean In vehicle speed PuT	27km/h	32km/h

From table 5 we can see that with the addition of Pink and Magenta metro line people need not to change the metro line

frequently, as connectivity is improved. Some of the examples are shown in the table.

**Table 5**

*Change in Metro Lines Post Phase II (due to Addition of New Metro Line)*

OD pairs of metro stations	Phase II	Current (2018)
Majlis Park to Dhaula kua	Yellow + Orange	Pink
Majlis park to Mayor vihar	Yellow + Blue	Pink
Majlis park to Rajouri	Yellow +Blue	Pink
Majlis park to Lajpat nagar	Yellow + Violet	Pink
Botanical to Hauz khas	Blue + Yellow	Magenta
Botanical to Janakpuri west	Violet + Blue	Magenta
Botanical to Kalkaji	Violet + Blue	Magenta

## 6. Conclusion

Public transit is one of the most important part of transportation system in a city. Delhi has a widespread bus transport system along with a metro transit system which is undergoing phases of planned expansion. The expansion of Delhi metro system is currently nearing completion of Phase III. This study compares the performance of metro transit in its phase II and current stages. The purpose of study is to show the demand of travel is increasing and to satisfy this demand good and efficient public transport is needed. For this purpose, Delhi metro is considered for our study, comparison is done between phase II metro network and current (2018) metro network and effect due to addition (Pink and Magenta) and extension of existing metro lines was carried out in macro simulation software VISUM.

Two metro networks i) phase II (2013) and ii) current (2018) were created and time table based traffic assignment with 4 min headway and start time 5:30AM and last train time 11:30PM is done for both the cases. In the result we found that passenger kilometer per day has been increased tremendously in current metro network (2018). Boarding and alighting has increased for almost all the station except one station which was further extended in phase III. Other statistics parameters like In vehicle time and journey time both have reduced for current network and in vehicle speed has increased. The reason behind this is the increase in ridership, addition and extension of metro lines. With the addition of new metro lines travel time is reduced as passenger need not to change the metro line frequently.

From the developed model and the obtained results, it can be concluded that in future to accommodate the increasing ridership and to shift private transport user to metro, frequency of metro should be increased and further addition of metro line should be planned to get better connectivity. For this DMRC is working as they planned Phase 4 metro line connecting south Delhi to Airport and extension of Red, Pink and Magenta. Line is planned by the end of year 2025.

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