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Trip-based Modal Shift Behaviour of Mode Users along the Proposed Extension Metro Corridor in Chennai (India)

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Abstract

Object of this study is to predict the 'Probability of Shift' to the proposed metro corridor from two-wheeler, car, bus and suburban rail in Chennai. To achieve this, a Stated Preference survey questionnaire was prepared and survey was conducted among two-wheeler users; car users; bus users and suburban rail users through face-to-face interview method. The collected SP data were coded, analysed and mode-wise/ trip-based binary logit models were developed using Statistical Software Tools (**SST**) software. From the developed models, it is observed that irrespective of mode & trip purposes, the choice of metro is fully driven by the proposed metro fare. From the predicted Probability of Shift, it is observed that car users are more willing to switch to metro as well as relatively price sensitive when comparing with other mode users.

Keywords: Trip-based Model, Metro Rail, Modal Shift Behaviour, Stated Preference data, Chennai

1. Introduction

Metro rail will constitute the principal mode of urban transport in India in near future. 'Chennai Metro Rail Limited' is the sole provider of metro rail transport service in Chennai which carries 2 lakhs passengers per day as of 2022 (CMRL website, 2022) and has not achieved its expected ridership. To this end, it would be useful to study the passenger shift behaviour from existing modes to the newly proposed extension of metro corridor and identify major determinants at the corridor level. Most of the presently available modal shift models are devoted to estimate the shift from one particular mode without considering other competitive modes. The basic concept of this modal shift model is an assumption that the amount of modal shift is conditioned by the relative attraction of metro rail while comparing to the operating performance of the available competitive modes (The Geography of Transport Systems website). The comparative advantages of metro rail are:

1. The metro rail system has proven to be most efficient in terms of energy consumption, space occupancy and numbers transported.
2. Eco-friendly – causes no air pollution, much less sound pollution.

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3. Greater traffic capacity – carries as much traffic as 7 lanes of bus traffic or 24 lanes of car traffic (either way).
4. Very low ground space occupation – 2 meter width only for elevated rail.
5. Faster – reduces journey time by 50% to 75%. (Source: HMRL website)

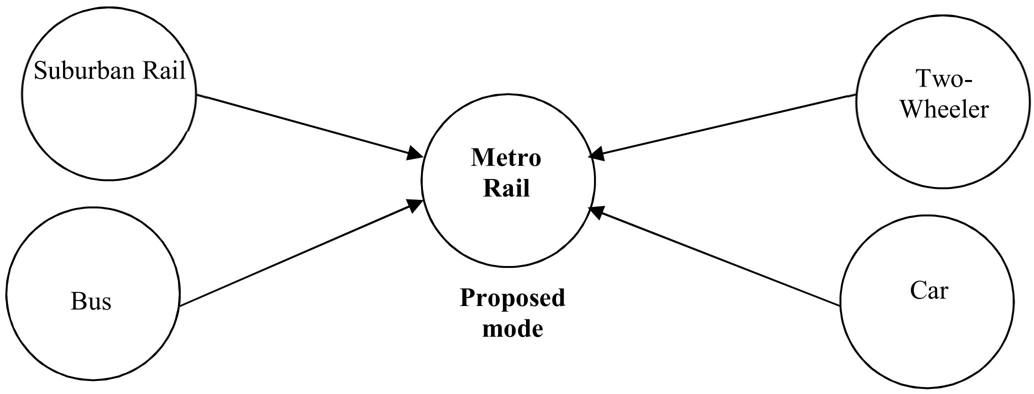


Figure 1: Expected impact of the proposed metro rail corridor

A successful metro system attracts mode shift from various private modes, thus controlling the carbon emissions at source (Jasti et al., 2021). In this study, shift from bus, suburban rail, two-wheeler and car were considered (Fig. 1). To predict the Probability of Shift to metro, a 'Stated Preference (SP)' questionnaire was designed in such a way that the probability can be predicted for various time saving as well as fare scenarios. Hence the study would bring out whether the commuters are sensitive to time or cost or both based on the estimated utility equation values. Also the study enables to find out the mode from which the maximum shift is expected.

This study was done as part of Feasibility Study (FS) Report for the extension corridor and was submitted to CMRL. The study also helps authors to further refine the SP questionnaire in their future work.

1.1 About Chennai

Chennai is the capital city of the Indian state of Tamil Nadu. Chennai is known as the ''Detroit of South Asia'' for its automobile industry. It is the fourth-most populous Metropolitan city in the country. As per population census records, Chennai has population of 8.2 million as of 2016.

1.2 Vehicle Population in Chennai

As of 1st April 2019, the total vehicle population of Chennai is close to 6 million including 3.74 million of two-wheelers. Growth trend of motor vehicle in the city is presented in Table 1.

Table 1: Vehicle growth in Chennai

Year	1981	1991	1998	2019	1998–2019 Growth
No. of vehicles	120,000	544,000	975,000	60,00,000	515.4%

1.3 Background for Chennai Metro

The city has acclimatized to multiple modes of Public Transport systems including an extensive bus network run by the 'Metropolitan Transport Corporation (MTC)'. The transportation network is augmented by the Chennai suburban railway network operated by the 'Southern Railway'. Furthermore, the Southern Railway runs the Chennai 'Mass Rapid Transit System (MRTS)' an elevated metropolitan railway system, which is in operation since 1995 to relieve congestion in the centre of the city. Despite these improvement measures, traffic congestion has continued to be an issue for both the residents and the city government. As a result, the Tamil Nadu government has decided to implement the Chennai metro rail project which will provide another mode of transportation for Chennai.

1.4 Chennai Metro Rail: Project Profile

A 'Detailed Project Report (DPR)' on Chennai Metro Rail Project was prepared and submitted by the 'Delhi Metro Rail Corporation Limited (DMRC)' who have successfully designed and implemented the Delhi Metro Rail Project. The DPR envisages the creation of two corridors under the proposed phase-I of the Chennai Metro Rail Project. Subsequently Phase-I (corridor I) has been proposed to extend on either end as shown in Table 2.

Table 2: Chennai metro rail corridor: Phase-I & its extensions

Corridor No.	*Corridor*	*Length (Km)*	*Status*
	Phase I		
I	Washermenpet to Airport (North-South corridor)	23.10	Operational
II	Chennai Central to St. Thomas Mount (East-West-South corridor)	22.00	Operational
	Phase I Extension		
I	Washermenpet to Wimco Nagar (Towards North)	9.05	Operational
I	Airport to Kilambakkam (Towards South)	15.30	FS Completed
	Total	69.45	

2. Study Corridor

According to 'Feasibility Study (FS)' Report, the 15.3 km elevated metro line from Chennai Airport to Kilambakkam via Tambaram is having 13 stations. Since it is fully elevated, construction will be easier/ cheaper compared to underground. The stretch is likely to attract many commuters to Chennai metro because it is very close to IT hubs, Anna Zoological Park and the proposed Kilambakkam bus stand (Fig. 2).


Inside View of Chennai metro

Figure 2: Study corridor

3. Literature Review

Literatures relevant to the present study were reviewed and the key observations are given below:

Factors influencing the intentions of single-occupant commuters to switch to buses and carpools were studied and suggested operating policies intending to encourage the use of high-occupancy vehicles (Tischer et al., 1979). They found that in buses, convenience was the important variable associated with shift intention. They also found that the perceptions of carpool comfort do not appear to be important. The factors like carpool schedule flexibility, cost, safety and a short wait in traffic were found to be the prime factors associated with potential shift to carpool.

A study was conducted in Malaysia to identify factors which are preventing switching of car users to the 'public transport (PT)' system (Nurdden et al., 2007). For this a survey was carried out among public and car users and binary logit models were developed. The study revealed that age, gender, car ownership, travel time, travel cost, household size and income were significant factors influencing the individual choice. Also, it was found that reduced travel time, reduced distance from home to PT station and subsidized fare would boost the usage of public modes.

A modal shift occurs when one mode gains a comparative advantage in a travel market over another. The comparative advantage can take various forms such as costs, capacity, time, flexibility or/and reliability. The kind of passengers travelling and their circumstances (socio-economic characteristics, purpose of trip etc.), largely impact the relative importance of each of these factors (Khaki et al., 2009).

The influence of introduction of exclusive bus lane on auto-rickshaw (three-wheeled motorized Para-transit vehicle) users in Chennai was studied using binary logit model (Vedagiri et al., 2010). For this, a SP data was collected using home-interview survey procedure. A binary logit model of mode-choice was then calibrated using the collected data and the model was also validated using a holdout sample. From this study it was found that the shift of auto-rickshaw users to the exclusive bus lanes varies with respect to 'Time of the Day (**ToD**)' as well as Level of Service (**LoS**) characteristics of the urban road.

The challenges and opportunities in implementing modal shift from private to PT in U.K. were discussed in detail (Batty et al., 2015). In reality there are factors like social, political and economic obstacles reducing the expected modal shift. The study concluded with: (1) traveller opinion needed to be recognized (2) quality of PT system needed to be improved to achieve shift

A study was conducted to understand the shift behaviour of private transport users and public transport users to the existing as well as the proposed metro corridors in Mumbai (Aditya et al., 2016). For this, a Revealed Preference survey was conducted among existing metro users and a Stated Preference survey was conducted among the public transport users along the proposed metro corridor. Discrete choice model based on RP data showed that 80% of metro users were using public transport before shifting to the new metro line and model based on SP data indicated that 60% of private mode users were willing to use the proposed metro.

The value of time (VoT) for the city of Alexandria was estimated through calibrating disaggregate linear-in parameter utility-based binary logit mode choice model of the city (Abdel-Aal, 2017). The mode attributes (travel time and travel cost) along with traveller attributes (car ownership and income) were selected as the utility attributes. Out of 20 models developed, only 2 models were considered successful in terms of the estimated correct signs and the magnitude of their significance (t-statistics value). The best two models estimated the value of time at Egyptian pound (LE) 11.30/hr and LE 14.50/hr with a relative error of +3.7% and +33.0%.

The recent introduction of metro rail in Chennai has lead to an increasing competition among PT modes (Selvakumar et al., 2018). To study the influence of metro on MTC bus transport, a *SP survey* was conducted among express bus travellers. Using the SP data, a modal shift model was calibrated to estimate the plausible shift from bus to metro rail. Results indicated that variables like fare-difference, age and income play an important role in the shift behaviour.

Possibility of shift from PT system toward private modes like car in India due to sudden outbreak of Corona virus was studied (Das et al., 2021). For this an online questionnaire survey was conducted and logistic regression models were developed. Results of logistic regression model indicated that commuters' socio-economic characteristics such as age, gender and income tend to influence mode switch preferences. Study concluded that efforts need to be made to upkeep the hygiene of PT system and this would restore the confidence of PT users.

Selected literatures from the year 1979 to 2021 pertaining to modal shift were reviewed. From this, it is concluded that most of the models were developed using binary logit method. None of the Indian literature studied the impact of metro on multiple modes.

Present study considers both travel-time saving as well as cost under Indian context and try to predict the Probability of Shift from different modes. Also four binary logit models (car & metro; MTC bus & metro; suburban rail & metro; two-wheeler & metro) were developed to understand the mode-wise shift behaviour in a better way.

4. Modelling Approach

Disaggregate approach was used in this study. Advantages of behavioural disaggregate models are: savings in data required to calibrate model; transferability of model; understood easily (Wright et al., 1989). Based on the earlier research work on the subject matter, two different approaches were used in disaggregate mode choice analysis: (1) Stated Preference (SP) Approach and (2) Revealed Preference (RP) Approach. The SP approach is having many advantageous than RP approach in predicting choice behaviour of the travellers (Hensher, 1994). They are:

1. Hypothetical, "stated" choices in controlled experiments
2. Ability to analyse reaction to future, not existing options
3. Low cost
4. Precisely specified choice set
5. Multiple answers from each respondent
6. Multiple choices formats (choices, ranking or rating)
7. Capability of analysing trade-offs among qualitative attributes

Hence, in the present study SP approach has been adopted for model development. Since, the modes considered were MTC bus and metro rail (binary situation), binary choice model has been used. The interpretation of variables is easy in logit model than probit model, and hence the logit model was adopted for the study. Fig. 3 depicts the modelling approach and the shaded portions of the flow-chart show the sequence of conceptual steps related to the model development in the present study.

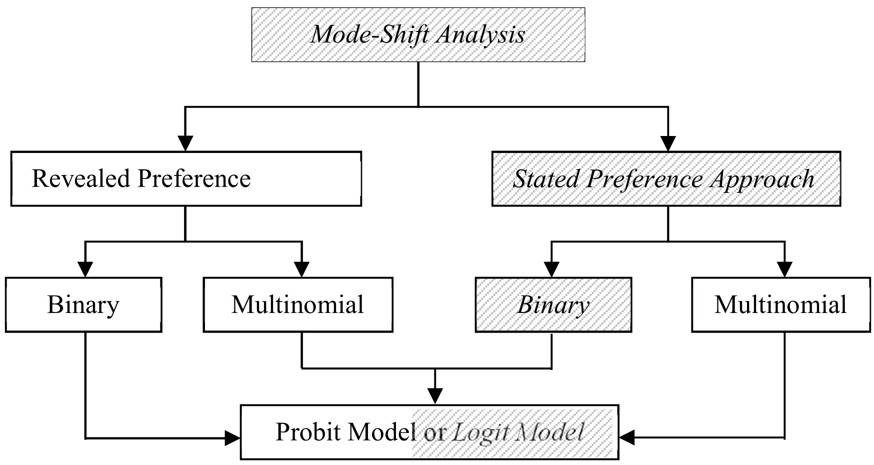


Figure 3: Modelling approach for modal shift analysis

Nevertheless, a specific survey should be conducted before establishing the models. This can be accomplished by using SP surveys.

5. Design of SP Questionnaire

Stated preference methods attempt to learn people's willingness to pay by directly asking them how much they value a certain environmental goods or services through carefully designed surveys (Niggol Seo, 2017). SP surveys are most widely used in transportation studies to reveal how changes to infrastructure or services will alter travel shift behaviour.

These are SP survey questionnaires that aim to collect data on the stated behaviour of users towards hypothetical available contexts (Borghetti et al., 2022).

A SP questionnaire was prepared to understand commuter shift behaviour. The survey was conducted among suburban rail users (**257 samples**), bus users (**251 samples**), two-wheeler riders (**304 samples**) and car users (**191 samples**) considering different trip purposes. The variables that are likely to affect the choice of metro can be divided into three general categories. They are as follows:

Socio-economic Characteristics: gender; age of the commuter; monthly family income in Indian Rupees (**INR**: 1 Euro ≈ 81 INR); vehicle ownership; place of work; frequency of travel; educational level; employment sector

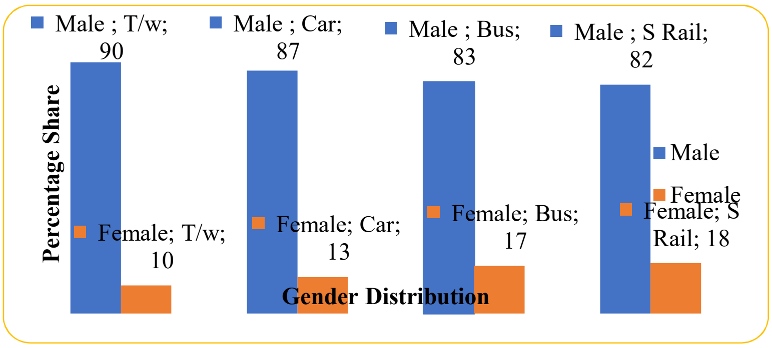
Details on Current Trip: purpose of trip; mode & stages of travel; trip length

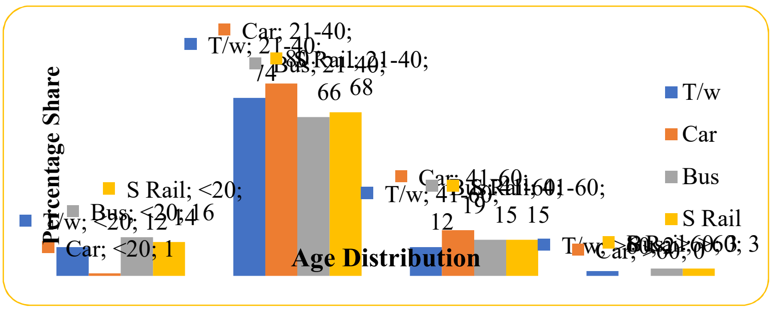
Stated Hypothetical Scenarios: (In total 4 scenarios as given below)

Scenario (1): travel time saving is 25%: 3 times the MTC bus fare
Scenario (2): travel time saving is 25%: 4 times the MTC bus fare
Scenario (3): travel time saving is 50%: 3 times the MTC bus fare
Scenario (4): travel time saving is 50%: 4 times the MTC bus fare

5.1 Socio-economic Profile of the Travellers

Socio-economic profile of the travellers in the study corridor is presented below:





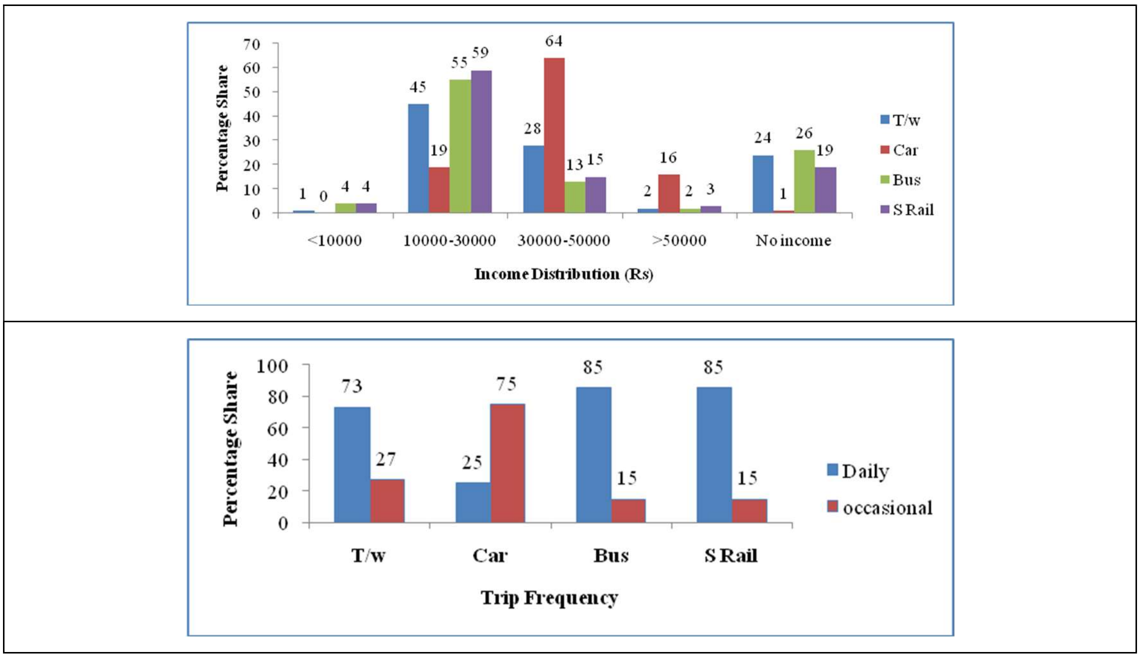


Figure 4: Socio-economic characteristics of suburban travellers

From the above charts (Fig. 4), it is observed that predominently male commuters (above 80%) falling in the age group of 21-40 with the monthly income range of INR 10,000-50,000 and making daily trip (above 70%) are travelling along the study corridor.

6. Model Development

The aim of this study is to analyse the shift behaviour from a selected mode namely suburban rail to proposed metro rail (binary in nature). The structure of the modal shift model looks like as given below:

$$P_{shift} = \frac{\exp(a_0 + a_1X_1 + a_2X_2 + \ldots + a_nX_n)}{1 + \exp(a_0 + a_1X_1 + a_2X_2 + \ldots + a_nX_n)}$$

where,

P_{shift} = Probability of Shift from mode considered to metro

X_1, X_2, X_3 ... are factors influencing change behaviour (factors includes socio-economic characteristics and travel characteristics of suburban rail passengers)

a_0, a_1, a_2 ... are model parameters to be estimated using model development exercise

For developing model, following steps were used (Fig. 5):

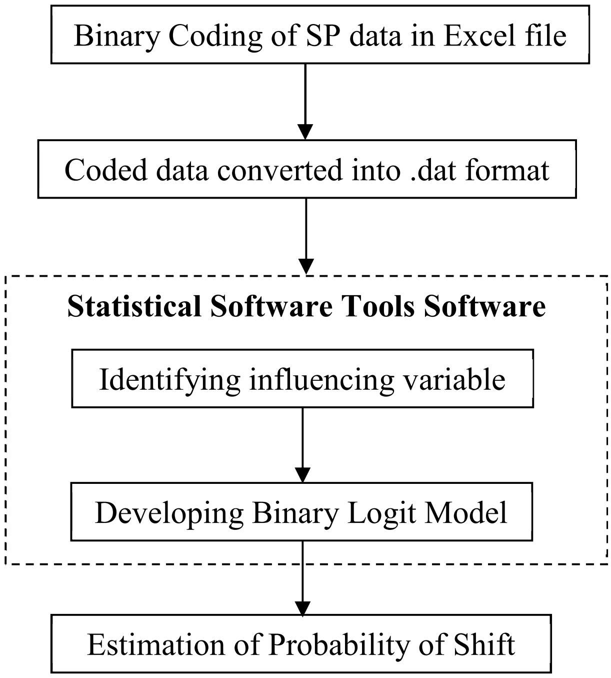


Figure 5: Steps involved in model development

The results of model calibration are given in the table below (Table 3).

Table 3: Results of model calibration

Mode	*Two-Wheeler*			*Car*			*MTC Bus*			*Suburban Rail*		
Trip Purpose	*Work*	*Education*	*Others*	*Work*	*Education*	*Others*	*Work*	*Education*	*Others*	*Work*	*Education*	*Others*
% Share	46.8	8.5	44.7	29.1	0	70.9	56.6	15.1	28.3	62.5	14.7	22.8
Variable	Estimated Coefficient with 't' value											
a	3.938 (3.75)	9.108 (3.65)	8.797 (9.17)	5.767 (7.54)	–	8.794 (11.9)	6.617 (7.00)	5.912 (3.27)	5.889 (5.96)	6.555 (8.54)	5.116 (2.33)	7.966 (6.37)
G_m	2.337 (2.78)		0.815 (2.05)	-1.009 (-3.17)	–	-1.268 (-3.48)	-1.419 (-4.68)	1.047 (1.56)	0.355 (1.03)	-0.398 (-1.90)	-1.633 (-2.54)	-1.713 (-3.53)
A_g	-0.279 (-0.82)	–	-0.327 (-1.15)	0.067 (0.09)	–	0.197 (0.87)	0.169 (0.50)	–	-0.456 (-1.60)	-0.824 (-4.00)	–	-0.372 (-1.16)
A_l	–	0.592 (0.95)	–	–	–	–	–	-0.215 (-0.41)	–	–	-0.005 (-0.01)	–
I_m	0.771 (3.31)	–	0.114 (0.36)	0.180 (0.47)	–	0.347 (1.25)	-0.092 (-0.40)	–	0.429 (1.44)	0.00 (0.00)	–	0.276 (0.88)
N_s	-0.372 (-0.92)	-0.446 (-0.31)	-0.614 (-1.75)	*	*	*	0.553 (2.46)	0.664 (1.69)	-0.134 (-0.70)	-0.044 (-0.23)	1.741 (3.18)	-0.114 (-0.48)
T_s	0.575 (0.66)	0.00 (0.00)	0.484 (0.49)	0.269 (0.26)	–	0.458 (0.59)	0.597 (0.67)	0.364 (0.20)	0.599 (0.54)	0.616 (0.92)	0.354 (0.21)	1.232 (1.10)
C_d	-2.336 (-13.30)	-3.297 (-5.68)	-3.055 (-12.80)	-1.642 (-9.06)	–	-2.637 (-15.6)	-2.757 (-14.20)	-3.142 (-7.22)	-2.063 (-9.88)	-2.217 (-17.00)	-3.398 (-8.29)	-2.223 (-10.30)
Initial LL	-436.7	-79.02	-415.9	-241.2	–	-586.4	-482.4	-129.6	-241.9	-707.0	-166.4	-257.9
Final LL	-262.5	-36.6	-210.2	-180.1	–	-331.4	-257.6	-63.2	-160.9	-446.5	-74.3	-162.1
$\rho2$	0.39	0.53	0.49	0.25	–	0.43	0.46	0.51	0.33	0.36	0.55	0.37

Notations:
a = mode Constant
G_m = Genders
A_g = Commuters in the age group of 41-60
A_l = Commuters with age below 20
I_m = Commuters have monthly income of INR 20,000 to 30,000
N_s = Number of stages (applicable for public transport)
T_s = Travel time saving by using metro
C_d = Cost of metro with respect to bus fare (3 times/ 4 times)
LL = Log-likelihood

7. Results and Discussions

Four binary logit models (two-wheeler & metro; car & metro; MTC bus & metro; suburban rail & metro) were developed to estimate the mode-wise shift to metro. The modes were shown in Fig. 6. From the developed models, following results were arrived:

- Gender: Male commuters those who make work trip using two-wheelers (+2.337/ t stat: +2.78) are more likely to switch to metro. Continuous increase of petrol price may largely be the cause for the switch. In contrast, male commuters those who make work trip using MTC bus (-1.419/ t stat: -4.68) were not willing to switch to metro.
- Age Group 41-60: Suburban rail work trip users between age group of 41-60 were less willing to shift to the proposed metro corridor (-0.824/ t stat:-4.00). The reason may be fare of metro is much higher than the suburban rail fare. The same may be justified from the estimated coefficient for the variable cost difference (-2.217/ t stat: -17.00) which was found to be highly significant for suburban rail users compared to all other modes.
- Number of Stages: Most PT users (MTC bus and suburban rail) are required to change their mode of travel to reach their destination. When the number of stages increases, following group of travellers were more willing to use metro:
    - MTC bus users making work trip (+0.553/ t stat: +2.46)
    - Suburban rail users making educational trip (+1.741/ t stat: +3.18)
- Propensity of Suburban commuters: It can be clearly observed that irrespective of mode users & trip purposes, the choice of metro is fully driven by the proposed fare difference between metro & MTC bus. This shows the peculiar propensity of the itinerary riders.
- 'Travel Time Saving' is lost significance in the choice of metro.

Two-wheeler **Car** **MTC Bus**

Suburban Rail **Metro**

Figure 6: Metro and other competitive modes

7.1 Comparing Results with Previous Study

Potential influence of Chennai metro on MTC bus was done for Mount Road metro corridor which is located in the core urban area of Chennai (Selvakumar et al., 2018). Present study corridor is an extension of the above corridor, but falls in the suburban area of Chennai. The model results were compared and following conclusions were arrived:

- Fare difference is the significant influencing factor inducing shift in both the studies.
- MTC bus users those who have age bracket 40-60 are likely to use metro (+0.511/ t stat: +2.54) in the urban area whereas in the suburban area bus riders making other purpose trips are less willing to use metro (-0.456/ t stat: -1.60). Traffic congestion and overcrowding of bus in the core urban area may attribute for inclination towards metro.
- MTC bus users with monthly income range INR 20,000-30,000 are willing to use metro in both the cases (Urban: +0.480/ t stat: +2.16 & Suburban: +0.429/ t stat: +1.44).

7.2 Estimation of Probability of Shift

From the calibrated modal shift models (Table 3), Probability of Shift to metro was calculated using the utility equations and the results are presented in Table 4 below:

Table 4: Predicted probabilities of shift to metro rail

Mode	*Travel time saving = 25%*		*Travel time saving = 50%*	
	Fare difference		*Fare difference*	
	3 times of MTC Bus Fare	*4 times of MTC Bus Fare*	*3 times of MTC Bus Fare*	*4 times of MTC Bus Fare*
Two-Wheeler	36%	4%	38%	5%
Car	52%	11%	54%	12%
MTC Bus	35%	4%	37%	5%
Suburban Rail	37%	6%	41%	7%
Average	**40%**	**6%**	**43%**	**7%**

From Table 4, it can be observed that the shift expected is close to 40% if the fare of metro is three times the MTC bus fare, whereas when the metro fare is four times the MTC bus fare, the shift is only 4-6%. This shows that the travellers are 'price sensitive'.

7.3 Price Elasticity of Demand

The coefficient of price elasticity of demand 'e' measures percentage change in the quantity of commodity demanded, resulting from a given percentage change in the price of the commodity. Following fare table (Table 5) was shown to the passengers for better understanding:

Table 5: Chennai MTC bus fare

Distance, Km	*MTC Bus Fare (INR)*	*3 times of MTC Bus Fare (INR)*	*4 times of MTC Bus Fare (INR)*	*% Change in Fare*
0-2	7	21	28	33.33
2-4	9	27	36	33.33
4-6	10	30	40	33.33
6-12	15	45	60	33.33
12-18	19	57	76	33.33
18-24	22	66	88	33.33

$$\text{Price Elasticity of Demand } (\mathbf{e}) = \frac{\text{Percentage Change in Probability of Shift}}{\text{Percentage Change in Fare}}$$

Using the above equations, percentage change in probability of shift and percentage change in metro fare are taken from Table 4 & Table 5 respectively and price elasticity of demand are calculated as shown in Table 6. Since the travel time saving has no influence in inducing shift, the shift values corresponding to 25% travel time saving is taken for calculation.

Table 6: Price elasticity of demand (PED)

Mode	*% change in Probability of Shift*	*% change in Fare*	*PED*
Two-wheeler	-32	33.33	-0.96
Car	-41	33.33	-1.23
MTC Bus	-31	33.33	-0.93
Suburban rail	-31	33.33	-0.93

From the above table, it is observed that the car users are relatively price sensitive when comparing with other mode users.

8. Conclusions

In this study CMRL is presented with an analysis made on the basis of fare difference (cost) for each pair of travel time saving scenarios. These fare differences are in terms of market price – rupees currently paid by the MTC bus users. The proposed fare differences are equivalent to values that they are willing to pay in Rupees; they are rupees actually forecast to be paid for metro. Hence the results are useful in framing nimble price policy for the newly proposed metro extension corridor. Following three fruitful results were arrived based on this study:

1. It can be clearly observed that irrespective of mode users & trip purposes, the choice of metro is fully driven by the proposed cost difference between Metro & MTC bus. This shows the peculiar propensity of the itinerary riders.
2. From the socio-economic analysis it is observed that predominently male commuters (above 80%) falls in the age group of 21-40 with the monthly income range of INR 10,000-50,000 and making daily trip (above 70%) are travelling along the study corridor.
3. Car users are relatively price sensitive when comparing with other mode users.

9. Future Work and Suggestion

1. Present study considered cost and travel time saving as stated scenarios. In future, other scenarios such as improving footpaths, cycle tracks and parking facilities in the metro stations etc. may be considered for model development.
2. From the study, it is understood that the commuters are not aware of the importance of travel time saving by using metro rail. CMRL must take steps to make aware of this benefit among the public.

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