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Planning and assessment framework for analysing the impact of a new public transport system in a city

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Abstract: This paper presents the framework to assess the impacts of the introduction of a new public transit system in a city, for example, metro, BRT, LRT etc. The proposed framework evaluates the economic, equity and environmental impacts of the proposed new public transport system and applies the framework to the metro in Delhi. Further, the study also presents a framework to link mobility and accessibility to equity. Utility theory is used to estimate the consumer surplus (as a measure of enhanced accessibility), and change in generalized cost from mode destination choice models and Gini coefficient is applied as a measure of equity. A systems dynamic approach is used to estimate the energy consumption and CO_2 emissions from passenger transport sector and identify the environmental benefits in terms of CO_2 emissions from metro system in Delhi. Finally the ecological footprint of commuting by different modes is estimated.

Key Words: public transport, economic, equity, environment

1. INTRODUCTION

Mobility and accessibility are declining in most of the developing cities of the world. There are over 14 rail transit facilities in developing world with some 20 years of record and it has become evident that cities with metros have better preserved downtowns (Gakenheimer, 1999). Transport policies of international funding agencies like the World Bank and the Asian Development Bank for developing countries also focus on the mobility and access needs of the people. World Bank policy on financing metros stated that they must be promoted only when they “are likely to produce high rates of return” (World bank, 1986). The discussion paper issued by World Bank by Slobodan Mitrich in 1997, advocates promotion of metros as development projects in the case of developing countries and use them as catalysts for sustainable urban transport strategy.

2. GENERAL FRAMEWORK

The concept of 3 Es originally refers to “Economy”, “Equity” and “Environment”. In the context of the present study certain indicators had been chosen which could be measured and a value assigned to them to make a comparative evaluation of the 3Es. The present study presents the development of a generic methodology for evaluating any new public transport system in a city like metro, LRT, BRT etc. The framework developed incorporates the evaluation of the three Es i.e. economy, equity and environmental aspects of the proposed public transport system. For the economic and equity evaluation, the framework evaluates changes in mobility (Bhandari et al., 2008), and accessibility (Bhandari et al., 2007; Bhandari et al., 2008; Bhandari et al., 2009) and links it with equity by applying the Gini coefficient. The environmental aspect deals with the energy consumption and CO_2 emissions, followed by the footprint of commuting by various modes (Bhandari et al., 2010).

2.1 Economy

Consumer surplus is an economic measure of consumer satisfaction, which is calculated by analyzing the difference between what consumers are willing to pay for a good or service relative to market price. A consumer surplus occurs when the consumer is willing to pay more for a given product than the current market price. Consumer surplus is the difference between total amount that consumers are willing to pay for a good or service (indicated by the demand curve) and the total amount that they actually pay (i.e market price of the product). For estimating the change that is associated with a particular policy, the consumer surplus due to that policy intervention is measured to see if the estimated benefits warrant the costs.

2.1.1 Accessibility benefits: user benefit evaluation using utility theory

Accessibility is a fundamentally spatial concept. "Accessibility" may be defined as the description of proximity to destinations of choice and the facilities offered by transportation systems. This definition takes into account the difference amongst the people for whom the measure is calculated, the activities that people access, the mode used and the time budget available to individuals to engage in different activities. Niemeier (1997) demonstrated that the 'logsum' formulation could be used not only as a measure of consumer welfare, but also a measure of accessibility. By definition, a person's consumer surplus is the utility, after conversion to money terms that a person receives in choice situation.

The logsum serves as a summary measure, indicating the desirability of the full choice set (Ben-Akiva and Lerman, 1985). The "logsum" is the log of the denominator of the logit choice probability. A number of studies have used the logsum measure in transport appraisal projects as shown in table 1. Figure 1 shows the change in consumer surplus due to a change in the supply (in this case, addition of new transport mode). Small and Rosen (1981) show that, if utility is linear in income (so that α_n is constant with respect to income), then this expectation becomes

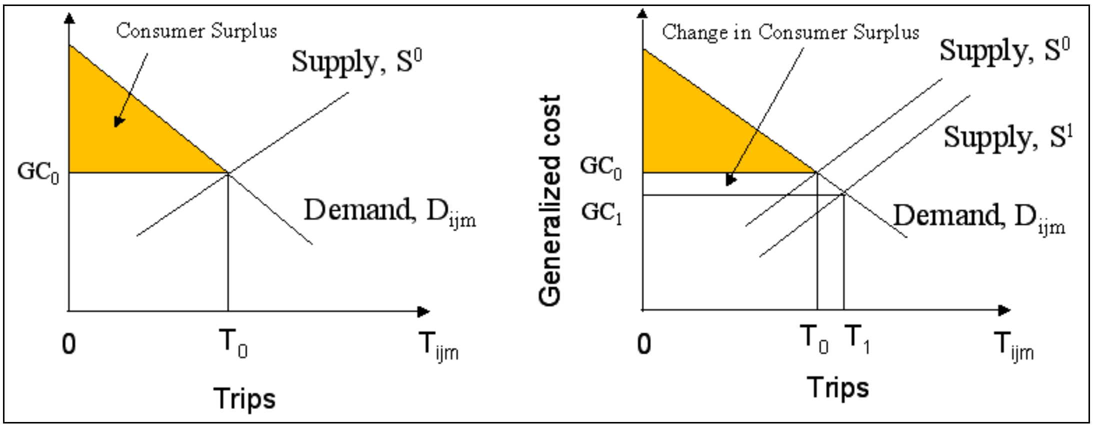
$$E(CS) = \frac{1}{\alpha_n} \ln\left(\sum_{j=1}^{J} e^{V_{nj}}\right) + C \qquad (1)$$

where, C is an unknown constant that represents the fact that the absolute level of utility cannot be measured. When using multinomial logit model, the consumer's surplus may be estimated using the logsum and a coefficient of cost.

The change in consumer surplus that results from change in alternatives and/or choice set is calculated twice: first under the conditions before the change, and again under the conditions after the change. The difference between the two results in the change in consumer surplus, given in equation 2. (Train, 2003)

$$\Delta E(CS_n) = \frac{1}{\alpha_n}\left[\ln\left(\sum_{j=1}^{J^1} e^{V_{nj}^1}\right) - \ln\left(\sum_{j=1}^{j^0} e^{V_{nj}^0}\right)\right] \qquad (2)$$

Where, subscripts 0 and 1 refer to before and after the change. Since the unknown constant C appears in the expected consumer surplus both before and after the change, it drops out in calculating the changes in consumer surplus. However for policy analysis absolute values are not required, rather only changes in consumer surplus are relevant, and the formula for calculating the expected consumer surplus can be used if the marginal utility of income is constant over the range of changes that are considered by the policy.



(a) Consumer surplus (b) Change in Consumer Surplus

Fig 1 Consumer surplus of transit riders

Table 1 Summary of applications of logsum in transport project appraisal

Model Application	Choices included	Marginal utility of income	Conversion method of utility into money
San Francisco (Castiglione et al., 2003)	Mode choice	Constant	Using a common in-vehicle time coefficient to get outcomes in minutes
Europe (EXPEDITE, 2002)	Mode-destination choice	Constant	Using an implied cost coefficient per purpose to get outcomes in euros
Austin (Gupta et al., 2004.,Kalmanje and Kockelman, 2004)	Mode destination and departure time choice	Not Constant	Using a cost coefficient per purpose to get outcomes in dollars
The Netherlands LMS (Koopmans and Kroes, 2004; De Raad, 2004)	Mode destination and departure time choice	Constant	Using time coefficients per purpose to get minutes, then using value of time to get euros
Oslo (Odeck et al., 2003)	Mode-departure time choice	Constant	Using a cost coefficient per purpose to get outcome in Kroner
The Netherlands TIGRIS (RAND Europe, 2004)	Mode-destination and departure time choice	Not Constant	No conversion to money used
Sacramento (USDoT, 2004)	Mode choice	Constant	Using a cost coefficient per segment to get outcomes in dollars

Source: Jong, et al., pp 882

2.2 Equity

2.2.1 Gini coefficient for equity evaluation*:*

In order to relate these measures of accessibility and mobility with equity, the most well established measure of equity, the Gini Coefficient is used (Corrado Gini, 1912).

$$G = 1/(2N^2 W_{avg}).\sum_{i=1}^{N}\sum_{j=1}^{N}\left|w_i - w_j\right| \qquad (3)$$

Where w_i and w_j are the welfare levels for individuals i and j respectively, and w_{avg} is the average welfare of all individuals, and N is the number of individuals.

The Gini coefficient represents the area of concentration (inequality) between the Lorenz curve and the straight line of perfect equality. The Gini coefficient ranges from zero where there is no concentration (perfect equality) to one, where there is an extreme concentration (perfect inequality).

The Lorenz curve is the graphical representation of cumulative distribution function of a probability distribution (Fig 2). A perfectly equal income distribution would be one in which every person has the same income. This can be depicted by the straight line y=x; i.e. like of perfect equality. By contrast, a perfectly unequal distribution would be one in which one person has all the income and everyone else has none. In that extreme case the curve would be at y = 0 for all x<100%, and y =100% when x = 100%. The curve is called the line of perfect inequality. Gini coefficient is the area between the line of equality and the Lorenz curve, divided by area under the line of equality. Gini coefficient is computed by dividing the area of the Lorenz curve by the area under the diagonal. i.e G = A/A+B, where G lies between 0 and 1.

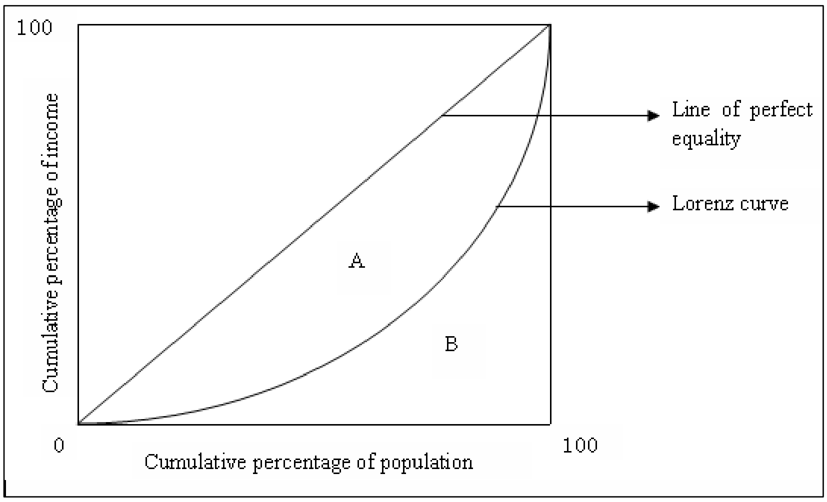


Fig 2 Representative Lorenz curve

2.2.2 Equity index of mobility

Generalized cost is thus the amount of money representing the overall cost and inconvenience to the transport user of traveling between a particular origin (i) and destination zone (j) by a particular mode (m). Genaralized travel cost (Ortuzar and Willumsen, 1994) varies by mode and is typically treated as a combination of various components of a journey. In principle it incorporates all aspects of this inconvenience including "quality" factors like discomfort and reliability. In practice generalized cost is usually limited to time; user charges (e.g. fares, tolls) and vehicle operating cost (VOC's) of the vehicle.

The change in generalized cost (GC) is used here as a measure of mobility. It is the amount of money representing the overall cost and inconvenience to the transport user of traveling between a particular origin (*i*) and destination zone (*j*) by a particular mode (*m*). In principle it incorporates all aspects of this inconvenience including "quality" factors like discomfort and reliability. In practice generalized cost is usually limited to time; user charges (e.g. fares, tolls) and vehicle operating cost (VOC's) of the vehicle.

$$GC_{ijm} = time\cos t_{ijm} + userch\arg es_{ijm} + VOCs_{ijm} \quad (4)$$

where, "time cost" is defined as the time in minutes * value of time in Rs/min

The value of time calculated here as the ratio of the parameter of time over the parameter of cost assumes that the utility function is linear in both time and cost and neither is interacted with any other variable.

$$V_{time} = \beta_{time} / \beta_{\cos t} \quad (5)$$

2.3 Environment

Energy consumption and CO_2 emissions from different modes are used here as an indicator to evaluate the environmental aspect. System dynamics as an important tool supporting policy experiments. A number of studies have applied this approach related to environment, such as, CO_2 emissions from cement industry (Anand et al., 2006) and CO_2 mitigation potential from India's passenger transport sector (Han, et al 2008; Han et al, 2010).

Figure 3 shows the relationships among the items of goal, policy and resulting effects in a system dynamics model. Each arrow indicates the influence of one element on the other. Symbols in rectangle, diamond and circle denote level, constant and auxiliary respectively. Double framed symbols represent arrays of each transport mode. The base year is taken as 2000, and 2020 is set as target year. The ultimate aim of the government is to adopt policies which are effective for CO_2 abatement. In this study we examine the effect of the introduction of metro system on CO_2 emissions. The two stock variables considered are road and rail, where rail refers to the share of metro. Total passenger mobility by each mode i.e road and metro is influenced by vehicle number, rail station number, total passenger, network length, fuel price and fuel intensity. Each of these influence the modal split, transport energy consumption and associated emissions. The base year for projection is 2006 and 2020 is set as target year. First a linear regression model is used to estimate the parameters of modal shares. These parameters are used as input in the system dynamic model to estimate the CO_2 emissions and energy consumption under different scenarios.

2.3.1 Ecological footprint

Ecological footprint method has been proposed as a standard methodology for evaluating the direct environmental implications of various alternatives under consideration developed by Mathis Wackernagel and William Rees at the University of British Columbia. Following the methodology adopted by Muniz and Galindo (2005), ecological footprint of commuting by different modes per trip is estimated. The equation used for the calculation of ecological footprint per trip for zone i is estimated using the equation below:

$$EF_i = \sum_z \left[\left[\sum_j EC_z EL_z D_{ij} trip_{ijz} \right] + L_z \right] \qquad (6)$$

Where, EF_i is ecological footprint per trip for zone i, EC_z is the energy consumption of mode of transport z per passenger kilometer (Mj/pkm), EL_z is the land per energy for mode z (ha/Mj), D_{ij} is the network distance between zones i and j, and $trips_{ij}$ are the trips made from zone i to j by mode z. L_z corresponds to the land uptake by mode z of transport in hectares.

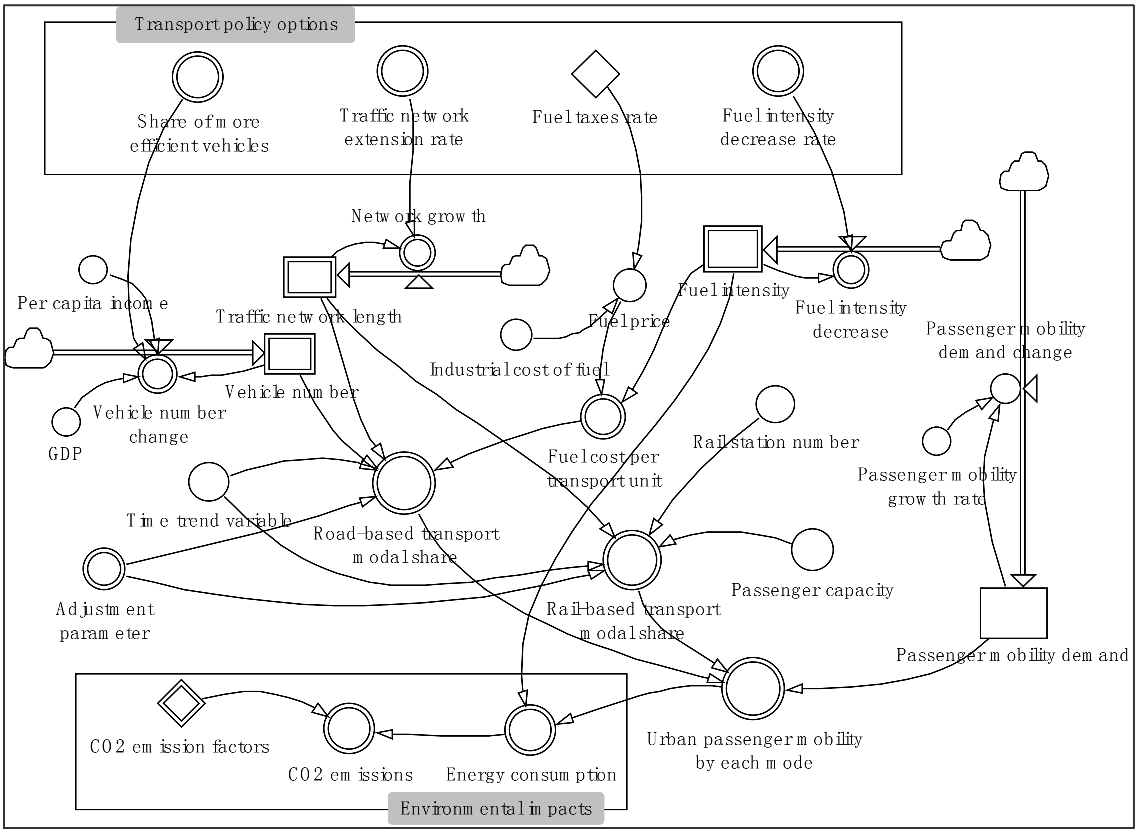


Fig 3 System dynamic model used in the study

4. Framework

Transit investment projects have been identified as both accessibility and mobility enhancing (Handy, S. 2005), but there is limited information as to how individuals value these changes in accessibility and mobility. Niemeier (1997) demonstrated that the 'logsum' formulation could be used not only as a measure of consumer welfare, but also a measure of accessibility. Mobility, on the other hand is seen as an individual's ability to travel to desired destinations or simply 'freedom of movement' (Levine and Garb 2002). The benefit of transportation improvements are viewed in terms of how well individual freedom is enhanced. In order to assess the accessibility and mobility benefits due to transit, the given framework uses the utility theory to estimate the consumer surplus (as a measure of enhanced accessibility), and change in generalized cost from mode destination choice models as a measure of change in mobility. In order to relate accessibility and mobility to equity, the Gini coefficient is then used. Fig 4 shows the broad concept of the framework, the details of which are described in fig 5.

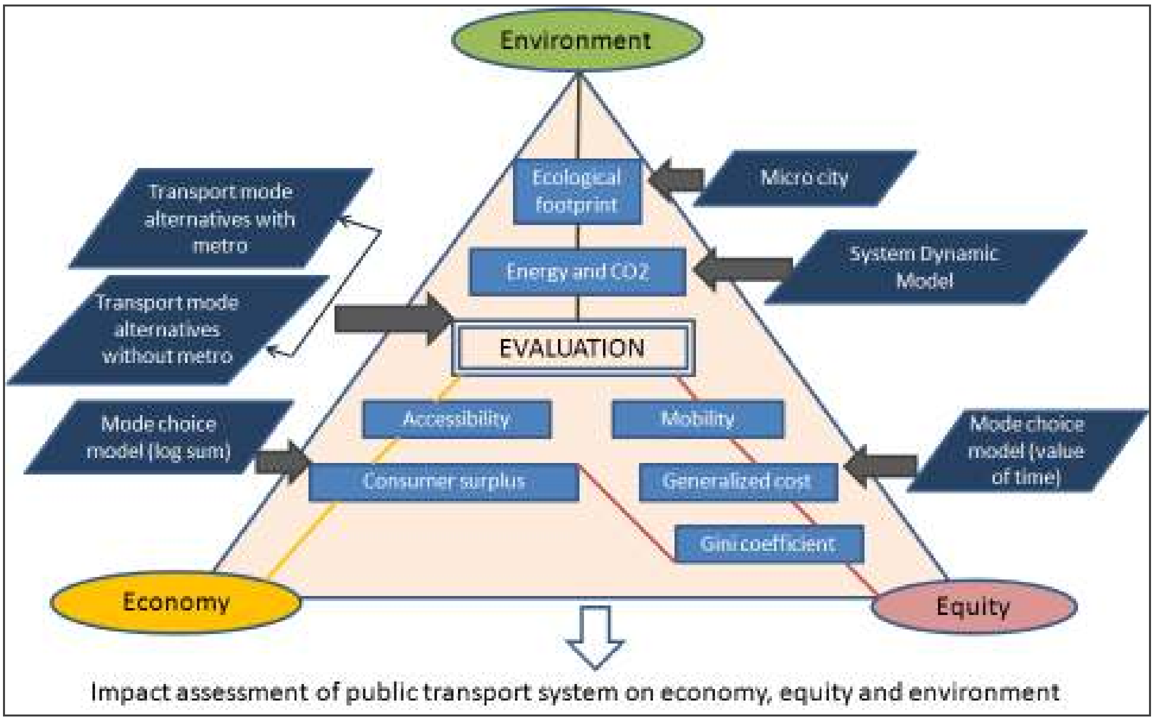


Fig 4 Schematic for impact assessment of public transport system

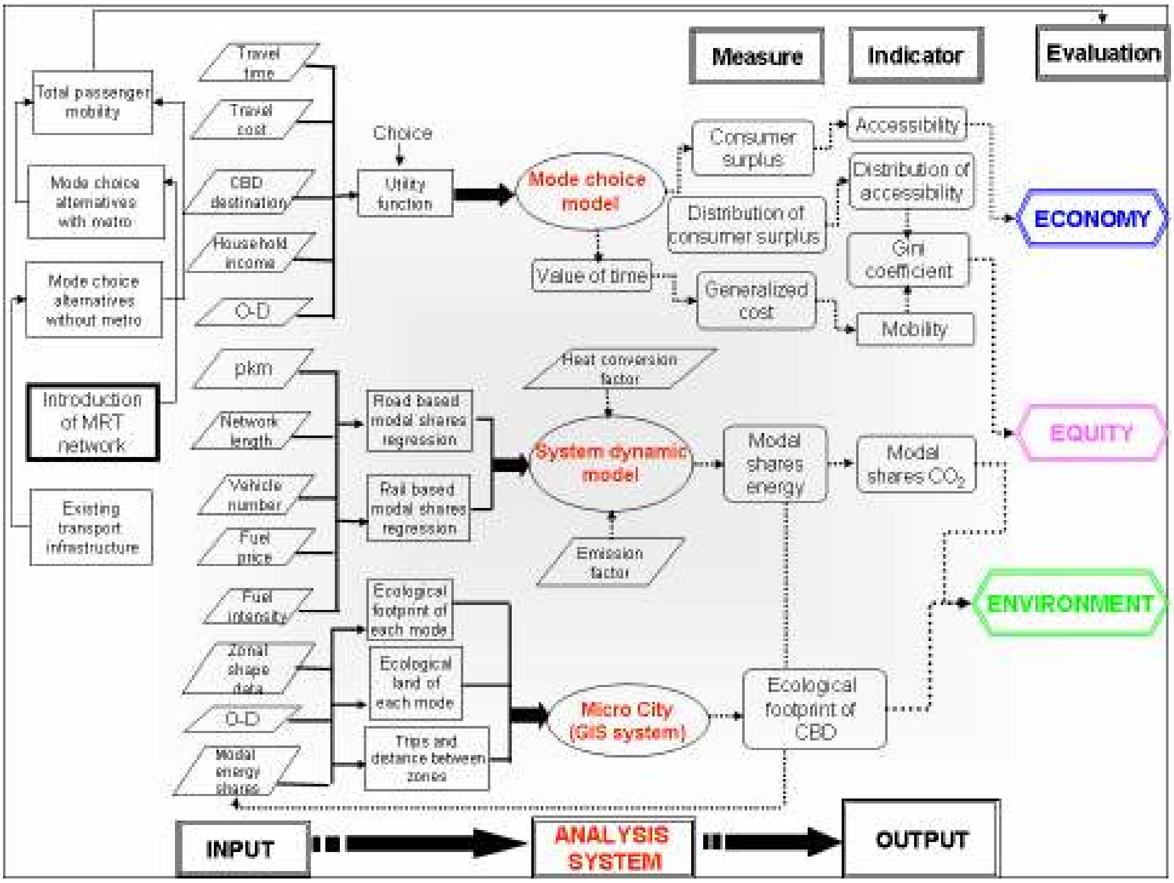
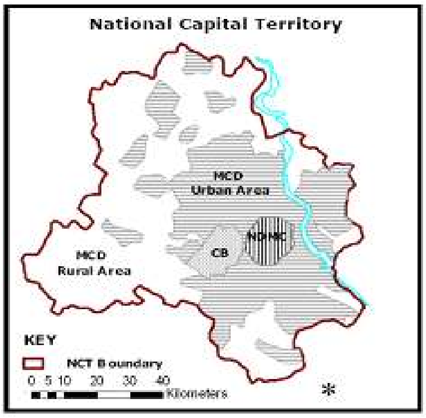


Fig 5 Details of the study framework adopted for impact assessment of public transport system

5. APPLICATION OF THE FRAMEWORK TO THE METRO IN DELHI

5.1 Study area

The national capital territory, Delhi (NCTD) consists of three sub-areas (Fig 6). New Delhi Municipal Corporation (NDMC) area is at the core. This is the imperial Delhi spread over an area of 42.74 sq. km. which was established in 1911. The Municipal Corporation of Delhi includes a total area of 1397 sq. km. (599.6 sq. km. of urban area and 797.7 sq. km. of rural area). It consists of the rather larger spread of Delhi. The Delhi Cantonment between airport and the NDMC area is spread over an area of 42.97 sq. km.



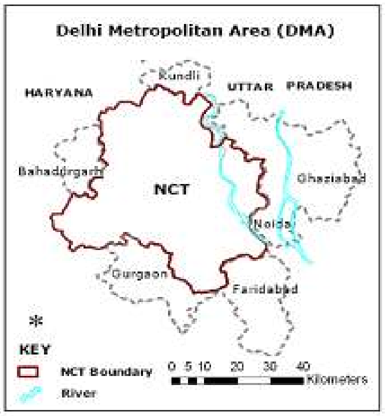


Fig 6 National Capital territory **Fig 7** Delhi Metropolitan area

Delhi is the converging point for five rail lines and five national highways. Growth of Delhi over the years has been on a ring and radial pattern, with reliance on road based public transport system. The draft master plan 2021 emphasizes the need for multimodal transport system, with an optimal mix of rail and road based systems. Integrated multimodal public transport has been proposed for the city, which includes: metro (6 corridors), at grade HCBS (26 corridors), elevated LRT (6 corridors), elevated monorail (3 corridors), integrated rail-cum-bus transit (IRBT) (2 corridors) (CDP, 2006 pp 11-21,22).

5.2 Data and methodology

Passenger mobility in Delhi is mostly road based, with rail constituting less than 1% of the total share in 2001 (Table 2). Table 3 gives the fare structure for bus and MRTS in Delhi. A commuter survey was carried out at 14 stations with total 6771 respondents to assess the benefits of the metro rail system in Delhi by the Delhi Metro Rail Corporation during July. The method of collecting data was by direct administration of survey through interview. Fig 8 and 9 shows the trip purposes, trip frequencies, the shift from different modes to metro and the reason for shift. Evidently, at a sizeable number of trips, 49% of the trips are performed on a daily basis and 34% of the respondents are using the metro occasionally. For trip purposes, work trips cover 59 % of the total trips made by metro (Figure 8a). Analysis shows that 82% of the commuters have shifted from public modes which include, bus, charted bus, Rural Transport Vehicles (RTVs), minibus, taxi and auto rickshaw. Remaining is the shift from private vehicle owners, which includes two wheelers (scooters and motor cycles) and cars. The respondents were also asked to rank the reasons due to which they shifted to metro. Out of the seven main reasons of comfort, time saving, economic, accessible, reliable, safe, and environmentally friendly, the three main reasons leading to the shift were comfort, time saving and safety (Figure 9b). It was also observed that about 77% trips are originated within 2 km of the metro stations and 82% of trips terminated within 2 km of metro stations.

RP survey data from two different sets are used to estimate the mode destination models for work trips in Delhi before and after the implementation of metro lines (Phase 1). The choice of modes before the introduction of metro lines include, bus, car and two wheeler; where as in the latter scenario an additional mode of metro is added. All the individual data sets are then distributed across the 208 traffic analysis zones in Delhi. In order to estimate the cost for different modes, the following procedure is adopted. First, the distance between the origin and destination zones on the road network is estimated by using TRANSCAD. Similarly the distance between the given OD pairs on the bus network and the metro is also estimated. Using the information regarding the distance and the speed of the particular mode (table 4), the values for travel time is estimated. Finally, to estimate the values of cost of each OD pair for car and two wheeler, the data of fuel efficiency, given in table 4 and distance travelled, is used. For the public transport modes, bus and metro the cost is estimated based on the fare structure (table 3) and the distance travelled. The average operating speed for metro is taken as 33 km/hr as specified in table 2.5. The values of travel time and travel cost for car, two wheeler, and bus and metro in the two scenarios i.e. "without metro" and "with metro" is used, along with the other specified variables, to estimate the mode-destination choice model. In the latter scenario, location specific terms in terms of significance of work trips to the CBD, is also estimated. SP data is used to examine the mobility preferences of the respondents in Delhi.

Table 2 Percent mode shares in 2001

S. No.	Mode	Percent
1	Cycle	4.42
2	Rickshaw	2.52
3	Walk	31.20
4	Car-Jeep	5.14
5	Scooter-Motorcycle	12.41
6	Auto rickshaw	2.00
7	Taxi	0.04
8	Bus	36.00
9	Charted Bus	5.96
10	Train	0.24
11	Other	0.06
	Total	100

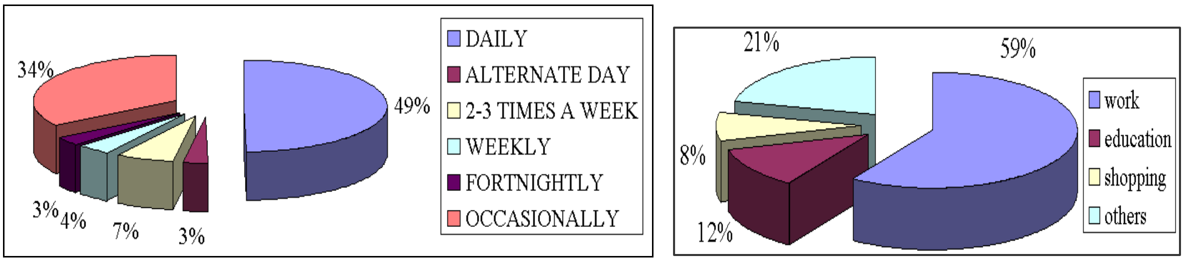
Table 3 Fare structures of public bus service and MRTS

	Bus		MRTS
4 Kms	Rs 2	Minimum	Rs 6
20 Kms	Rs 10	Maximum	Rs 22
30 Kms	Rs 10		

Table 4: Mode characteristics in Delhi

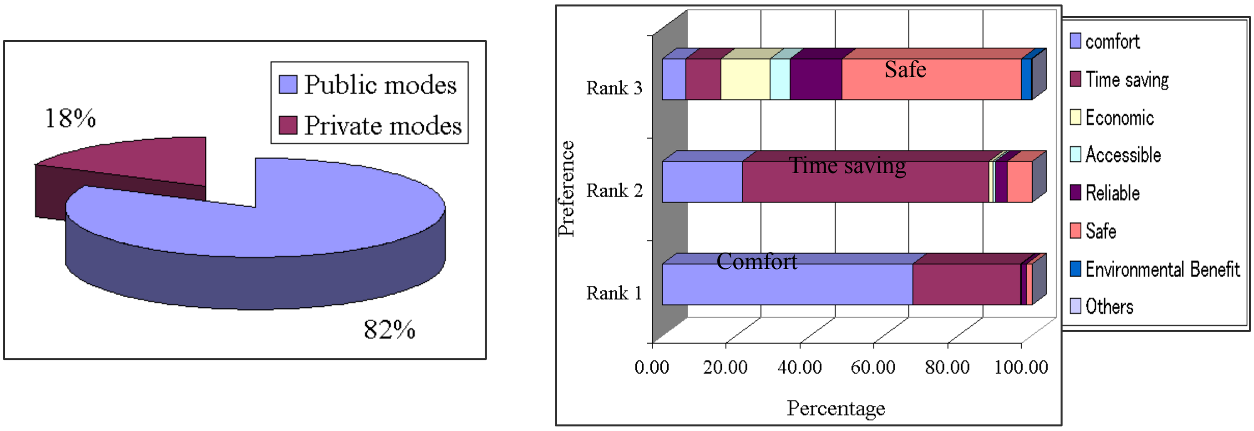
Vehicle type	Occupancy	Fuel Efficiency (Km/lit)	Vehicle utilization (Km/year)	Speed (Km/hr)
Car	2.6	10.9	9500	25*
Two wheeler	1.6	44.4	9000	30*
Three wheeler	1.8	20	25000	-
Bus	52	4.3	70000	20**

Source: Bose and Srinivasachary (1997), * CDP (2006), ** CRRI (2003)



(a) Trip Frequency (b) Trip Purpose

Fig 8 Delhi metro user profile survey results for trip frequencies and trip purposes



(a) Shift from private and public transport modes (b) Reasons for modal shift

Fig 9 Modal shift shares and reasons for Delhi metro users

5.3 RESULTS

5.3.1 Mode choice model

Table 5 gives estimated parameters in the model for each scenario. The parameters of time and cost bring expected signs. The transit specific variable of destination zone CBD for work trips shows significant coefficients as compared to that of other modes. The overall performance of the estimated models may be considered significant as indicated by the ρ 2, along with the individual coefficient estimates which are also significant and show expected signs. Metro shows significant parameters for work trips to CBD where as the other modes, two wheeler and cars do not show any significant relation for such trips to CBD. The log of household income show significant results for both car and metro. However, metro show a higher value when compared to car. It may be inferred as the preference of individuals of higher income for metro as it a faster and more comfortable mode as compared to car, since car users may have to face serious congestion condition on road.

For estimating the GC from the above model, time cost and out of pocket cost of the travelers for each mode has been used. In order to estimate the gain in mobility due to the implemented metro system, the established quantitative measure of equity, the Gini coefficient is estimated (Wessa, P. 2008). The generalized cost of each mode is estimated in two scenarios; i.e. with metro and without metro. For estimating the generalized cost in each scenario, the value of time of each scenario is applied. The change in generalized cost represents the mobility benefit of each mode. The change in generalized cost is Rs 3 for bus, Rs 9 for car and Rs 12 for two wheeler as shown in Table 6. In order to estimate the benefit /month, it is assumed that a person works for 20 days in a month and makes two work trips each day.

Table 5 Estimated model coefficients for two scenarios

		Without metro	With metro
Travel time value (min)		-0.0103 (-1.93)	-0.0543 (-4.34)
Travel cost value (Rs)		-0.0207 (-7.34)	-0.0521 (-6.21)
Mode Constant	Car	-9.84 (-8.55)	-6.61 (-2.02)
	Two Wheeler	-4.61 (-4.30)	-2.86 (-1.21)
	Bus	0	0
	Metro	-	-10.30 (-4.70)
Destination Zone CBD (dummy variable)	Car		0.356 (0.823)
	Two Wheeler		-0.715 (-2.12)
	Bus		0
	Metro		0.832 (2.51)
Log Household Income (Rs/month)	Car	2.28 (7.62)	1.74 (2.25)
	Two Wheeler	0.847 (3.07)	0.915 (1.61)
	Bus	0	0
	Metro		2.54 (4.92)
Summary Statistics	No of Observations	1249	309
	ρ^2	0.434	0.163
Value of Time		Rs/hr 28.57	Rs/hr 62.31
Change in VoT		Rs/hr 33.74	

Note: Values in parenthesis are t-statistic

Table 6 Generalized cost for different modes

Modes	Without metro (Rs)	With metro (Rs)	Benefit (Rs)	Benefit/month (Rs)
Bus	35	32	3	120
Car	89	80	9	360
Two wheeler	63	51	12	480
Metro		34		

Table 7 Equity measure for different modes

Equity measure	Bus	Car	Two wheeler
Gini coefficient	-0.00523	-0.0153	-0.0198

5.3.2 Logsum measure of accessibility

Table 8 gives estimated parameters in the model for each scenario. The parameters of time and cost bring expected signs. The transit specific variable of destination zone CBD for work trips shows significant coefficients as compared to that of other modes. The overall performance of the estimated models may be considered significant as indicated by the ρ 2, along with the individual coefficient estimates which are also significant and show expected signs. The log of household income show significant results for both car and metro. However, metro show a higher value than car. It may be inferred as the preference of individuals for metro as it a faster and more comfortable mode as compared to car, since car users may have to face serious congestion condition on road. The average income of travelers who use rail was found to be much higher than the average income of travelers who use bus by (Winston et al. 1998).

Table 8 Estimated model coefficients for logsum calculation

		Without metro	With metro
Travel time value (min)		-0.0103 (-1.96)	-0.0535 (-4.28)
Travel cost value (Rs)		-0.0207 (-7.34)	-0.0512 (-6.15)
Mode Constant	Car	-9.84 (-8.55)	-6.67 (-2.04)
	Two Wheeler	-4.61 (-4.30)	-3.11 (-1.32)
	Bus	0	0
	Metro	-	-10.00 (-4.66)
Log Household Income (Rs/month)	Car	2.28 (7.62)	1.78 (2.34)
	Two Wheeler	0.847 (3.07)	0.903 (1.60)
	Bus	0	0
	Metro		2.58 (5.06)
Summary Statistics	No of Observations	1249	309
	ρ^2	0.434	0.163
Value of Time		Rs/hr 28.57	Rs/hr 62.35

Note: Values in parenthesis are t-statistic

Table 9 Results of equity measures before and after introduction of metro

Equity measure	No metro	With metro	Change in equity
Gini Coefficient	0.399	0.221	-0.178

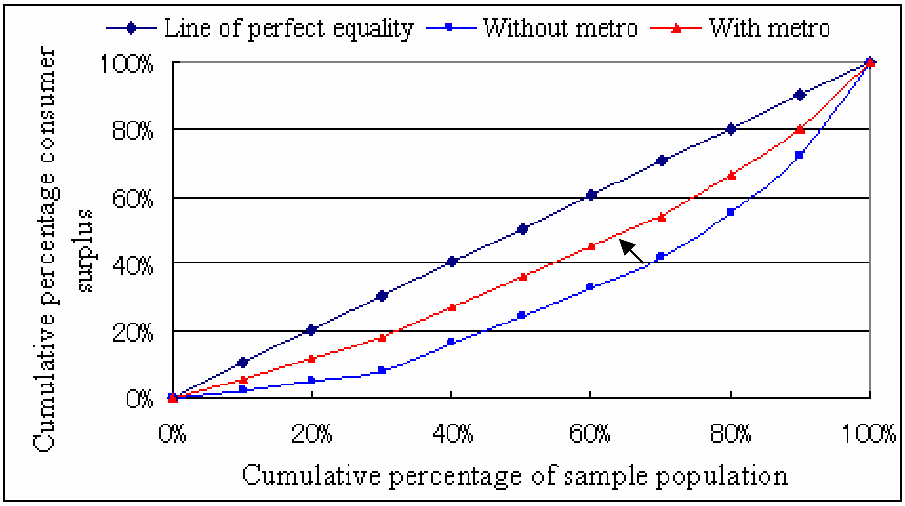


Fig 10 Lorenz curve for accessibility

5.3.3 Passenger mobility and environmental implications

Liner regression model is used to estimate each parameter associated with road based and rail based systems using the simple regression given below

Road based system $$MS_{i,j,t} = C_{i,j} + a_{1,i,j}VN_{i,j,t} + a_{2,i,j}NET_{i,j,t} + a_{3,i,j}FC_{i,j,t} + a_{4,i,j}T \quad (7)$$

Rail based system $$MS_{MRTS,t} = C + a_1 CAP_t + a_2 NET_t + a_3 STN_t + a_4 T$$

where, subscript i represents mode, t denotes time and j represents fuel type; MS is modal split in percentage; CAP is passenger capacity, which is assumed to have a positive effect on the modal share of metro; NET is traffic network length including roads and metro lines. Extension of network length is one of the most important measures encouraging modal share. FC is fuel cost per transport unit, calculated by multiplying fuel price with fuel intensity. Fiscal policy option of levying fuel tax can be evaluated using this parameter. The more fuel cost of a mode is the less attractiveness it will have; STN is rail station number, which is used as an indicator for the accessibility to metro. T is time trend variable, which takes value 1 through 6 from 2001 to 2006; C is a constant. Stepwise estimation is adopted to eliminate the multicollinearity among the independent variables although it is recognized that this has very serious technical pitfalls but is easier to interpret than say factor analysis.

Energy consumption specific for each fuel type and CO_2 emissions are estimated based on the following equations

$$\begin{aligned} EC_{j,t} &= \sum_i PKM \cdot MS_{i,j,t} \cdot FI_{i,j,t} \cdot a_j \\ EM_t &= \sum_j EC_{j,t} \cdot b_j \end{aligned} \tag{8}$$

where, subscript m denotes air pollutant; *EC* is energy consumption; *EM* is emissions; *P-KM* is total passenger mobility; *a* is heat conversion factor, which takes value as 3.2×10^7 J/l for gasoline, 3.6×10^7 J/l for diesel, 3.9×10^7 J/m^3 for CNG and 3.6×10^6 J/kWh for electricity; *b* is CO_2 emission factor per unit heat generation, which is complied from the revised IPCC 1996 guidelines for national GHG inventories. The average electricity generating mix in India is used for estimating pollutant emissions from electricity-based metro system as follows: 70% coal, 15% hydroelectric, 10% natural gas and 5% others (Pew Center on Global Climate Change, 2001). The emission factor for CO_2 estimated are 68.61, 73.33, 55.82 and 73.91 ton/TJ for Gasoline, Diesel, CNG and electricity respectively.

5.3.4 Ecological footprint of commuting

In order to examine the development benefit/ environmental benefit of MRTS to the CBD zones of NCT, the ecological footprint measure is adopted. The principal advantage of the footprint measure is that it adopts a physical variable – units of land area, as a common metric for comparing given alternatives. The footprint measure is applied to estimate the footprint per trip for direct energy usage for each mode. The data on the total number of trips attracted to the CBD by different modes is known. By applying the percentage shift of the trips by bus, car and two wheeler to metro, the change in ecological footprint of the CBD due to commuting trips is estimated. The environmental benefit of MRTS to the CBD may thus be inferred. Microcity (Zhou, 2007) platform is used to estimate the footprint of commuting.

5.3.4.1 Land taken up by transport infrastructure

Delhi has 23% of its land area allocated to roads. Total area of Delhi is 1484 sq. km which is equal to 148300 hectares. The land area of roads is therefore 34109 Hectares. From the traffic volume surveys its is observed that cars constitute 35.02%, Two wheelers 30.34% and buses 5.5% of road space. Using these percentages we get the road space area occupied by car, two wheeler and bus as 11944.97 hectares, 10348.67 hectares and 1875.99 hectares respectively. Land uptake of phase 1 and 11 of metro is 348.71 hectares (RITES, 2005).

5.3.4.2 Ecological land for each mode

For fossil fuel energy sources, the conversion factors are estimates of the land area needed to absorb the excessive CO_2 released by energy burning. Data on typical forest productivity shows that an average forest can accumulate approximately 1.05 tonnes of carbon per hectare per year. This means that one hectare of average forest can annually absorb CO_2 emission generated by the consumption of 60 GJ of biomass fuel (Wackernagel, 1998; Wackernagel and Rees, 1996). The conversion factor for each energy type for each mode is approximated by adjusting this value by specific carbon intensity of energy type. For example conversion factor for coal is 55 GJ/ha/yr compared to values of 71 and 93 for liquid and gaseous fossil fuels per hectare per year respectively (Wackernagel, 1998). For estimating the conversion factor for electricity, the generation mix used in India has been applied which comprises of 70% coal, 15% hydroelectricity, 10% CNG and 5% others. The conversion factor for metro that use electricity has been proportionally adapted.

5.3.4.3 Direct energy consumption for each mode

Energy consumption for each mode of transport is estimated using the system dynamic model in sections 2.3 and 5.3.3. Using these information the footprint of direct energy use for each mode is estimated and shown in table below. Muniz and Galindo (2005) estimated the ecological footprint of commuting in Spain. Following the methodology adopted by them, (as given in equation 6) EF of commuting by different modes per trip is estimated. The equation used for the calculation of ecological footprint per trip for zone i is estimated using the equation below:

Table 10 Footprint of direct energy consumption for different modes in Delhi

Mode	Energy consumption during commuting (Gj/pkm) (a)	Energy-to-land ratio (ha/Gj) (b)	Footprint (ha/pkm) (a*b)
Car	$0.7.92*10^{-4}$	$1.41*10^{-2}$	$1.11*10^{-5}$
Two wheeler	$3.58*10^{-4}$	$1.41*10^{-2}$	$5.04*10^{-6}$
Bus	$4.54*10^{-4}$	$1.08*10^{-2}$	$4.88*10^{-6}$
Metro	$1.5*10^{-6}$	$5.91*10^{-3}$	$8.86*10^{-9}$

Where, EF_i is ecological footprint per trip for zone i, EC_z is the energy consumption of mode of transport *z* per passenger kilometer (Mj/pkm), EL_z is the land per energy for mode *z* (ha/Mj), D_{ij} is the network distance between zones *i* and *j*, and $trips_{ij}$ are the trips made from zone *i* to *j* by mode *z*. L_z corresponds to the land uptake by mode *z* of transport in hectares.

Table 11 Footprint of commuting per trip by each mode

Mode	Footprint per trip (ha)
Car	$1.07*10^{-4}$
Two Wheeler	$4.26*10^{-5}$
Bus	$3.21*10^{-4}$
Metro	$7.30*10^{-7}$

The total trips to the CBD zones by bus, car and two wheeler which shifted to metro is then used to estimate the change in footprint of CBD after the introduction of metro due to commuting trips. The percentage of trips to CBD by bus is 73.2%. Car and two wheeler trips constitute 12.1% and 14.7% respectively. The footprint of CBD due to commuting trips before the introduction of metro is 0.077 ha, which reduces to 0.000223 ha because of a considerable shift of a number of trips to metro.

5. RESULTS

International funding agencies like the World Bank, Asian Development Bank, Department of International Development (DFID), U.K. advocate inclusion of social assessments in transportation projects and prioritize poverty alleviation as an objective. The projects funded by them have also focused on mobility and access needs of the people. Hence the evaluation of transport projects from the perspective of social development goals become important, especially for large projects where the impacts are spatially and temporally extensive. The present study therefore targets the socio-economic and environmental impacts of Delhi metro rail.

Major contributions of the study can be summarized as follows:
1. The study presents a comprehensive evaluation framework which could be applied to any public transport system to understand the economic, equity and environmental benefits of transport infrastructure.
2. The study presents the link between mobility and equity applying the generalized cost as a measure of mobility.
3. A link between accessibility and equity is also presented, by applying the consumer surplus as a measure of accessibility.
4. The environmental benefit of metro to CBD is examined by applying the ecological footprint methodology,

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