EVALUATION OF INFRASTRUCTURE DESIGN STRATEGIES ON MASS TRANSIT COMMUTER MODE SHARE

M.Tech. Final Report in partial fulfillment for the award of the degree of

Master of Technology

In

Infrastructure Design and Management

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TECHNICAL UNIVERSITY OF MUNICH

May 2018

Dedicated to

my parents and loved ones

Declaration by Student

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b. The work has not been submitted to any other Institute for any degree or diploma.
c. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the Institute.
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Date: 30th April, 2018 **Signature of the Student**

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Certificate by supervisor(s)

This is to certify that the project report entitled ***'Evaluation of Infrastructure Design Strategies on Mass Transit Commuter Mode Share',*** submitted by ***Eeshan Bhaduri*** to Indian Institute of Technology Kharagpur, is a record of bona fide project work carried out by him under our supervision.

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Acknowledgements

I would like to extend my foremost and most sincere gratitude to my guide Prof. Dr. Arkopal Goswami, who was gracious enough to accept me as his student and guide me in my pursuit. In the same vein, I would also like to thank Prof. Dr. –Ing. Rolf Moeckel, whom I am greatly indebted to, for accepting to be my co-guide.

I take this moment to also thank Prof. Dr. Bharath Aithal and our thesis coordinator Prof. Dr. Ankhi Banerjee who have constantly supported me through my time as an MTech. Student, going above and beyond their duties.

I also thank DAAD, the *German Academic Exchange Program,* and TUM, *Technical University of Munich* for enabling me to carry out a part of my research in Germany.

I also take this space to acknowledge the feedback I received from my PhD supervisors, Dipanjan Nag & Chandan M C in India and Dr. Carlos Llorca, Hema Rayaprolu & Usman Ahmed in Germany, who helped to shape this thesis.

It goes without saying that none of this would be possible without the support of my parents and friends like Pankaj and Sangeet who helped greatly during the data collection phase in Kolkata.

I will also like to thank Shagufta for her extended support at any issue for whole of this period which assured that the difficult periods are to be only short & temporary.

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Abstract

Old can be smart too – this concept forms the bedrock of one of the most ambitious projects of the Indian Government; i.e. “Smart Cities Mission”, launched in 2015. Essentially a “smart city” integrates various infrastructural services with several ways of resource optimization to ensure prolonged well-being of its citizens. With an overarching aim to become smart, old and highly congested cities like Kolkata must consider the aspect of sustainable mobility, which is reliable, safe, eco-friendly and affordable.

Mass Transit (MT) provides distinct advantages over Private Vehicles (PV) and Intermediate Public Transport (IPT) in terms of congestion cost saving as well as environmental pollution control. Studies show that with respect to fuel and congestion cost-saving, integrated MT system is a proven solution compared to PV; and to attract discretionary PV users to MT, major strategies should include the three service measures of speed, frequency and reliability. Although numerous studies explain the impact of service improvement measures in terms of speed and travel time, it can be argued that very few clearly deal with multiple MT modes and multiple policies simultaneously which resembles better with our actual mode choice behavior. Situation for MT has been further worsened by IPT acting as a competitor rather being an ideal feeder which perhaps could be a solution to last mile connectivity problem which is clearly reflected in the comparative transport indices where Kolkata lies at bottom in most of those compared to other big metros in India.

This ongoing research attempts to dig deep into evaluation of MT service improvement measures to revamp its present dire state and also to understand the economic practicability. A Multinomial Logit mode choice model is developed based on revealed preference dataset of (a) the existing traffic scenario and (b) Three MT modes – Train, Subway & Bus and one IPT mode – Auto-Rickshaw. The model is used to predict policy impacts in terms of modal shift. It broadly considers two service improvement domains (a) travel time and (b) frequency & reliability, attainable through three major strategies (a) network improvement (b) lane management and (c) introduction of new bus rapid transit system (BRTS). Finally, the modal shift to bus mode is assessed to evaluate the best potential strategy for MT sustainability. It has been found that fundamental solutions like network improvement can prove to have near equivalent impact to comparatively higher cost and time intensive strategies like BRTS and/or lane management. Simultaneously the project also underlines and compares the impacts of some tough policies like auto-rickshaw removal from arterial street or on-street parking removal to support those. These results are helpful to the concerned authorities for policy-making of optimal transport facility design in future smart cities.

[*Keywords:* mass transit, service improvement, logit model, mode choice, modal shift, policy]

Table of Contents

List of Figures

List of Tables

List of Abbreviations

MT	Mass transit
PT	Public transit
PV	Private Vehicle
IPT	Intermediate public transport
RP	Revealed preference
SP	Stated preference
MNL	Multinomial Logit
NL	Nested Logit
ILM	Incremental logit model
IIA	Independence of irrelevant alternatives
BRTS	Bus rapid transit system
LOS	Level of service

Chapter 1 - Introduction

This chapter lays the foundation for this thesis. The existing scenario has been briefly described, which leads to the motivation for this research. It is followed by the problem statement; and then research objective and scope have been quantized by the end of this chapter. Expected deliverables and a basic outline of the project, are also a feature of this chapter.

1.1 Motivation

1.1.1 Present scenario of transport sector in India

Indian cities have been traditionally dependent on buses as dominant mode of transport because of its advantages to carry more people at a time and being economical as well. These advantages had been facilitated by the mixed land use model that allows neighborhoods to provide for all the facilities ranging from housing to educational institutions to retail and healthcare. This in-turn has resulted in the minimizing of trip lengths as well as the decreased dependence on personal motorized transport. The average trip length in medium and small size cities is less than 5 km, as shown in below.

Figure removed due to possible copyright infringements

Figure 1-1 Travel mode share across population across different Indian cities (Ministry of Urban Development, Handbook of Urban Statistics, 2016)

Such city/neighborhood design also encourages the use of non-motorized modes and public transportation, which includes the para-transit modes (also referred to as intermediate public transport modes) and consequently lowering the average trip lengths as is shown in below.

Figure removed due to possible copyright infringements

Figure 1-2 Percentage share of Trip lengths across different Indian cities (Ministry of Urban Development, Handbook of Urban Statistics, 2016)

Unfortunately though, the bus fleet size is degrading fast (20%-40% drop from 2000-2008) even in big metros like Delhi, Mumbai, Kolkata (Ministry of Urban Development, Handbook of Urban Statistics, 2016) as shown in whereas the private vehicle (PV) and intermediate public transport (IPT) is increasing to fill the void.

Figure removed due to possible copyright infringements

Figure 1-3 Increase in vehicle population and Decline in STU fleet size (National Transport Development Policy Committee, 2014)

Existing performance evaluation reports of traffic condition done by Indian Government itself clearly shows a huge gap in ‘mass transport’ (MT) infrastructure, plagued by inadequate capacity and financial reasons, specifically in Kolkata which includes (a) Depleting fleet size of MT (b) Unreliable service of most MT services, and (c) Less or no coordination between different MT modes (National Transport Development Policy Committee, 2014). The poor state of MT modes in cities like Kolkata have been further magnified by IPT modes which act as a competitor rather being an ideal feeder service which perhaps could be a solution to last mile connectivity problem. In the absence of adequate provision of MT infrastructure especially in cities like Kolkata, including public transport, congestion diseconomies outweigh the benefits of agglomeration forcing people to switch to PV and IPT like auto-rickshaw.

1.1.2 Past work and research gap

Figure 1-4 Implication of BRTS across different continents (Ministry of Urban Development, Report of the High Powered Committee on Decongesting Traffic in Delhi, 2016)

For solution of the congestion problem different strategies are being taken up by Government of India such as following:

I. Strategy I (Improving PT & Dis-Incentivizing use of PV)
   - Multi-modal integration & ITS
   - Bus service improvements
II. Strategy II (Road safety & Traffic improvement)
   - Road network optimization
III. Strategy III (Development of TOD*)*

It is agreed that BRTS is a proven solution across continents as we can find out from Figure 1-4 but at the same time it can be argued that where and when to implement BRTS can impact the urban transport structure hugely as it is seen in the case of BRTS in Ahmedabad in India. In an overall aspect Ahmedabad BRTS is an accepted success but it is not same for all the corridors.

Figure removed due to possible copyright infringements

Figure 1-5 Implication of BRTS in Narol-Naroda corridor, Ahmedabad (KT & Munshi, 2015)

It can be found out from that after implication of BRTS corridor in Narol-Naroda stretch in Ahmedabad, India, bicycle and walk modal share has dropped and motorbikes & Auto-Rickshaw modal share has increased from the figure above, which is completely opposite to the desired scenario. So now it is to be decided as a transportation planner what is the right way to go for us - will we be taking bigger irrational goals or we should focus on small changes to make a bigger impact.

Different literatures regarding the design of infrastructures as well as transport policies to attract PV and IPT users back to public transit had been reviewed. Chakrabarti (2017) discusses effective strategies for increasing transit's competitiveness relative to auto, and hence attracting people from their own cars to public transits. It is being emphasized that parallel to the rail network expansion and Transit oriented development across US cities investors need to put much importance to key aspects of bus service quality like speed, frequency and reliability to cause the more shift from private cars to transit. Although it just identifies the key aspects through modeling not going in detail to the mode choice model and how will be the share of modes in futuristic scenarios of implication of these parameters in case of nationwide mode choice model.

Fatima & Kumar (2014) make point about the implication of public bus transit in Indian cities and for the research purpose uses VISSIM for traffic simulation but the case study is majorly based on the stated preference survey and no revealed preference survey is being taken to understand the mode choice of existing scenario in detail. If we could have got a combined stated and revealed preference survey the results could have been more reliable. Dissanayake & Morikawa, (2010) and Anwar & Yang (2017) show with help of binary logistics model that a direct bus service with hourly interval is more efficient strategy compared to Park & Ride service causing approximately 4.7 times higher modal shift to MT.

At the same time, it can be argued that there are very few studies which clearly deal with multiple MT modes and multiple policies at same time which resembles better with our actual mode choice behavior. That is why this thesis approaches to work on that focus area without any pre-fixed bias about any transit policy.

1.2 Research aims and objectives

The broad aim of this research project is to facilitate the sustainable usage of bus transit in Indian subcontinent condition. Hence the major objectives to realize this scenario are as followed:

i. Measure current commuter behavior (mode choice model);
ii. Design future strategies (scenario development) and
iii. Predict the impact of strategies on user behavior (modal shift analysis)

The main tasks for achieving above mentioned objectives of the project are as followed:

i. To build a mode choice model for Public Transport users of 4 types of modes i.e. Train, Subway, Bus *(Public & Private)* and Auto-Rickshaw (for both study corridors)
ii. To estimate the model with full dataset to encompass as much variation in mode choice behavior as possible.
iii. To re-estimate the model with 80% of full dataset (random) and validate it with the rest 20% data for 10 times to remove the stochasticity.
iv. To Assess the shift in modal share to bus from other modes in 3 futuristic scenarios of improved travel time & improved headway / frequency
v. To evaluate the transit improvement policies based on the predicted modal shift to bus on the study corridor(s) as a representative of the city.

1.2.1 Scope

The research project starts with the aim of finding out impact of different service improvement measures in shift of modal share to bus mode in two busy corridors in Kolkata, India to optimise the strategic planning procedure. The scopes of the work are listed as below.

i. Majorly three types of dataset are collected in the case study survey –
    a. Travel time survey
    b. Public perception survey
    c. Occupancy & Travel cost survey
ii. Travel time survey (total dataset size=45 for each corridor) had been done for 4 modes (Train, Subway, Bus and Auto-Rickshaw). It's worth mentioning that subway travel time

data has been collected based on e-timetable and schedule variability for subway is negligible. The survey comprises of the information regarding

a. Arrival time at each intermediate stop
b. Departure time at each intermediate stop
c. Waiting time in signal and,
d. Waiting time without signal

iii. Public perception survey (total dataset size=218) had been done for 4 modes (Train, Subway, Bus and Auto-Rickshaw) which comprises of the information regarding
   a. Personal Characteristics (Socio-economic character)
   b. Household Characteristics
   c. Trip Characteristics (including walking trip & Trip chaining details)
   d. Satisfaction measures (point scale)
iv. Occupancy and Travel cost survey (total dataset size=60) had been done for 4 modes (Train, Subway, Bus and Auto-Rickshaw) which comprises of the information regarding
   a. Occupancy at peak and non-peak hour
   b. Fare hierarchy
v. All the datasets were collected for 1-month period from 26th July, 2017 to 26th August, 2017 and in-spite of being it rainy season in Kolkata the survey was done mostly during normal weather condition to minimize the effect of external factors in mode choice.
vi. The slot selection for the case-study hours were done based on literature reviews which suggested to ignore weekends as well as Monday and Friday for having irregular travel behaviour nature on those days. At the same time as many as 6 persons were chosen for doing the public perception survey to remove the personal bias towards documentation.
vii. The input would be used to setup a mode-choice model estimation framework, in which various configurations of the variables are evaluated.

1.2.2 Limitation and Assumption

The limitations of the study can be summarised as below.

i. Absence of stated preference survey data for simulation of mode choice behavior of public transport users in the improved scenarios.
ii. Absence of traffic volume survey so exact futuristic travel time cannot be obtained through simulation in VISSIM though working with a certain range of (changed) travel time in improved scenario will serve the purpose.
iii. Choice of corridor is not representative of whole Kolkata as the traffic as well as street characters differ a lot across various corridors in Kolkata.
iv. Absence of dataset comprising Private Cars and Ola/Uber users in the survey as only Public transport users' datasets are captured in the Bus/Subway station surveys.

v. Dataset size: Considering similar research works the dataset size was limited to consider different mode choice variable at a requisite statistical significance level which can cause the weak validation performance of the model.

1.3 Geographical scope: Case study corridors

Figure 1-6 Case Study Corridors (1. Tollygunje to Kalighat and 2. Garia to Gariahat)

Two (2) corridors/segments selected in Kolkata, West Bengal– one is from Tollygunje to Rashbehari Crossing/ Kalighat Metro Station is approximately 3 Km and another is from Garia to Gariahat market which is approximately 6.5 Km.

The area has highly mixed-use development with residential density high towards Tollygunje and Garia and Recreation and Commercial activities are densified in the other end of the segment. In between Garia and Gariahat market Jadavpur University is a major educational institution whereas both the corridors are well connected with other parts of the city as well as the proposed BRTS corridor.

Corridor A - Tollygunje to Rashbehari Crossing/ Kalighat Metro Station corridor **(Deshapran Sashmal Road)** is 3 lane road for whole study length whereas **Corridor B -** Garia to Gariahat market **(Subodh Chandra Mallick Road)** is a mix of 2 lanes and 3 lanes as Sukanto setu to Garia stretch has width 2 lanes and sometimes less than that also. The schematic street sections details are provided below for better understanding.

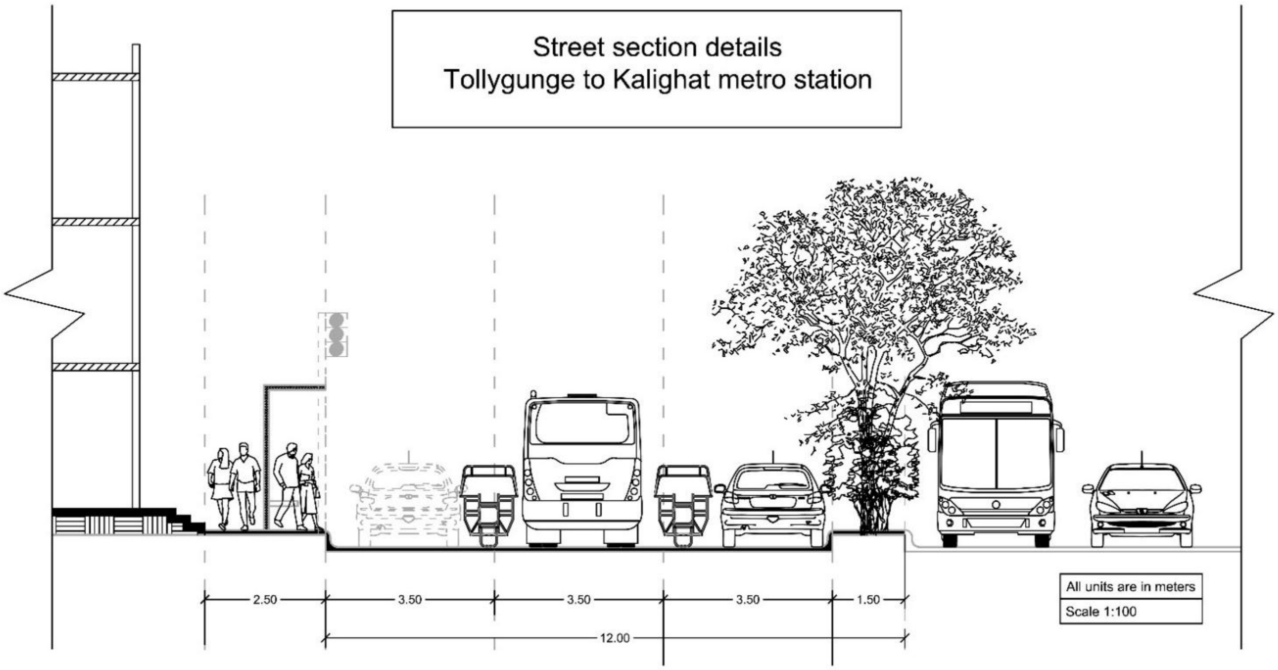


Figure 1-7 Street section details of corridor A (3 lane wide)

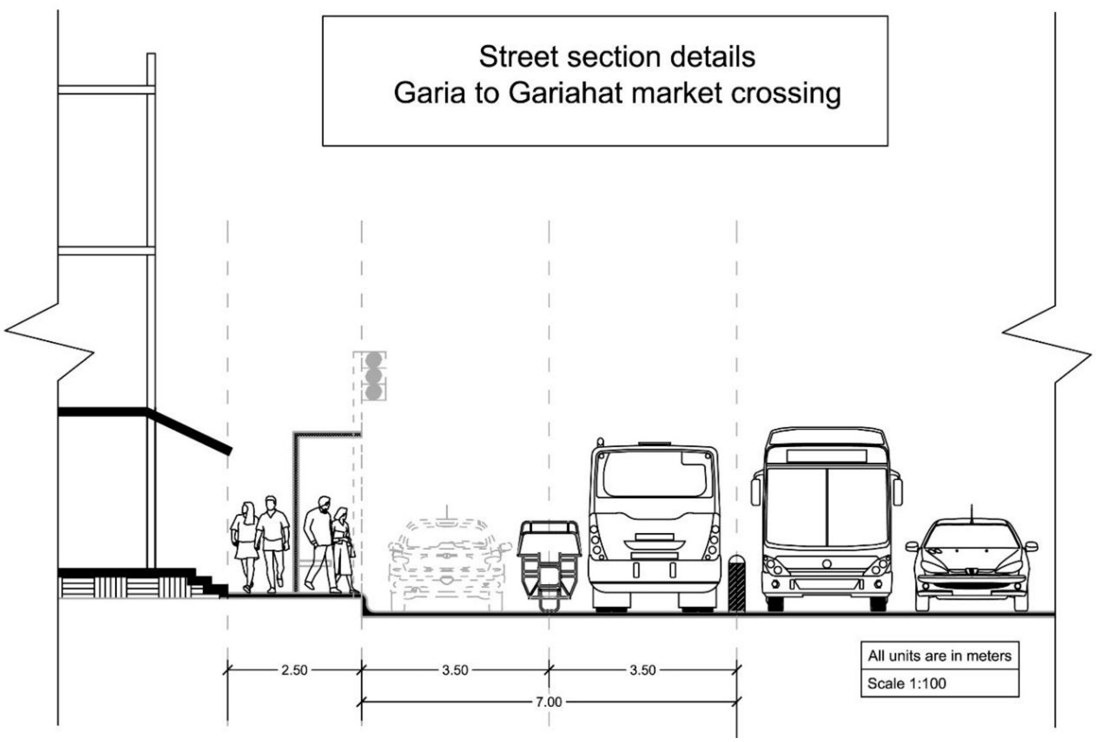


Figure 1-8 Street section details of corridor B (2 lane wide stretch shown)

1.4 Organisation of Report

As previously mentioned, this thesis aims to evaluate the transportation policies related to public transit improvement for Kolkata district in West-Bengal state in India. This objective is achieved in a structured manner. The report begins with,

Chapter 1 - by introducing the motivation behind the work and the present scenario. After which, the objective, scopes and limitations have been outlined.

Chapter 2 - gives the outline of the approach which has been taken to achieve the final goal of this thesis.

Chapter 3 - consists of literature review, in which all the basic concepts and necessary terminologies in the context of this work is laid out. It ends with conclusions arrived upon after vetting the existing literature.

Chapter 4 - steps for preparation of the database for building the logit model, which is the basic input as it translates the case study area details into a format understood by the statistical software, are laid out. This chapter also deals with model validation aspect.

Chapter 5 - features further application of the statistical software for futuristic scenario analysis, and results and repercussions of those results are discussed in depth.

Chapter 6 - provides the concluding remarks along with the scope for further research on the same topic.

Chapter 2 - Approach

This thesis is focused towards the mass transit that is being emphasized in urban planning for the Indian cities especially the Million plus ones. The idea is to utilize a mode choice modeling framework to estimate the impact of the service and infrastructure improvement measures in terms of improved travel time and expanded peak hour on the segment's commuter mode share. This approach involves five major exercises:

1. Brainstorming research objectives and framing of the outline;
2. Designing survey instrument and conducting station-based survey over one-month period;
3. Formulation of a suitable mode choice model (considering small dataset size);
4. Prediction of choice probabilities in three futuristic scenarios with transit service improvement measures using the mode choice mode and
5. Evaluation of different transit improvement strategies based on the modal shift inflicted by it.

The steps that have been adopted to execute this exercise are as following:

i. Review of the mode choice modeling framework;
ii. Review of studies on mass transit improvement strategies and travelers' response to different transportation system changes;
iii. Exploration of available data (survey records);
iv. Specification of model choice set, variables, and structure;
v. Estimation of model parameters and analysis of results;
vi. Development of prediction scenarios along with dataset preparation for prediction; and
vii. Scenario analysis for the prediction of impacts of service improvement measures.

An easier interpretable description of the thesis methodology is given in the following flowchart.

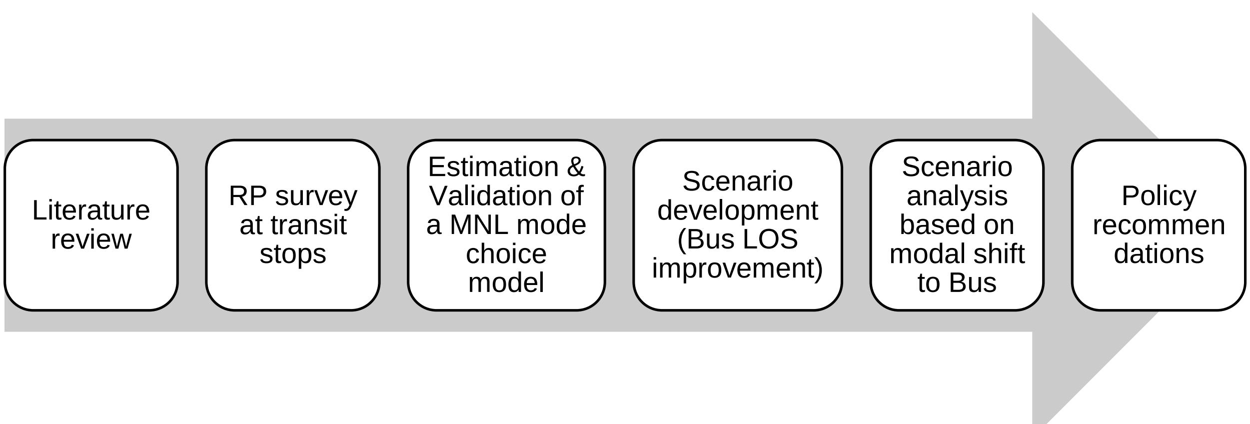


Figure 2-1 Flow chart of thesis methodology

Chapter 3 - Literature review

3.1 Discrete Choice Modeling Framework

The discrete choice framework instructs to model individual's choice behaviour econometrically with help of the principle of utility maximization (Ben-Akiva & Lerman, 1985). Alternatively explained, individuals are modelled to choose the alternative with the highest utility compared to other alternatives present. In the domain of transportation, utility represents the attractiveness of an alternative which is expressed as a function of alternative's attributes (Ortúzar & Willumsen, 2011). In this theory we assume that individuals (homogenous population) behave rationally, are well informed about all alternatives and are provided with a mutually exclusive and collectively exhaustive choice set (Ortúzar & Willumsen, 2011).

There are mainly two broad steps of discrete choice modeling. Firstly, each alternative is assigned a utility in the form of a parameterized function expressed by its attributes and unknown parameters (Ben-Akiva & Lerman, 1985). These unknown parameters are then estimated from a sample of observed choices made by a set of individuals under similar choice condition. These two steps – model specification and model estimation constitute the modeling framework.

One of the important hurdle during model specification is to build the utility function where most transport researchers assume an additive, linear-in-parameter function. The theory requires researchers to assume a universal choice set and to assign each individual decision maker an individual choice set based on his/ her travel time or cost budgets (Ben-Akiva & Lerman, 1985). In general, these individual constraints are taken care by socio-economic characteristics into the utility function.

Under this modeling framework, all individuals with the same attribute values and similar socio-economic characteristics would choose same alternative, one with the highest utility. However, in reality it's not the same because individuals are not perfectly rational and models are not perfect too. Therefore, to address this issue, a probabilistic choice approach based on random utility theory is adopted where the utility function also has a stochastic nature (Oppenheim, 1995). Consequently, the utility function of an alternative i for an individual n, U_{in}, is expressed as a combination of measurable, systematic component, V_{in}, and a random component, ε_{in}, as shown in Equation 3.1.

Equation 3.1

$$U_{in} = V_{in} + \varepsilon_{in} \text{ (Ortúzar \& Willumsen, 2011)}$$

In this equation, the systematic component, V_{in}, is the parameterized function of the observable attributes of the alternative i which can be written as in Equation 3.2.

Equation 3.2

$V_{in} = \beta_{1i}X_{1in} + \beta_{2i}X_{2in} + \beta_{3i}X_{3in} + \dots\dots\dots + \beta_{ki}X_{kin}$ (Ortúzar & Willumsen, 2011)

Where, X_{1in}, X_{2in}, ……., X_{kin} are the k independent variables that include both attributes of the alternative i and socio-economic variables of the individual] n; and

β_{1i} , β_{2i},…, β_{ki} are the unknown parameters which are assumed to be constant across individuals, and may vary across alternatives.

In this utility form, the random component, ε_{in}, caters to all the unobserved variation among individuals as well as other observational errors during survey. It is assumed as a random variable which follows a certain probability distribution. This in turn makes the utility function also random. Therefore the probability that an alternative is chosen is the alternative having maximum utility amongst all (Ben-Akiva & Lerman, 1985). Considering a choice set containing two alternatives I and j, the probability that the individual n chooses the alternative i, P_{in}, is the probability that the utility of alternative i, U_{in}, is greater than or equal to the utility of alternative j, U_{jn}.

Equation 3.3

$P_{in} = \text{Probability}\{ U_{in} >= U_{jn}\}$ (Ben-Akiva & Lerman, 1985)

When the utilities in Equation 3.3 are expressed in terms of their systematic and random components, probability P_{in}, can be written as shown in Equation 3.4

Equation 3.4

$P_{in} = \text{Probability}\{(\varepsilon_{in} - \varepsilon_{jn}) >= (V_{jn} - V_{in})\}$ (Ben-Akiva & Lerman, 1985)

In order to calculate probabilities as described above, a certain probability distribution is assumed for the random error components and then the β parameters are estimated using maximum likelihood estimation (Ben-Akiva & Lerman, 1985) (Ortúzar & Willumsen, 2011).

There are different types of discrete choice models based on different assumptions made on the distribution pattern of the random component. Out of those, the logit class of models are found to be assuming a logistic distribution of the error components which makes it most widely used type of model. Within the logit model class, multinomial logit (MNL) and nested logit (NL) are most used discrete choice models employed in travel demand forecasting research work along with specific use of incremental logit model in case of introduction of a new mode. That's why we briefly review those types in following sub chapters.

3.1.1 Multinomial Logit

Multinomial logit model is the type of logit models which are applied to choice sets containing more than two alternatives. Similar to other type of logit models, MNL also assumes logistic distribution for error component. All individual error components are independent and Gumbel distributed with a location parameter η and scale parameter μ > 0 (Ben-Akiva & Lerman, 1985). When a constant term is added to the systematic utility component of the alternatives, η is set to null. Now the probability that an individual n chooses an alternative I from a choice set C_n, P_{in}, is expressed by MNL model as in Equation 3.5.

Equation 3.5

$$\mathrm{P_{in}} = \exp(\mu\, \mathrm{V_{in}})\,/\textstyle\sum_{j}^{\mathrm{Cn}} \exp(\mu\, \mathrm{Vin}) \quad \text{(Ben-Akiva \& Lerman, 1985)}$$

Here, the systematic utilities of alternatives, V_{in} and V_{jn} are linear-in-parameter as in Equation 3.5 with an additional constant term, and for convenience, the scale parameter μ is set to 1.

Another crucial aspect of the MNL model is the IIA property (Independence from Irrelevant Alternatives) which states that when choice probabilities of two alternatives are non-zero, their ratio is independent of any other alternative in the choice set (Ortúzar & Willumsen, 2011). This property is evident from Equation 3.5. By virtue of this property, the addition or removal of an alternative to or from the choice set has the same effect on every other alternative in the choice set. But in reality, alternatives are not completely independent, for example, when new transit operations are introduced in a city, current captive riders are more likely to switch to the new service than current captive drivers are. This inability of MNL models to capture correlations between alternatives is addressed in the nested logit modeling framework. Nevertheless, MNL models are still applied in the majority of mode choice models owing to their simple mathematical form, and ease of estimation and interpretation (Koppelman & Bhat, 2006).

3.1.2 Nested Logit

The nested logit model addresses the IIA problem by grouping together alternatives those are similar and choice-making is a multi-step decision which is shown in Figure 3-1.

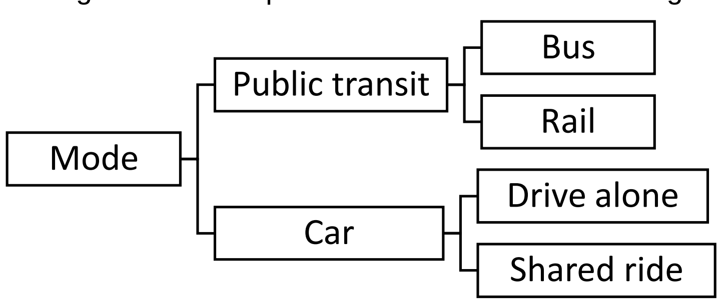


Figure 3-1 Sample nesting structure (Koppelman & Bhat, 2006)

The NL model assumes that the random error terms are shared between some alternatives (Koppelman & Bhat, 2006). This makes the utility equation of a particular alternative bus (as an example) as shown in below:

Equation 3.6

$U_{bus} = V_{pt} + V_{bus} + \varepsilon_{pt} + \varepsilon_{bus}$ (Koppelman & Bhat, 2006)

Where,

ε_{pt} = Common random component and, V_{pt} = Common observed component

Similar to MNL model here too the error components are assumed to follow a Gumbel distribution but with a scale factor μ_{pt}, or more commonly $\theta_{pt} = {}^{1}/_{\mu pt}$

The probability of choosing a nested alternative is based on the conditional probability of choosing the nested alternative times the marginal probability of choosing the nest (Munizaga & Ortuzar, 1999), as shown in the following equation:

Equation 3.7

$Pr_{bus} = (Pr_{bus/pt}) * Pr_{pt}$

Where,

Equation 3.8

$Pr_{bus/pt} = e^{(Vpt+\theta pt*\tau pt)} / (e^{Vda} + e^{Vsr} + e^{(Vpt+\theta pt*\tau pt)})$ and,

Equation 3.9

$$\tau pt = \log[e^{Vbus/\theta pt} + e^{Vrail/\theta pt}]$$

The log sum parameter otherwise known as nesting coefficient, corresponds to how similar alternatives are within a nest. It should vary between 0 and 1 (Koppelman & Bhat, 2006), where 0 represents perfect correlation making the model deterministic. The selection of an appropriate nest structure for a model is done through reasonable judgement and statistical evidence. At the same time proposed nests are tested against each other and the MNL model to find out better representation of observed behavior.

3.1.3 Incremental Logit

The development of incremental logit model can be mainly attributed to the fact that there is scarcity of time and cost budget to build a new full-fledged model every time we analyses mode choice of an area. Existing mode choice model remains essentially unchanged, only the incremental adjustment (such as revised travel time or fare) is accounted for. Model was built to test transit alternatives but could be used to test other modes as well. (Koppelman, Predicting transit ridership in response to transit service changes, 1983). It's also worth noting that IIA problem also applies for ILM as it is not built as a nested mode choice model.

As we are more interested in introduction of BRTS as a part of scenario analysis while keeping existing bus service same or improving, we will be focusing only on the ILM framework when new transit service is introduced keeping existing one. The rideshare of new transit mode will be as shown in following equation:

Equation 3.10

$$\mathrm{P}_{\text{new transit,t+1}} =$$

$$\frac{\{\text{Pexist transit, t} \; * \; e^{(S\ new\ transit,t+1-S\ exist\ transit,t)}\}}{\text{P exist transit, t} \; * [\; e^{(S\ new\ transit,t+1-S\ exist\ transit,t)} + e^{(S\ exist\ transit,t+1-S\ exist\ transit,t)}\} + (1-\text{Pexist transit, t})}$$

And the rideshare of the existing transit mode is shown in below:

Equation 3.11

$$\mathrm{P}_{\text{new transit,t+1}} =$$

$$\frac{\{\text{Pexist transit, t} \; * \; e^{(S\ exist\ transit,t+1-S\ exist\ transit,t)}\}}{\text{P exist transit, t} \; * [\; e^{(S\ new\ transit,t+1-S\ exist\ transit,t)} + e^{(S\ exist\ transit,t+1-S\ exist\ transit,t)}\} + (1-\text{Pexist transit, t})}$$

Therefore, total share on transit can be calculated using Equation 3.12

Equation 3.12

$$\mathrm{P}_{\text{total transit,t+1}} = \mathrm{P}_{\text{exist transit,t+1}} + \mathrm{P}_{\text{new transit,t+1}}$$

Again, the new shares for other modes would be as following Equation 3.13 below.

Equation 3.13

$$\mathrm{P}_{\text{ mode,t+1}} = \mathrm{P}_{\text{mode,t}} * \frac{1-\text{Ptotal transit,t+1}}{1-\text{Ptotal transit,t}}$$

3.2 Mass transit development strategies and ridership

3.2.1 Scenario worldwide – selected cities and transport policies overview

Urban transportation system is a vital cog in the wheel for its own economy as planned transport connections have strong relationship with better infrastructure. It improves the planning procedure of funding ensuring integration among mass transit, local economy and infrastructure development. As different countries across the world have taken up different initiatives to improve public transportation system, the Table 3-1 below provides the best ten initiatives.

Table 3-1 Summary of transit development policies (Jeffrey, 2018)

Id	Case study	Policy aim	Location
1	Improving existing bus routes, time tables and bus stops	Improve bus quality and service	Nottingham, UK
2	Integrating planning of bus service with other mass transit modes	Improve bus quality and service	Helsinki, Finland
3	Authority reformation to directly control bus service	Improve bus quality and service	London, UK
4	Provision of long term funding certainty for infrastructure	Encouraging investment in transport sector	Paris, France
5	Funding transport projects through local taxes, fees and charges	Cost-benefit alignment for transport sector	UK (City councils)
6	Utilisation of BIG data to improve	Increase service efficiency	London, UK
7	Sharing data to improve	Increase service efficiency	Dublin, Ireland
8	Creation of real time map of road condition	Increase service efficiency	Boston, USA
9	Increase in accessibility to commercial hubs in the city centre	Provision of better links to city centre from wider zones	Manchester, UK
10	Introduction of bus system in a mid-sized city	Provision of better links to city centre from wider zones	Oregon, USA

It can be observed that most of the planning policies are related with development as well as improvement of service aspect of public transportation system rather than introducing altogether a new transit. Another point to be noted is that most of the cities in the above mentioned list are metropolitan with considerable population base which resembles better with Indian cities compared to new cities around the world. Simultaneously, the implication of new transit service also includes intensive designing of service infrastructure for sustainable level of service.

3.2.2 Mass transit improvement strategies

It is important to study different mass transit improvement strategies and their possible impact in qualitative as well as quantitative manner in order to develop the scenarios at later stage of this research study. Transit improvement strategies can be broadly divided into two groups – (1) small/medium/large service improvement and (2) transit improvement along with support strategies (e.g. ridership incentive, transit-oriented development etc.). Similarly, the impacts can also be grouped into two types – (1) net impact and (2) marginal impact (considering impact happening within excess capacity). Moreover, other type of grouping of impacts can also be – (1) direct and (2) indirect/ leverage effect (e.g. accessible land use pattern, diverse transport system etc.) (Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc; Texas A&M Transportation Institute; ARUP, 2013).

To make transit better there can be four major approaches – (1) improves service quality, (2) increases affordability, (3) provides basic mobility and (4) reduces auto travel. The types of benefits associated with all these approaches can also be grouped into three categories – (1) user benefits (e.g. convenience, speed, cost, financial saving), (2) mobility benefits (e.g. Physically/socially/economically disadvantaged people) and (3) efficiency benefits (e.g. Congestion cost reduction. road and parking facility, pollution emission). Therefore transit availability based on quality of service concept can be subdivided into four types – (1) spatial availability (e.g. pedestrian access, park and ride), (2) temporal availability (frequency, passenger arrival pattern), (3) information availability and (4) capacity availability (Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc; Texas A&M Transportation Institute; ARUP, 2013). In a nutshell it can be inferred that most important factors in transit improvement strategies for a corridor level transportation planning purpose, are as follows:

1) Mode and service concept
    a) Type of transit (e.g. Carrying capacity, comfort etc.)
    b) Type of service and operating hours (e.g. fare characteristics, special service etc.)
2) Operating environments
    a) Service way (grade separated or not)
    b) Service pattern (traffic characteristics and facility design)

3) Operating pattern/ concept
   a) Capacity
   b) Speed
   c) Reliability

3.2.3 Commuter response to transit trip satisfaction

The variables are identified to be significant factors for transit quality of service through different on-board surveys, along bus routes with varying service characteristics (e.g., frequency, loading, reliability, amenity provision) and customers were asked to rate their overall satisfaction with their trip, along with their satisfaction about specific aspects of their trip (e.g., frequency, reliability). The result (Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc; Texas A&M Transportation Institute; ARUP, 2013) shows the factors contributing most to stated overall satisfaction of the commuters with a transit trip as shown in Table 3-2 below.

Table 3-2 Factors contributing to satisfaction of transit trip

Rank	A	B	C	D	E
1	*Frequency*	*Frequency*	*Frequency*	*Frequency*	Frequency
2	Waiting time	*Reliability*	*Close to home*	*Reliability*	Waiting time
3	*Reliability*	*Waiting time*	*Reliability*	Close to home	Close to home
4	*Close to home*	Close to home	*Waiting time*	Close to destination	Reliability
5	Service span	Close to destination	Close to destination	Waiting time	Service span
6	Close to destination	Service span		Service span	
7	Friendly drivers				

After extensive literature review on bus LOS improvement strategies as well as the factors those play important role in increasing bus ridership, majorly three types could be identified – (1) network improvement measures (transit scheduling, frequency, routing, signalling etc.), (2) lane management (high occupancy, exclusive bus lane etc.) and (3) introduction of new transit service (BRTS). The sensitivity of commuters to transit service are either expressed in terms of [1]

[1] *Italics* signifies replies given by more than 50% respondents and others by at least 33% respondents

modal shift (increase in bus ridership) or elasticity (service elasticity of +0.8 indicates, for example, a 0.8 percent increase and/or decrease in transit ridership in response to each 1 percent service increase and/ or decrease) (Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc; Texas A&M Transportation Institute; ARUP, 2013).

Commuters' Sensitivity to network improvement

Network improvement strategies can be broadly grouped as follows:

1. Transit scheduling and frequency
   1.1. Bus frequency change

Both historical and more recent elasticities of bus service changes exhibit a service elasticity average that is on the order of +0.5 (it can vary from +0.3 to 1.0). (John E. (Jay) Evans, 2004)

   1.2. Service hour change

The one impact assessment conclusion that can be reasonably drawn is that both types of service time change (weekday and weekend) contributes substantially to the outstanding ridership response, reflected in a service elasticity of +1.14. (John E. (Jay) Evans, 2004)

   1.3. Combined service frequencies

In situations where the provision of new or expanded express bus service has resulted in increased overall frequency of service exhibiting service elasticities on the order of +0.9. A combination of increased service and express runs may attract additional patronage — possibly half again as much — as would a similar bus trip increase applied to local service alone. (John E. (Jay) Evans, 2004)

   1.4. Regularized schedule

The restructuring generally accomplished within the constraint that total bus service hours not be increased by more than 4 percent increases ridership around 20%. (John E. (Jay) Evans, 2004)

   1.5. Transit reliability change

In general, the effects on ridership of lack of reliability will be even more pronounced than the increase in waiting time alone indicates. This effect is attributable to the uncertainty about if and when the next vehicle will arrive and consequent anxiety and annoyance to passengers. London Transport has estimated that elasticities with respect to "unplanned" service cuts (i.e., lost vehicle-miles) are some 33 percent larger than with respect to scheduled service cuts (John E. (Jay) Evans, 2004).

2. <u>Bus routing and coverage</u>
   2.1. Comprehensive service expansion

Service elasticities calculated for response to increases in bus miles or hours operated are typically in the +0.6 to +1.0 range, although individual results as low as +0.3 are not uncommon. Results well into the range of elastic response, over +1.0, are not uncommon either. The service expansion elasticity average is +0.7 to +0.8. In contrast, changes in frequency alone result in elasticities averaging +0.5, while changes in service accompanying the introduction of express operation result in elasticities averaging +0.9. There is, however, considerable variability and overlap surrounding these averages, reflecting different starting conditions, expansion programs, operating environments and demographics. (H.Pratt & John E.(Jay) Evans, 2004)

Service increases in the off-peak were found to affect off-peak ridership more than peak service increases affect peak ridership in an examination of 30 British cities. Off-peak service elasticities averaged +0.76 versus +0.58 for peak period service. (H.Pratt & John E.(Jay) Evans, 2004)

Commuters' Sensitivity to lane management

Bus exclusive lanes may focus on serving buses only, or primarily carpools, or more commonly, a mix of buses, vanpools, and carpools. Projects with the higher bus volumes, which are almost all radial to urban central areas, generally have the higher person movement in this type of lanes. Central Business Districts (CBDs) are the major source of facility users.

1. <u>Exclusive freeway bus lanes</u>

An average of 39 percent of all AM peak-hour peak-direction person travel was being carried on the exclusive bus only facilities ranging from 49 percent to 25 percent for different US case study cities. The bus only facilities along most of the freeways, carried more persons per lane in the AM peak hour peak direction than the general-purpose lanes. (Turnbull, S.Levinson, Pratt, E.Evans, & U.Bhatt, 2006)

Commuters' Sensitivity to introduction of new transit service

Studies of ridership based upon applying elasticities to arterial street BRT lines in Boston, Los Angeles, and Vancouver (BC) found that actual ridership was up by about 20% more than that resulting from improved travel times and service frequencies. Accordingly, a 25% increase in base ridership above the gains obtained by elasticity computations is a suggested upper limit for full-featured BRT. Common practice applies up to a 12-minute in-vehicle travel time "bias constant" for rail rapid transit. That is, the travel times for mode-split modeling purposes would be 12 minutes shorter for rail in comparison to local bus service. Accordingly, a maximum 10-minute bias constant is suggested for full-featured BRT. (Kittelson & Associates, Inc.; Herbert S. Levinson Transportation Consultants, 2007)

For example, a high-level BRT system using a grade-separated busway with uniquely designed vehicles would have a bias constant of 9.5 minutes of in-vehicle travel time, while a minimal system operating on city streets would have a bias constant of 4.3 minutes of in-vehicle travel time (or increases in base ridership of 24% and 11%, respectively, when elasticities are used). (Kittelson & Associates, Inc.; Herbert S. Levinson Transportation Consultants, 2007)

Chapter 4 - Modeling Framework

The current model adopts a discrete choice modeling framework described in previous section and is based on data from a Field Study done in Kolkata. The construction of the model and its functioning is explained in this chapter. It gives an overview of the data used and demonstrate the model specification and estimation respectively.

4.1 Design of survey

As different literature suggests, there are predominantly two approaches to analyze modal shift – (1) revealed preference (RP) approach and (2) stated preference (SP) approach. Here RP approach has been followed as it is based on actual mode choice behavior which suits better for building a mode choice model. All those data were collected through bus station survey, conducted along two busy arterial roads in Kolkata, India - one is three (3) lane wide while the other one is a mix of two (2) and three (3) lanes. As found in different literatures on mode choice model, there are typically three types of variables –

1) Alternative specific (e.g. travel time, waiting time, service headway etc.)
2) Individual specific (e.g. age, gender, income, car ownership etc.)
3) Trip specific (e.g. number of transfers, bus stop density, trip purpose etc.)

Accordingly, the questionnaire was prepared with two major sections – General data – (a) socio-economic data and (b) household data and Travel data – (a) trip related information. Simultaneously, there was another type of survey done on same corridors i.e. Corridor characteristics survey which includes each of the following features for all four modes in peak and off-peak hours -

1) Travel time between two nodes and in between consecutive stops in the study stretch
2) Number of stops served by any particular mode
3) Occupancy (number of people in any particular mode)
4) Boarding and alighting time of passengers on every stop
5) Boarding and alighting number of passengers on every stop
6) Waiting time in and without signal

Moreover, data of the existing signaling system (g/c ratio, curb volume, vehicle type share etc.) of all major intersections in the study corridors was also collected from the research group working in ‘Future of cities’ project in Civil Engineering department in IIT Kharagpur.

4.2 Execution of survey

The field survey was done over a period of one month from 26th July, 2017 to 26th August, 2017 in Kolkata. Each part of the survey work was evenly distributed amongst six interviewers (Masters Students in IIT Kharagpur) to remove any kind of bias in the response. Whole of this work had been done from Tuesday to Thursday of every week during the above-mentioned time period as it was found in different literatures that the travel behaviour is different in weekends as well as Monday and Friday from the general working weekdays. Although the survey period falls within the monsoon period prevalent in this region, the survey days was more or less free of environmental interference as selected intentionally.

4.3 Survey responses

4.3.1 Field Study

Available Dataset from the RP survey results -

<u>Class I - General</u>

- **Persons (socio-economic)**
    1. Type of residence
    2. Age
    3. Gender
    4. Occupation
    5. Income
    6. Driving license possession
- **Household**
    1. Household size
    2. No. Of working household members
    3. Vehicle ownership

<u>Class II – Travel (RP Data)</u>

- **Trips**
    1. Origin
    2. Destination purpose
    3. Travel cost
    4. Travel time (in range)
    5. Transport mode
    6. Trip chains/legs
    7. Use of household auto
    8. Waiting time
    9. Preference reason

4.3.2 Model Dataset

A total 211 trips with detailed information about trip legs were extracted from the available survey dataset. 7 nos. of trip records were neglected for errors or insufficient data.

4.4 Model Specification

4.4.1 Choice Set

Categorization of modes: **Mode Hierarchy**

1. Train
2. Subway
3. Bus
4. Auto rickshaw

As one would expect, it can be observed in Figure 4-1 and Figure 4-2, “Auto-Rickshaws” are dominant for short commutes, and longer commutes are predominantly made by “Train” and the trips with intermediate trip lengths has a mixed share of all 4 modes. Interestingly, a significant share of “Auto-Rickshaws” commuting already seems to prevail for trips up to 15 km.

At the same time, it should also be noticed that the number of trip records (frequency distribution) are also decreasing with the trip length increasing which can cause the occasional spikes in the modal share graph (data inflicted defects).

In the following Figure 4-3, the mode "Bus" is further classified into "Public" and "Private" and "Public "Bus" is further classified into "AC" and "Non-AC" types.

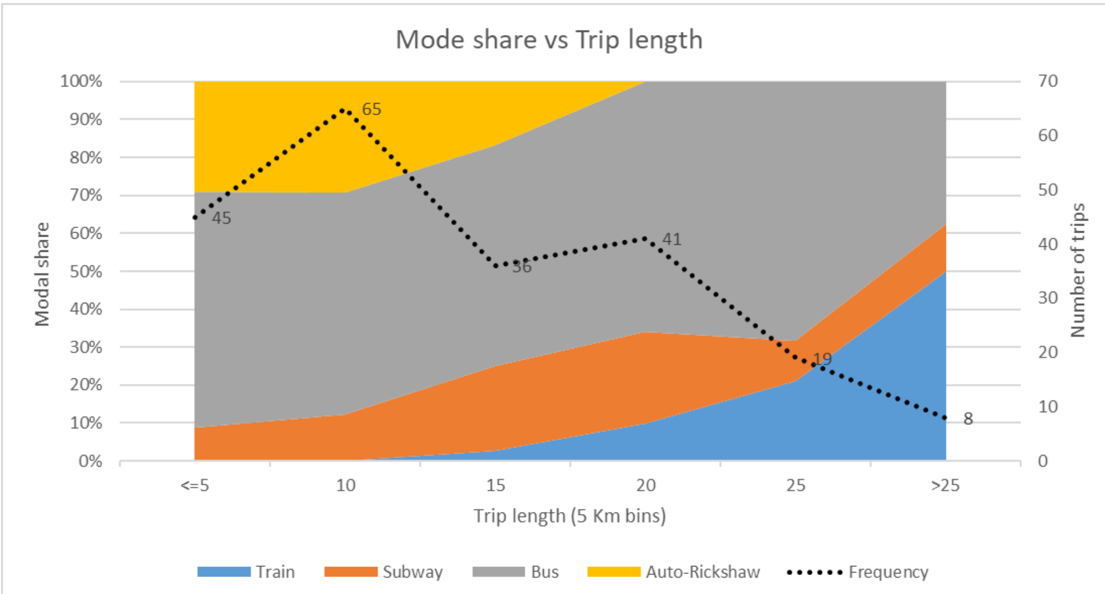


Figure 4-1 Distribution of modal shares and total trips by trip length

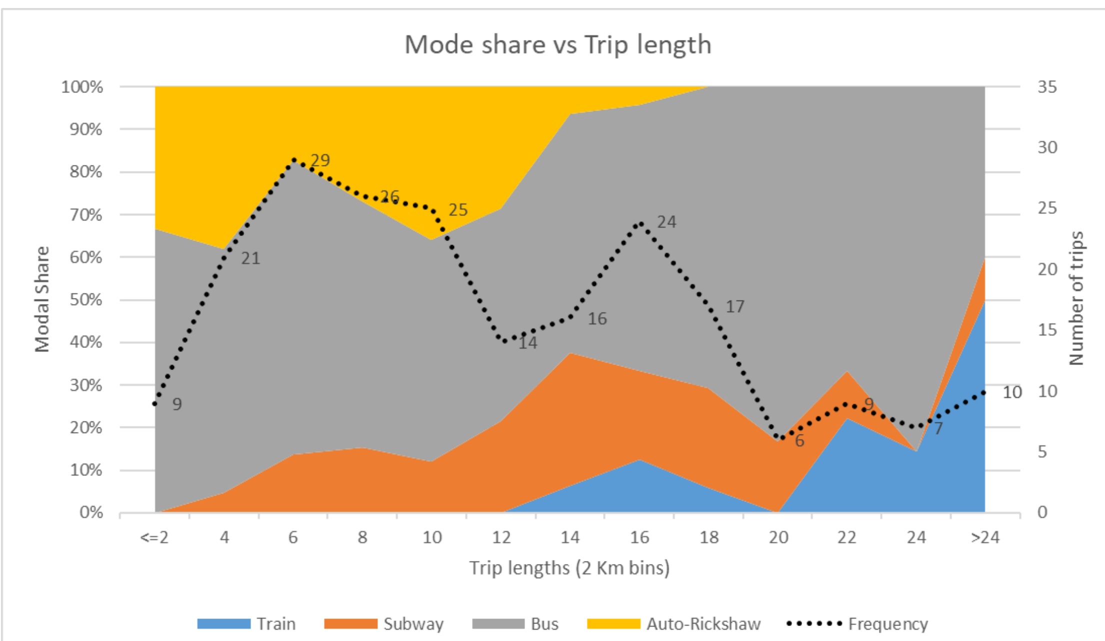


Figure 4-2 Distribution of modal shares and total trips by trip length (Trip length bin size changed-2Km)

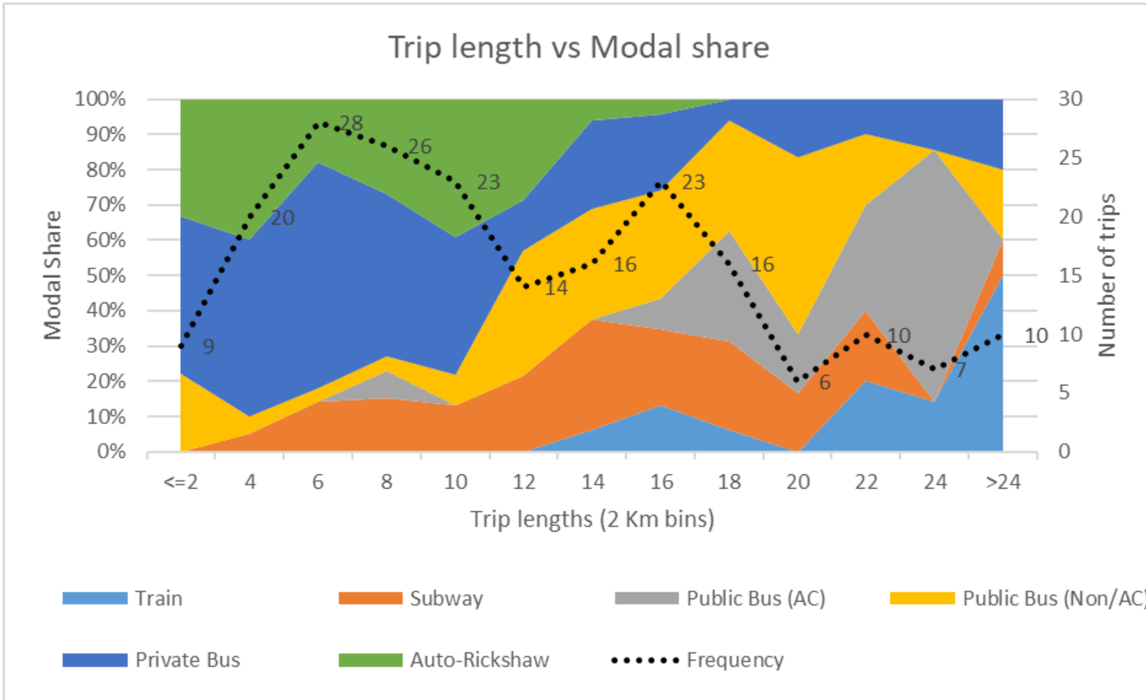
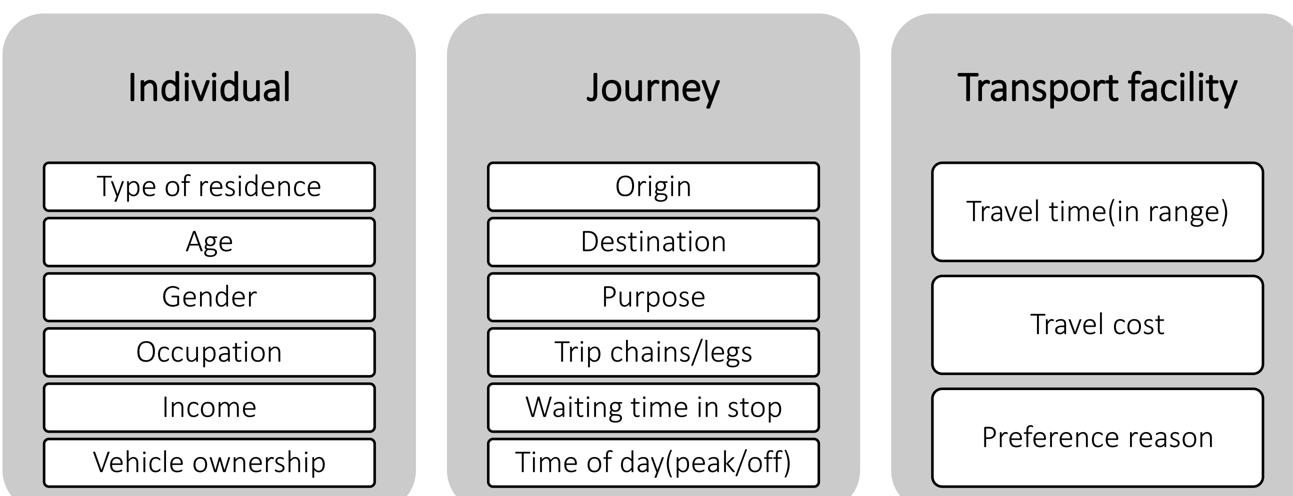


Figure 4-3 Distribution of modal shares and total trips by trip length (Bus is further classified)

The present aim is to model the individual choice preferences leading to the above mode share patterns. The explanatory variables used to achieve this are discussed in the next section.

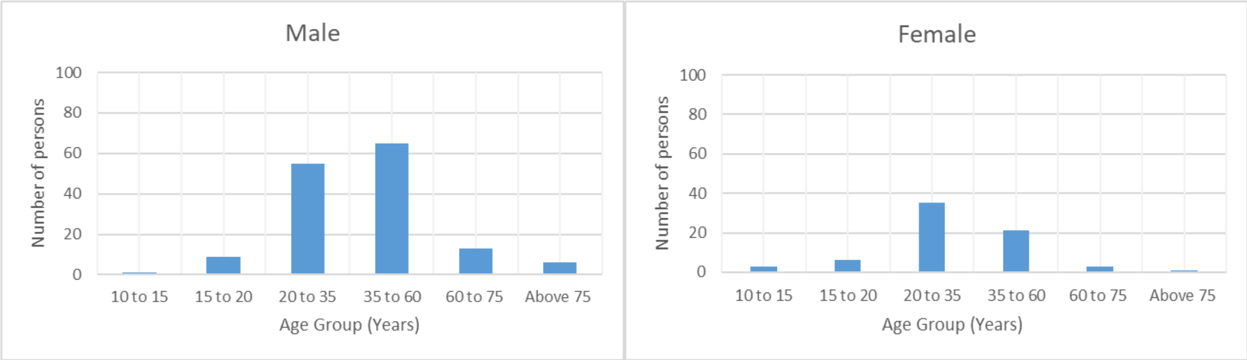
4.4.2 Explanatory variables

1. Individual characteristics
2. Journey characteristics
3. Transport facility characteristics



Age and Gender

Age and gender are the two most common individual-specific variables considered in mode choice models (Fatima & Kumar, 2014). Among the respondents 68.3% are males and 31.7% are females. In this model dataset, we find most male as well female population to be in 20-55 years categories which is expected as this age-group bracket is most active road users. The frequency distribution of male and female commutes in the dataset by their ages is depicted.



(a) (b)

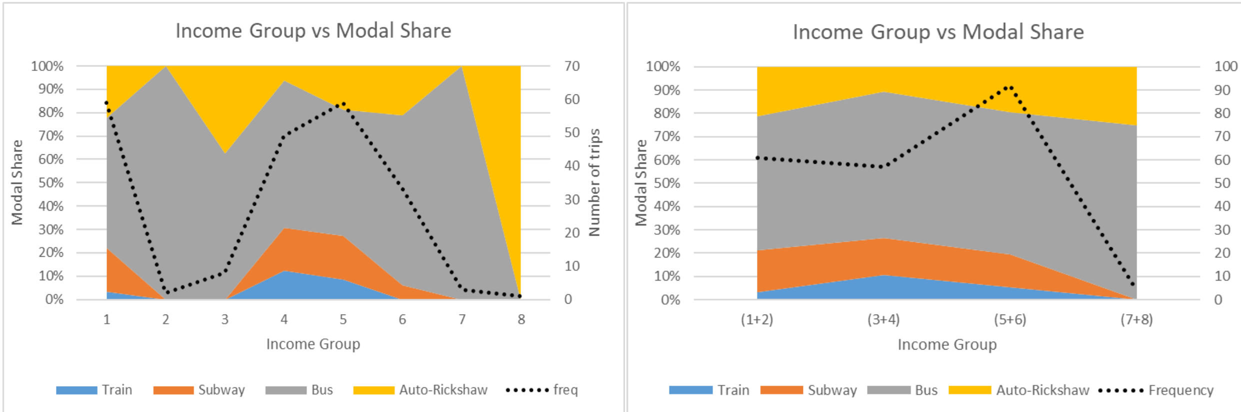
Figure 4-4 Distribution of (a) age groups and (b) gender

Income

Individuals' choice preferences are greatly influenced by their income budgets (Fatima & Kumar, 2014) (Chakrabarti, 2017). Income Groups are clubbed in the following way. In Figure 4-2 (b), each of the consecutive groups are clubbed together to find a smoother pattern.

	Monthly Income
1	None
2	< 5000 INR
3	>5000 - 10000 INR
4	>10000 - 20000 INR
5	>20000 - 30000 INR
6	>30000 - 40000 INR
7	>40000 - 50000 INR
8	>50000 INR

It should also be considered that here only individual income is considered not household therefore it does not give a clear picture of those who can afford high travel cost despite earning less e.g. Students from high income households.



(a) (b)

Figure 4-5 Distribution of income groups (a) 8 income bracket and (b) 4 income bracket vs modal shares

Education

Survey data reports the highest education level obtained by individuals. To analyze differences in choice behavior among individuals with college and/or school education and those without, following grouping was considered.

Level of Education
1 8th Grade
2 High School
3 Graduate / Diploma

It can be found out that people with low education tend to choose "Bus" mainly which can be related to the fact that those people generally have low income jobs which do not permit them to use other modes and there can also be locational properties which can be attributed to the fact that subway services is not wide-spreaded.

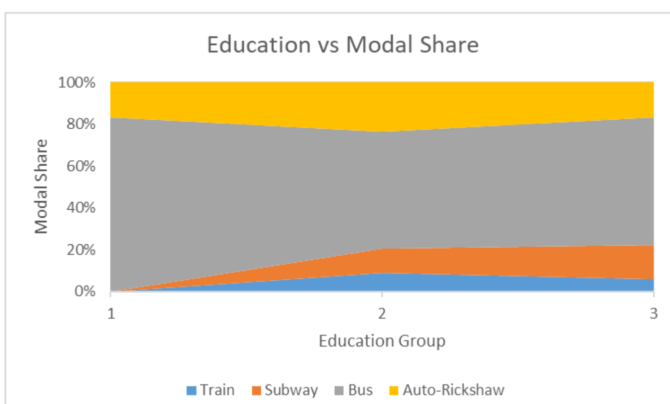


Figure 4-6 Distribution of education groups and modal shares

Household size and number of working household members

Household attributes like household size, number of children and number of employed people have an influence on individuals' choice of mode. For instance, household members may combine or chain individual trips, making auto travel convenient. To capture this effect, these variables were proposed for consideration in the model. In this model dataset, there is a tendency of using auto-rickshaw for people with lower household size and more people using subway with household size 3. The sudden fall in the train share in group of household size 5 can be data induced defect also.

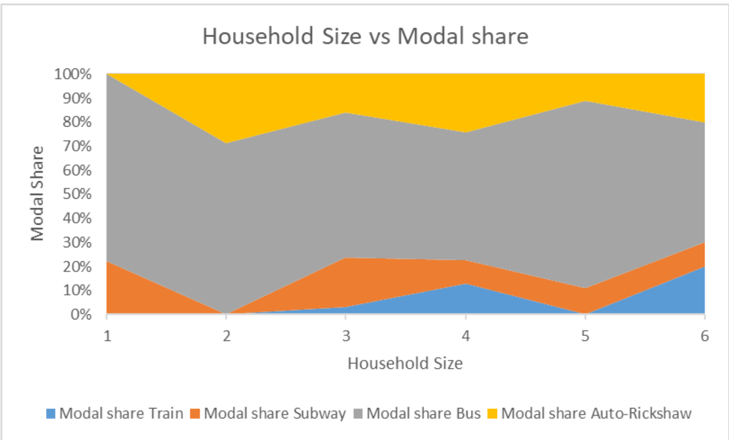


Figure 4-7 Distribution of household and modal shares

Vehicle ownership

Having access to an auto significantly increases one's propensity to drive to work. To capture this, auto availability for individuals' in the dataset was proposed to be evaluated as the number of autos available to the individual calculated as given following equation

Vehicle ownership = Number of household vehicles (2 wheelers + 4 wheelers) / Number of household members possessing driver's license.

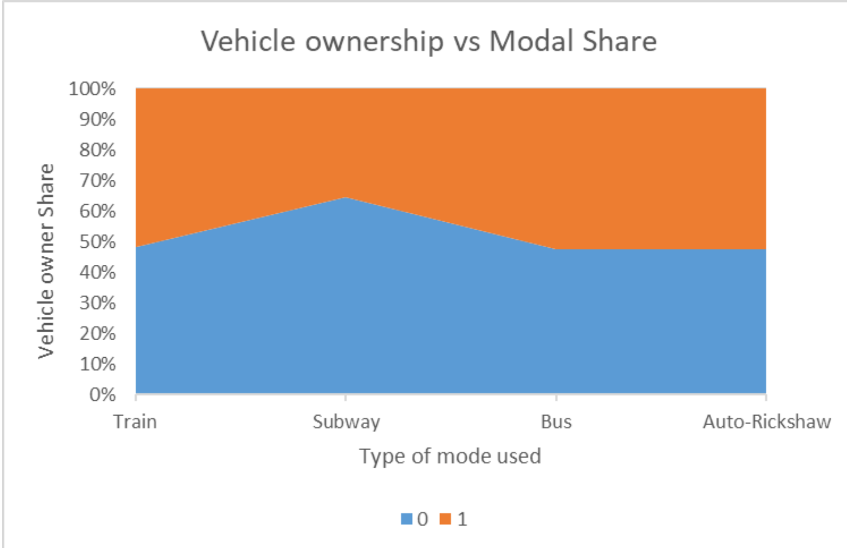


Figure 4-8 Distribution of vehicle ownership and modal shares

Trip Purpose

The choice is found to be related with trip purpose in some literatures. The parameter Trip Purpose is a binary variable where there are three types of trip purposes considered (1) Home based work (HBW), (2) Home based education (HBE) and (3) Home based other (HBO). If the person has made the trip in one of the above-mentioned purposes, then it is coded as 1 otherwise as 0.

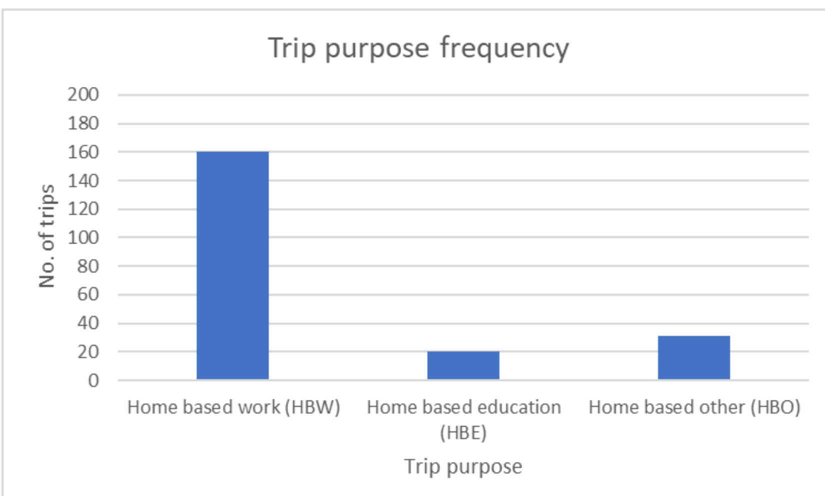


Figure 4-9 Trip frequency for different trip purposes (both corridors combined)

Time of day (peak / off-peak)

The choice of mode is expected to be affected by the time of day, especially by traffic peak hours. Given an opportunity, travelers would try to avoid trips during peak hours to escape congestion on roads and crowds in transit. Their effect could be observed in the proposed model application with the help of a dummy variable differentiating peak-hour trips from off-peak hour trips. Although the following Figure 4-10 shows the number of survey records collected in each of the three phases of a day. Hence, its essentially a property of survey rather than the commuters in that context.

For this, trip start times given in the survey data grouped as follows were used -

Trips made in time groups 08:00 to 11:00 and 17:00 to 20:00 were considered as peak-hour trips, represented by 1, and trips starting during 14:00 to 17:00 time group was marked 0.

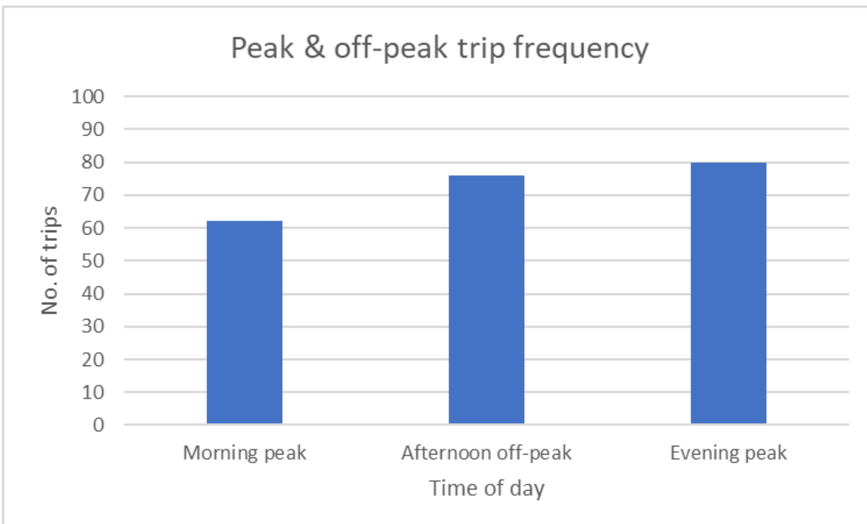


Figure 4-10 Trip frequency in peak and off-peak hour (both corridors combined)

Travel time

Travel time is generally measured in terms of its components – access time, in-vehicle time, and egress time. Additionally, waiting time and number of transfers are included for transit trips. The whole trip duration is considered as the total travel time for the model.

Furthermore, the survey data only reports the travel times corresponding to the modes used by the individuals. Travel times for modes that were not chosen, therefore, had to be calculated. Ideally, these times should be estimated through a route choice assignment exercise but due to the lack of locational information, the times were calculated from travel distances and average speeds instead. To estimate the travel times, first average speed of the reported trips by different modes was considered from secondary sources.

Table 4-1 Average travel speed matrix for different modes & no. of records

period	Auto-Rickshaw	Subway	Private Bus	Public Bus (Non/AC)	Public Bus (AC)	Train
Morning Peak (sample)	**27**	**5**	**33**	**20**	**10**	**7**
SPEED (Km/hr)	16	34	16	26	26	36
Afternoon offpeak (sample)	**35**	**13**	**52**	**14**	**6**	**2**
SPEED (Km/hr)	18	34	24	30	34	36
Evening Peak (sample)	**80**	**18**	**25**	**13**	**4**	**5**
SPEED (Km/hr)	16	34	16	26	26	36
Total Trips	142	36	110	47	20	14

Travel cost

Travel cost is measured with respect to the chart provided below which depends on the distance travelled and each mode has a separate base fare upon which additional cost is added based on kilometre travelled. Travel cost is an important parameter with respect to the mode choice model though mostly single coefficient is considered across all the modes as out of pocket cost is perceived as same for all the modes.

Table 4-2 Travel cost matrix for different modes

Auto-Rickshaw		Subway		Bus		Train	
Dist_slab **(Km)**	**Fare** (INR)	**Dist_slab** (Km)	**Fare** (INR)	**Dist_slab** (Km)	**Fare** (INR)	**Dist_slab** (Km)	**Fare** (INR)
0	6	0	5	0	7	0	5
1	7	5	10	3	8	5	5
2	8	10	15	6	10	10	5
3	9	15	20	10	12	15	5
4	10	20	25	14	14	20	5
5	11	25	30	18	16	25	10
6	12	30	35	22	18	30	10
7	13	35	40	26	20	35	10
8	14	40	45	30	22	40	10
9	15			34	24	45	15
10	16			38	26	50	15
11	17			42	28	55	15
12	18					60	15
13	19					65	20
14	20					70	20
15	21					75	20
16	22					80	20
17	23						
18	24						
19	25						
20	26						

Number of transfers

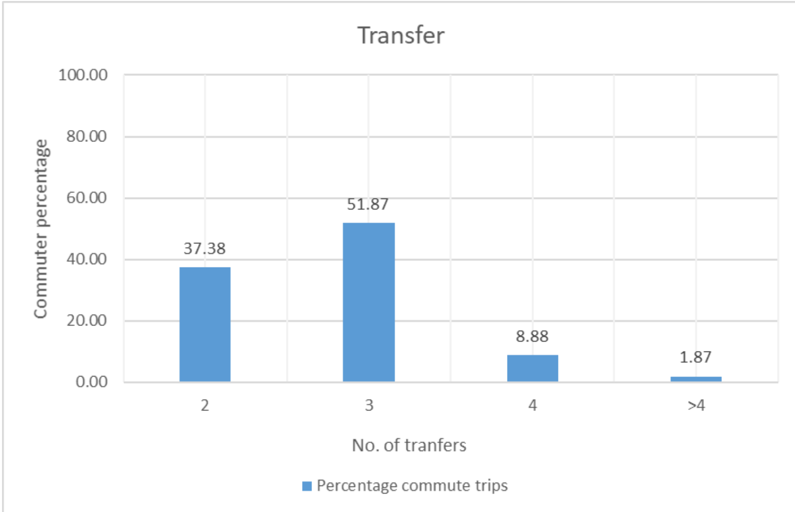


Figure 4-11 Number of transfers vs. commuter percentage

Number of transfers is another important trip specific variable which has a negative impact on choosing a mode if one needs to break his/her trip more. It can be observed from Figure 4-11 that most people have 3 transfers (2 transfers are minimum as access & egress modes are different from main trip mode for every record). It is worth noting as trip chaining happens despite several overlapping bus routes running on both the corridors.

Mode type change (during a single trip)

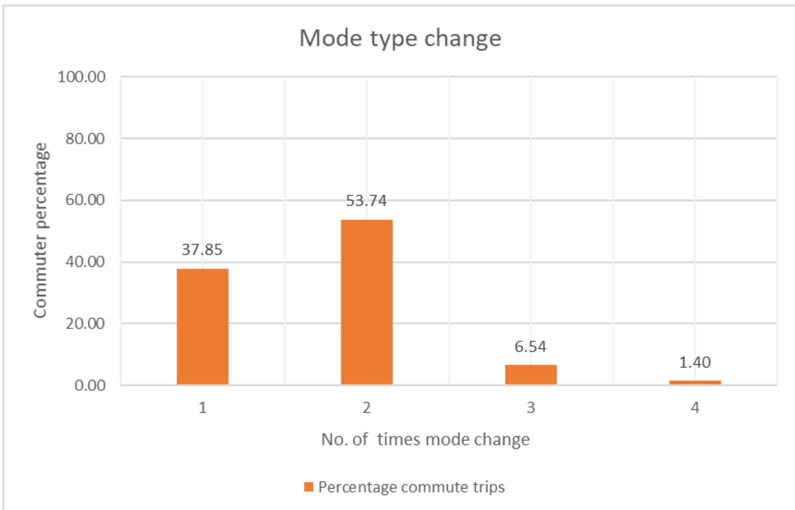


Figure 4-12 Mode type change vs commuter percentage

The Figure 4-12 above can be studied in conjunction with Figure 4-11 as both of them indicate to the fact that majority of the commuters need to break their trip at least once which in turn increases waiting time and considering schedule variability for bus on both corridors can play a huge role in one's mode choice behavior.

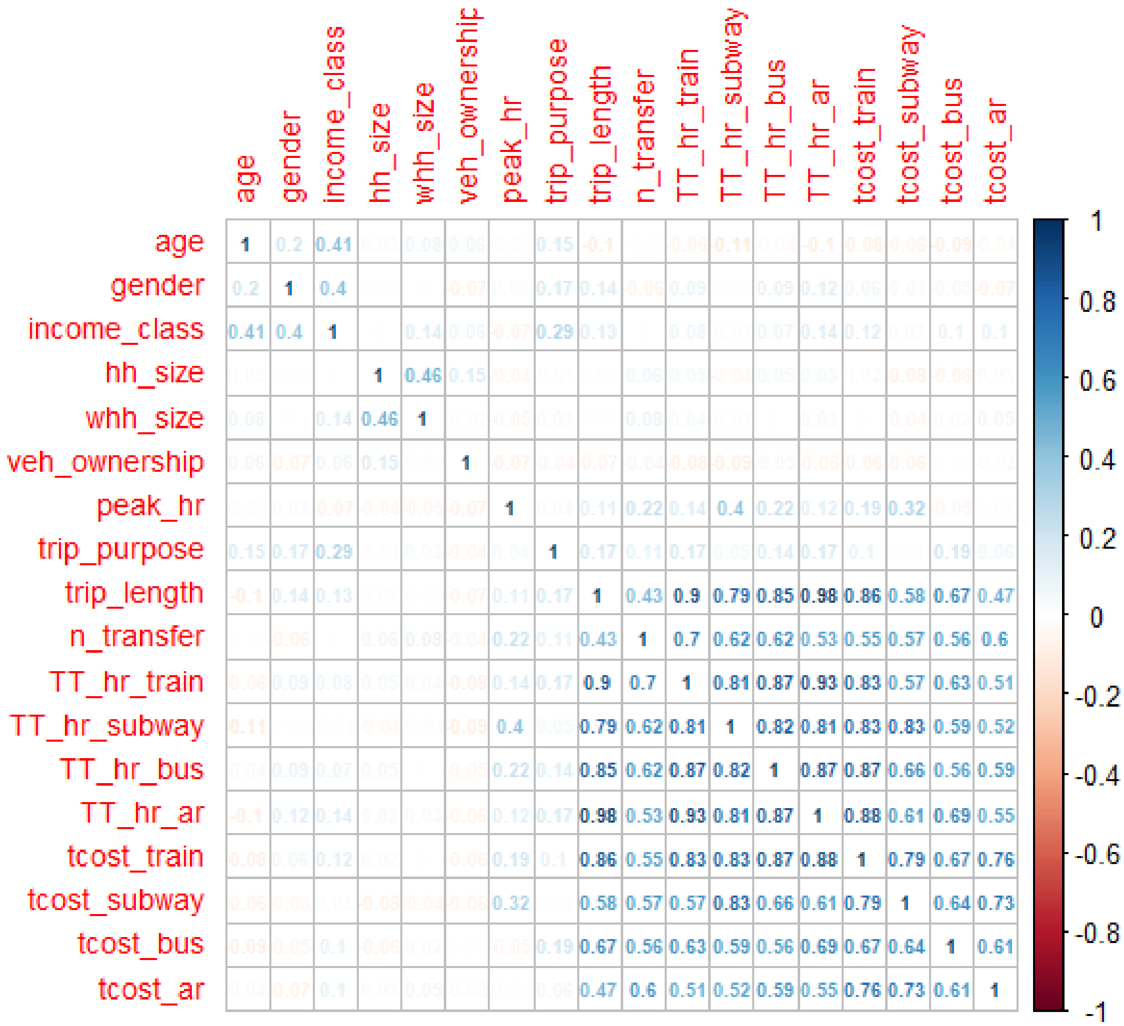


Figure 4-13 Variable correlation square plot

From the correlation matrix, we can deduce that travel time is highly correlated with other alternative specific variables which will need further attention considering these attributes for the mode choice model in MNL. The variables like 'travel time' (similar for 'travel cost') of different modes is one explanatory variable respectively, hence the correlations among travel times of different alternatives do not imply any harm to the model's framework. [2]

[2] Where, hh = Household, whh = working household, hr = hour, TT = Travel time, ar = Auto-rickshaw and tcost = Travel cost

Table 4-3 Correlation between different variables

Id	Variables	Variables with correlation (>0.50)	Variables with correlation (0.25 - 0.50)	Remarks
1	age		income_class	
2	gender		income_class	
3	income_class		age	
			gender	
4	hh_size		whh_size	
5	whh_size		hh_size	
6	veh_ownership			
7	peak_hr		tcost_subway	
			TT_hr.subway	
8	trip_purpose		income_class	
9	trip_length	tcost		**high to low from train to ar**
		TT_hr		**Very high for all 4 modes**
			n_transfer	
10	n_transfer	tcost		**approx. same for all 4 modes**
		TT_hr		**approx. same for all 4 modes**
			trip_length	
11	TT_time_hr	tcost		**high to low from train to ar**
		n_transfer		
		trip_length		
12	tcost	TT_hr		
		n_transfer		
		trip_length		

It's worth noting that the variables considered in the final mode choice equation are not even having medium correlation amongst themselves. The variables inside the coloured boxes are the ones considered for the final model. The variables are as following:

I. age,
II. travel time in hours,
III. peak hour,
IV. vehicle ownership and
V. trip purpose.

4.4.3 Results and Discussion

An MNL estimation using mlogit package with variables is called in R-Studio, the calling expression is as follows:

Equation 4.1

$$\text{mlogit (choice alternative specific variable} \mid \text{individual specific variable} \mid \text{alternative specific variables with coeffcients differing across alternatives, data} = \text{dataset)}$$

Table 4-4 MNL estimation results (R – ‘mlogit’ package)

Variable(s)	Estimate	Pr(>|t|)	Significance
bus:(intercept)	2.61449	$5.87e^{-07}$	***
subway:(intercept)	-1.01066	0.13611	
train:(intercept)	-2.24903	$2.70e^{-09}$	***
TT_hr	-6.93211	$< 2.2e^{-16}$	***
bus * peak_hr	-0.95616	0.08372	.
subway * peak_hr	-1.04916	0.0667	.
subway * (veh_ownership)^2	-1.06393	0.20352	
bus * age_2	0.9606	0.06526	.
subway * age_2	1.17498	0.04921	*
subway * trip_HBW	-1.14735	0.03807	*

As already explained in sub-chapter 3.1.1 utilities are comprised of a measurable systematic component and a random error component. Systematic components are expressed as additive linear-in-parameter functions of known explanatory variables and unknown parameters, and random components are assumed to follow a certain probability distribution. Under this framework, the utilities of the four alternatives of the model’s choice set are written as follows –[3]

[3] *** 99.9% significance level, ** 99% significance level, * 95% significance level, . 90% significance level

Equation 4.2

$U_{mode} = V_{mode} + \varepsilon_{tmode}$

The expressions for final mode choice equations for all four modes becomes,

Equation 4.3

$U_{bus} = 2.61449 – 6.93 * TT\_hr_{bus} – 0.95616 * peak\_hr + 0.9606 * age\_2$

$U_{subway} = -1.01066 – 6.93 * TT\_hr_{subway} – 1.04916 * peak\_hr - 1.06393 * veh\_ownership$

$+ 1.17498 * age\_2 – 1.14735 * trip\_HBW$

$U_{train} = -2.24903 – 6.93 * TT\_hr_{train}$

$U_{auto\text{-}rickshaw} = 0 – 6.93 * TT\_hr_{auto\text{-}rickshaw}$

Table 4-5 Statistical summary of the MNL estimation (R – ‘mlogit’ package)

No. of Observations	211
No. of iterations	6
Log-Likelihood:	-134.19
McFadden R^2:	0.39928
Likelihood ratio test: chisq	-178.38(p.value = < 2.22e-16)

The complete result output of the estimation from R is shown in Appendix B for further reference. The estimation was performed with the mode auto as the reference as it is the most represented. The estimates are hence to be understood with respect to Auto-Rickshaw considered as the base mode. A discussion of the results is as follows:

Total Travel Time (variable id: TT_hr)

The total travel time for 3 modes (Subway, Bus & Auto-rickshaw) is constantly negative when different coefficients for each mode is taken in the estimation of the mode choice model but it comes positive for the mode train which is counter-intuitive that is why a single coefficient across all the modes is taken for the parameter/ variable of total travel time.

In the beginning of estimation process when In-vehicle travel time and waiting time were taken separately then in vehicle travel time coefficient in estimation was turning out to be positive which is counter intuitive and cannot be explained from any secondary resource also so the new variable total travel time is taken which is sum of those two alternative specific variables.

Age (variable id: age_2)

Age is an individual specific variable which is found to be statistically significant (relative) in case of 2 modes – Bus and Subway but not for the mode Train. The variable 'age' has been grouped into 4 categories – (1) 0 - <20 years, (2) 20 – 35 years, (3) 35 – 60 years and (4) >60 years based on in general education and retirement age prevailing in the region. As expected according to different literature review and by intuition, the sign of the variable is positive which suggests that as individuals are young, they prefer to use transit and subway as those options are more cost-saving (more fitting to their income strata) and they are physically better capable to use underground subway stations as most of it lack escalators/elevators, a problem for aged persons.

Peak Hour (variable id: peak_hr)

Peak hour is another in trip specific variable which is also found to be statistically significant (relative) in case of 2 modes – Bus and Subway but not for the mode Train. Similar to gender parameter the variable Peak hour is taken to be as a Binary/dummy variable (for peak hour value =1 or for non-peak hour value=0).

Expectedly the sign is negative for the parameter in case of both the alternatives – bus and subway and it can also be supported from different literature (Appendix A). At the same time for the mode subway the value is more negative which can also be supported with the analogy that the overcrowding aspect during peak hour is huge in case of subway compared to bus which is proven through the peak hour occupancy study during case study analysis.

Trip Purpose (variable id: trip_HBW)

Trip purpose is another individual specific variable which is found to be statistically significant only for 1 mode - Subway but not for the mode Bus as well as Train. The variable Trip Purpose is a binary variable as it has been coded for three major trip purposes – home based work, home based education and home based other trips.

Though the sign of the coefficient is being intuitive as it's showing a negative sign which can be explained by the real-life situations like overcrowding as well as long queue for subways during office hours.

Vehicle Ownership (variable id: veh_ownership)

Vehicle ownership is another individual specific variable which is found to be statistically significant only for 1 mode - Subway but not for the mode Bus as well as Train. In fact, we also use square function of the parameter which makes the overall statistical significance of the model better.

Logically, the availability of an auto and/or motorbike reduces one's tendency to use the other modes. That is why the negative sign in the coefficient is very much intuitive.

Mode specific constants

The mode-specific constants shown in the results capture the effects of the unobserved variables and measurement errors. auto-rickshaw has a constant value of 0 because it is the base mode. Only one of the other three modes have positive constant- Bus and two have negative constants - subway and train relative to auto, indicating that all else being equal, Train is the least likely to be chosen, followed by subway and auto-rickshaw.

The mode train takes the highest constant as it is the least represented in the dataset, and its attributes were perhaps not well captured by the model. At the same time the negative constant for subway can be attributed to the fact that the city currently has only one corridor and significant part of the city has poor/weak accessibility to it which is a major influential factor in mode choice. To estimate the accuracy of the model fit, choice probabilities will be predicted for the same model dataset using the estimated parameters at a later stage of estimation process.

However, one should be careful about the fact that the model does not consider 'car' mode although one's general intuition indicates that bus mode will only attract more ridership from 'car' mode as only improvement in service quality has been planned for bus. It should also be kept in mind that the model could not perform equally well for all the modes in validation tests and if there was a large dataset, the model probably could have considered more explanatory variables with requisite statistical significance.

4.4.4 Re-estimation of Logit model

The dataset size for the estimation process was not large as compared to other models prepared in similar kind of research therefore to build confidence in the signs and magnitudes of constant as well as variables those were selected in the mode choice model, built based on the full dataset (211 nos. data), an attempt was taken to re-estimate 10 times with same variables for 80% of full dataset size (169 nos. data). In each of the attempts the survey records were selected randomly with help of excel random number generation.

As an aggregated result of all those 10 attempts it can be found that R^2 and Log-likelihood value has (+/-) 4.26% and (+/-) 5.81% percentage standard deviation respectively which indicates that there is not any significant departure from mean value. In the same line when percentage standard deviation for the magnitude of mode specific constants are calculated, those were observed to be (+/-) 6.19%, (+/-) 37.64% and (+/-) 10.78% respectively for bus, subway and train. The deviation for subway mode is high probably because one corridor has significantly better accessibility to subway and it may occur due to random selection that re-estimation dataset consists of significant higher share of any particular corridor dataset. Although in every case the signs and the mean value is consistent with the full dataset model.

Table 4-6 Re-estimation with first 10 attempts with random set comprising 80% of full dataset

			Intercept/Constant			Alt. specific coeff.	Individual specific coefficient			Trip specific coefficient		
Model run id	R^2	Log-Likelihood	bus	subway	train	Total Travel time (TT_hr)	Age (age_2)		Vehicle Occupancy (veh_occupancy^2)	Peak Hour (peak_hr)		Trip purpose (trip_HBW)
						Coeff. = Negative	Coeff. = Positive		Coeff. = Negative	Coeff. = Negative		Coeff. = Negative
						all modes	bus	subway	subway	bus	subway	subway
1	0.384	-107.95	2.89	-1.7	-2.34							
2	0.388	-105.65	2.38	-1.52	-2.75							
3	0.390	-113.51	2.51	-0.91	-2.26							
4	0.383	-113.06	2.53	-0.6	-2.07							
5	0.397	-106.12	2.71	-0.94	-2.21							
6	0.393	-106.01	2.51	-1.14	-2.22							
7	0.411	-105.03	2.54	-1.21	-2.48							
8	0.391	-110.8	2.83	-0.32	-1.97							
9	0.361	-116.82	2.41	-0.85	-2.1							
10	0.428	-92.838	2.59	-1.35	-2.71							

Table 4-7 Re-estimation results for all attempts (20 times) and statistical significance threshold

Pr(>|t|) < 0.10		Frequency for high significance	**20**	**17**	**15**	**6**	**14**	**11**	**15**
Pr(>|t|) < 0.25		Frequency for medium significance	**0**	**2**	**3**	**10**	**6**	**7**	**3**
Pr(>|t|) > 0.25		Frequency for insignificance	**0**	**1**	**2**	**4**	**0**	**2**	**2**

At the same time the choice of the variables set in the full model can be justified through analyzing all the attempts by the frequency of variables in terms of statistical significance. For this purpose, three different significance threshold level as shown in Table 4-7 above are used instead of general levels as suggested by default in R statistical software because of small dataset size. As it is found *'Travel* time' is highly significant and all other variables is significant combined high and medium threshold for at least 80% of times. This underlines the fact that the choice of variable set in full model dataset is not random in nature rather consistent enough.

Table 4-8 Full model comparison with model without constants and constants-only model

	Model type		
	Constants only (coefficients = 0)	No constants	Full model (constants+coefficients)
Log-likelihood value	-223.38	-188.26	-134.19
Mc-Fadden R^2	-2.2204E-16		0.399
chisquare value	-5.6843E-14		178.38
Likelihood ratio index	**0.399274778**		

The comparison shown in Table 4-8 indicates that the variables improves the ability to explain mode choice behavior. The log-likelihood value of the full model improves over the constants-only model by almost 40% and R^2 improves significantly. The model with variables but no constants is still having improvement compared to constants-only and increase in log-likelihood value is also substantial with constants added (full model). This could mean that the constants do play an important role as well as the variables though the values of constants are not too big, which is encouraging.

4.5 Model validation

4.5.1 Confusion matrix - kappa Statistic

A confusion matrix, or a misclassification matrix, was also created for each of the 10 attempts to see the effectiveness of the validation process. Each of these validation attempts are made with 20% records of full dataset (42 nos. record) where the model was re-estimated with corresponding 80% of full dataset. The sum of each row represents the actual number of observations while the sum of each column represents the predicted number. The diagonal cells are the matched observations while the non-diagonal cells show how much each mode is misclassified as another mode choice. The individual match rate is the percentage of correctly predicted observations over the number of actual observations, which shows the accuracy of predictions. The aggregate match rate is the total number of predicted observations, correctly and incorrectly predicted, over the actual number of observations per mode.

Table 4-9 Sample confusion matrix (validation run 4)

FULL MODEL CONFUSION MATRIX - validation purpose								
		Predicted						
		Auto-Rickshaw	Bus	Subway	Train	**Actual Total**	Individual Match (%)	**Aggregate Match (%)**
Actual	Auto-Rickshaw	2	1	3	0	6	33.33333	83.33333
	Bus	0	24	0	0	24	100	104.1667
	Subway	3	0	5	1	9	55.55556	122.2222
	Train	0	0	3	0	3	0	33.33333
	Predicted Total	5	25	11	1	42		

It can be observed from Table 4-9 that the model has quite good aggregate match rate and moderately good individual match rate too. If all the validation attempts are considered, then a high misclassification individual rate can be found for the mode train in almost all the cases and in some attempts for other modes subway and auto-rickshaw. It seems most train trips are misclassified as subway trips, which may indicate these modes share many similar characteristics. This could also be due to heavy dominance of the bus mode and very low number of observations for the mode train in the dataset.

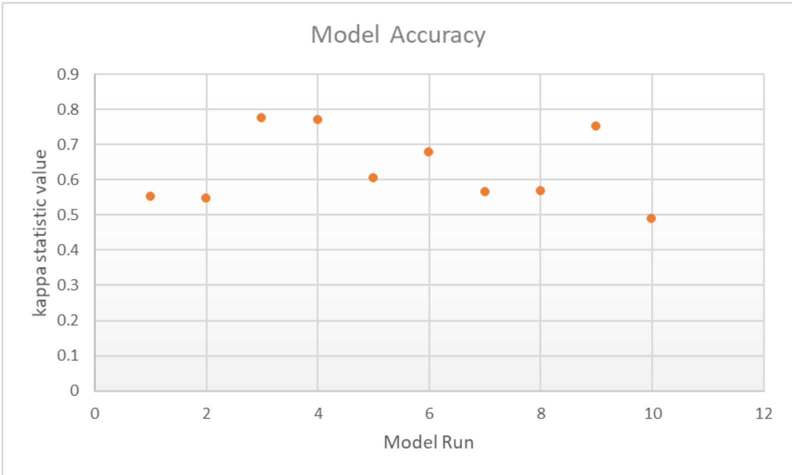
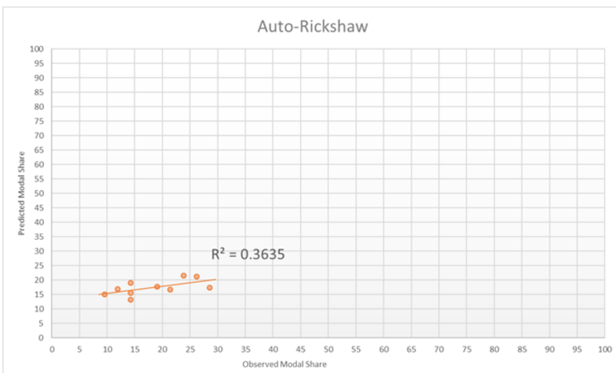


Figure 4-14 kappa statistic for 10 model-validation run

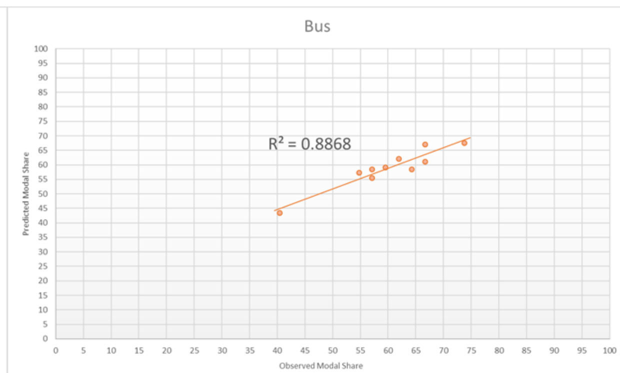
The prediction accuracy of the model can also be adjudged through the kappa statistic value which varies from 0.5 to 0.8 as shown in Figure 4-14 above. This in conjunction with confusion matrices indicate that the model performs moderately in terms of prediction for the modes *train, subway* and *auto-rickshaw* whereas it predicts the share of bus quite well most probably because it’s significant dominance in modal share.

4.5.2 Model fit by modal share

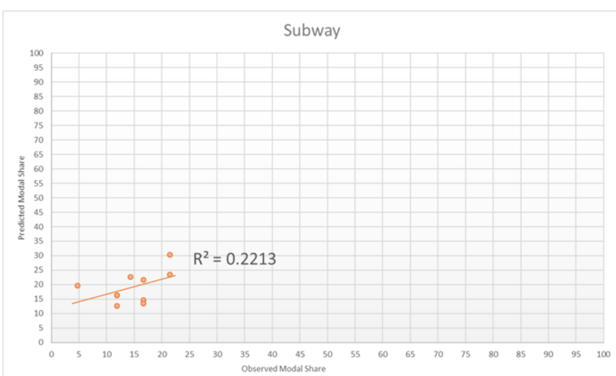
There are various ways to evaluate the validation process of a model. During estimation, the log-likelihood and McFadden’s R^2 value are relied upon as comparisons between validation attempts. To check the overall fit, the model is used to predict mode choice probabilities, and the prediction is compared against the observed modal share from the original data. The prediction was done using R platform on the randomly selected datasets. To account for stochasticity, the prediction here is a depiction of 10 validation attempts.



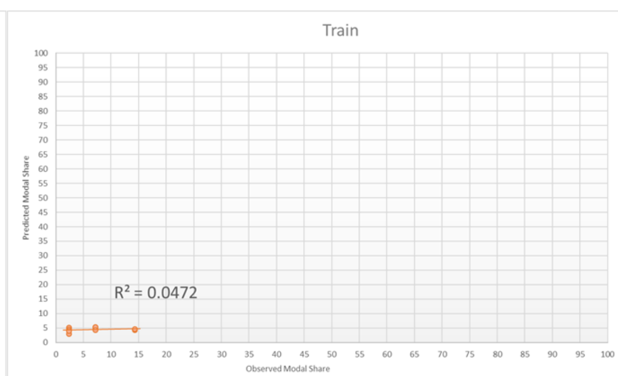
(a)



(b)



(c)



(d)

Figure 4-15 Observed vs. Predicted modal share for modes (a) Auto-Rickshaw, (b) Bus, (c) Subway and (d) Train

Figure 4-15 shows that the predicted versus observed modal shares correlate very strongly for the mode bus and moderately for the modes subway & auto-rickshaw. The weakest correlation belongs to the mode train. However, it should be kept in mind that the mode *train* has the smallest number of trip records, only going up to 13 trips that too only in one corridor.

4.5.3 Model fit by trip length

The number of trips per mode per distance is aggregated in 5 km distance brackets, up to maximum 25 km. The predicted modal shares are graphed against the observed modal shares.

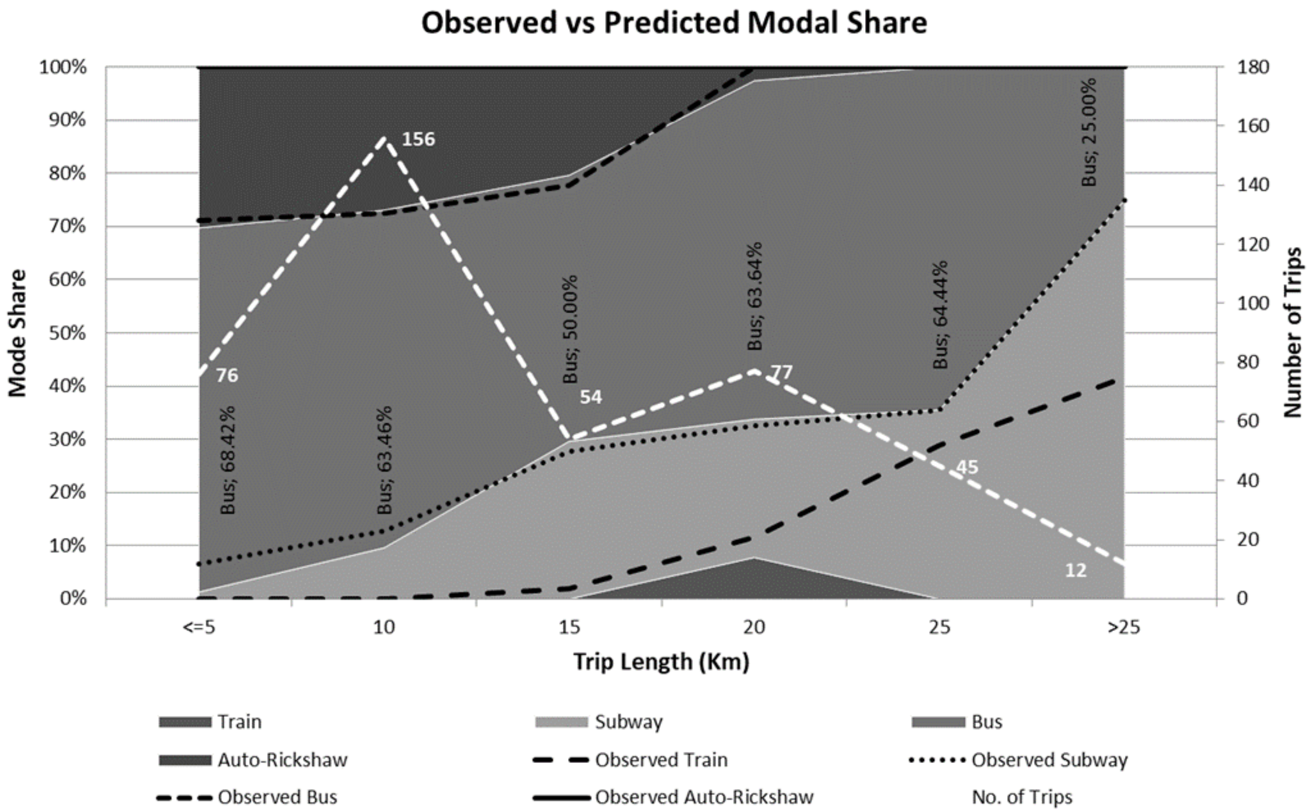


Figure 4-16 Distribution of modal share by trip length (observed vs predicted)

The Figure 4-16 indicates that the predicted modal shares grossly follow the overall pattern of the observed modal shares, especially for shorter distances and for all the modes. The pattern is not so closely matched at longer distances specifically between the modes subway and train because there are very few actual trips made at such distances. That is why most of the train trips are mis-classified as subway trips. It should be taken into consideration that most trips are short to medium-distance bus trips, and the model captures that behavior well.

Chapter 5 - Scenario Analysis

The major objective of this thesis is to assess the impact of different policy interventions in public transit improvement on commuter mode share. For this assessment, a commuter mode choice model was built based on field survey as described in Chapter Chapter 4 - above. This model was then applied to different scenarios of the policy interventions. The results of this application of the model to the scenarios are described in this chapter.

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Figure 5-1 Study area (hatched) & network (existing & proposed) map of city of Kolkata Metropolitan area

The transportation network of Kolkata is literally a labyrinth which is quite apparent from the

Figure 5-1above. At the same time significant portion of the transit corridors are overlapping in nature making the network far from being optimized. In this chapter the impact of different transit improvement policies has been analysed. It can give a new direction instead of inducing a new transport corridor or a new mode every time to solve the age old ‘congestion’ problem.

5.1 Scenario development

5.1.1 Field study

To understand the operational behavior of different modes along the corridor various mode related characteristics were observed during the field survey, conducted in the same period as the perception survey. Similarly, these data-points were collected in three phases of the day – two peak periods in morning and evening and afternoon off-peak period. The available datasets are as followed:

Class I – Mode related characteristics

- Corridor travel time
- Frequency of signalized intersection
- Waiting time (with & without signal)

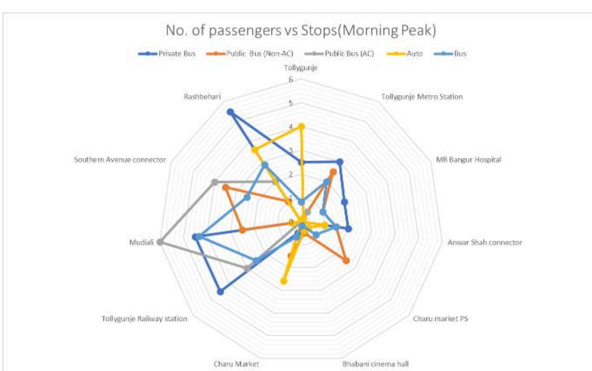
Class II – Mode and Traveler related characteristic

- Demand of the mode (No. of passengers boarding and/or alighting)
- Vehicular occupancy and/or comfortable occupancy (depends on vehicle type)

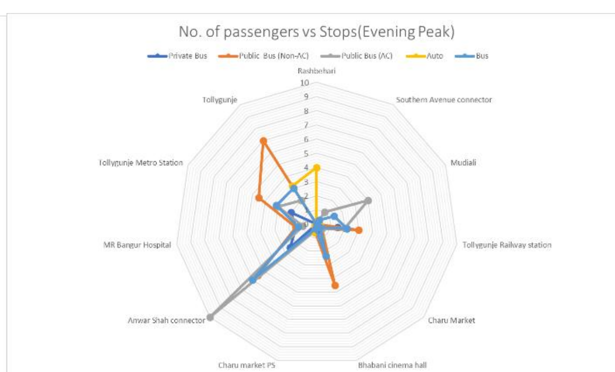
5.2 Data analysis

5.2.1 Analysis of corridor A - Tollygunge to Kalighat metro station corridor

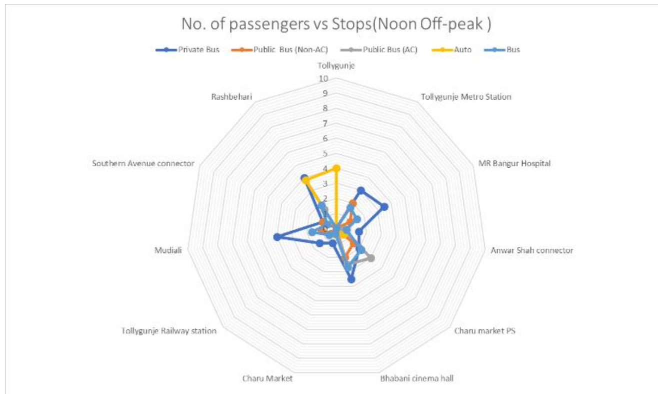
Analysis I – No. of passengers vs. Stops



(a)



(b)



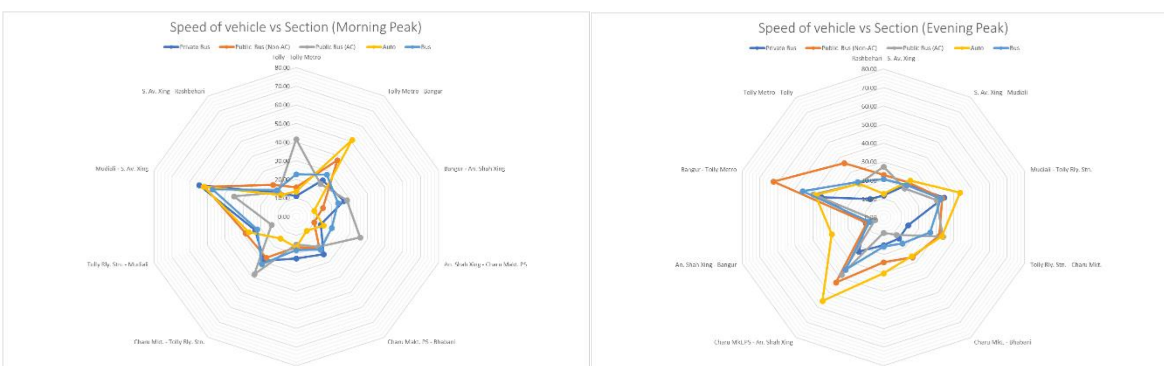
(c)

Figure 5-2 Passenger demand vs. Stops (a) morning peak, (b) evening peak and (c) afternoon off-peak

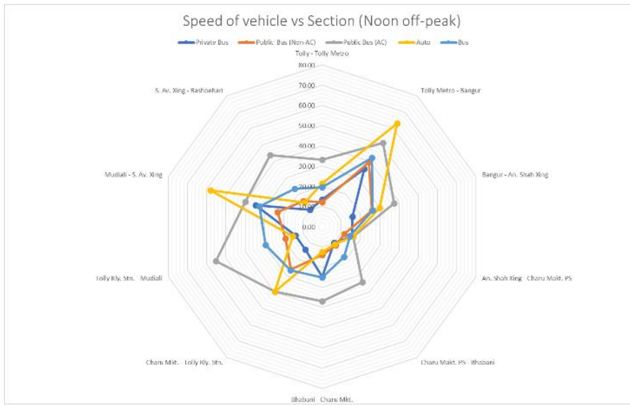
It can be clearly observed from Figure 5-2 above that passenger demand is not constant across all the stops, in fact there are huge gap in the demand for different stops. This situation probably occurs because of very closely spaced stops (3.6 stops on average per km on this corridor).

Scenario intervention(s): As we can find sudden peaks in the graph we can merge other stops in the vicinity based on the average walking speed or skip-stop service can also be introduced to avoid pressure during peak hours. The major stops in terms of passenger demand found out to be: (1) Tollygunge, (2) Anwar Shah connector, (3) Tollygunge railway station, (4) Mudiali, and (5) Kalighat metro station.

Analysis II – Average vehicular speed vs. Corridor



(a) (b)



(c)

Figure 5-3 Average speed (different modes) vs. Stops (a) morning peak, (b) evening peak and (c) afternoon off-peak

It can be inferred from Figure 5-3 above that average vehicular speed fluctuates along the corridor with sudden peaks making it prone to accidents as well as it causes schedule deviation rendering to unreliable service. This variation is also a result of competition between different modes as buses waits intentionally for longer period in a stop to get more passengers which consequently causes delay and congestion. Moreover, it helps to determine major stops for skip-stop operation.

Scenario intervention(s): Sudden fluctuation of vehicular speed can be resolved through optimized station planning and location (avoid major intersection) when skip stop operation or merging procedure is involved for public transits.

Analysis III – Average travel time vs. Time of day

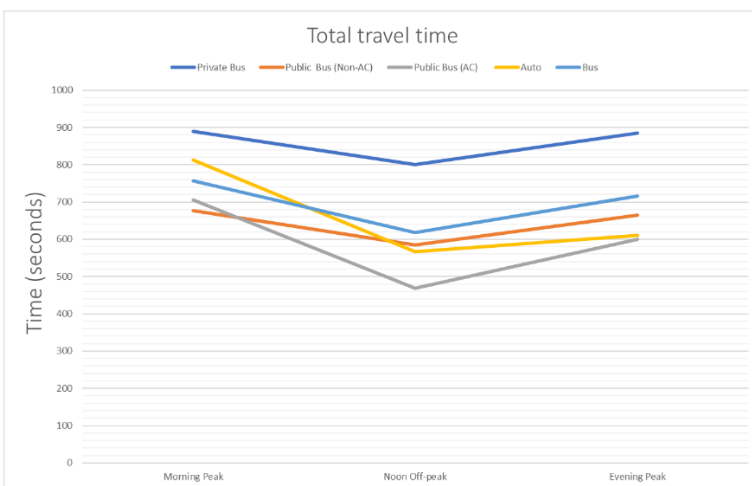


Figure 5-4 Average total travel time vs. Time of day

It can be seen in Figure 5-4 above that travel time along the corridor for all types of mode is higher during peak hours which is in line with general intuition. Simultaneously travel time difference between auto-rickshaw and bus was not found to be significant which is quite practical considering most of the arterial streets in Kolkata are overly saturated. It can also be observed that the travel time for private buses are significantly higher than other type of buses which is probably due to absence of strict traffic laws and their own unruly traffic behavior.

Scenario intervention(s): The capacity of the streets can be increased through different options like removal of auto-rickshaw or adding a bus only lane (or a reversible contraflow lane) which facilitates the use of public transit by overall improvement of vehicular speed and subsequently travel time.

Analysis IV – Average waiting time vs. Time of day

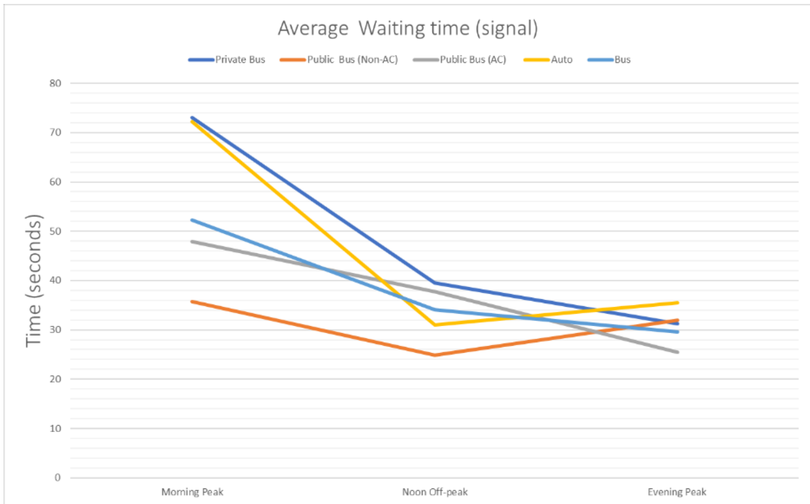


Figure 5-5 Average waiting time vs. Time of day

Figure 5-5 above shows that waiting time, with and without signal combined, along the corridor for all types of mode is higher during morning peak hours. This is probably because of intentional waiting time to capture more passengers in stops especially for private buses and auto-rickshaw which invariably causes congestion for full length of the section whereas the trend is opposite in evening peak as expected.

Scenario intervention(s): The waiting time in the stops have a direct relation with the bus stop capacity and queuing effect on the streets which in turn affects the reliability of the service.

<u>Analysis V – Average vehicle occupancy(crowdedness) vs. Time of day</u>

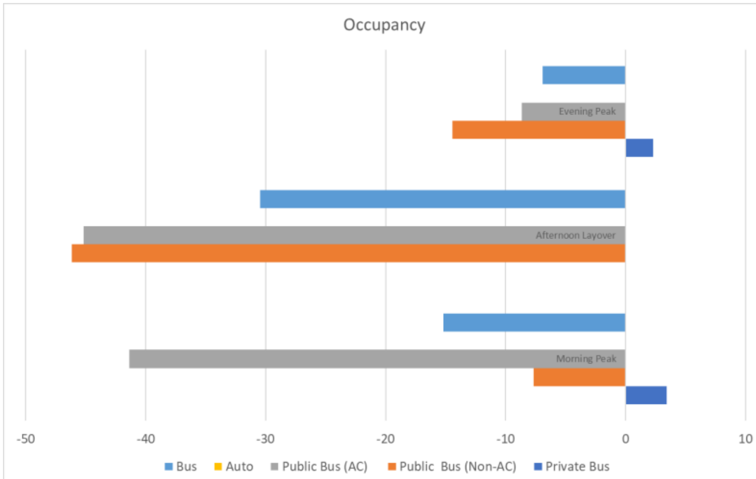


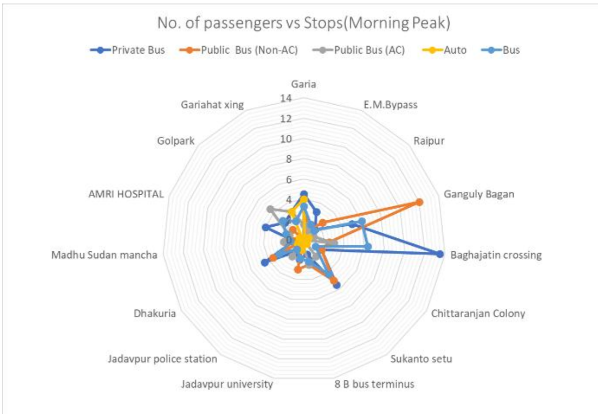
Figure 5-6 Average vehicle (comfortable) occupancy vs. Time of day

Average comfortable vehicle occupancy is calculated by adding all the no. of people could stand comfortably with no. of seats in the vehicle to consider variation in carrying capacity of different type of vehicle. Figure 5-6above suggests that even for the peak period the occupancy level of buses is lower than it's carrying capacity which shows people's choice of other faster mode like subway for travel time saving as well as inherent cause like high no. of overlapping routes running on the corridor. In case of auto-rickshaw the different demand curve does not essentially shows inclination of people to that mode rather those modes do not ply without being fully occupied which is reflected in high waiting time Figure 5-5.

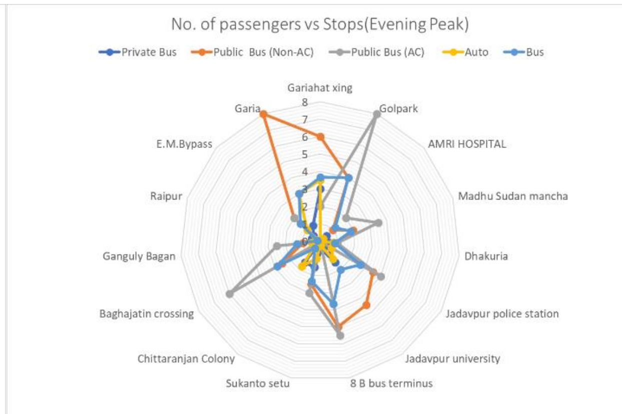
Scenario intervention(s): Bus schedule and service frequencies should be thoroughly planned out to cater to the peak hour demand as well as off-peak efficiently enough.

5.2.2 Analysis of corridor B - Garia to Gariahat market (Gariahat Crossing) corridor

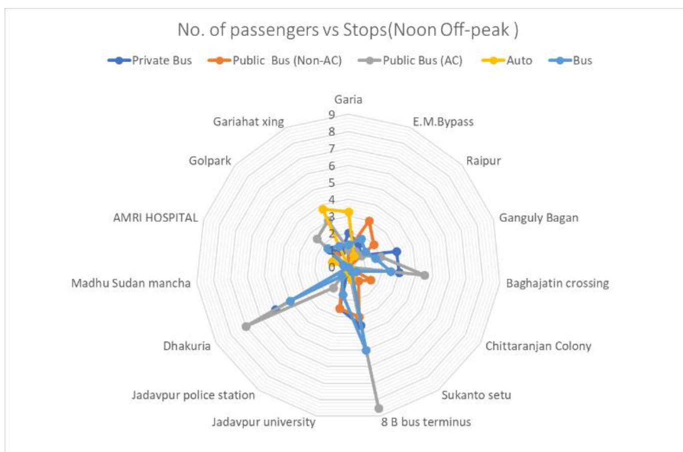
Analysis I – No. of passengers vs. Stops



(a)



(b)



(c)

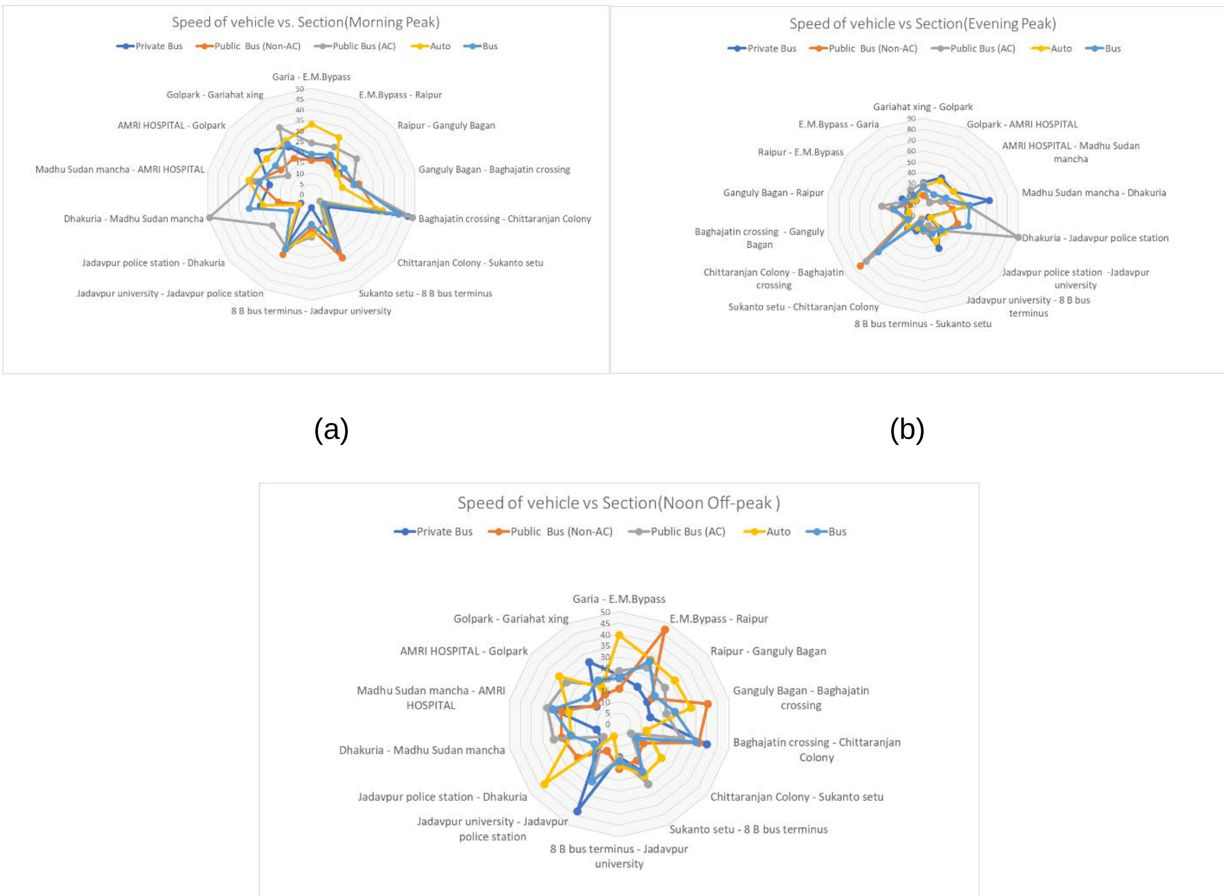
Figure 5-7 Passenger demand vs. Stops (a) morning peak, (b) evening peak and (c) afternoon off-peak

Similar to the other corridor, Figure 5-7 above also gives the same impression that passenger demand is not constant across all the stops, in fact there are clear differences in the demand for different stops like the other corridor. This situation probably occurs because of very closely spaced stops although slightly better than previous one (2.08 stops on average per km on this corridor).

Scenario intervention(s): As we can find sudden peaks in the graph we can club together stops with low demand to bring more uniformity, based on the average walking speed.

Otherwise skip-stop service can also be introduced to avoid pressure during peak hours. The major stops (8nos.) in terms of passenger demand found out to be: (1) Garia, (2) Raipur, (3) Baghajatin crossing, (4) Sukanto Setu crossing, (5) Jadavpur University, (6) Dhakuria, (7) AMRI hospital and (8) Gariahat market crossing.

Analysis II – Average vehicular speed vs. Corridor



(a) (b)

(c)

Figure 5-8 Average speed (different modes) vs. Stops (a) morning peak, (b) evening peak and (c) afternoon off-peak

It can be inferred from Figure 5-8 above that average vehicular speed fluctuates along the corridor with sudden peaks making it likely to accidents as well as it causes schedule deviation rendering to unreliable service. This variation is also a result of competition between different modes as buses waits intentionally for longer period in a stop to get more passengers which consequently causes delay and congestion. Expectedly more variation in the graphs can be observed during off-peak hours compared to both peak-hour graphs because of previously mentioned reason.

Scenario intervention(s): Sudden fluctuation of vehicular speed can be resolved through optimized station planning and location (avoid major intersection) when skip stop operation or merging procedure which in turn reduces bus interference and betters dwell time variability.

Analysis III – Average travel time vs. Time of day

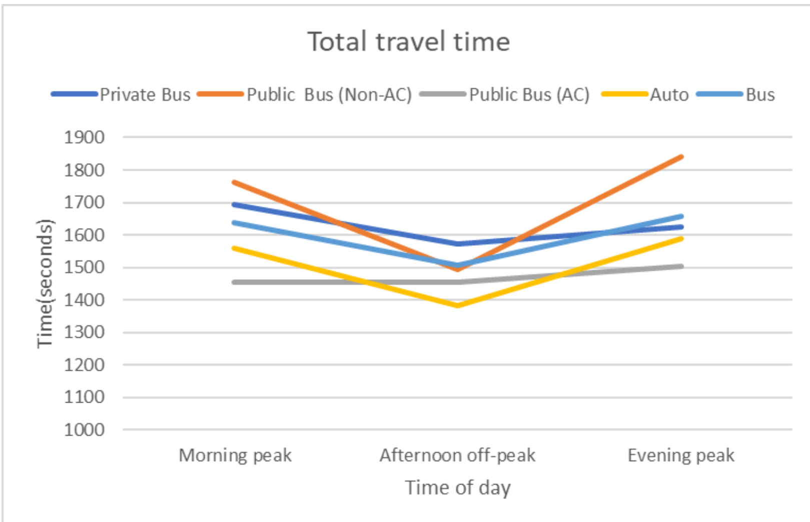


Figure 5-9 Average total travel time vs. Time of day

It can be seen in Figure 5-9 above that travel time along the corridor for all types of mode is higher during peak hours which follows general intuition. Simultaneously travel time difference between auto-rickshaw and bus was not found to be significant which is quite practical considering most of the arterial streets in Kolkata are overly saturated. It can also be observed that the travel time for 'public bus' is higher than 'private bus' which may be due to its large size not ideal for narrow stretch of the corridor.

Scenario intervention(s): The capacity of the streets can be increased through different options like removal of auto-rickshaw or adding a bus only lane (or a reversible contraflow lane) which facilitates the use of public transit by overall improvement of vehicular speed and subsequently travel time.

Analysis IV – Average waiting time vs. Time of day

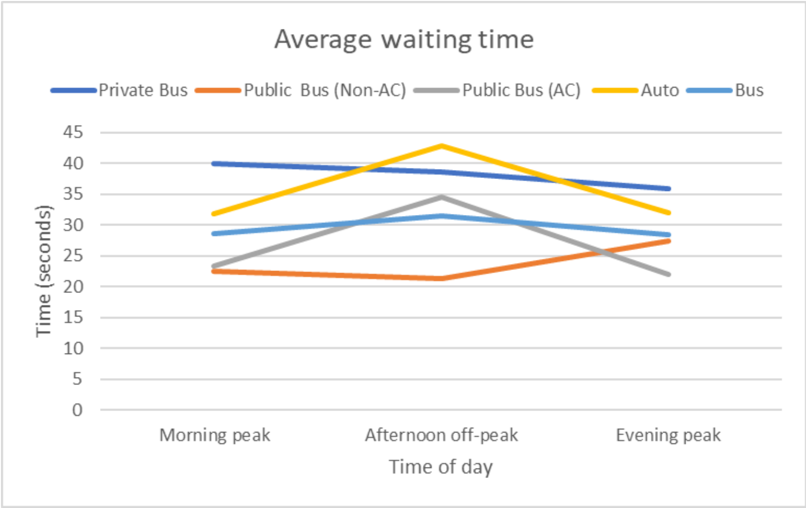


Figure 5-10 Average waiting time vs. Time of day

Figure 5-10 above shows that waiting time, with and without signal combined, is almost same for both peak hour span especially for bus mode on average but for auto-rickshaw it's opposite probably because of intentional waiting time to capture more passengers in stops during off-peak and same applies for private buses during morning peak. This invariably causes congestion for full length of the section as some parts of this corridor is quite narrow (less than 2 lanes).

Scenario intervention(s): The waiting time in the stops have a direct relation with the bus stop capacity and queuing effect on the streets which in turn affects the reliability of the service.

Analysis V – Average vehicle occupancy(crowdedness) vs. Time of day

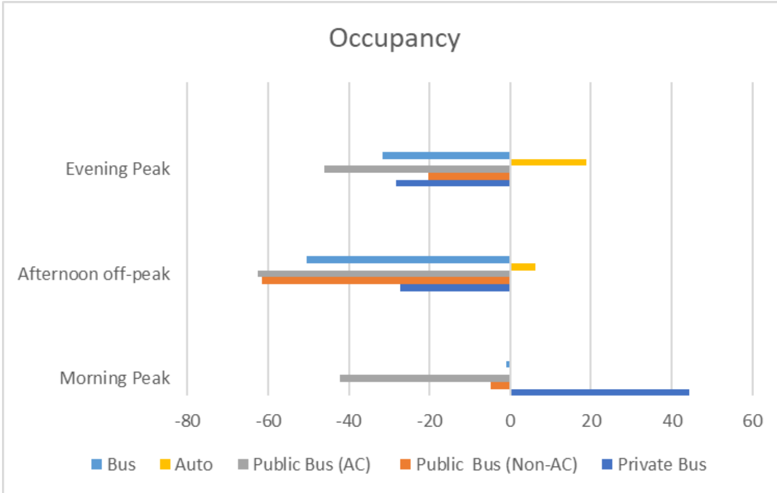


Figure 5-11 Average vehicle (comfortable) occupancy vs. Time of day

Average comfortable vehicle occupancy is calculated by adding all the no. of people could stand comfortably with no. of seats in the vehicle to consider variation in carrying capacity of different type of vehicle. Figure 5-11 above suggests that even for the peak period the occupancy level of buses is lower than it's carrying capacity which shows people's choice of other faster mode like subway for travel time saving as well as inherent cause like high no. of overlapping routes running on the corridor. In case of auto-rickshaw the different demand curve does not essentially shows inclination of people to that mode rather those modes do not ply without being fully occupied which is reflected in high waiting time Figure 5-11.

Scenario intervention(s): Bus schedule and service frequencies should be thoroughly planned out to cater to the peak hour demand as well as off-peak efficiently enough. New peak hour services can be introduced in current off-peak slots keeping in mind general working hours in educational institutions and commercial sector.

5.3 Transit capacity and speed calculation

To build up different scenarios and to find out which variables could be changed to alter the travel speed a detailed literature study was done which resulted in estimation of transit capacity and speed in two study corridors separately based on the methods published in the reports by Transportation Research Board. (Kittelson & Associates, Inc.; Parsons Brinckerhoff; KFH Group, Inc; Texas A&M Transportation Institute; ARUP, 2013)

5.3.1 Estimation of existing bus lane capacity

Step 1- Defining facility

i. 2-way couplet
ii. towards downtown area

Step 2- Calculation of bus stop demand data

i. Mean Dwell time = Observed from field study
ii. Dwell time variability (C_v) = Observed from field study
iii. Failure rate = 15-30% (can be computed)
iv. Passenger demand peak hour factor(PHF) = (boarding + alighting passengers in peak hour) / (4 x Passenger demand during peak 15 mins)

Step 3- Calculation of bus stop location data

I. Positions relative to road way = Off-line (no curb extension present so bus pulls out of travel lane to serve a stop)
II. Positions relative to intersection = far-side (located immediately after intersection)
III. Bus stop design type = Linear
IV. Number of Loading area = 1 for each stop
V. Bus facility type = type 2 bus lane (allows bus to move adjacent lane to move around other vehicles using that lane)
VI. Traffic signal timing = g/C ratio (should be gathered from literature/ secondary source)
VII. Traffic volume (should be gathered from literature/ secondary source)
VIII. Curb lane traffic volume (veh/hr)
IX. Left turning traffic volume & capacity (veh/hr)
X. Parallel Pedestrian crossing volume conflicting with left-turning traffic
XI. Setting a design bus stop failure rate and

XII. Determine Dwell time (field measured)

Step 4- Determination of loading area capacity

B_l = {3600 (g/C)} / {t_c + t_d (g/C) + t_{om}}

where,

Clearance time (t_c) = Start-up Time (t_{su}) + Re-entry time (t_{re})

Mean Dwell time = t_d

Operating margin (t_{om}) = Standard normal variable corresponding to a desired failure rate (Z) * Coefficient of variation of dwell times (C_v) * Average dwell time (t_d)

Clearance time (t_c) = 9-20 seconds on average

Start-up Time (t_{su}) = 10 seconds on average

Re-entry time (t_{re}) = (can be computed)

Step 5- Determination of bus stop capacity

Bus stop capacity B_s = N_{el} * B_l * f_{tb}

For all stops number of effective loading area (N_{el}) = 1

i. Adjust capacity for traffic blockage

Traffic blockage adjustment factor (f_{tb}) = 1- f_l*(v_{cl} / c_{cl})

where,

Stop location factor (f_l) = 0.50 (based on far side bus stop location and type2 bus lane)

ii. Capacity of curb lane through movement (c_{th}) = Saturation flow rate (s_f) * (g/C)
iii. Capacity of curb left turn movement (c_{lt}) = 1450*(g/C) *(1-(pedestrian volume/2000))
iv. Curb lane capacity (c_{cl}) = Volume weighted (c_{th}) + Volume weighted (c_{lt})

5.3.2 Estimation of existing bus lane speed

Step 1- Defining facility

i. 2-way couplet
ii. towards downtown area

Step 2- Calculation of bus stop demand data

i. average stop spacing = stops/Km in each direction (should be field observed)
ii. average dwell time = (should be field observed)
iii. scheduled number of buses at critical stop = (should be field observed)
iv. traffic signal timing and phasing = (should be field observed)
v. traffic interference = signals/Km in each direction

Step 3- Determination of section maximum capacity

It should be the input of the section capacity determined in section 5.3.1 above.

Step 4- Determination of base bus running time rate

i. calculate unimpeded bus running time rate

travel time rate a bus would experience if it could travel along the facility without traffic signal or traffic delays

$t_u = \{ t_{rs} + Ns (t_{dt} + t_{acc} + t_{dec} + t_{sta})\} / 60$

where,

unimpeded running time rate = (t_u)

time spent at running speed (t_{rs}) = L_{rs} / (c_f * v_{run})

Distance travelled at running speed per Km (L_{rs}) = L_{mk} – N_s L_{ad}

distance travelled at less than running speed

(L_{ad}) = 0.5*a*(t_{acc})2+0.5*d*(t_{dec})2+ L_{sta}

Acceleration time (t_{acc}) = (c_f * v_{run}) / a

Deceleration time (t_{dec}) = ($cf * v_{run}$) / d

Bus running speed on facility = (v_{run})

Conversion factor = c_f

time required to travel through station (t_{sta}) = L_{sta} / (1/ $cf*v_{st}$ - 1/ $cf*vr_{un}$)

ii. calculate additional running time losses (t_l)

Running time losses based on type of traffic.

iii. calculate base bus running time rate

$t_r = t_u + t_l$

Step 5- Adjustment for bus congestion

i. bus v/c = Scheduled no. of Bus in per hour / Max capacity of street
ii. bus-bus interference factor(f_{bb})

Step 6- Determination of average section speed

i. No adjustment for no skip-stop (f_{sp}) = 1
ii. For skip-stop operation = 0.87 (based on traffic volume)

Step 7- Determination of average section speed

iii. Section running time rate(t_s) = t_r / f_{bb} * f_{sp}
iv. Average Section speed (S_s) = 60/ t_s

5.4 Development of Scenarios

The scenarios are developed according to three major types of transit improvement interventions – (1) Improvement in existing network (capacity and speed constraints improvement), (2) Lane management and (3) Introduction of new transit service (BRTS).

The evaluation of the scenarios is based on modal shift incurred by it with parallel consideration of approximate cost and time budget of each intervention with help of literature survey (Kittelson & Associates, Inc.; Herbert S. Levinson Transportation Consultants, 2007). The following table outlines the cost for different types of transit improvement strategies. The time span though varies largely across different countries.

Table 5-1 Cost and Time budget outline for different types of transit improvement strategies

Id	***Major strategy***	***Sub-strategies***	***Cost budget (millions)***	***unit***
1	BRTS implications	At grade BRTS	5 MM $	Lane-mile
2		Arterial lane reconstructed	2.7 MM $	Lane-mile
3		Grade separated BRTS	20 MM $	Lane-mile
4	Lane management implications	Adding a new lane	2.5 MM $	Lane-mile
5		Existing arterial lane conversion	0.075 MM $	Lane-mile
6	Network implications	Transit signal priority	0.022 MM $	Per intersection
7		Bus queue jumps	0.01 MM $	Per intersection
8		Curb extension	0.06 MM $	

The threshold and colour coding for different cost and time budget are as followed:

Colour code	High	Medium	Low
Cost budget range	>5 million $	>1 – 5 million $	0 – 1 million $
Time budget range	>5 years	>3 – 5 years	0 – 3 years

5.4.1 Scenario 1: Improvement in existing network (Capacity and Speed constraints improvement)

The capacity improvement scenarios deal with different variables and design interventions e.g. dwell time, signal duration, bus priority design (queue jumps and curb extension) as well as parking and auto-rickshaw removal from arterial streets and combination thereof. The methods to calculate the changes in the variable 'travel time' in mode choice model it's necessary to know the changed travel speed of bus mode when the above mentioned capacity constraints are altered. The change has been calculated according to the method mentioned below and it's also worth mentioning that the benefits of the service improvement measures are sensitive to intervening stretch length. For exhaustive details of all sub scenarios refer to AppendixVIII.

Table 5-2 Selected sub scenarios (capacity constraints) of scenario-1 ***(Improvement in network)***

Id	Time budget	Cost budget	Capacity Constraints	Change in variables	Methods	Intervention length
1.01			•Average Dwell time •Dwell time variability	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.6**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value)	**Full stretch**
1.02			•Dwell time improvisation **•Bus priority signalling**	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.6** •g/C Ratio **= 0.4**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value) •Increase g/C ratio	**Full stretch**
1.03			•Dwell time improvisation •Bus priority signalling **•Use queue jumps and curb extension**	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.7** •g/C Ratio **= 0.45** •bus priority design **= No re entry delay**	•Reduction in Re-entry time (reduction in dwell time)	**Full stretch**

The scenarios related with improvement of speed constraints considers variables and design interventions e.g. stop spacing / stop density, skip stop operation, bus schedule (frequency of buses at critical stop at peak hour) etc. and combination thereof. The changes have been calculated based on the methods mentioned below and in all the cases the measure has been applied to full stretch length. For exhaustive details of all sub scenarios refer to AppendixIX.

Table 5-3 Selected sub scenarios (speed constraints) of scenario-1 ***(Improvement in network)***

Id	**Time budget**	**Cost budget**	**Speed Constraints**	**Change in variables**	**Methods**	**Intervention length**
1.08			•Average stop spacing	•Average stop spacing = **Increased**	•Merge less popular stops	**Full stretch**
1.09			•Average stop spacing **•Introduce skip-stop operation**	•Average stop spacing = **Increased** •Skip stop factor **=0.87**	•Merge less popular stops •Add skip stop operation calculation from TCRP report	**Full stretch**
1.10			•Average stop spacing **•Schedule of Buses at critical stop**	•Average stop spacing = **Increased** •No. of bus/hr at critical stop **= 20% overlap removed**	•Merge less popular stops •Reduce no. of buses with overlapping route	**Full stretch**

5.4.2 Scenario 2: Improvement in lane management

Lane management is second scenario type which deals with the variables and design interventions where both speed and capacity constraints are improved upon related to lane specification. At the same time measures also considers parking and auto-rickshaw removal from arterial streets for scenario development. For exhaustive details of all sub scenarios refer to AppendixX.

Table 5-4 Selected sub scenarios of scenario-2 ***(Improvement in lane management)***

Id	Time budget	Cost budget	Speed Constraints	Capacity Constraints	Change in variables	Methods	Intervention length
2.04			•Average **stop spacing** •**Schedule** of Buses at **critical stop** •Introduce **skip-stop operation**	•Dedicated bus lane from existing road width in **extended peak hours span** •Bus priority signalling	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow **= decreased** •curb lane volume **= bus only lane** •new peak hour slots **= 8-11, 12-14, 15-17, 18-22** **•g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width •**Change peak hour variable**	**Selected stretch**
2.16			•Average **stop spacing** •**Schedule** of Buses at **critical stop** •Introduce **skip-stop operation**	•Introducing contraflow **car lane** in **extended peak hours span (NO car allowed on peak direction)** **•Removal of Auto-Rickshaw from arterial street** **•Bus priority signalling**	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed. •Skip stop factor =0.87 •saturation flow **= same** •curb lane volume **= decreased by 60%** •new peak hour slots **= 8-11, 12-14, 15-17, 18-22** **•g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width •**Change peak hour variable** **•g/C Ratio = 0.4**	**Selected stretch**

5.4.3 Scenario 3: Introduction of new service (BRTS)

Introduction of new transit service like BRTS is third scenario type which deals with the variables and design interventions where both speed and capacity constraints are changed upon major service improvement with and without improving existing bus service. For exhaustive details of all sub scenarios refer to AppendixXI.

Table 5-5 Selected sub scenarios of scenario-3 ***(Introduction of new transit service BRTS)***

Id	Time budget	Cost budget	Speed Constraints	Capacity Constraints	Change in variables	Methods	Intervention length
3.01				•**24 hrs** Grade separated bus lane from **parking removal (1 lane for Bus+1 lane for BRTS)** •Bus priority signalling	•saturation flow **= increased for BRTS / decreased for Bus** •curb lane volume **= increased for Bus / decreased for BRTS** **•g/C Ratio = 0.4**	•Calculate changed vehicular speeds for BRTS buses based on traffic volume change •Calculate changed vehicular speeds for other Buses based on traffic volume change •Calculate changed vehicular speeds for auto-rickshaw mode •Calculate changed waiting time	**Selected stretch**
3.02			•Average **stop spacing** **•Schedule** of Buse`s at **critical stop** •Introduce **skip-stop operation**	•**24 hrs** Grade separated bus lane from parking **removal (1 lane for Bus+1 lane for BRTS)** •Bus priority signalling	•saturation flow = increased for BRTS / decreased for Bus •curb lane volume = increased for Bus / decreased for BRTS **•Avg. stop spacing = more** **•No. of bus/hr at critical stop = 20% reduction** •Skip stop factor =0.87 •g/C Ratio = 0.4	•Same as above	**Selected stretch**

5.5 Prediction

In this thesis, the sub-scenarios described in the previous section were used to assess the impact of different policy interventions in an incremental manner. As discussed in section 4.4.2 , based on the data available, the attributes related to transport facilities that could be altered during prediction were respectively travel time and peak-hour. Therefore, scenarios with varying travel times and peak-hour variable calculated based on varying average transit speeds were tested.

It should also be noted that in the mode choice model car and other means of transport have not been considered so actual value of rise in transit share will be somewhat less than the predicted ones as those modes will certainly attract some ridership and as this is a MNL model increase in mode share probabilities in bus mode has been taken away from other modes based on their existing respective mode shares which may not be the case. We should also consider the fact that the increase in bus modal share may seem too high as modal share of specifically 2 corridors are considered for analysis instead of whole city.

In this context, all the sub-scenarios of scenario 1 & 2 were predicted on the scenario dataset by applying the commuter mode choice model in R platform and for scenario 3, incremental mode choice model was used as conventional mode choice model fails to predict precisely in case of addition of a new mode like BRTS. The prediction for different scenarios has been done separately for two corridors to find out differences, if any, in mode share change as accessibility for subway and train is poor in case of Garia – Gariahat corridor.

Comparison between Corridors (Impact of policy interventions)

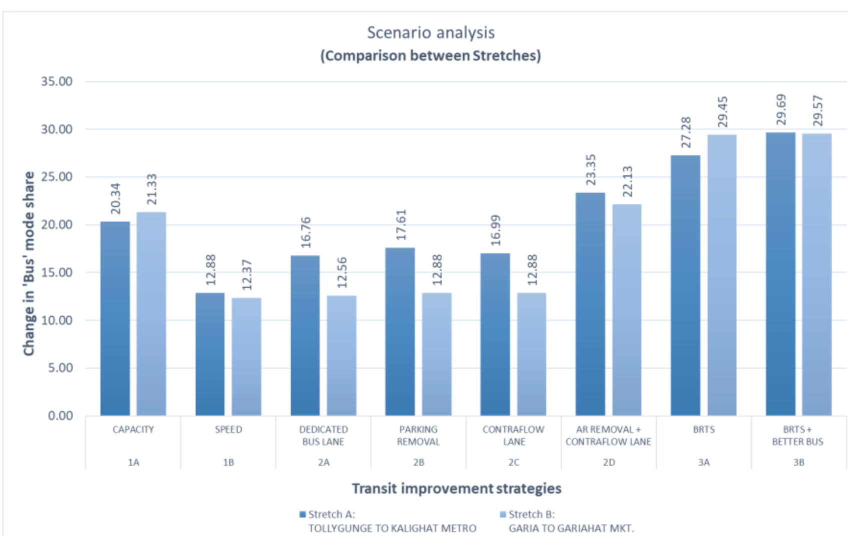


Figure 5-12 Change in commuter mode share in Corridors A and B predicted for scenarios

If the change (increase in all scenarios) in bus mode share analysed and compared for all the scenario types between two corridors i.e. **Corridor A**: Tollygunge to Kalighat metro station and **Corridor B**: Garia to Gariahat market, a stark similarity can be found out. The increase in mode share is very much close in value especially for Scenarios 1 (1A & 1B – Speed and capacity constraints improvement) and Scenarios 3 (3A & 3B – Introducing BRTS) and more importantly follows a same pattern for both the corridors.

At the same time, it can be observed from Figure 5-12 that increase in modal share for corridor A is more than corridor B for Scenario 2 (2A, 2B, 2C & 2D – Types of lane management) probably because significant portion of corridor B has road width equal to just 2 lanes or even less than that which renders it practically unfeasible to reserve a lane only for bus.

Further it is also worth noting that change in modal share is very close for **scenario 1** (Speed and capacity constraints improvement) and **scenario 2** (Lane management) whereas **Scenario 3** (Introducing BRTS) causes a significant increase over the other scenarios.

Detailed analysis at corridor level

Corridor A: Tollygunge to Kalighat metro station

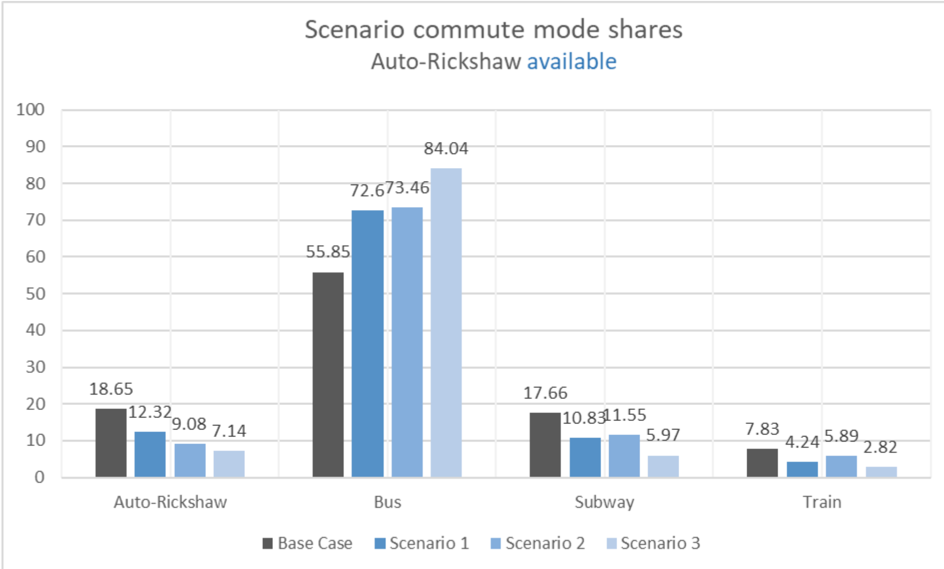
For better analysis, the prediction results have been further analysed at two levels:

a) Level 1: Comparison **between** scenarios
b) Level 2: Comparison **within** scenarios

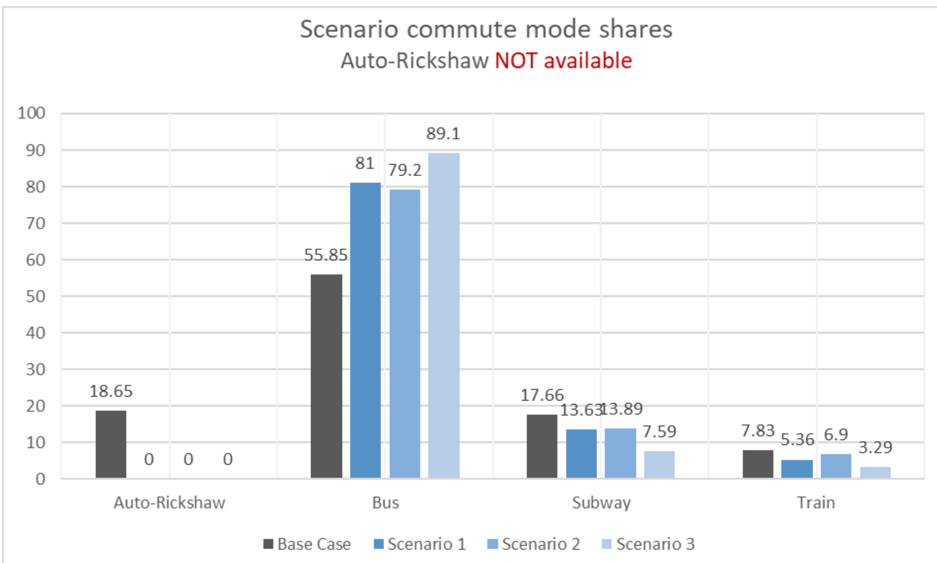
5.5.1 Level 1A: Comparison between Scenarios (best case sub scenarios)

Here the prediction results are further subdivided into two categories to find out the impact of availability of auto-rickshaw on mass transit commuter mode share.

a) Scenarios when auto-rickshaw is available
b) Scenarios when auto-rickshaw is not available



(a)



(b)

Figure 5-13 Commuter mode share predicted for scenarios (a) auto-rickshaw available and (b) auto-rickshaw not available

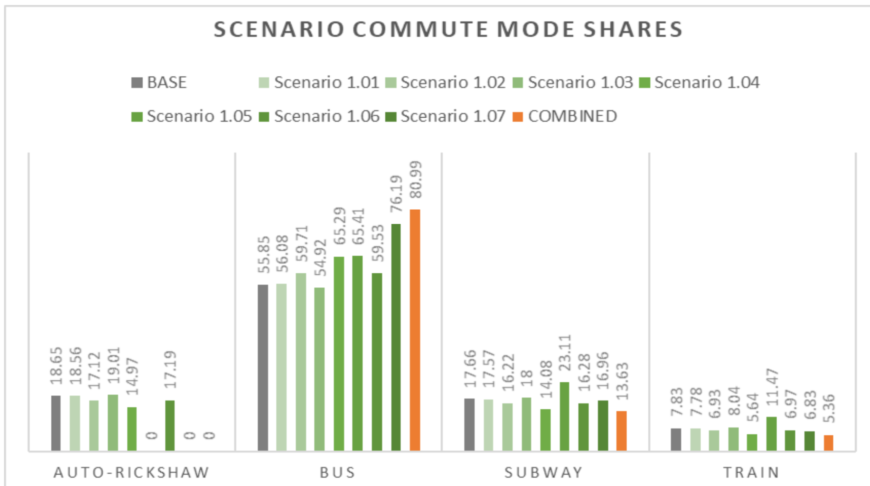
There are two points which can be inferred from above figures – (i) increase in mode choice probabilities through simple speed & capacity improvement techniques **(scenario 1)** are almost equal or even greater than comparatively cost & time intensive lane management techniques **(scenario 2)** and (ii) removal of auto-rickshaw increases significantly choice probability for bus across all the scenarios.

5.5.2 Level 2A: Comparison within Scenarios

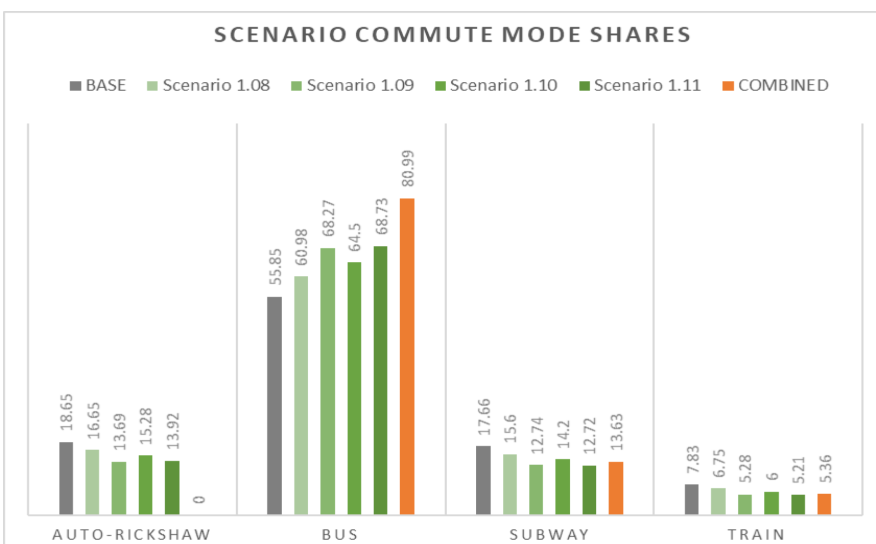
Level 2A.1: Scenario 1 – sub scenarios

Here the prediction results are further subdivided into two categories to find out the impact of improving various capacity and speed constraints on mass transit commuter mode share.

a) Scenario 1.01 – 1.07 - Scenarios with **capacity** improvement measures (AppendixVIII)
b) Scenario 1.08 – 1.11 - Scenarios when **speed** improvement measures (AppendixIX)



(a)



(b)

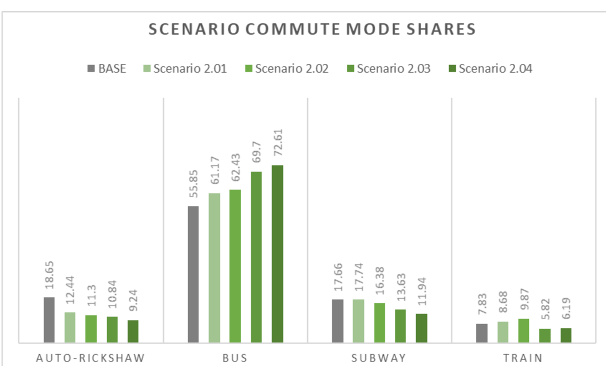
Figure 5-14 Change in commuter mode share predicted for scenario level 2.1 (a) above and (b) below

It can be found out from the predictions that inclination to public transit increases with travel time reductions where simply a combined set of capacity improvement strategies increase the bus share approximately by 20% which is quite significant. Whereas in a similar approach a combined set of speed improvement strategies increase the transit share approximately by 13%. Simultaneously when we consider both the speed and capacity improvement strategies together it can result in an increase of transit share approximately by 25%. It should be mentioned that skip-stop operation provides significant rise in modal share as bus interference factor is reduced along with better scheduling which causes major increase in travel speed for bus. The best-case scenario expectedly comes when auto-rickshaw is removed along with obtaining an extra lane through parking removal which are highly ambitious but not unrealistic.

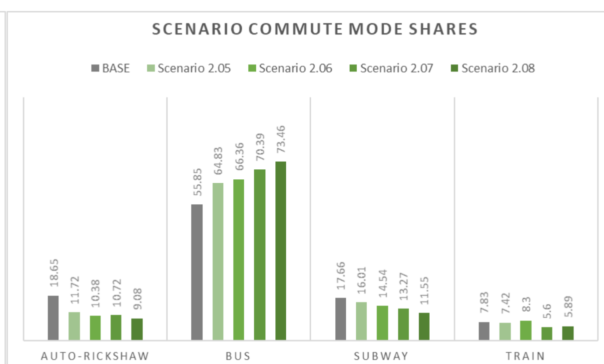
<u>Level 2A.2: Scenario 2 – sub scenarios</u>

Here the prediction results are further subdivided into four categories to find out the impact of lane management on mass transit commuter mode share.

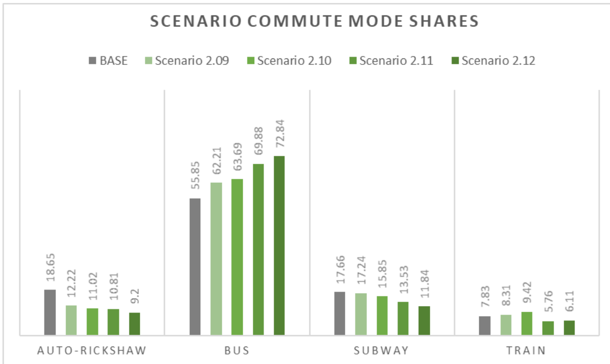
a) Scenario 2.01 – 2.04 - Scenarios with dedicated bus lane from existing road width (AppendixX)
b) Scenario 2.05 – 2.08 - Scenarios when dedicated bus lane(s) from parking removal (AppendixX)
c) Scenario 2.09 – 2.12 - Scenarios when contraflow lane for cars but no car in peak direction (AppendixX)
d) Scenario 2.13 – 2.16 - Scenarios when contraflow lane for cars but no car in peak direction allowed and removal of auto-rickshaw (AppendixX)



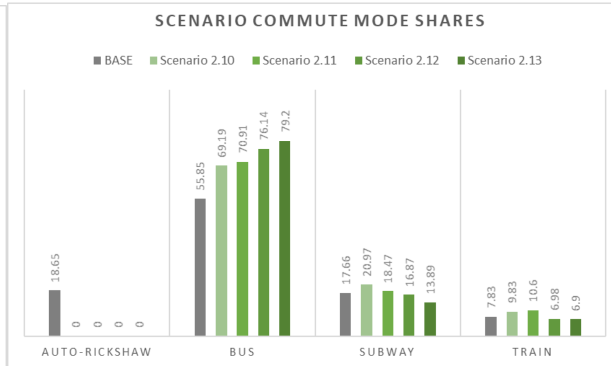
(a)



(b)



(c)



(d)

Figure 5-15 Change in commuter mode share predicted for scenario level 2.2 (a) above left, (b) above right, (c) below left and (d) below right

The predictions show that bus modal share expectedly increases with better lane management strategies. All the sub scenarios clearly show that whenever speed improvement strategies are coupled with the lane management strategies there is significant rise in transit share. Introduction of new peak hour services (Scenario 2.02, 2.04, 2.06, 2.08, 2.10, 2.12, 2.14 & 2.16) during afternoon off peak increase mode share consistently for all sub-scenarios although does not cause huge increase in transit share when applied without bus priority strategies. It should still be noted as small increase can also be attributed to the fact that during non-peak hours people mostly chose bus for travel cost saving. Simultaneously it can be found out that adding speed improvement measure (Scenario 2.03, 2.05, 2.07, 2.09, 2.11, 2.13, 2.15 & 2.17) makes a significant impact in increasing mode share for bus consistently. The best-case scenario among all lane management interventions comes up when car use has been restricted along with removal of auto-rickshaw from arterial street.

Level 2A.3: Scenario 3 – sub scenarios

Here the prediction results are further subdivided into two categories to find out the impact of introduction of a new service like Bus rapid transit system (BRTS) on mass transit commuter mode share.

a) Scenario 3.01 - Scenarios with additional BRTS service, no improvement of existing bus service (AppendixXI)
b) Scenario 3.02 - Scenarios with additional BRTS service and speed improvement measures for existing Bus service (AppendixXI)

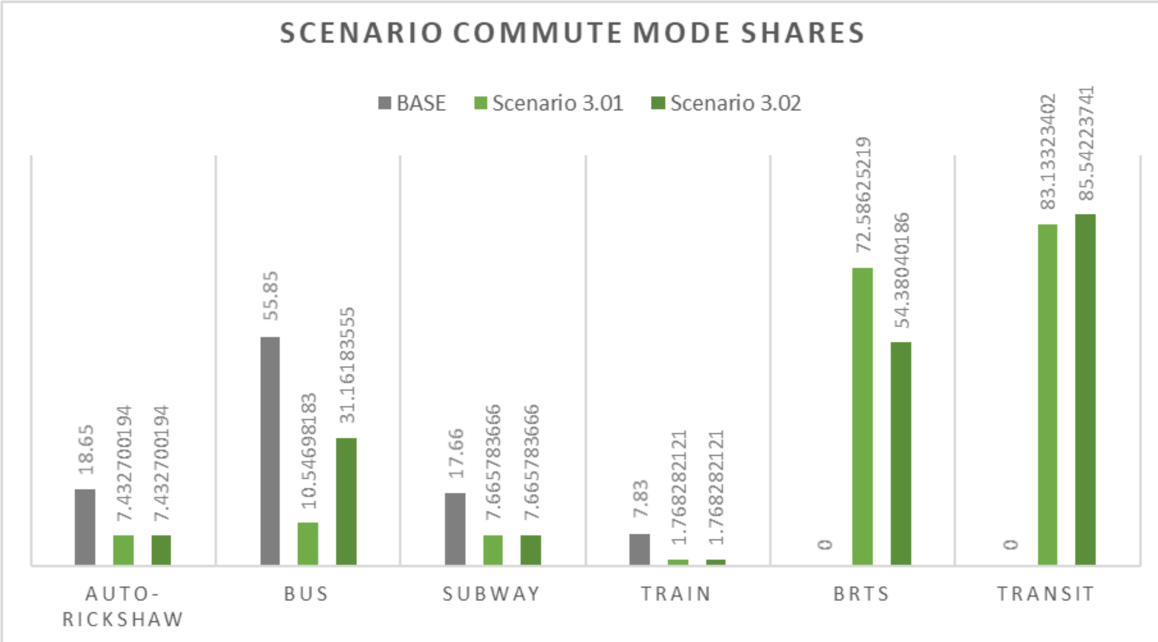


Figure 5-16 Change in commuter mode share predicted for scenario level 2.3 (a) and (b)

It can be seen from the figure above, obtained by application of incremental mode choice model that BRTS is the strategy which causes highest increase in the transit modal share which is approximately 28-30% from the base case scenario. At the same time, we should also notice that improvement in the existing bus significantly draws commuter from BRTS mode but aggregated change in modal share does not differ too much.

Corridor B: Garia to Gariahat market

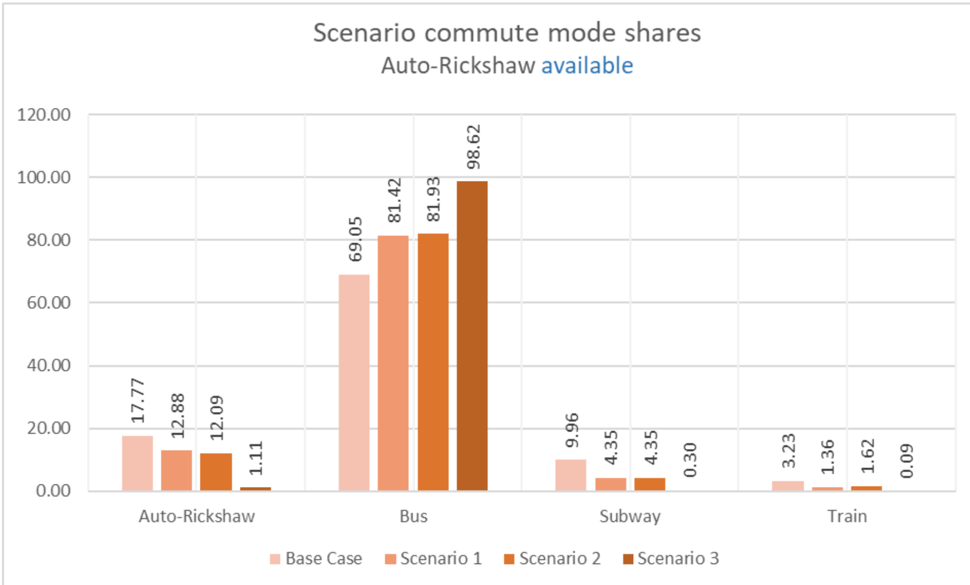
For better analysis, the prediction results have been analysed at two levels:

c) Level 1: Comparison **between** scenarios
d) Level 2: Comparison **within** scenarios

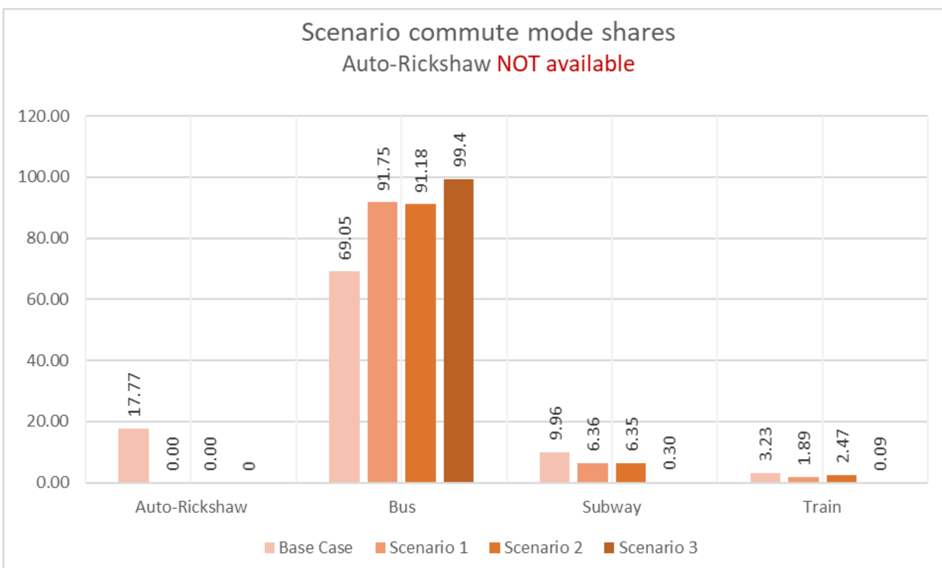
5.5.3 Level 1B: Comparison between Scenarios (best case sub scenarios)

Here the prediction results are further subdivided into two categories to find out the impact of availability of auto-rickshaw on mass transit commuter mode share.

c) Scenarios when auto-rickshaw is available
d) Scenarios when auto-rickshaw is not available



(a)



(b)

Figure 5-17 Change in commuter mode share predicted for scenarios (a) auto-rickshaw available and (b) auto-rickshaw not available

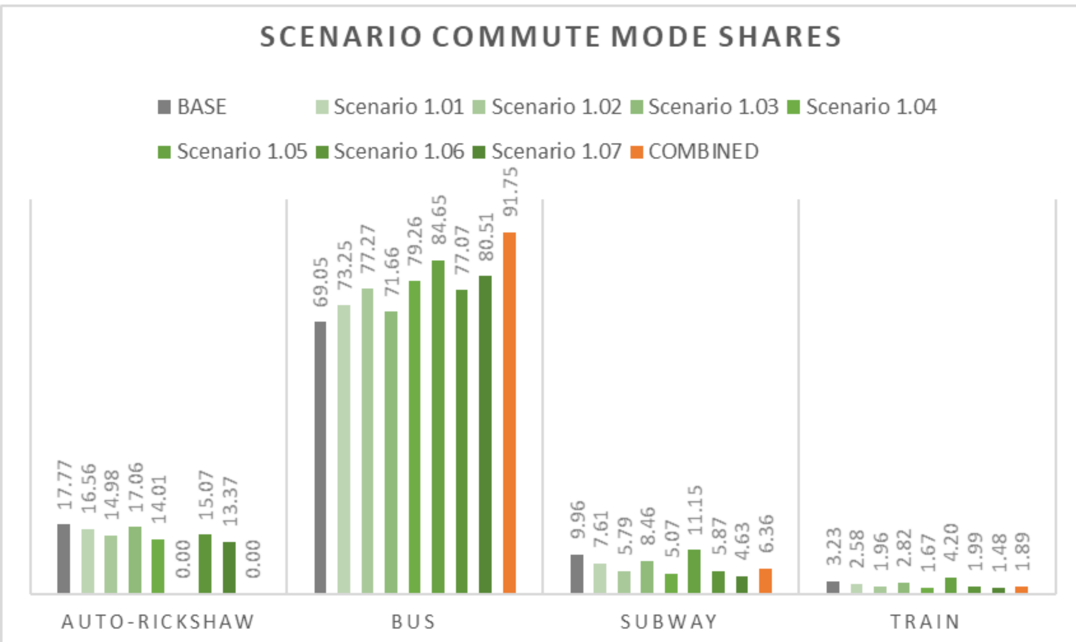
Similar to the other corridor it can also be identified that– (i) increase in mode choice probabilities through simple speed & capacity improvement techniques **(scenario 1)** is greater than comparatively cost & time intensive lane management techniques **(scenario 2)** and (ii) removal of auto-rickshaw does increase choice probability for bus across all the scenarios. In addition, it's worth noting that introduction of BRTS causes sharp drop in choice probabilities in all other modes probably because of existing poor accessibility of bus and train mode in chosen corridor (Corridor B) which actually caused initial high modal share for bus and corresponding low share for all other modes.

5.5.4 Level 2B: Comparison within Scenarios

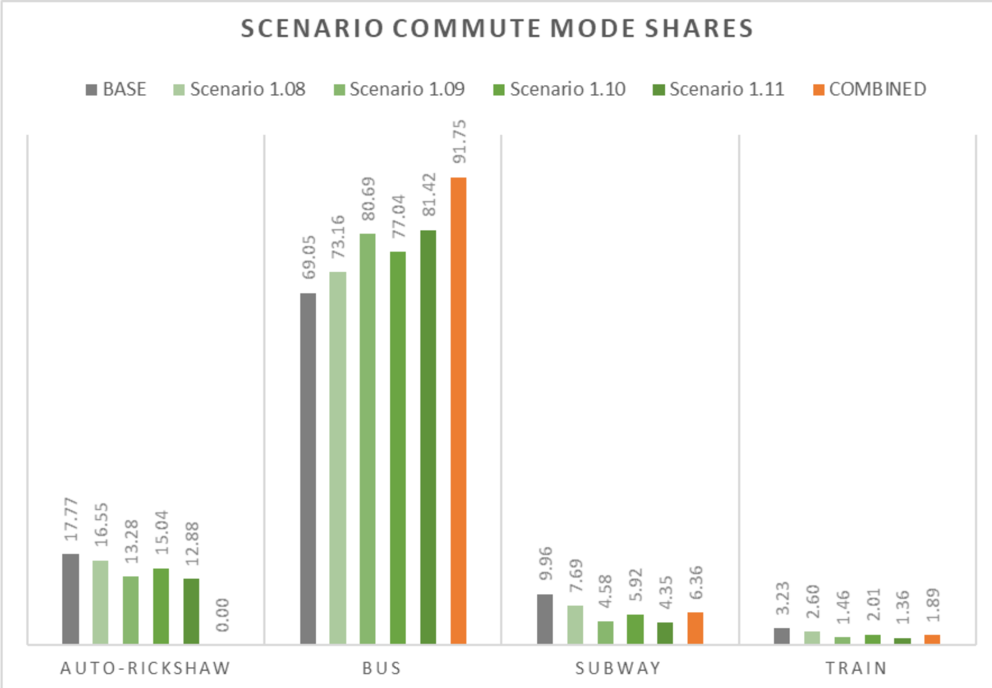
Level 2B.1: Scenario 1 – sub scenarios

Here the prediction results are further subdivided into two categories to find out the impact of improving various capacity and speed constraints on mass transit commuter mode share.

a) Scenario 1.01 – 1.07 - Scenarios with **capacity** improvement measures (AppendixVIII)
b) Scenario 1.08 – 1.11 - Scenarios when **speed** improvement measures (AppendixIX)



(a)



(b)

Figure 5-18 Change in commuter mode share predicted for scenario level 2.1 (a) above and (b) below

The change in mode choice probabilities follows similar pattern as in other corridor with the combination of speed and capacity improvement techniques resulting in highest change (22.70%). It should also be kept in mind that the mode choice probabilities for bus is significantly higher in this corridor compared to the other mostly due to poor accessibility of other mass transit modes.

Level 2B.2: Scenario 2 – sub scenarios

Here the prediction results are further subdivided into four categories to find out the impact of lane management on mass transit commuter mode share.

a) Scenario 2.01 – 2.04 - Scenarios with dedicated bus lane from existing road width (AppendixX)
b) Scenario 2.05 – 2.08 - Scenarios when dedicated bus lane(s) from parking removal (AppendixX)
c) Scenario 2.09 – 2.12 - Scenarios when contraflow lane for cars but no car in peak direction allowed (AppendixX)
d) Scenario 2.13 – 2.16 - Scenarios when contraflow lane for cars but no car in peak direction allowed and removal of auto-rickshaw (AppendixX)

Figure 5-19 Change in commuter mode share predicted for scenario level 2.2 (a) above left, (b) above right, (c) below left and (d) below right

As in the other corridor there are couple of inferences that can be drew upon – (i) speed and bus priority techniques shows a direct impact on increasing mode choice probabilities for bus (6-6.5%) and (ii) extended peak hour also impacts on increasing bus choice probabilities.

Level 2B.3: Scenario 3 – sub scenarios

Here the prediction results are further subdivided into two categories to find out the impact of introduction of a new service like Bus rapid transit system (BRTS) on mass transit commuter mode share.

a) Scenario 3.01 - Scenarios with additional BRTS service, no improvement of existing bus service (AppendixXI)
b) Scenario 3.02 - Scenarios with additional BRTS service and speed improvement measures for existing Bus service (AppendixXI)

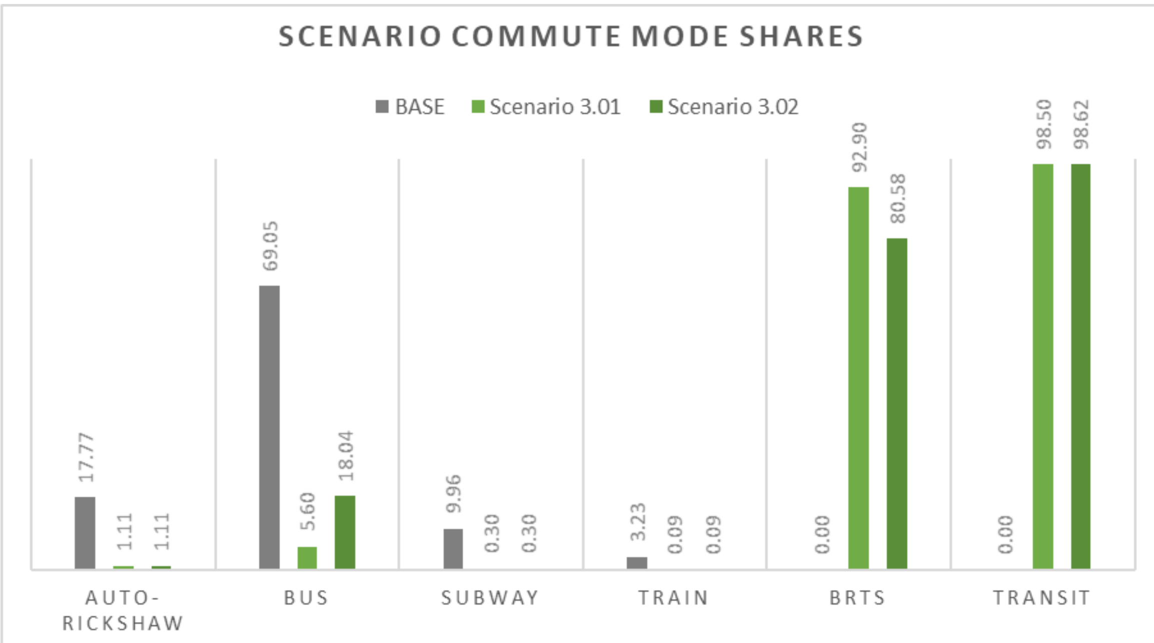


Figure 5-20 Change in commuter mode share predicted for scenario level 2.3 (a) and (b)

It can be seen from the figure above, obtained by application of incremental mode choice model that BRTS is the strategy which causes highest increase in the transit modal share which is approximately 28-30% from the base case scenario. At the same time, we should also notice that 'Transit' (BRTS + Bus) share is apparently too high in scenarios but it's better to keep in mind that the model does not consider 'Car' mode which holds a significant portion of mode share in reality which resulted in such high share for bus. Apart from that poor accessibility of other modes also add up to cause significant higher share of bus from the beginning itself.

Chapter 6 - Discussion & conclusion

6.1 Summary

This research work, as mentioned in Section 1.2, focuses on the evaluation of transit development strategies based on the modal shift that particular strategy incurs. At the same time the survey was done on two corridors having different traffic and network characteristics which make it more interesting to observe how these strategies work for both. As corridor B suffers from the accessibility issues for two out of four modes i.e. train and subway, the *bus* modal share is generally high as commuters are forced to depend on that. That's why the results have been summarized in terms of modal shift, in other words, change in the modal share of *bus* mode. It can be found out that both the corridors' modal share changes are similar as in every case both the corridors fall in the same group (low/ medium/ high). It should also be noted that the groups have been made on 10% modal share increase based on the fact that the results are of corridor level, not city level so in general the modal shift may seem slightly exaggerated. Moreover, the corridor which has a better modal share increase under each of these strategies has been marked in green colour. This result can be used a policy tool to invest in a particular strategy as all come similarly effective for both corridor types.

Table 6-1 Summary of improvement strategies (in terms of modal shift)

Id	Scenario	Sub-scenario	Modal shift (to bus mode)		
			Low (<10%)	Medium (10%-20%)	High (>20%-30%)
1.01 – 1.07	Network improvement	Capacity improvement			A+**B**
1.08 – 1.13		Speed improvement		**A**+B	
2.01 – 2.04	Lane management	Dedicated bus lane from existing road width		**A**+B	
2.05 – 2.08		Dedicated bus lanes(2) from existing road width & parking removal		**A**+B	
2.09 – 2.12		Introduction of contraflow lane for cars		**A**+B	
2.13 – 2.16		Introduction of contraflow lane for cars & auto-rickshaw removal from arterial street			**A**+B
3.01	Introduction of new transit system	Introduction of BRTS			A+**B**
3.02		Introduction of BRTS & improvement of existing bus service			**A**+B

Where A = Corridor A and B = Corridor B

6.2 Conclusions

This thesis focuses on the rationality of huge investment on so called high yielding 'transit improvement strategies' whereas we often overlook fundamental ones. That is why, in this thesis it has been tried to evaluate all these strategies to find out the optimised way of future planning in transportation sector. In this project only bus mode has been considered for analysing the modal shift to it because it is the predominant mode in Indian condition. This fact is once more underlined in the base case scenario (observed in survey records) where bus modal share is 61% approximately.

The study helps to identify the causal factors e.g. 'travel time', 'age', 'gender' etc. which play important role in modal shift to bus through a MNL. Moreover, as a tool for evaluation, the model's prediction of modal shift to bus mode, occurred due to each strategy has been calculated in an incremental manner (30 scenarios in total) to clearly understand even minor changes. The change in mode share (probability to shift) has been found by calculating the travel time difference (under traffic flow condition C for Indian subcontinent) of all four modes as basis.

The broad scenario analysis gives an indication to travellers' sensitivity or response to system changes. Considering the modal shift shown in Figure 5-13 upon implementing scenario 1, 2 and 3, some major inferences can be drawn upon:

1. For scenario 1, it can be observed that there is a modal shift to bus by 16.75% when auto-rickshaw is allowed on arterial street and an equivalent modal shift by 17.61% for scenario 2. Similarly, comparable modal shifts are seen for Scenario 1 and 2 (25.15% and 23.35% modal shift respectively) when auto-rickshaw is not allowed on arterial street. Network improvement measures (scenario 1) require less time and cost compared to scenario 2 and 3, whereas scenario 2 is more time complicated in implementation when compared to 1. Hence, it can be inferred that scenario 1 could be a better strategy than 2.
2. For BRTS strategy (scenario 3), it can be observed that there is a modal shift to bus by 28.19% when auto-rickshaw is allowed on arterial street and a modal shift by 16.75% for scenario 1. Similarly, the modal share is found to be 33.25% and 25.15% respectively for Scenario 3 and 1 when auto-rickshaw is not allowed on arterial street. Scenario 3 proves to be the most effective strategy of the lot but the modal shift incurred by it does not differ largely from the modal shift caused by network improvement measures (scenario 1) Thus, evaluation of the trade-off between time, cost and ease of implementation is of great importance to the policy makers while selecting such strategies.

3. Auto-rickshaw removal from arterial streets can prove to be more advantageous strategy in case of scenario 1 compared to scenario 2 and scenario 3 which anyway frees up exclusive lane (space) for bus. The modal share differences are 8.4%, 5.74% and 5.06% between situations when auto-rickshaw is available or not respectively for scenario 1, 2 and 3.

At the same time, it can also be pointed out that small dataset size does not always necessarily plagues the model and even though this model is based on small number of records it performs average to well in re-estimation and somewhat in validation too. A certain level of confidence on the model can be built upon based on iterative (10 times in this case) re-estimation exercise as well as validation attempts can also be done on various aspects to evaluate model performance.

6.3 Recommendations

6.3.1 Policy suggestions for corridor A (Tollygunje to Kalighat Metro Station)

As the traffic characteristics has been already analysed in section 5.2.1 and modal shift shown in section 5.5.2 acts as an indicator for policy making with respect to corridor A. The policies that could be formulated are as follows:

1. Use of site specific bus preferential treatments like queue jumps and curb extension can be very much effective when applied to major junctions in the corridor e.g. Tollygunje, Anwar Shah connector, Rashbehari.etc.
2. Use of auto-rickshaw as a feeder network rather than a competitor for bus on arterial street seems to be a better effective strategy than parking removal from streets.
3. Proper scheduling of bus routes through discontinuation of overlapping routes and parallel introduction of skip-stop service causes significant rise in bus attractiveness. Total 11 no. of stops can be planned as per travel demand analysis, in these study 6 major stops were selected.
4. Bus priority signalling should be introduced in all stops for better transit service rather than using it only for major intersections.
5. Instead of full-fledged BRTS, express Bus (lane reservation) along with improved bus service seems to be an ideal combination.

6.3.2 Policy suggestions for corridor B (Garia to Gariahat market)

All of the policies mentioned for corridor A also applies for corridor B except the last one as it doesn’t have enough road width to accommodate such express service. Moreover, the modal shift benefits for network improvement strategy (scenario1) and lane management strategy (scenario 2) being almost equal and combination of speed and capacity improvement being significant (shown in Figure 5-17 and Figure 5-18) advocates for implementation of scenario 1.

6.4 Suggestions for future research

It can be interesting to carry on with this research as there are certain areas which can be improved upon. Instead of considering just two corridors we can consider a better comprehensive survey of whole city considering all the available modes which could have better representation of city's travel behaviour.

Again, we could also consider stated preference or more detailed survey to understand people's tendency to shift for transit improvement in a different manner. Other than that, it's expected to resolve the limitations documented in section 1.2.2.

Chapter 7 - List of references

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Appendix I: Explanatory variables used in similar studies

		Comparison of parameters across logit-based mode choice models in urban context													
		Author	Vedagiri & Arasan (2009)	Vedagiri & Arasan (2009)	Fatima & Kumar (2014)	Ramli et al. (2010)	Javanmardi et al. (2015)	Chalermpong (2010)	Enam & Choudhury	Paleti et al. (2014)	Dissanayake and Morikiwa (2010)	Abdel-Aty (2001)	Sohoni et al. (2016)	Anwar & Yang (2016)	Chakrabarti (2017)
		Purpose	Modal Shift analysis	Modal Shift analysis	BRTS Feasinbility analysis	Improved Travel Demand	Choice of mode **(MNL model)**	Mode choice within MT catchments	Mode choice model for Dhaka City		Choice of mode **(NL model)**	MNL model for Florida	Modal shift on introduction of new		
		Likelihood Ratio (ρ^2	0.334	0.43	0.358	0.467	0.623	0.2631	0.27		0.39		0.51	0.554(nagelkarke value)	
	Id	**Sample Size**	600	400	1250	174	40497	322	6000		1205		246	4410	1381
Group -1 Constants	1	**Constant**	-0.66	-1.87	-2.807	2.028		hired transit (taxi) base					8.89	-9.206	0.439
	2	**Constant - train**					2.93(Transit)								
	3	**Constant - subway**						1.5762							
	4	**Constant - bus**					2.19		0						
	5	**Constant - autorickshaw**							-1.15						
		Constant - walk					2.77								
		Constant - bike					0								
		Constant - drive					2.19	2.4415	0.344						
Group -2 alternative specific variables	1	**Travel Time**	7.09	8.39	-2.0073	-0.143	-1.04(hours)	-0.0618(MT) & -0.062 (drive)	1.4 (for long tt) and 2.03 (for short tt)	-0.165(min)	-0.55(hours)	-0.048(IVTT)	-0.0758	-7.559(min)	-0.732
	2	**Waiting Time**										-0.031	-0.0426		
	3	**Travel Cost**			-0.0215		-0.13	-0.0295(MT) & -.0265 (drive)			-2.15	-1.446(low fare) & -1.823(high fare)	-0.0487		
	4	**Service headway**								-0.324					-0.965
	5	**Toll-parking-fare**								-0.81					
	6	**Schedule deviation**													-2.59
	7	**Discomfort**											-1.741		
Group -3 individual specific variables	1	**Gender**	0.62	1.3	0.065		0.33		0.912(female)		1.63			0.381	
	2	**Age**	0.67 (41-60 yrs)						0.555(18-25 yrs)					-0.083	
		Seniority (65 yrs+)					-1(walk)								
		License												1.729(drive)	0.122(drive)
	3	**Income Group (High)**			0.177				0.43						
	4	**Income Group (Medium)**			0.185				2.28						
	5	**Income Group (Low)**			1.548	0.3*10^7	-0.77(income^5)								
		Occupation												1.436(staff/student)	
	11	**House condition**				-0.363									
	12	**Household Size**				-0.028									
		working Household Size													4.45
	13	**Car ownership**				-0.027	1.4 (drive) & 0.66 (bus)								
Group -4 trip specific variables	1	**number of transfers**					-0.17 (transit)					-0.478			
	2	**Peak hour or Overcrowding**								-0.09					
	3	**Probability of delay**								-0.069					
	4	**early/late arrival**								-0.007					
	5	**density of bus stops**													0.1
	6	**Trip Length (access+in-veh)**			-10.772						1.61(dist>30Km)			-4.391(Km)	
	7	**Trip Purpose (Work)**	0.71		1.078		-1.8(bus) & 0.45(transit)		1.09						
	8	**Trip Purpose (Others)**		1.36	-0.1		0.2(bus) & 0.82 (drive)								
	9	**Walk Time**	-0.58(>10 mins)	-0.88			-0.39 (access) & -0.23 (egress)	-0.0017 (access for MT)				-0.143 (walk) & -0.063(drive)			
	10	**Trip Frequency**				-1.063								-1.129(trip per week)	

Appendix II: R Results development

Attempt Id	Variables	Coeff.	R^2	t - value	% insig.	Remarks
1	tot_time_hr	-6.58	0.33	-9.28	0	single coefficient for time for all 4 modes
2	tot_time_hr		0.45		28	positive coeff. For train
3	tot_time_hr+age		0.33		72	**negative coeff.for age** For all 3 modes but none significant
4	tot_time_hr+age+gender		0.36		80	**negative coeff.for age** For all 3 modes but none significant + negative coeff.for subway and positive for bus & train but none significant
4A	tot_time_hr+I(bus*age)+I(bus*gender)+I(subway*age)+I(subway*gender)		0.34		80	bus:gender becomes too insignificant (strange !!!)
4B	tot_time_hr+I(bus*age)+I(bus*gender)+I(subway*age)+I(subway*gender)+I(bus*peak_hr)+I(subway*peak_hr)		0.35			bus:gender becomes slighlty more significant and peak hour for both bus & subway is near significance threshold
4C	**tot_time_hr+I(bus*age)+I(bus*gender)+I(subway*age)+I(subway*gender)+I(bus*peak_hr)+I(subway*peak_hr)+I(subway*trip_pur)**		**0.355**			**subway:trip_pur has a negative coefficient**
5	tot_time_hr+whh_size		0.33		42	**negative coeff.for subway & bus (more negative for subway)** and positive for train but none significant

Appendix III: Dataset arranged in wide format (sample)

	mode	age	age_1	age_2	age_3	age_4	gender	veh_availability	peak_hr	trip_pur	trip_HBW	trip_HBE	trip_HBO	alt	TT_hr	freq_hr	chid
1.ar	FALSE	3	0	1	0	0	1	0	1	4	1	0	0	ar	0.425	10	1
1.bus	TRUE	3	0	1	0	0	1	0	1	4	1	0	0	bus	0.34	7.5	1
1.subway	FALSE	3	0	1	0	0	1	0	1	4	1	0	0	subway	0.2444444	10	1
1.train	FALSE	3	0	1	0	0	1	0	1	4	1	0	0	train	0.38	3	1
2.ar	TRUE	4	0	0	1	0	1	0	1	2	1	0	0	ar	0.2787879	10	2
2.bus	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	bus	0.76875	7.5	2
2.subway	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	subway	0.2694444	10	2
2.train	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	train	0.4825	3	2
3.ar	TRUE	4	0	0	1	0	1	0	1	2	1	0	0	ar	0.3060606	10	3
3.bus	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	bus	0.80625	7.5	3
3.subway	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	subway	0.2861111	10	3
3.train	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	train	0.4975	3	3
4.ar	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	ar	1.03125	10	4
4.bus	TRUE	3	0	1	0	0	1	0	1	2	1	0	0	bus	0.7515152	7.5	4
4.subway	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	subway	0.5416667	10	4
4.train	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	train	0.7275	3	4
5.ar	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	ar	0.69375	10	5
5.bus	TRUE	3	0	1	0	0	1	0	1	2	1	0	0	bus	0.5666667	7.5	5
5.subway	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	subway	0.3638889	10	5
5.train	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	train	0.4875	3	5
6.ar	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	ar	0.2625	10	6
6.bus	TRUE	3	0	1	0	0	1	0	1	2	1	0	0	bus	0.17	7.5	6
6.subway	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	subway	0.1722222	10	6
6.train	FALSE	3	0	1	0	0	1	0	1	2	1	0	0	train	0.315	3	6
7.ar	TRUE	4	0	0	1	0	1	0	1	4	1	0	0	ar	0.719697	10	7
7.bus	FALSE	4	0	0	1	0	1	0	1	4	1	0	0	bus	1.03125	7.5	7
7.subway	FALSE	4	0	0	1	0	1	0	1	4	1	0	0	subway	0.3861111	10	7
7.train	FALSE	4	0	0	1	0	1	0	1	4	1	0	0	train	0.5875	3	7
8.ar	TRUE	4	0	0	1	0	0	1	1	2	1	0	0	ar	0.7090909	10	8
8.bus	FALSE	4	0	0	1	0	0	1	1	2	1	0	0	bus	1.13125	7.5	8
8.subway	FALSE	4	0	0	1	0	0	1	1	2	1	0	0	subway	0.4305556	10	8
8.train	FALSE	4	0	0	1	0	0	1	1	2	1	0	0	train	0.6275	3	8
9.ar	FALSE	3	0	1	0	0	0	1	1	2	1	0	0	ar	0.75625	10	9
9.bus	TRUE	3	0	1	0	0	0	1	1	2	1	0	0	bus	0.5627273	7.5	9
9.subway	FALSE	3	0	1	0	0	0	1	1	2	1	0	0	subway	0.4194444	10	9
9.train	FALSE	3	0	1	0	0	0	1	1	2	1	0	0	train	0.6175	3	9
10.ar	TRUE	4	0	0	1	0	1	0	1	2	1	0	0	ar	0.4166667	10	10
10.bus	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	bus	0.84375	7.5	10
10.subway	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	subway	0.3027778	10	10
10.train	FALSE	4	0	0	1	0	1	0	1	2	1	0	0	train	0.5125	3	10

Appendix IV: Bus transit capacity calculation (Tollygunge – Kalighat Metro Corridor)

Id	Sub-Id	Variable Name	Abbrvn.	Units	Expression	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8	Stop 9	Stop 10	Stop 11
A. Bus stop demand data						Tollygunje	Tollygunje Metro	Bangur	Anwar Shah Xing	Tollygunje Circular Rd. Xing	Bhabani Cinema Hall	Charu Mkt.	Tollygunje Railway Station	Mudiali	Southern Avenue Xing	Kalighat Metro Xing
1		Mean Dwell time	t_d	seconds		46.94	16.33	27	27.88	12.76	8.82	14.23	16.38	27.38	43.11	48
2		Dwell time variability	C_v			0.45	1.18	0.91	0.77	1.73	2.08	1.18	1.20	0.89	1.00	0.59
3		Failure rate				100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
4		Passenger demand peak hour factor	PHF			0.65	0.75	0.75	0.6	0.75	0.75	0.75	0.5	0.6	0.6	0.6
B. Bus stop location data																
1		Positions relative to road way														
	1.1	On -line				off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line
	1.2	Off-line														
2		Positions relative to intersection														
	2.1	Near Side														
	2.2	Far Side				far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side
	2.3	Mid Block														
3		Bus stop design type														
	3.1	Linear				linear	linear	linear	linear	linear	linear	linear	linear	linear	linear	linear
	3.2	Non-Linear														
4		Number of Loading area				2	2	2	2	2	2	2	2	2	2	2
5		Bus facility type				Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2
6		Traffic signal timing	g/C			0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
7		Traffic volume														
	7.1	Curb lane traffic volume		PCU/hr		800	650	650	650	855	650	650	650	700	650	800
	7.2	Left turning traffic volume		PCU/hr		200	50	50	50	250	20	50	50	20	20	475
	7.3	Parallel Pedestrian crossing		ped/hr		200	100	100	100	200	100	200	250	250	100	200
C. Determination of loading area capacity																
1		Clearance time	t_c	seconds	$t_c = t_{su} + t_{re}$	13	13	13	13	13	13	13	13	13	13	13
2		Start-up Time	t_{su}	seconds		8	8	8	8	8	8	8	8	8	8	8
3		Re-entry time	t_{re}	seconds		5	5	5	5	5	5	5	5	5	5	5
4		Standard normal variable corresponding to a desired failure rate	Z		(see table below)	0	0	0	0	0	0	0	0	0	0	0
5		Loading area capacity	B_l	bus/hr	$B_l = \{3600\ (g/C)\} / \{t_c + t_d\ (g/C) + t_{om}\}$	39.8788863	60.3385664	51.1848341	50.552331	64.1787497	69.0272274	62.5398112	60.2880429	50.9097766	41.6457795	39.4160584

Design Failure Rate	Z
1.0%	2.330
2.5%	1.960
5.0%	1.645
7.5%	1.440
10.0%	1.280
15.0%	1.040
20.0%	0.840
25.0%	0.675

Source: *TCRP Report 26 (21).*

Id	Sub-Id	Variable Name	Abbrvn.	Units	Expression	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8	Stop 9	Stop 10	Stop 11
						Tollygunje	Tollygunje Metro	Bangur	Anwar Shah Xing	Tollygunje Circular Rd. Xing	Bhabani Cinema Hall	Charu Mkt.	Tollygunje Railway Station	Mudiali	Southern Avenue Xing	Kalighat Metro Xing
D. Determination of bus stop capacity																
1		Number of effective loading area	N_{el}			1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
2		Traffic blockage adjustment factor	f_{tb}		$(f_{tb}) = 1- f_l*(v_{cl} / c_{cl})$	0.76089068	0.77054567	0.77054567	0.77054567	0.63644163	0.77839321	0.77027431	0.77013839	0.82934113	0.84131634	0.6687242
	2.1	Stop location factor	f_l			0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	2.2	Capacity of curb lane through movement	c_{th}	PCU/hr	$(c_{th}) = (sf) * (g/C)$	2100	1500	1500	1500	1500	1500	1500	1500	2100	2100	2400
	2.3	Saturation flow rate	s_f	PCU/hr		7000	5000	5000	5000	5000	5000	5000	5000	7000	7000	8000
	2.4	Capacity of curb left turn movement	c_{lt}	PCU/hr	$(c_{lt}) = 1450*(g/C)*(1-(pedestrian volume/2000))$	391.5	413.25	413.25	413.25	391.5	413.25	391.5	380.625	380.625	413.25	391.5
	2.5	Curb lane capacity	c_{cl}	PCU/hr	(c_{cl}) = Volume weighted (c_{th}) + Volume weighted (c_{lt})	1672.875	1416.40385	1416.40385	1416.40385	1175.87719	1466.56154	1414.73077	1413.89423	2050.875	2048.1	1207.45313
3		Bus Stop capacity	B_s	Bus/hr	$B_s = N_{el} * B_l * f_{tb}$	56.1354251	86.0131986	72.9644665	72.0628273	75.5651515	99.401101	89.1196986	85.8957524	78.109908	64.8189585	48.7631734

	On-Line Loading Areas: Random Arrivals		On-Line Loading Areas: Platooned Arrivals		Off-Line Loading Areas: All Arrivals	
Loading Area #	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas	Efficiency %	Cumulative # of Effective Loading Areas
1	100	1.00	100	1.00	100	1.00
2	75	1.75	85	1.85	85	1.85
3	70	2.45	80	2.65	75	2.60
4	20	2.65	25	2.90	65	3.25
5	10	2.75	10	3.00	50	3.75

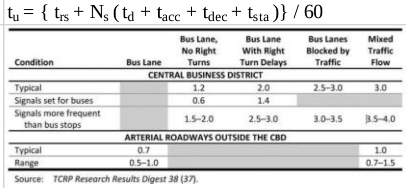
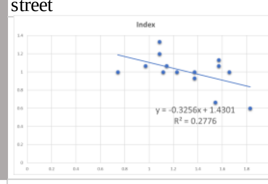
Bus Stop Location	Lane Type: Type 1	Type 2	Type 3
Near side	1.0	0.9	0.0
Mid-block before or after traffic signal	0.9	0.7	0.0
Far side	0.8	0.5	0.0

Source: *TCRP Report 26 (21).*
Note: f_l = 0.0 for contraflow bus lanes, median busways, and grade-separated busways regardless of bus stop location or lane type, as right turns are either prohibited or do not interfere with bus operations.

TABLE IV. SATURATION FLOW RATE OBTAINED ADOPTING IRC (1994) PCU VALUES

Approach Name	Width W (m)	Saturation Flow Rate: PCU/hr/approach width	Saturation Flow Rate: PCU/hr/meter
University	9	8397	933W
Darpan	10.2	11781	1155W
Gurukul	8	9320	1165W
Commerce College	7.1	9109	1283W

Appendix V: Bus transit speed calculation (Tollygunge – Kalighat Metro Corridor)

Id	Id	Variable Name	Abbrvn.	Units	Expression		Full Stretch
A. Bus stop demand data							
1		average stop spacing	N_s	Stops/Km			3.6
2		average dwell time	t_d	seconds			26.25727273
3		scheduled number of buses at critical stop		Bus/hr			94
4		traffic signal timing and phasing		Signals/Km			3
5		traffic interference					
A1. Determination of section maximum capacity							
							48.76317341
B. Determination of base bus running time rate							
1		Time spent at running speed	t_{rs}	seconds	$(t_{rs}) = L_{rs} / (c_f * v_{run})$		37.74844604
	1.1	Bus running speed on facility	v_{run}	Km/hr			50
	1.2	Conversion factor	c_f				0.278
	1.3	Distance travelled at running speed per Km	L_{rs}	metres	$(L_{rs}) = L_{mk} – N_s L_{ad}$		524.7034
	1.4	Length of a mile or Km	L_{mk}				1000
2		Distance travelled at less than running speed	L_{ad}	metres	$(L_{ad}) = 0.5*a*(t_{acc})^2+0.5*d*(t_{dec})^2+ L_{sta}$		132.0268333
	2.1	Acceleration time	t_{acc}	seconds	$(t_{acc}) = (c_f * v_{run}) / a$		11.58333333
	2.2	Deceleration time	t_{dec}	seconds	$(t_{dec}) = (c_f * v_{run}) / d$		9.266666667
	2.3	time required to travel through station	t_{sta}	seconds	$(t_{sta}) = L_{sta} / (1/ c_f*v_{st} - 1/ c_f*v_{run})$		0
	2.4	Average Bus acceleration	a	m/s^2			1.2
	2.5	Average Bus deceleration	d	m/s^2			1.5
	2.6	Bus speed through station	v_{st}	Km/hr	0 if not busway operation		0
	2.7	Length of Station	L_{sta}	metres	0 if not busway operation		0
3		unimpeded bus running time rate	t_u	minutes/Km	$t_u = \{ t_{rs} + N_s (t_d + t_{acc} + t_{dec} + t_{sta})\} / 60$		3.455577131
4		additional running time losses	t_l	minutes/Km			0
5		base bus running time rate	t_r	minutes/Km	$t_r = t_u + t_l$		3.455577131
C. Adjust for skip-stop operation							
		Skip-stop factor	f_{sp}		1 if no skip stop		1
D. Adjust for bus congestion							
		bus v/c			Scheduled no. of Bus in per hour / Max capacity of street		1.927684222
		bus-bus interference factor	f_{bb}				0.60
E. Determination of average section speed							
		Section running time rate	t_s	minutes/Km	$(t_s) = t_r / f_{bb} * f_{sp}$		5.781289502
		Average Section speed	S_s	Km/hr	$(S_s) = 60/ t_s$		10.37830747

Condition	Bus Lane	Bus Lane, No Right Turns	Bus Lane With Right Turn Delays	Bus Lanes Blocked by Traffic	Mixed Traffic Flow
CENTRAL BUSINESS DISTRICT					
Typical		1.2	2.0	2.5–3.0	3.0
Signals set for buses		0.6	1.4		
Signals more frequent than bus stops		1.5–2.0	2.5–3.0	3.0–3.5	3.5–4.0
ARTERIAL ROADWAYS OUTSIDE THE CBD					
Typical	0.7				1.0
Range	0.5–1.0				0.7–1.5

Source: *TCRP Research Results Digest 38 (37).*

Appendix VI: Bus transit capacity and speed calculation (Garia – Gariahat market Corridor)

Id	Sub-Id	Variable Name	Abbrvn.	Units	Expression	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8	Stop 9	Stop 10	Stop 11	Stop 12	Stop 13	Stop 14	Stop 15
A. Bus stop demand data						**Garia**	**E.M.Bypass**	**Raipur**	**Ganguly Bagan**	**Baghajatin crossing**	**Chittaranjan Colony**	**Sukanto setu**	**8 B bus terminus**	**Jadavpur university**	**Jadavpur police station**	**Dhakuria**	**Madhu Sudan mancha**	**AMRI HOSPITAL**	**Golpark**	**Gariahat xing**
1		Mean Dwell time	t_d	seconds		41.1111111	23.125	21.1111111	20.3333333	21.3529412	18.8823529	10.1111111	32.3529412	17.5	17.1111111	38.3333333	7.66666667	8.27777778	9.33333333	34.7222222
2		Dwell time variability	C_v			1.0565148	1.2828019	1.40818738	1.67714377	1.38335083	1.67467723	1.5793239	1.24031188	1.56126584	1.72718728	1.32673541	1.83434984	1.86086458	1.7931986	1.06769524
3		Failure rate				100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
4		Passenger demand peak hour factor	PHF			0.65	0.75	0.75	0.6	0.75	0.75	0.75	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
B. Bus stop location data																				
1		Positions relative to road way																		
	1.1	On -line				off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line	off-line
	1.2	Off-line																		
2		Positions relative to intersection																		
	2.1	Near Side																		
	2.2	Far Side				far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side	far-side
	2.3	Mid Block																		
3		Bus stop design type																		
	3.1	Linear				linear	linear	linear	linear	linear	linear	linear	linear	linear	linear	linear	linear	linear	linear	linear
	3.2	Non-Linear																		
4		Number of Loading area				2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5		Bus facility type				Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2	Type 2
6		Traffic signal timing	g/C			0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
7		Traffic volume																		
	7.1	Curb lane traffic volume		PCU/hr		700	600	650	700	800	750	850	850	800	800	800	700	650	650	855
	7.2	Left turning traffic volume		PCU/hr		300	0	0	50	200	0	50	150	0	200	50	150	150	150	450
	7.3	Parallel Pedestrian crossing		ped/hr		200	100	100	100	200	100	200	250	300	100	100	100	200	250	300
C. Determination of loading area capacity																				
1		Clearance time	t_c	seconds	$t_c = t_{su} + t_{re}$	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
2		Start-up Time	t_{su}	seconds		10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
3		Re-entry time	t_{re}	seconds		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
4		Standard normal variable corresponding to a desired failure rate	Z			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5		Loading area capacity	B_l	bus/hr	$B_l = \{3600\ (g/C)\} / \{t_c + t_d\ (g/C) + t_{om}\}$	39.5121951	49.2307692	50.625	51.1848341	50.4534213	52.2630231	59.8890943	43.7142857	53.3333333	53.6423841	40.754717	62.4277457	61.7731173	60.6741573	42.4918033

Id	Sub-Id	Variable Name	Abbrvn.	Units	Expression	Stop 1	Stop 2	Stop 3	Stop 4	Stop 5	Stop 6	Stop 7	Stop 8	Stop 9	Stop 10	Stop 11	Stop 12	Stop 13	Stop 14	Stop 15
						Garia	**E.M.Bypass**	**Raipur**	**Ganguly Bagan**	**Baghajatin crossing**	**Chittaranjan Colony**	**Sukanto setu**	**8 B bus terminus**	**Jadavpur university**	**Jadavpur police station**	**Dhakuria**	**Madhu Sudan mancha**	**AMRI HOSPITAL**	**Golpark**	**Gariahat xing**
D. Determination of bus stop capacity																				
1		Number of effective loading area	N_{el}			1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
2		Traffic blockage adjustment factor	f_{tb}		$(f_{tb}) = 1- f_l*(v_{cl}/ c_{cl})$	0.70744522	0.8	0.78333333	0.75393268	0.67290197	0.75	0.70379025	0.6736952	0.80952381	0.76166536	0.72068563	0.72378416	0.73878636	0.80918508	0.59178289
	2.1	Stop location factor	f_l		far-side and type 2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	2.2	Capacity of curb lane through movement	c_{th}	veh/hr	$(c_{th}) = (sf) * (g/C)$	1800	1500	1500	1500	1500	1500	1500	1500	2100	2100	1500	1500	1500	2100	1800
	2.3	Saturation flow rate	s_f	veh/hr		6000	5000	5000	5000	5000	5000	5000	5000	7000	7000	5000	5000	5000	7000	6000
	2.4	Capacity of curb left turn movement	c_{lt}	veh/hr	$(c_{lt}) = 1450*(g/C)*(1-$ (pedestrian volume/2000))	391.5	413.25	413.25	413.25	391.5	413.25	391.5	380.625	369.75	413.25	413.25	413.25	391.5	380.625	369.75
	2.5	Curb lane capacity	c_{cl}	veh/hr	(c_{cl}) = Volume weighted (c_{th}) + Volume weighted (c_{lt})	1196.35714	1500	1500	1422.375	1222.875	1500	1434.79412	1302.46324	2100	1678.3125	1432.07813	1267.125	1244.19231	1703.22115	1047.23684
3		Bus Stop capacity	B_s	Bus/hr	$B_s = N_{el} * B_l * f_{tb}$	51.7125202	72.8615385	73.3640625	71.3913507	62.8078824	72.5149445	77.9763177	54.4826936	79.8730159	75.5864601	54.3369769	83.5907946	84.4287026	90.8287528	46.5199558

Appendix VII: Bus transit capacity and speed calculation (Garia – Gariahat market Corridor)

Id	Id	Variable Name	Abbrvn.	Units	Expression	Corridor Existing
A. Bus stop demand data						
1		average stop spacing	N_s	Stops/Km		2.08
2		average dwell time	t_d	seconds		21.4216231
3		scheduled number of buses at critical stop		Bus/hr		94
4		traffic signal timing and phasing		Signals/Km		3
5		traffic interference				
A1. Determination of section maximum						
						46.5199558
B. Determination of base bus running time						
1		Time spent at running speed	t_{rs}	seconds	$(t_{rs}) = L_{rs} / (c_f * v_{run})$	52.1859127
	1.1	Bus running speed on facility	v_{run}	Km/hr		50
	1.2	Conversion factor	c_f			0.278
	1.3	Distance travelled at running speed per Km	L_{rs}	metres	$(L_{rs}) = L_{mk} – N_s L_{ad}$	725.384187
	1.4	Length of a mile or Km	L_{mk}			1000
2		Distance travelled at less than running speed	L_{ad}	metres	$(L_{ad}) = 0.5*a*(t_{acc})^2+0.5*d*(t_{dec})^2+ L_{sta}$	132.026833
	2.1	Acceleration time	t_{acc}	seconds	$(t_{acc}) = (c_f * v_{run}) / a$	11.5833333
	2.2	Deceleration time	t_{dec}	seconds	$(t_{dec}) = (c_f * v_{run}) / d$	9.26666667
	2.3	time required to travel through station	t_{sta}	seconds	$(t_{sta}) = L_{sta} / (1/ c_f*v_{st} - 1/ c_f*v_{run})$	0
	2.4	Average Bus acceleration	a	m/s^2		1.2
	2.5	Average Bus deceleration	d	m/s^2		1.5
	2.6	Bus speed through station	v_{st}	Km/hr	0 if not busway operation	0
	2.7	Length of Station	L_{sta}	metres	0 if not busway operation	0
3		Unimpeded bus running time rate	t_u	minutes/Km	$t_u = \{ t_{rs} + N_s (t_d + t_{acc} + t_{dec} + t_{sta})\} / 60$	2.33518148
4		Additional running time losses	t_l	minutes/Km		0
5		Base bus running time rate	t_r	minutes/Km	$t_r = t_u + t_l$	2.33518148
C. Adjust for skip-stop operation						
		Skip-stop factor	f_{sp}		1 if no skip stop	1
D. Adjust for bus congestion						
		bus v/c			Scheduled no. of Bus in per hour / Max capacity of street	2.02063821
		bus-bus interference factor	f_{bb}			0.57
E. Determination of average section speed						
		Section running time rate	t_s	minutes/Km	$(t_s) = t_r / f_{bb} * f_{sp}$	4.06158329
		Average Section speed	S_s	Km/hr	$(S_s) = 60/ t_s$	14.7725642

Appendix VIII: Detailed sub-scenarios of Scenario 1 – Improvement in existing network (Capacity improvement)

Id	Time Impact	Cost Impact	Speed Constraints	Capacity Constraints	Change in variables	Methods	Stretch applicability
1.01				•Average Dwell time •Dwell time variability	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.6**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value)	**All**
1.02				•Dwell time improvisation **•Bus priority signalling**	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.6** •g/C Ratio **= 0.4**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value) •Increase g/C ratio	**All**
1.03				•Dwell time improvisation **•Introduction of near side stop** **•Bus priority signalling**	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.6** •g/C Ratio **= 0.4** •stop location factor **= 0.90 (type 2 lane)**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value) •Change type of bus stop factor •Increase g/C ratio	**All**
1.04				•Dwell time improvisation •Bus priority signalling **•Use queue jumps and curb extension**	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.7** •g/C Ratio = **0.45** •bus priority design **= NO re entry delay**	•Reduction in Re-entry time (reduction in dwell time)	**All**
1.05				•Dwell time improvisation **•Remove auto-rickshaw from arterial streets**	•Average Dwell time = **45 sec / 30 sec** •curb lane volume = **no auto-rickshaw**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value) •Decrease the Traffic volume	**Selected**
1.06				•Dwell time improvisation **•Remove on-street Parking**	•Average Dwell time = **45 sec / 30 sec** •saturation flow = **increased**	•Reduce dwell time based on TCRP calculation •Reduce variability based on TCRP calculation (average value) •Increase saturation volume of the street	**Selected**
1.07				•Dwell time improvisation •Bus priority signalling •Remove auto-rickshaw from arterial streets •Use queue jumps and curb extension •Remove on-street Parking	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.6** •g/C Ratio **= 0.45** •bus priority design **= NO re entry delay** **•saturation flow = increased** **•curb lane volume = no auto-rickshaw**		**Selected**

Appendix IX: Detailed sub-scenarios of Scenario 1 – Improvement in existing network (Speed improvement)

Id	Time Impact	Cost Impact	Speed Constraints	Capacity Constraints	Change in variables	Methods	Stretch applicability
1.08			•Average stop spacing		•Average stop spacing = **Increased**	•Merge less popular stops	**All**
1.09			•Average stop spacing **•Introduce skip-stop operation**		•Average stop spacing = **Increased** •Skip stop factor **=0.87**	•Merge less popular stops •Add skip stop operation calculation from TCRP report	**All**
1.10			•Average stop spacing **•Schedule of Buses at critical stop**		•Average stop spacing = **Increased** •No. of bus/hr at critical stop **= 75**	•Merge less popular stops •Reduce no. of buses with overlapping route	**All**
1.11			•Average stop spacing **•Schedule of Buses at critical stop** **•Introduce skip-stop operation**		•Average stop spacing = **Increased** •No. of bus/hr at critical stop **= 75** •Skip stop factor **=0.87**		**All**
1.12			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Dwell time improvisation •Introduction of near side stop •Bus priority signalling •Remove auto-rickshaw from arterial streets •Use queue jumps and curb extension •Remove on-street Parking	•Average Dwell time = **45 sec / 30 sec** •Dwell time variability = **0.7** •g/C Ratio **= 0.45** •bus priority design **= NO re entry delay** **•Average stop spacing = Increased** **•No. of bus/hr at critical stop = 75** **•Skip stop factor =0.87** **•saturation flow = increased** **•curb lane volume = no auto-rickshaw**		**Selected**

Appendix X: Detailed sub-scenarios of Scenario 2 – Lane management (part 1/2)

Id	Time Impact	Cost Impact	Speed Constraints	Capacity Constraints	Change in variables	Methods	Stretch applicability
2.01				•Dedicated bus lane from existing road width in **existing peak hours**	•saturation flow = **decreased** •curb lane volume = **bus only lane**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.02				•Dedicated bus lane from existing road width in **extended peak hours span**	•saturation flow = **decreased** •curb lane volume = **bus only lane** •new peak hour slots = **8-11, 12-14, 15-17, 18-21**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**
2.03			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Dedicated bus lane from existing road width in **existing peak hours span** •Bus priority signalling	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow = **decreased** •curb lane volume = **bus only lane** **•g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.04			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Dedicated bus lane from existing road width in **extended peak hours span** •Bus priority signalling	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow = **decreased** •curb lane volume = **bus only lane** •new peak hour slots = **8-11, 12-14, 15-17, 18-22 and •g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**
2.05				•Dedicated bus lane from **parking removal** in **existing peak hours (2 lanes for Bus)**	•saturation flow = **increased** •curb lane volume = **bus only lane**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.06				•Dedicated bus lane from **parking removal** in **extended peak hours span(2 lanes for Bus)**	•saturation flow = **increased** •curb lane volume = **bus only lane** •new peak hour slots = **8-11, 12-14, 15-17, 18-21**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**
2.07			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Dedicated bus lane from **parking removal** in **existing peak hours span(2 lanes for Bus)** **•Bus priority signalling**	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow = **increased and •g/C Ratio = 0.4** •curb lane volume = **bus only lane**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.08			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Dedicated bus lane from **parking removal** in **extended peak hours span(2 lanes for Bus)** **•Bus priority signalling**	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow = **increased** •curb lane volume = **bus only lane** •new peak hour slots = **8-11, 12-14, 15-17, 18-22 and •g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**

Appendix X: Detailed sub-scenarios of Scenario 2 – Lane management (part 2/2)

Id	Time Impact	Cost Impact	Speed Constraints	Capacity Constraints	Change in variables	Methods	Stretch applicability
2.09				•Introducing contraflow **car lane** in **existing peak hours (NO car allowed on peak direction)**	•saturation flow **= same** •curb lane volume **= decreased by 50%**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.1				•Introducing contraflow **car lane** in **extended peak hours span (NO car allowed on peak direction)**	•saturation flow **= same** •curb lane volume **= decreased by 50%** •new peak hour slots **= 8-11, 12-14, 15-17, 18-21**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**
2.11			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Introducing contraflow **car lane** in **existing peak hours span (NO car allowed on peak direction)** •Bus priority signalling	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow **= same** •curb lane volume **= decreased by 50%** **•g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.12			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Introducing contraflow **car lane** in **extended peak hours span (NO car allowed on peak direction)** •Bus priority signalling	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow **= same** •curb lane volume **= decreased by 50%** •new peak hour slots **= 8-11, 12-14, 15-17, 18-22 and •g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**
2.13				•Introducing contraflow **car lane** in **existing peak hours (NO car allowed on peak direction)** **•Removal of Auto-Rickshaw**	•saturation flow **= same** •curb lane volume **= decreased by 60%**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.14				•Introducing contraflow **car lane** in **extended peak hours span (NO car allowed on peak direction)** **•Removal of Auto-Rickshaw**	•saturation flow **= same** •curb lane volume **= decreased by 60%** •new peak hour slots **= 8-11, 12-14, 15-17, 18-21**	•car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**
2.15			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Introducing contraflow **car lane** in **existing peak hours (NO car allowed on peak direction)** **•Removal of Auto-Rickshaw from arterial street** **•Bus priority signalling**	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed •Skip stop factor =0.87 •saturation flow **= same** •curb lane volume **= decreased by 60%** **•g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width	**Selected**
2.16			•Average stop spacing •Schedule of Buses at critical stop •Introduce skip-stop operation	•Introducing contraflow **car lane** in **extended peak hours span (NO car allowed on peak direction)** **•Removal of Auto-Rickshaw from arterial street** **•Bus priority signalling**	•Average stop spacing = Increased •No. of bus/hr at critical stop = Changed. •Skip stop factor =0.87 •saturation flow **= same** •curb lane volume **= decreased by 60%** •new peak hour slots **= 8-11, 12-14, 15-17, 18-22 and •g/C Ratio = 0.4**	•Merge less popular stops •Reduce no. of buses with overlapping route •car & auto rickshaw volume reduced •Change saturation flow based on available road width •Change peak hour variable	**Selected**

Appendix XI: Detailed sub-scenarios of Scenario 3 – Introduction of new transit service BRTS

Id	Time Impact	Cost Impact	Speed Constraints	Capacity Constraints	Change in variables	Methods	Stretch applicability
3.01				**•24 hrs** Grade separated bus lane from **parking removal (1 lane for Bus+1 lane for BRTS)** •Bus priority signalling	•Saturation flow **= increased for BRTS / decreased for Bus** •curb lane volume **= increased for Bus / decreased for BRTS** **•g/C Ratio = 0.4**	•Calculate changed vehicular speeds for BRTS buses based on traffic volume change •Calculate changed vehicular speeds for other Buses based on traffic volume change •Calculate changed vehicular speeds for auto-rickshaw mode •Calculate changed waiting time	**Selected**
3.02			**•Average stop spacing** **•Schedule of Buse`s at critical stop** **•Introduce skip-stop operation**	**•24 hrs** Grade separated bus lane from **parking removal (1 lane for Bus+1 lane for BRTS)** •Bus priority signalling	•saturation flow **= increased for BRTS / decreased for Bus** •curb lane volume **= increased for Bus / decreased for BRTS** **•Average stop spacing = Increased** **•No. of bus/hr at critical stop = 75** **•Skip stop factor =0.87** **•g/C Ratio = 0.4**	•Calculate changed vehicular speeds for BRTS buses based on traffic volume change •Calculate changed vehicular speeds for other Buses based on traffic volume change •Calculate changed vehicular speeds for auto-rickshaw mode •Calculate changed waiting time	**Selected**