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How sustainable is the growth of mass transit system in developing countries – an Indian perspective

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Abstract

In the modern urban world, transport researchers and policy makers are vehemently emphasizing the use of mass transit modes, primarily due to their distinct advantage in achieving congestion reduction, and for being environment friendly. In order to achieve high mass transit ridership, it is necessary to attract people to such modes so as to make them appealing and attractive when compared to personal motorized modes of transport. At the same time, it is also vital to assess different mass transit improvement alternatives and adopt a policy that leads to the sustainable development. India is currently witnessing a proliferation of new urban mass rapid transit systems, even in non-metropolitan areas. These are expensive to build and often do not realize their full potential even after decades of operations. This begs the question – can operational service quality improvement alternatives of existing public transit, provide users with benefits, comparable to a new mass rapid transit system? This paper evaluates the probability of modal shift to bus mode from non-mass transit modes on introduction of different service improvement measures applicable to Indian context. A multinomial logit mode choice model was developed based on a revealed preference dataset consisting of users' travel behavior in existing traffic scenario where three mass transit modes – suburban rail, subway/ metro rail & bus, as well as the intermediate public transit mode auto-rickshaw are available. The model is used to predict impacts of three major policies - (1) existing network improvement, (2) lane management and (3) introduction of bus rapid transit system in terms of level of service improvements of bus transit and bus transit mode share. Results show that improvement in existing bus transit is more beneficial compared to lane management strategy and even comparable to bus rapid transit system considering the cost and time budget which may be used as a policy making tool by authorities for future city planning.

Keywords: sustainability, policy, bus rapid transit, logit, modal shift, level of service

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1. Introduction

In today's world, the 'sustainability' factor has undoubtedly turned into a key attribute in every infrastructural development policy which plays an important role in optimizing the output for greater benefit of society. Evidently most of the development proposals, irrespective of any specific domain, use the term 'sustainability' at will. Unfortunately, quite a few of those mix it up with a wrong notion that 'sustainability' corresponds only to state-of-the-art infrastructure whereas policy level changes to optimize the use of existing infrastructure amenities can be hugely beneficial. Therefore, when about 50% of world's population are concentrated in cities which is further projected to rise to nearly 70% by 2050 (Bräuninger et al., 2012), we need to balance resource allocation to various modes of transport.

The document 'Our Common Future' (Brundtland Commission, 1987), popularly known as the 'Brundtland report' was the first to define 'sustainability' as: economic development that meets todays' generation needs without compromising the opportunity and ability for future generation. The efforts to focus on the sustainability aspect of development culminated into the United Nations Millennium Declaration, signed in September 2000 where world leaders formed 8 goals that all 191-member states have agreed to achieve by 2015 known as millennium development goals (MDG). The goal of ensuring environment sustainability is of paramount importance in that list which is directly related to transportation sector which influences the urban development pattern and thus energy use (Murray, 2001). The deteriorating condition of transport with increasing levels of congestion, auto dependency and high levels of pollution, particularly in big metro areas disapprove the notion of sustainable economic performance, social welfare as well as environmental resilience.

1.1. Sustainability and transportation

If we try to closely analyse the relation between sustainability and transportation, it's better to begin by defining sustainable mobility. According to the definition by the Centre of Sustainable Transportation, Canada there are 3 major criteria for a mobility system to be sustainable (Bräuninger et al., 2012); firstly, it allows basic access needs to be met in a safe and consistent manner with human and ecosystem health, secondly, it is affordable, efficient, offers transport mode-choice and is supportive of economy growth, thirdly, it restricts emissions and waste, minimizes consumption of non-renewable resources, reuses and recycles its components and minimizes the use of land and noise production. It was found that mobility pattern dictates the transport system thus affecting population density which in turn controls per capita energy use and thereby affect overall sustainability of urban ecosystem (Bräuninger et al., 2012). Hence, in the transportation sector, public transit directly relates to 'sustainability' as it provides basic mobility to the majority of the population, more so in developing countries. In this research work we are focussing on the second and third aspect of 'sustainable mobility' i.e. how public transit development policies support 'sustainable' growth of the system.

There are different policies to promote the sustainable mobility across the world which can be predominantly grouped into 3 types – avoid, shift and improve (ASI) (Bräuninger et al., 2012). ASI corresponds to the policy interventions like shortening trip lengths and/or compact planning, promoting modal shift to public transit and improving sustainability of all modes respectively. It's worth mentioning here that ASI do not work in a similar way different countries as avoid strategies tend to be more successful in poorer countries whereas richer countries having widespread motorisation mainly relies on shift strategies (Bräuninger et al., 2012) .

In this paper authors are focusing on the impact of the improvement policies mentioned above as many of the transport planning agencies have been of late prioritising measures like priority development of public transport, incorporation of intelligent transportation system (ITS) instead of new transit alternative, different approaches like coordination of activities (e.g. peak hour scheduling), route management (e.g. removal of overlapping routes), management of traffic flows (e.g. use of paratransit as feeder network), structure variation of vehicle fleet, are proving to be effective solution to transportation problem (Makarova et al., 2017). Such policies could be rational in the context of a developing country like India.

1.2. Sustainable transportation in developing countries

Most developing countries specifically in Asia lack integrated land use-transportation planning and consequently suffers from the weakness of loose land use control which has aggravated several problems like unplanned urban sprawl and severe traffic congestion (Satiennam et al., 2006). In this context mass rapid transit (MRT) like bus rapid transit (BRT) and subway has been promoted as a one-size-fits-all solution which is in complete contrast with the reality. According to the data from Global BRT, 163 cities have implemented BRT, mostly after the year 2000 and this proliferation can be attributed to perceived low capital cost, flexibility and potential for integration with non-motorized transport (NMT)(Cao et al., 2015). Hence, it’s not surprising that countries like India are highly enthusiastic about BRT systems – with 6 operational and 13 currently being planned or under construction(Rizvi & Sclar, 2014). At the same time similar reaction has been shown to subway/metro projects specifically in smaller cities without a robust MT system e.g. Jaipur and Kochi in India which likely points to the political influence over these major infrastructural projects instead of assessing ‘sustainability’ quotient. Different news sources confirm that subway projects in all 4 megacities in India i.e. Delhi, Mumbai, Chennai and Kolkata are running in loss due to reasons like lack of foresight of ridership in newly introduced routes, financial fiasco and land acquirement issues. The amount of financial loss is huge as those news articles mentioned varies from 100 crores to as high as 300 crores per annum. Still we must accept that quite a few BRT projects, a major one being Delhi BRT, and most of the subway projects have turned into politically motivated projects, rather than being driven by transport analyses (Rizvi & Sclar, 2014).

The strategic components for successful implementation of any line haul service should incorporate fundamental interventions like provision of a good feeder network, partial/ full elimination of low ridership parallel/ adjacent routes, introduction of signal priority system and over all of these should have planned promotional strategies. Unfortunately, however most of these features are missing in most of these newly introduced MRT service, if not all. Therefore, the transit development proposals prophesying new transit system induction should be carefully tailored to cater the needs of the mass as recent research works show that there may not be substantial modal shift to MRT if policy is not responsive to tackle majority users’ sentiments (Cao et al., 2015). Hence, the planning for MRT should incorporate a three-dimensional planning strategy combining planning steps (what), strategy and tactics (how) and timing (when).

The success of any mass transit (MT) project depends on three crucial aspects – firstly, public participation in planning as well as operational stages, secondly, well designed feeder network and lastly, enough demand rate for sustaining high quality service of MT in future years. Although Indian transport domain seems to work differently as several new MRT projects mostly subway systems have been launched over last decade for cities like Varanasi or Kanpur which probably cannot justify sustainability of such project well. It’s worth mentioning that after a long wait, the Union Cabinet of Government of India seems to have taken the right step forward by approving a new metro rail policy in 2017 which emphasizes comprehensive mobility plan having multi-modal integration and alternative analysis along with a financial to assessment of the viability of any new subway project (Ministry of Housing and Urban Affairs, 2017). It provides the motivation to analyse various MT specifically public transit usage improvement policies.

In the real world, transit improvement measures largely depend on the context and intrinsic specifications of each targeted sample and individual motivations to use any particular mode(Redman et al., 2013). As we have already discussed in the previous sections about concepts of sustainability in the transportation domain, we can infer that sustainable urban transport may not require complete eradication of any mode but rather must influence the trade-offs among individual mobility, quality of life, environment and social aspect. Encouraging the modal switch to sustainable transport modes i.e. public transport should aim to optimize temporal, social, environmental and effective benefit-cost ratios. Hence, the goal of this paper is to assess the public transit improvement measures to have a deep understanding and eventually influence travel mode choice to public transports in an Indian perspective.

2. Methodology

One approach to enhance the level of service (LOS) for public transit (bus) mode to attract captive intermediate public transit (IPT) and private vehicle users back to MT and hold on to its current users. Different policy initiatives to have been evaluated based on its impact on LOS improvement and users’ sensitivity (modal shift) to it. This paper intends to estimate this probable shift from IPT modes and parallel MT modes i.e. rail to bus mode in consideration with Indian traffic condition using an appropriate modeling technique i.e. multinomial logit model. As a part of it the authors of this paper have studied the existing bus transit routes and services along two corridors in the city of Kolkata, India to determine its performance, measured in terms of travel speed of bus in the study corridors. Subsequently, through the analysis, the study recommends alternative policy scenarios that suggest increased efficiency in bus transit could be achieved at a much lower cost of implementation indicating equivalency to overall BRT efficiency.

As different literature suggests, there are predominantly two approaches to analyse users' sensitivity to any policy initiative – (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 and thereafter one or two key variables were changed to estimate peoples' response to bus level of service (LOS) improvement and travel time has been taken as an indicator to assess the change. The study analyses how people react to different policies and subsequent LOS improvement by shifting to bus from IPT as well as other parallel MT modes. A multinomial logit model (MNL) was mostly used along with incremental logit model (ILM) in some specific cases and both were calibrated and validated for this purpose.

Development of scenarios was done through transit speed which was in turn used as an input to calculate transit capacity in the study stretch. The factors those were used and altered as well to build up different scenarios were – mean dwell time, dwell time variability, average stop spacing, average dwell time, scheduled number of buses at critical stop, traffic signal phasing and bus facility type (TCRP Report) .

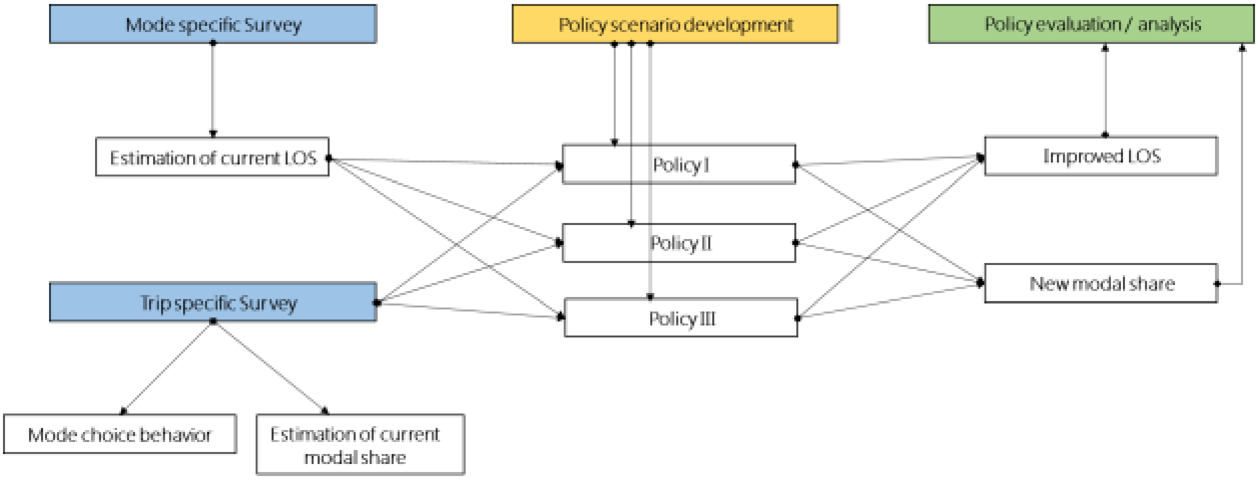


Fig. 1. Flow chart of methodology.

3. Survey design and analysis

3.1. Study area

There were two types of survey done for the research work documented in this paper. Firstly, trip specific survey (RP data) at different bus stations (intercept survey) and secondly, mode specific survey to find out operational characteristics of different modes. All those data were collected along two particular stretches Kolkata, India where there is reasonable accessibility to all four modes (suburban rail, subway, bus and auto-rickshaw). In this paper those are marked as Corridor A - Tollygunje to Rashbehari Crossing/ Kalighat Metro Station corridor (approx. 3Km stretch selected) (Deshapran Sashmal Road), a 6 lane road for whole study length whereas Corridor B - Garia to Gariahat market (approx. 6.5Km stretch selected) (Subodh Chandra Mallick Road) is a mix of 4 lanes and 6 lanes with variable width.

The area has highly mixed-use development with residential density high towards Tollygunje and Garia and recreation and commercial activities are concentrated in the other end of the segment. In between Garia and Gariahat market Jadavpur University, a major educational institution is located and both the corridors are well connected with other parts of the city.

Fig. 2. Study area (hatched) & network (existing & proposed) map of Kolkata Metropolitan area

3.2. Survey dataset

During the trip specific survey, the respondents were asked to base their response on the trips they were making or about to make. The questionnaire had two major sections –

General data – (a) socio-economic data and (b) household data
Travel data – (a) trip related information

In the same line of explanation, the explanatory variables can also be subdivided in three categories –

1) Individual specific variables (age, gender, occupation etc.)
2) Journey specific variables (origin-destination, trip purposes, time of day etc.)
3) Transport facility specific variables (travel time, travel cost etc.)

A total two hundred and eleven (211) trips with detailed information about trip legs were extracted from the available survey dataset out of which seven (7) nos. of trip records were neglected for errors or insufficient data. In the second segment of the survey which dealt with mode specific characteristics was collected data regarding following variables for all 4 types of mode for peak as well as non-peak hours.

1) Corridor travel time
2) Vehicular speed in the corridor
3) Frequency of signalized intersection
4) Waiting time (with & without signal)
5) Demand of the mode (No. of passengers boarding and/or alighting)

3.3. Analysis of survey dataset

3.3.1. Commuters' present choice

This section reveals the present mode preference for the commuters which has been considered as the base scenario later to build upon the policy scenarios and assess the change in commuters' sensitivity to bus transit after policy implication.

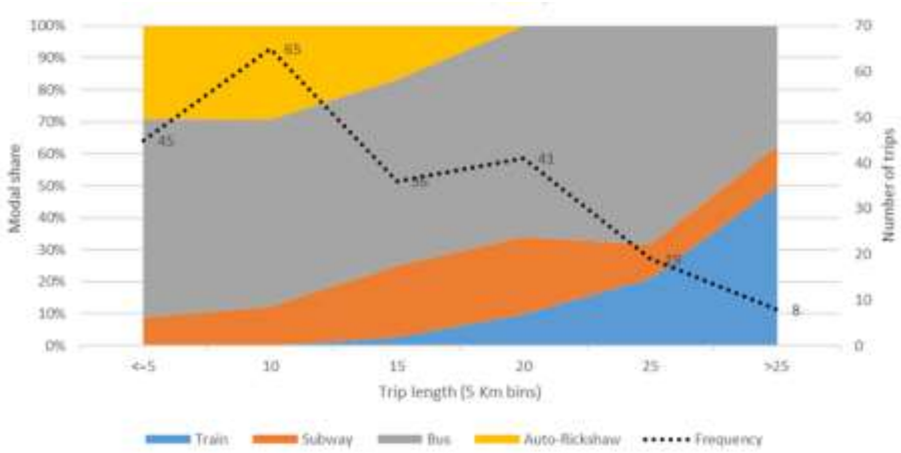
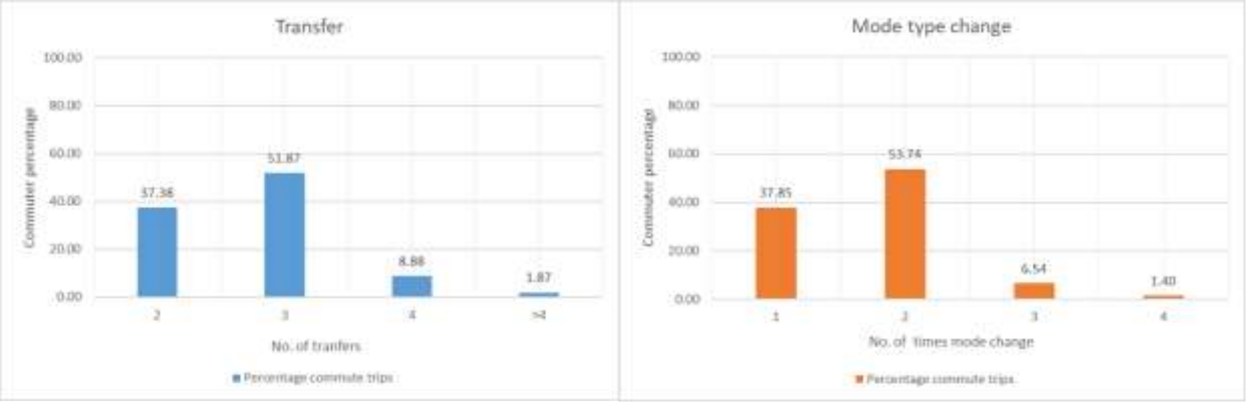


Fig. 3. Distribution of modal shares and total trips by trip length (corridor A and corridor B)

It can be observed from the figure above, auto-rickshaws are dominant for shorter commutes (trips up to 15 km), and longer commutes are predominantly made by suburban rail and the trips with intermediate trip lengths has a mixed share of all 4 modes. The observed mode shares of suburban rail, subway, bus and auto-rickshaw are 6.16%, 15.16%, 61.61% and 18% respectively. Anyway, bus transit is the dominant mode share across all trip lengths.

3.3.2. Findings from trip specific survey

Information regarding the individual and journey specific variables was collected through trip specific survey to find out the driving factors for commuters' mode preference and simultaneously intervention area for policy planning. There are two interesting findings from trip specific survey which highlights problem area for existing transit system specifically public transit – number of transfers and change of mode during transfer.



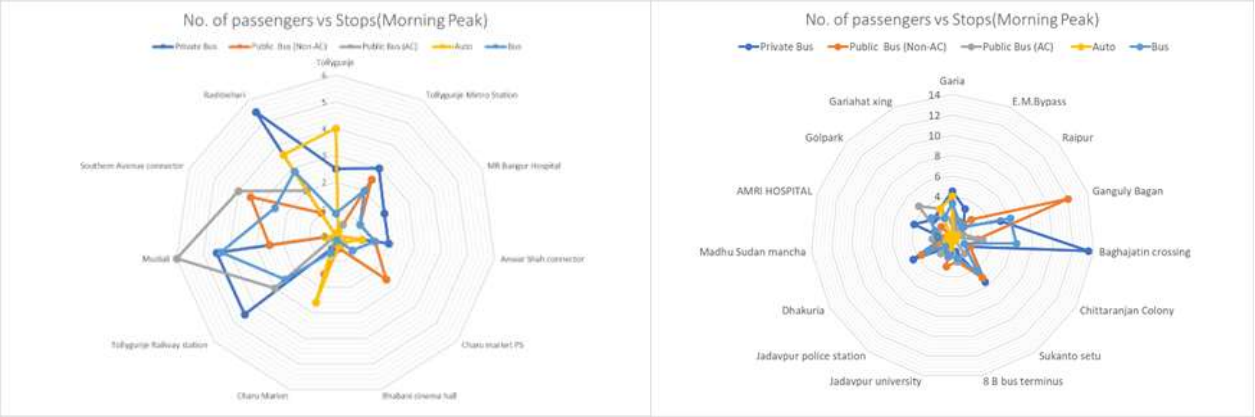
(a) (b)

Fig. 4. (a) Number of transfers vs. commuter percentage and (b) Mode type change vs. commuter percentage

Number of transfers is an 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 above 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 that trip chaining happens despite several overlapping bus routes running on both the corridors which means that the routes are not solving the last mile connectivity problem or those are not well planned. The second figure above can be studied in conjunction with the first one 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 in-turn overall travel time and also considering schedule variability for bus on both corridors can play a huge role in one's mode choice behavior.

3.3.3. Findings from mode characteristics survey

Mode characteristics survey gives an idea about operational nature of the available modes and helps to identify underlying problems which can be improved upon with development policies.



(a) (b)

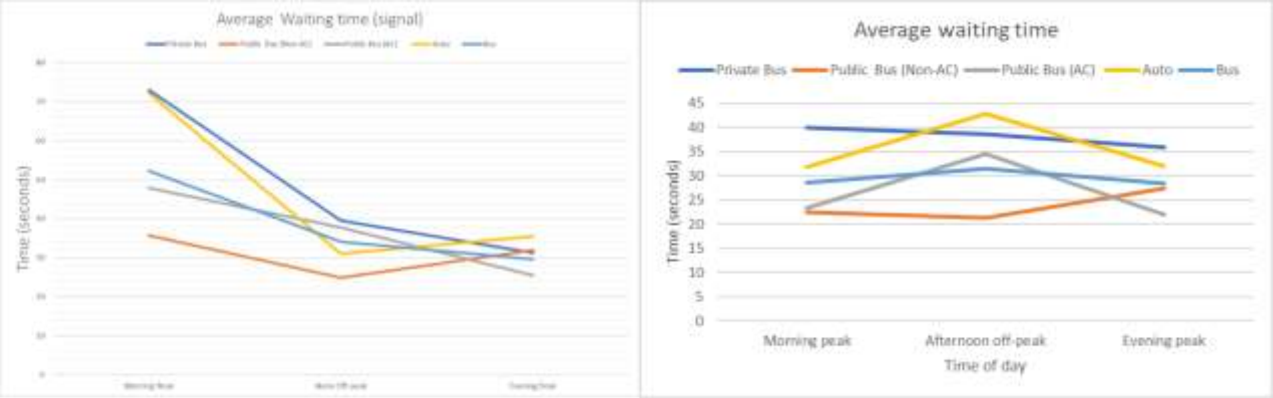
Fig. 5. Passenger demand vs. Stops during peak hours in (a) Corridor A and (b) Corridor B

It can be clearly observed from figures 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. Hence, policy should incorporate ideal stop planning.

(a) (b)

Fig. 6. Average speed (different modes) vs. Stops during peak hours in (a) Corridor A and (b) Corridor B

It can be inferred from figures 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.



(a) (b)

Fig. 7. Average waiting time vs. Time of day in (a) Corridor A and (b) Corridor B

Figures above show 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. This results into high variability in the dwelling time in bus stops which reduces service reliability.

4. Modeling

4.1. Model specification

The correlation between different variables are analysed in R-Studio to identify the variables in the mode choice equation. The correlation threshold has been set as 0.5 to consider highly correlated variables. It’s also worth noting that there are no such variables in the final mode choice model which are correlated by any manner and Table 1 provides descriptions about the variables considered for modeling.

Table 1. Analysis of variables

Id	Variables	Variables with high correlation	Remarks
1	age		‘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. The variable will be assigned value 1, if it’s in one category and 0, otherwise.
2	gender		The variable will be assigned value 1, if male and 0, if female.
3	income class		Individual income has been considered instead of household which gives a wrong interpretation of those who can afford high travel cost despite earning less.
4	hh_size		Number of people in a single household.
5	whh_size		Number of earning member in a single household.
6	veh_ownership		Vehicle ownership = Number of household vehicles (2 wheelers + 4 wheelers) / Number of household members possessing driver’s license
7	peak_hr		Trips made in time groups 08:00 to 11:00 Hrs and 17:00 to 20:00 Hrs were marked as peak-hour trips, represented by 1, and trips made during 14:00 to 17:00 Hrs was marked 0.

8	trip_purpose		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 mentioned purposes then it is coded as 1 otherwise as 0.
9	trip_length	t_cost; TT_hr	Total distance travelled in kilometres adding up individual trip leg distances.
10	n_transfer	t_cost; TT_hr	Number of transfer = (Total number of trip legs - 1)
11	TT_hr	n_transfer; trip_length; t_cost	Total travel time in hours adding up individual trip leg travel time.
12	t_cost	TT_hr; n_transfer; trip_length	Total travel cost in rupees adding up individual trip leg travel cost.

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

4.2. Model estimation

The variables, selected for the final mode choice model, are not at all correlated because such correlated variables do not augment well for MNL model. The model was estimated by maximum-likelihood estimation using Newton-Raphson method as it picks the values of model parameter which make the observed data more likely to occur than any other values. For model estimation statistical software platform ‘R-Studio’ was used.

The variables those are in the final mode choice equation are shown in table 2 along with their statistical significance and coefficients. It is worth mentioning that auto-rickshaw has been considered as the base mode i.e. auto-rickshaw has a zero intercept value. As the full dataset size was considerably small compared to dataset size used in similar research work, 100% of it was taken for estimation purpose. Simultaneously some variables (e.g. trip_HBW) come to be statistically significant only for selected alternatives (mode) out of four modes in consideration for the logit model. Those are represented as ($mode_i$ * $variable_k$).

The final mode choice equations (utility equation) are as follows:

$$U_{bus} = 2.61449 - 6.93 * TT\_hr_{bus} - 0.95616 * peak\_hr + 0.9606 * age\_2 \tag{1}$$

$$\begin{aligned} U_{subway} = {} & -1.01066 - 6.93 * TT\_hr_{subway} - 1.04916 * peak\_hr - 1.06393 * veh\_ownership \\ & + 1.17498 * age\_2 - 1.14735 * trip\_HBW \end{aligned} \tag{2}$$

$$U_{suburban\ rail} = -2.24903 - 6.93 * TT\_hr_{suburban\ rail} \tag{3}$$

$$U_{auto\text{-}rickshaw} = 0 - 6.93 * TT\_hr_{auto\text{-}rickshaw} \tag{4}$$

4.3. Model performance

4.3.1. Significance of model out put

There are mainly two ways to judge the explanatory ability of the mode choice model in the development stage. First of those are the value of McFadden R^2 (similar to normal R^2) and second one is Log-likelihood value.

The goodness-of-fit measure for the model during model development stage can be assessed by likelihood ratio index,

$$\rho^2 = LL(0) - LL(P)/LL(0) \tag{5}$$

Where, LL (P) = Log-likelihood of estimated model; LL (0) = Log-likelihood of zero-coefficient model. The summary of the model estimation is shown in table 3.

The value of ($\rho 2$) index varies between 0 (no fit) and 1 (perfect fit) in order to compare alternative models. Although its meaning is clear in the limits (0 and 1), values around 0.4 are usually considered excellent fits (Ortúzar & Willumsen, 2011). It can be observed from different literatures that the value of McFadden R^2 also varies from 0.30 - 0.50 in similar mode choice models (Anwar & Yang, 2017) (Chakrabarti, 2017) (Alvinsyah, Soehodho, & Nainggolan, 2005). The McFadden R^2 value of the model comes as 0.39928. Hence it can be claimed that the model performs considerably good with respect to both of these index (Log-likelihood & McFadden R^2).

4.3.2. Validation by trip length fit approach

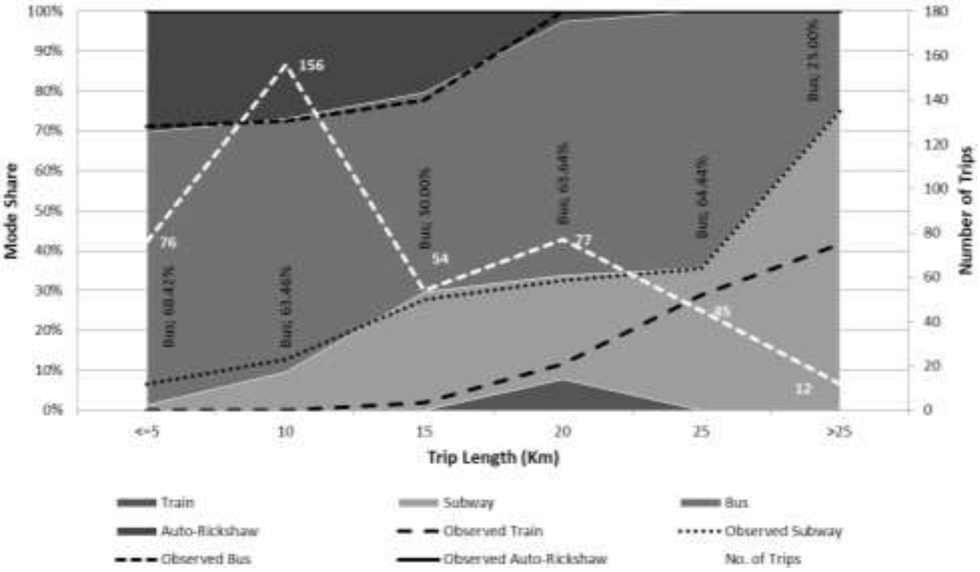


Fig. 8. Distribution of mode share by trip length (observed vs. predicted).

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.

indicates that the predicted modal shares grossly follow the overall pattern of the observed modal shares (observed mode share of suburban rail, subway, bus and auto-rickshaw are 6.16%, 15.16%, 61.61% and 18% respectively whereas predicted mode share are 4.51%, 19.11%, 58.95% and 17.39%), especially for shorter distances and for all the modes.

It is worth mentioning that the pattern is not so closely matched at longer distances specifically between the modes ‘Subway’ and ‘Suburban rail’ because there are very few actual trips made at such distances. That is why most of the ‘Suburban rail’ trips are misclassified 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.

5. Policy impact analysis

5.1. Scenario development

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 the study corridor separately based on the methods published in the reports by Transportation Research Board. 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 different travel times and peak-hour variables which were in turn calculated by varying average transit speeds were tested.

As an output of this the policy scenarios were broadly classified into three major and eight sub categories –

1. Policy scenario 1 – Network characteristics improvement
    1.1. Sub-scenario 1.1 – Improvement in capacity constraints
    1.2. Sub-scenario 1.2 – Improvement in speed constraints

2. Policy scenario 2 - Improvement in lane management & operational hours
    2.1. Sub-scenario 2.1 – Introduction of dedicated bus lane
    2.2. Sub-scenario 2.2 – Addition of a bus lane by parking removal
    2.3. Sub-scenario 2.3 – Shifting of private vehicles to single contraflow lane
    2.4. Sub-scenario 2.4 – Shifting of private vehicles and auto-rickshaw to single contraflow lane
3. Policy scenario 3 - Introduction of a new BRTS service
    3.1. Sub-scenario 3.1 – Introduction of new BRTS
    3.2. Sub-scenario 3.2 – Introduction of new BRTS and improvement in existing bus service

Table 2.Development of policy scenarios

Id	Constraints	Change in variables	Methods	Stretch applicability
1.1	Dwell time improvisation Bus priority signaling 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 reentry delay saturation flow = increased curb lane volume (no auto-rickshaw)	Reduce dwell time based on TCRP calculation Reduce variability based on TCRP calculation (average value) Increase saturation volume of the street	Most of the interventions for whole stretch and some in selected part
1.2	Average stop spacing Schedule of Buses at critical stops Introduce skip-stop operation	Average stop spacing = Increased No. of bus/hr. at critical stop = 75 Skip stop factor =0.87	Merge less popular stops Reduce no. of buses with overlapping route	Whole stretch
2.1	Dedicated bus lane from existing road width in extended peak hours' span Bus priority signaling	saturation flow = decreased curb lane volume = bus only lane new peak hour slots = 8-11, 12-14, 15-17, 18-21 g/C Ratio = 0.45	car & auto rickshaw volume reduced Change saturation flow based on available road width Change peak hour variable	Selected
2.2	Dedicated bus lane from parking removal in extended peak hours' span (2 lanes for Bus) Bus priority signaling	saturation flow = increased curb lane volume = bus only lane new peak hour slots = 8-11, 12-14, 15-17, 18-21 g/C Ratio = 0.45	Same as above	Selected
2.3	Introducing contraflow car lane in extended peak hours' span (NO car allowed on peak direction) Bus priority signaling	saturation flow = same curb lane volume = decreased by 50% new peak hour slots = 8-11, 12-14, 15-17, 18-21 g/C Ratio = 0.45	Same as above	Selected
2.4	Introducing contraflow car lane in extended peak hours' span (NO car allowed on peak direction) Removal of Auto-Rickshaw Bus priority signaling	saturation flow = same curb lane volume = decreased by 60% new peak hour slots = 8-11, 12-14, 15-17, 18-21 g/C Ratio = 0.45	Same as above	Selected
3.1	24 hrs. Grade separated bus lane from parking removal (1 lane for Bus+1 lane for BRTS)	Saturation flow = increased for BRTS / decreased for Bus	Calculate changed vehicular speeds for BRTS buses based on traffic volume change	Selected

Id	Constraints	Change in variables	Methods	Stretch applicability
	Bus priority signaling	curb lane volume = increased for Bus / decreased for BRTS g/C Ratio = 0.40	Calculate changed vehicular speeds for other Buses based on traffic volume change Calculate changed vehicular speeds for auto-rickshaw mode Calculate changed waiting time	
3.2	Average stop spacing Schedule of Buses 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 signaling	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	Same as above	Selected

5.2. Improvement in level of service for arterial street

The impact of the policies mentioned in the previous section can be estimated in two ways – qualitative index and quantitative measure. Level of service or LOS is a widely accepted index for measuring the capacity improvement of the streets. Here authors have marked both the arterial street as class II type (free flow speed 48 – 55Km/hr.) as both of those have 3-5 signals/ Km stretch and parking facilities. The desirable LOS for urban arterial streets is of category C. In this paper every LOS category has been further subdivided into two sub-categories by taking the average of the sum of respective upper and lower limit. The existing level of services for corridor A – Tollygunge to Kalighat metro station are E- & D- for peak and non-peak hours respectively and it’s similar for corridor B also.

Table 3 Bus level of service Criteria for Arterials (Class II) (Transportation Research Board, 1994)

Level of Service (LOS)	Sub Level of service (Sub-LOS)	Average travel speed (Km/ hr.)
A	A+	> 55
	A-	>48 - < = 55
B	B+	> 43 - < = 48
	B-	>38.50 - < = 43
C	C+	> 34 - < = 38.50
	C-	> 29 - < = 34
D	D+	> 26 - < = 29
	D-	> 22 - < = 26
E	E+	> 19 - < = 22
	E-	> 16 - < = 19
F	F+	> 10 - < = 16
	F-	< = 10

Table 4 Improved bus level of services after different policy interventions

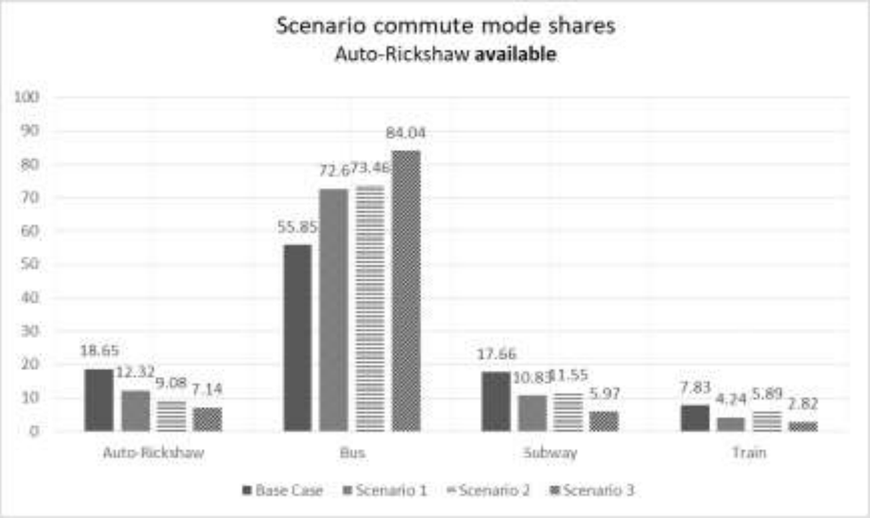
Id	Policy	Improved LOS in corridor A	Improved LOS in corridor A	Improved LOS in corridor B	Improved LOS in corridor B
		Peak hours	Non – peak hours	Peak hours	Non – peak hours
1.1	Improvement in capacity constraints	D-	C-	D-	C-
1.2	Improvement in speed constraints	E+	D+	D-	C-
2.1	Introduction of dedicated bus lane	E-	D-	E-	D-
2.2	Addition of a bus lane by parking removal	E+	D+	E-	D-
2.3	Shifting of private vehicles to single contraflow lane	E+	D+	E-	D-
2.4	Shifting of private vehicles and auto-rickshaw to single contraflow lane	E+	D+	E-	D-
3.1	Introduction of new BRTS	C+ for BRTS	C+ for BRTS	C+ for BRTS	C+ for BRTS
3.2	Introduction of new BRTS and improvement in existing bus service	D- for Bus & C+ for BRTS	C- for Bus & C+ for BRTS	D- for Bus & C+ for BRTS	C- for Bus & C+ for BRTS

5.3. Analysis of scenarios

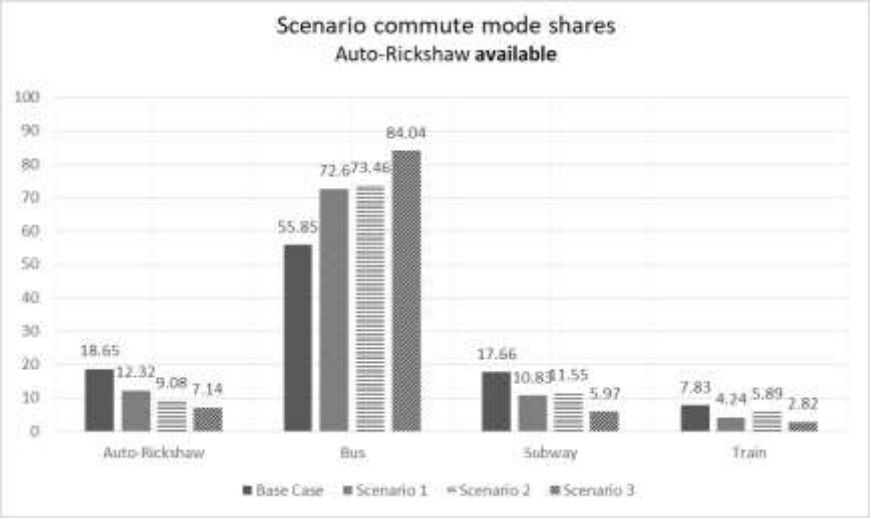
In this study, the sub-scenarios described previously were used to assess the impact of different policy interventions in an incremental manner. Moreover, the scenarios and their impact on both the corridors has been compared in two stages, the first one being comparison between major scenarios and the second one focusing on the sub scenarios comparison.

5.3.1. Stage I - Comparison between scenarios

Here the prediction results are analysed to find out the impact of availability of auto-rickshaw on bus transit commuter mode share as well as to assess as well as to compare the impact of three major service improvement strategies.



(a)



(b)

Fig. 9. Mode share predicted for scenarios (a) auto-rickshaw available and (b) auto-rickshaw not available

5.3.2. Stage II - Comparison within 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 (1.1 & 1.2 – Speed and capacity constraints improvement) and Scenarios 3 (3.1 & 3.2 – Introducing BRTS) and more importantly follows a same pattern for both the corridors. 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.

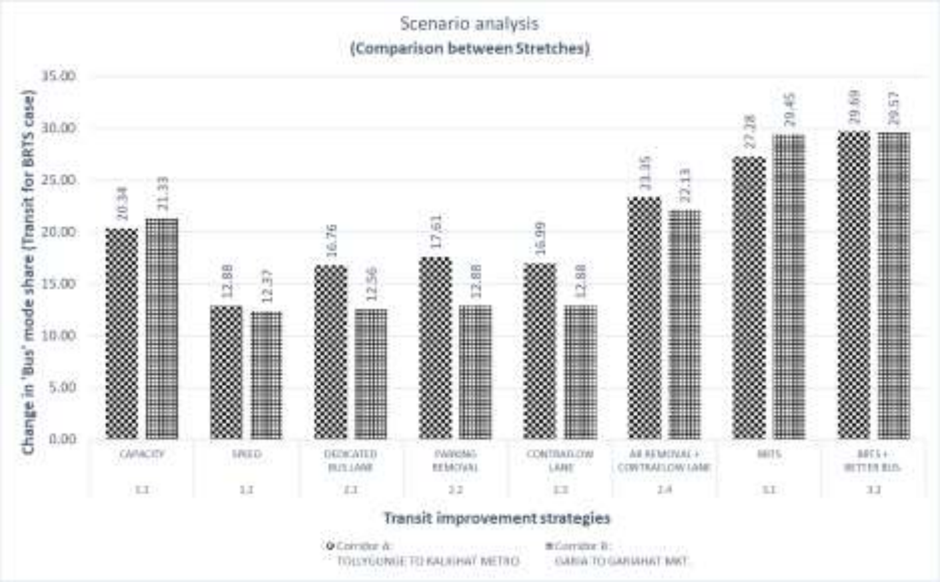


Fig. 10. Change in commuter mode share in corridor A & B predicted for scenarios

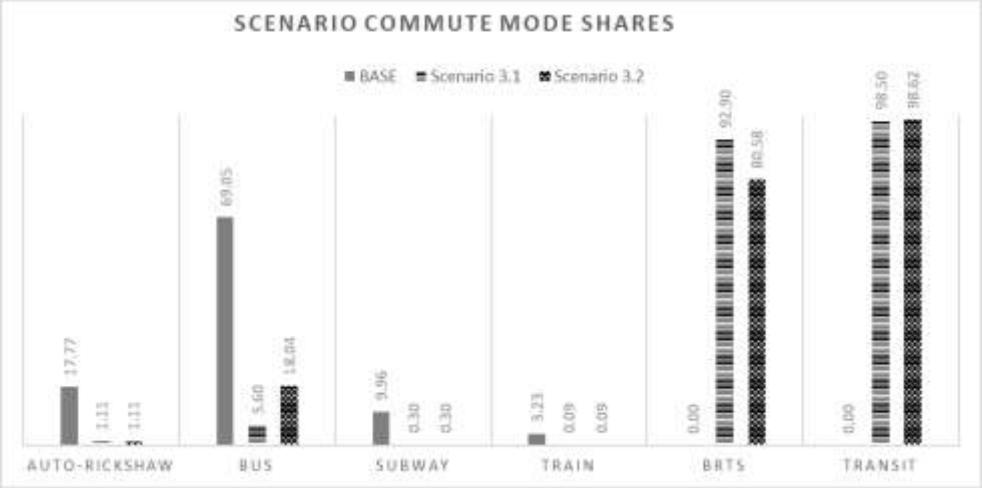


Fig. 11. Change in commuter mode share in corridor A predicted for BRTS scenarios (scenario 3)

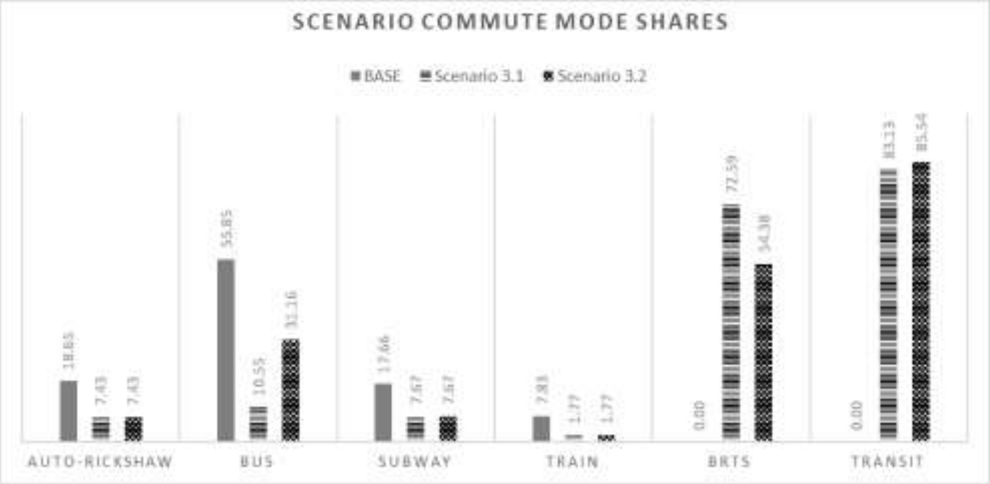


Fig. 12. Change in commuter mode share in corridor B predicted for BRTS scenarios (scenario 3)

6. Conclusions

This study argues that implementation of specific operational improvement packages to existing public transit network can yield comparable benefits to that of an entirely new MRT system. A new MRT system is expensive to deploy, takes years to become operational, and may not be economically viable for several urban areas. The study develops certain number of scenarios of operational improvements to existing bus service in Kolkata and compares their benefits, in terms of average travel speed, to that of a proposed BRTS. The model results, in terms of both bus LOS and modal shift that each strategy incurs, clearly suggests that fundamental improvements in transit service e.g. planned stop spacing, uniformity in dwell time, schedule reliability, skip-stop operation, bus priority signaling, bus preferential intersection etc. can facilitate a modal shift to bus, which is comparable to the BRTS scenario. The result also gives an indication to travelers' sensitivity or response to system changes. Considering the modal shift shown upon implementing scenarios, some following inferences can be drawn:

For scenario 1 (i.e. improvement in existing bus transit network), it can be observed (Fig. 9) that there is a modal shift to bus by 16.75% when auto-rickshaw is allowed on the arterial street and an equivalent modal shift by 17.61% for scenario 2 (i.e. lane management & extended service duration). 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 the arterial street. Usually, network improvement measures (scenario 1) require less time and cost compared to scenario 2 (i.e. lane management & extended service duration) and 3 (i.e. introduction of BRTS with & without improving existing bus transit). Whereas scenario 2 is more time intensive when compared to 1. LOS improvement measure (

Table 4) supports the argument as scenario 1 (sub-scenario 1.1) shows more (LOS rise by 2 sub-categories) improvement of LOS (e.g. D- from existing E- in peak hours) whereas none of the scenario 2 strategies was able to replicate such LOS betterment. Thus, we can infer that scenario 1 could be a better sustainable strategy than 2.

At the same time 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 the arterial street and a modal shift by 16.75% for scenario 1. Similarly, the modal shares are found to be 33.25% and 25.15% respectively for Scenario 3 and 1 when auto-rickshaw is not allowed on the arterial street. Scenario 3 proves to be the most effective strategy, but the modal shift incurred by it does not differ greatly from the modal shift caused by network improvement measures (scenario 1). It can also be inferred from

Table 4 that the LOS of BRTS (i.e. C+ irrespective of peak or non-peak hours) and existing bus transit (i.e. C- & D- for non-peak & peak hours) does not differ much specifically in non-peak hours. Thus, evaluation of the trade-off between time, cost and ease of implementation is of great importance to the policy makers while selecting BRTS strategies.

It can also be found out from Fig. 11 and Fig. 12 that mode share for BRTS drops by 12.32% and 18.21% respectively for corridor A and B whereas the mode share for bus increases by almost equivalent amount after existing bus service is improved simultaneously with introduction of BRTS. Therefore, transport planner s should be more realistic when introducing a new transit mode as improvement of existing mode can be a solution to greater extent.

Hence, the research work in this paper clearly indicates the fact that improving the existing MT system rather than induction of new rapid transit system (e.g. introduction of a new MRT system or bus dedicated lanes) altogether is a sustainable policy in developing countries as it provides comparable benefits (attracts people to MT) at arguably a much lower cost (time and labour) and also reaps the benefits of avoiding delays due to political issues (land acquirement and time span of single administrative regime) .

7. Site-specific policy recommendations

As the bus LOS and modal shift has been already analysed in previous section, these act as indicators for policy making with respect to the study corridors the policies that could be formulated are as follows:

1. Use of site specific bus preferential treatments (capacity constraints improvements) like queue jumps and curb extension can be very much effective when applied to major junctions in the corridor.
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 selected.
4. Bus priority signaling should be introduced in all stops for better transit service rather than using it only for major intersections.
5. Instead of full-fledged grade separated BRTS, improved existing bus service (network improvement) with will be an ideal solution.

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