Social Cost-Benefit Analysis of Delhi Metro

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Abstract:
The growing demand for public transport in mega cities has serious effects on urban ecosystems, especially due to the increased atmospheric pollution and changes in land use patterns. An ecologically sustainable urban transport system could be obtained by an appropriate mix of alternative modes of transport resulting in the use of environmentally friendly fuels and land use patterns. The introduction of CNG in certain vehicles and switching of some portion of the transport demand to the metro rail have resulted in a significant reduction of atmospheric pollution in Delhi. The Delhi Metro provides multiple benefits: reduction in air pollution, time saving to passengers, reduction in accidents, reduction in traffic congestion and fuel savings. There are incremental benefits and costs to a number of economic agents: government, private transporters, passengers, general public and unskilled labour. The social cost-benefit analysis of Delhi Metro done in this paper tries to measure all these benefits and costs from Phase I and Phase II projects covering a total distance of 108 kms in Delhi. Estimates of the social benefits and costs of the project are obtained using the recently estimated shadow prices of investment, foreign exchange and unskilled labour as well as the social time preference rate for the Indian economy for a study commissioned by the Planning Commission, Government of India and done at the Institute of Economic Growth. The financial internal rate of return on investments in the Metro is estimated as 17 percent while the economic rate of return is 24 percent. Accounting for benefits from the reduction of urban air pollution due to the Metro has increased the economic rate of return by 1.4 percent.

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I. About Metro Rail in Delhi

Delhi, the capital city of India, is one of the fastest growing cities in the world with a population of 13 million as reported in the Census of India Report for the year 2000. Until recently, it was perhaps the only city of its size in the world depending almost entirely on roads as the sole mode of mass transport. The total length of the road network in Delhi has increased from a mere 652 km in 1981 to 1122 km in 2001 and it is expected to grow to 1340 km in the year 2021. This increase in road length is not at par with the phenomenal growth in the number of vehicles on these roads in Delhi. The cumulative figure of registered private and government buses, the main means of public transport, is 41,872 in 1990 and it is expected to increase to 81,603 by the year 2011. The number of personal motor vehicles has increased from 5.4 lakhs in 1981 to 30 lakhs in 1998 and is projected to go up to 35 lakhs by 2011. With gradual horizontal expansion of the city, the average trip length of buses has gone up to 13 km and the increased congestion on roads has made the corresponding journey time of about one hour. Delhi has now become the fourth most polluted city in the world, with automobiles contributing more than two thirds of the total atmospheric pollution. In this context, the decision of the Government of India to develop a mass transport system for Delhi providing alternative modes of transport to the passengers was most appropriate.

The first concrete step in the launching of an Integrated Multi Mode Mass Rapid Transport System (MRTS) for Delhi was taken when a feasibility study for developing a multi-modal MRTS system was commissioned by the Government of the National Capital Territory of Delhi (GNCTD) at the instance of the Government of India in 1989 and completed by Rail India Technical and Economic Services Limited in 1995 (RITES, 1995a, 1995b). The Delhi Metro (DM) planned in four phases is part of the MRTS. The work of Phase I and part of Phase II is now complete while that of phase III is in progress. The first phase of DM consists of 3 corridors divided in to eight sections with a total route of 65.1 kms, of which 13.17 kms has been planned as an underground corridor, 47.43 kms as elevated corridors and 4.5 kms as a grade rail corridor. The second phase covers 53.02 kilometers of which the underground portion, grade and elevated section are expected to be 8.93 kilometers, 1.85 kilometers and 42.24 kilometers respectively. The construction of the first phase of DM was spread

over 10 years during 1995-96 to 2004-05 while that of the second phase, which started in 2005-2006 is expected to be complete by 2010-11. The total capital cost of DM at 2004 prices for Phase I and Phase II are estimated as Rs. 64,060 and Rs. 80,260 million, respectively. Phases III and IV of DM will cover most of the remaining parts of Delhi and even extend its services to some areas such as Noida and Gurgaon belonging to the neighbouring states of Delhi. Table 1 provides some of these details.

Table 1: Overview of the MRTS

	Phase I (1995 - 2005)	**Phase II (2005 –2011)**
Distance	65.10 km	53.02 km
Corridors	1) Shahdara - Barwala (22)	1) Vishwa Vidhyalaya- Jahangirpuri (6.36)
	2) Vishwa Vidhyalaya- Central Secretariat (11)	2) Central Secretariat- Qutab Minar (10.87)
	3) Barakhamba Road - Dwarka (22.8)	3) Shahdra- Dilshad Garden (3.09)
	4) Barakhamba Road – Indraprastha (2.8)	4) Indraprastha- New Ashok Nagar (8.07)
	5) Extension into Dwarka Sub city (6.5)	5) Yamuna Bank- Anand Vihar ISBT (6.16)
		6) Kirti Nagar- Mundka (18.47)
Investment	Rs 6406 crores (2004 prices)	Rs 8026 crores (2004 prices)
	Phase III	**Phase IV**
Distance	62.2 km	
Corridors	1) Rangpuri to Shahabad Mohammadpur	1) Jahangirpuri to Sagarpur West
	2) Barwala to Bawana	2) Narela to Najafgarh
	3) Jahangirpuri to Okhla Industrial Area Phase I	3) Andheria Mod to Gurgaon
	4) Shahbad Mohammadpur to Najafgarh	

Source: RITES (2005a)

This study attempts the social cost-benefit analysis of Phases I and II of DM. The Delhi Metro provides a number of benefits. It reduces the travel time of people using the road and metro, number of accidents on the roads and the atmospheric pollution in Delhi. The remaining part of this study is planned as follows. Section II provides a financial evaluation of DM. Section III attempts the description of economic benefits and costs and various stakeholders of DM and the methods of economic evaluation used. Section IV presents an analysis of economic benefits and costs of the project. Section V describes the income distributional effects of DM, while Section VI provides conclusions.

II. Financial Costs and Benefits of the Metro

It is important to examine the financial feasibility of DM before actually taking up its economic appraisal. The financial evaluation of a project requires the analysis of its annual cash flows of revenue and costs considering it as a commercial organization operating with the objective of maximizing private profits. The financial capital cost of DM represents the time stream of investment made by it during its lifetime. The investment expenditures made by the project in one of the years during its life time constitutes the purchase of capital goods, cost of acquisition of land and payments made to skilled and unskilled labour and material inputs for project construction. The operation and maintenance cost of the project constitutes the annual expenditure incurred on energy, material inputs for maintenance and payments made to skilled and unskilled labour. The investment goods and material inputs used by the project are evaluated at market prices, given the definition of market price of a commodity as producer price plus commodity tax minus commodity subsidy. If the government gives some commodity tax concessions to DM, they are reflected in the prices paid by DM for such commodities. If the financial capital cost of the project is worked out as the time flow of annualized capital cost, the annual cost of capital has to be calculated at the actual interest paid by it. This could be done using information about the sources of funds for investment by DM and the actual interest paid by it to each source. For example, if part of the investment of DM is financed out of loans provided by the government at the subsidized interest rate, the annual cost of this investment has to be calculated at the subsidized interest rate.

Table 2 provides the sources of funding investments of DM (phases I and II). More than 60 percent of the funds required for investment are raised as debt capital. Around 30 percent of total investments of DM are raised through equity capital with the Government of India (GOI) and GNCTD having equal shares in it. The remaining 10 percent of the investments of DM will be covered out of the revenues it earns. As reported in RITES (1995a), the DM had been provided with the following concessions by GOI to make the project viable, namely (a) The cost of land equivalent to Rs. 2180 million has been provided as an interest free subordinate loan by GOI/GNCTD to be repaid by the DM within 5 years after the senior debt is repaid fully by the twentieth

year of taking the loan (b) The risk associated with the exchange rate fluctuations is borne by government in case of foreign debt, (c) The DM is exempted from payment of income tax, capital gains tax, property tax and customs duty on imports, (d) The DM is permitted to generate resources through property development over a period of 6-20 years and (e) No dividend is paid on GOI share of equity till the senior debt is repaid fully by the twentieth year.

Table 2: Sources of Funding

Cost Financed By	Phase I	Phase II
1) Equity (50% each by GOI & GNCTD)	30%	30%
2) Long Term Debt (OECF, Japan) @ 3% p.a. or less	60%	56%
(with a 10 year moratorium period and 10 year repayment period)		
3) Revenues From Property Development	7%	5%+ 5% (internal resources)
4) Subordinate Debt	3%	4%

Source: RITES (1995a)

Table 3 provides information about various components of capital cost for Phase I of DM. The total project cost of Rs. 64,060 million at 2004 prices for Phase I consists of the foreign exchange cost of Rs. 7720 million and the domestic material and labour cost of Rs. 56,340 million. The corresponding figure for the Phase II of DM is Rs. 80,260 million at 2004 prices.

Table 3: Cost Estimate of DM (Phase I)

(Rs. Million)

Items	Foreign Exchange	Local Cost	Total
Civil works	0	31327	31327
Electrical works	0	6970	6970
Signaling and telecommunication	2574	1930	4504
Rolling stock	4596	6403	10999
Land	0	3339	3339
General establishment and consultancy charges	322	4779	5101
Contingencies	230	1593	1823

Source: RITES (1995a)

Table 4: Estimates of Financial Flows of Investment by DM (Phases I and II) During its Life Time

(Rs. Million)

Year	Capital Cost	Year	Capital Cost	Year	Capital Cost	Year	Capital Cost
1995	2574	2007	20411	2019	361	2031	43290
1996	3937	2008	23331	2020	1543	2032	15150
1997	6036	2009	17861	2021	18901	2033	0
1998	8625	2010	5281	2022	1183	2034	0
1999	9498	2011	1271	2023	1183	2035	0
2000	10110	2012	361	2024	1183	2036	0
2001	9069	2013	361	2025	0	2037	0
2002	7353	2014	361	2026	0	2038	0
2003	4917	2015	361	2027	0	2039	0
2004	1945	2016	361	2028	0	2040	0
2005	4061	2017	361	2029	0	2041	58770
2006	12381	2018	361	2030	0		

Source: Estimated as explained in the text.

Table 5: Estimates of Financial Flows of Operation and Maintenance (O&M) Expenditures by DM (Phases I and II) During its Life Time

(Rs. Million)

Year	O&M	Year	O&M	Year	O&M
2005	3123	2017	10484	2029	20149
2006	3253	2018	10981	2030	21255
2007	3387	2019	11507	2031	24628
2008	3527	2020	12127	2032	26042
2009	3674	2021	13763	2033	27562
2010	7822	2022	14374	2034	29198
2011	8006	2023	15032	2035	30958
2012	8366	2024	15738	2036	32852
2013	8745	2025	16498	2037	34891
2014	9145	2026	17316	2038	37086
2015	9568	2027	18195	2039	39449
2016	10013	2028	19141	2040	41993

Source: Estimated as explained in the text.

Table 4 provides the estimated financial flows of capital cost of DM at 2004 prices during its lifetime. RITES (1995a, 2005b) provide the estimates of operation and maintenance cost (O&M cost) of DM. These estimates are made using information about the trends of the O&M cost of Calcutta Metro and the suburban sections of the

Bombay Railway and the results of some optimization studies conducted. Table 5 provides the estimates of O&M cost of DM at 2004 prices during the lifetime of the project.

The financial benefits from the Metro are the fare box revenues and the revenues from advertisement and property development, as reported by RITES. Revenue streams for Phases I and II, as reported by RITES (1995b, 2005b) have been taken. The main source of revenue of the MRTS system is the fare box collection, which is a product of the total passenger ridership on the MRTS as reported in Tables 6 and 7 and the fare charged. RITES (1995b) considered four rates per trip: Rs 3, 4, 5, 6 at April 1995 prices and the fare sensitivity of ridership. Full ridership is expected to materialize on the metro with a fare comparable to the DTC bus fare of Rs. 3 per passenger trip. However, with higher fares, the ridership is expected to decline given that the willingness of passengers to travel by the metro depends on the value they place on time savings, frequency and safety of service, comfort and ease of travel, capacity to pay, etc. The financial model consisting of Rs. 5 per passenger trip and an annual fare increase of 7.5 per cent was considered optimal by RITES. The revenue collected by DM every year during its life time consists of revenue from the passenger traffic diverted from the road to the Metro and the revenue from serving part of the growing passenger traffic demand in Delhi. Table 8 presents the estimates of revenue collected by DM during its lifetime. Considering the estimates of financial flows of DM during the period 1995-2041, the financial cost-benefit ratio is estimated as 2.30 and 1.92 at 8 percent and 10 percent discount rates, respectively. The financial internal rate of return of DM is estimated as 17 percent.

Table 6: Fare Sensitivity of Ridership on the Metro

Fare Rate	**Percentage Ridership**
(In Rs/Passenger trip)	
3	100%
4	90%
5	75%
6	50%

Source: RITES (1995b)

Table 7:Estimates of Daily Passenger Trips by Metro
(in lakhs)

Year	Daily Passenger Trips
2002	12.63
2003	20.15
2004	23.86
2005	31.85
2006	33.17
2007	34.55
2008	35.97
2009	37.46
2010	39.01
2011	40.63
2012	41.81
2013	43.03
2014	44.29
2015	45.58
2016	46.91
2017	48.28
2018	49.69
2019	51.14
2020	52.63
2021	54.17

Source: RITES (1995b, 2005b)

Table 8: Estimates of Financial Flows of Revenue Earned by DM (Phases I and II) During its Lifetime
(Rs. Million)

Year	Revenue	Year	Revenue	Year	Revenue
2005	15052	2018	67722	2031	128687
2006	17152	2019	74284	2032	133307
2007	19407	2020	82806	2033	134177
2008	21826	2021	92342	2034	139477
2009	24421	2022	99126	2035	140477
2010	33762	2023	106242	2036	146547
2011	37112	2024	115557	2037	147687
2012	41057	2025	116067	2038	154657
2013	44511	2026	119127	2039	155947
2014	50847	2027	119717	2040	163947
2015	49633	2028	123227	2041	165437
2016	5627	2029	123897		
2017	62209	2030	127927		

Source: Estimated as explained in the text.

III. Identification of Economic Benefits and Costs of Metro

Description of economic benefits and costs of the Delhi Metro requires the identification of the changes brought out by it in the transport sector of the economy. Most importantly, DM contributes to the diversion of a very high proportion of current passenger traffic from road to Metro and serves part of the growing passenger traffic demand in Delhi. As a result, there will be a reduction in the number of buses, passenger cars and other vehicles carrying passengers on Delhi roads with the introduction of the Metro. There will be savings in travel time for passengers still traveling on roads due to reduced congestion and obviously also for those traveling by Metro. The Metro also brings about a reduction in air pollution in Delhi because of the substitution of electricity for petrol and diesel and reduced congestion on the roads. There will also be a reduction in the number of accidents on the roads.

Investment in the Metro could result in the reduction of government investments on road developments and buses as also in the private sector investment on buses, passenger cars and other vehicles carrying passengers. There will be reductions in motor vehicles' operation and maintenance charges to both the government and the private sector. There could be cost savings to passenger car owners in terms of capital cost and operation and maintenance costs of cars if they switch over from road to Metro for travel in Delhi. The fare box revenue collections by Metro will be at the cost of the revenue, accruing earlier to private and the government bus operators and hence constitutes a loss in income.

The Delhi public will gain substantially with the introduction of the Metro service. It saves travel time due to a reduction of congestion on the roads and lower travel time of the Metro. There will be health and other environmental benefits to the public due to reduced pollution from the transport sector of Delhi. Land and house property owners gain from the increased valuation of house property prices due to the Metro. The Metro has the effect of increasing the income of the regional economy of Delhi vis a vis the rest of the Indian economy. Given that the per capita income of Delhi is far higher than the national per capita income, the redistribution of income in favour of Delhi may not be desirable from the point of view of income distribution in the Indian economy. The Metro provides employment benefits to the unskilled labour especially during its

construction period. This labour is otherwise unemployed or under employed in the Indian economy. Table 9 describes the benefit and cost flows due to the Metro.

Table 9: Benefit and Cost Flows of Delhi Metro Investment

Investment

- Investment of Metro: I_m
- Investment reduced due to Metro
  - Private buses: I_{bpri}
  - Public buses: I_{bpub}
  - Personal vehicles (cars and two-wheelers): I_{pv}
- Savings in Investment Cost of Road Infrastructure: I_{ri}

Operation and Maintenance (O&M) Charges

- O & M charges of Metro: O_m
- O & M charges reduced due to Metro due to fewer vehicles on road and decongestion
  - Private buses: O_{bpri}
  - Public buses: O_{bpub}
  - Personal vehicles (cars and two-wheelers): O_{pv}

Revenue

- Revenue of Metro: R_m
- Tax Revenue to Government: R_t
- Revenue loss due to Metro
  - Private buses: R_{bpri}
  - Public buses: R_{bpub}

Benefits

- Reduction in pollution: B_{pp}
  - Due to reduction in number of vehicles on road
  - Due to reduction in congestion on roads
- Savings in travel time: B_{stt}
  - Due to reduction on congestion on roads
  - Due to reduction in travel time for Metro passengers
- Reduction in accidents: B_{ra}

Foreign Exchange Costs and Benefits

- Investment cost: I_{mf}
- Savings in fuel cost: B_f

Various economic agents relevant for Metro could be identified as the government, passengers, transporters, general public and unskilled labour. Unskilled labour employed on the Metro gains to the extent of the difference between the project wage rate and the shadow wage rate. The social premium on investment and savings and foreign exchange accrue to the society represented by the General Public.

The flows of net economic benefits (NEB) of DM to the various economic agents could be computed as follows:

Government: $NB_g = (R_m + O_{bpub} + I_{bpub} + I_{ri} + R_t) - (I_m + O_m + R_{bpub} + R_t)$

Passengers: $NB_p = ((R_{bpri} + R_{bpub}) - R_m) + B_{st} + (I_{pv} + O_{pv}) + B_{ra}$

Transporters: $NB_t = O_{bpri} - R_{bpri}$

Unskilled labour: $NB_{ul} = (1 - P_{DUL})(I_{ml} + O_{ml})$ (1)

General public: $NB_{gp} = B_{pp} + (P_I - 1)(s_g NB_g + s_p NB_p + s_t NB_t + s_{ul} NB_{ul} + s_{gp} NB_{gp}) + (P_F - 1)(B_f - I_{mf}) - P_{IUL}(I_{ml} + O_{ml})$

where, s_g, s_p, s_t, s_{gp} and s_{ul} represent respectively average rates of savings of government, passengers, transporters, general public and unskilled labour and

P_{DUL}: Ratio of marginal productivity of labour and project wage rate

P_I: Shadow price of investment

P_F: Ratio of shadow price of foreign exchange and market exchange rate

P_{IUL}: ratio of indirect opportunity cost of labour and project wage rate

The annual economic benefits of DM could be computed as

$$NEB = NB_g + NB_p + NB_t + NB_{UL} + NB_{gp} \quad (2)$$

Finally, the estimates of annual flows of social benefits of DM are obtained by applying the estimates of income distributional weights to the incomes accruing to various economic agents from the Metro. Given the estimates of flows of annual economic benefits to the various agents described in Table 9, the net annual social benefits after accounting for income distributional effects of DM could be computed as,

$$NSB = w_g . NB_g + w_p . NB_p + w_t . NB_t + w_{UL} . NB_{UL} + w_{gp} . NB_{gp} \quad (3)$$

Two methods are used for the estimation of net present value of economic benefits (NPEB), the social cost-benefit ratio and the social rate of return of DM in this study.

One method assumes that there is a sub-optimal level of savings in the Indian economy and uses the social time preference rate as the rate of discount, the shadow price of investment, the shadow price of unskilled labour consisting of the direct and indirect opportunity cost of unskilled labour employment and the shadow price of foreign exchange in the estimation of annual flows of economic benefits and costs of DM. Another method assumes that there is no sub-optimal level of savings in the Indian economy and uses the rate of return on investment as the social rate of discount, shadow price of unskilled labour consisting of direct opportunity cost and the shadow price of foreign exchange.

IV. Measurement of Economic Costs and Benefits of Metro

The economic costs of the Metro are calculated after excluding the tax component from the financial costs. In a recent study, Murty and Goldar (2006) have estimated the effective state VAT and MODVAT rates on durable commodities in India as 3.8 percent and 6.36 percent, respectively. Since these taxes are levied on the same base, the total effective tax rate applicable for durable commodities in India is roughly 10 percent. The effective tax could be interpreted as the revenue the Indian Government (central and states) gets if there is an increased demand for a commodity by one unit at margin (Ahmad and Stern 1984; Murty and Ray 1989). If the taxes are ad valorem, it implies an increase in the revenue of the government if there is an increase in a rupee worth of expenditure on that commodity. These taxes are also interpreted as shadow taxes. No tax payments are considered on the expenditures incurred by the DM for the employment of unskilled labour. Table 10 provides estimates of the economic cost of DM for some select years during its lifetime.

Table 10: Components of Economic Capital and O&M Cost

(Rs. Million)

	Capital Cost			O&M Cost	
	Foreign	**Unskilled**	**Domestic**	**Unskilled**	**Domestic**
Year	**Exchange**	**Labour**	**Material**	**Labour**	**Material**
1995	1390	257	695	0	0
2000	5460	1011	2730	0	0
2005	2193	406	1097	156	2671
2010	2852	528	1426	391	6687
2015	0	36	292	478	8180
2020	0	154	1250	606	10369
2025	0	0	0	825	14106
2030	0	0	0	1063	18173
2035	0	0	0	1548	26469
2040	0	0	0	2100	35905

Source: Estimated as explained in the text.

Reduction in the number of vehicles on road

The growth rates of registered cars, two-wheelers, three wheelers, taxis and buses in Delhi are calculated as 9.8, 11, 8, 5 and 7 percent, respectively using data for these vehicles for the period 1971-2002. To calculate the number of vehicles going off the road due to the introduction of MRTS the following exercise is conducted. The registered number of vehicles for each category of these vehicles in Delhi for the period 2002-42 is estimated using the above mentioned growth rates. RITES (1995a) has reported that out of the total registered vehicles, only 28 percent of cars, 40 percent of two-wheelers and 65 percent of taxis and three wheelers are on the roads. It is also reported, depending upon the area and the density of population through which the Metro line passes, that only 30 percent of vehicles on road are influenced by Phase I of the Metro. It is further mentioned that 45 percent of cars, 70 percent of two-wheelers, and 25 percent of buses out of the influenced traffic are diverted to Metro. It is assumed that modes of transport like taxis and three wheelers are on the road by choice and hence they will not be diverted due to the Metro. Table 11 reports estimates of diverted traffic to Metro (Phases I and II) for some selected years during 2005-06 to 2042-43.

Table 11: Reduction in Vehicles Due to Metro (Phases I & II)

Year	Cars & Jeeps	Two wheelers	Buses	Total
2005-06	50586	284433	3398	338418
2010-11	80731	479286	4767	564784
2015-16	238737	1496497	12388	1747622
2020-21	381006	2521685	17374	2920065
2025-26	608055	4249185	24368	4881609
2030-31	970409	7160124	34178	8164711
2035-36	1548697	12065226	47936	13661859
2040-41	2471600	20330607	67233	22869440
2042-43	2979770	25049341	76975	28106087

Source: Estimated as explained in the text

The economic benefits from the reduced number of vehicles on Delhi roads due to the Metro could be identified as the following:

- Savings in Foreign Exchange due to reduced Fuel Consumption
- Reduction in Pollution
- Savings in Time for all passengers using Metro and Roads
- Savings in Accidents
- Savings in Vehicle Operating Cost (VOC) due to decongestion for residual traffic
- Savings in Capital and Operating cost of diverted vehicles
- Savings in the cost of Road Infrastructure

Savings in fuel consumption

There are savings in fuel consumption (inclusive of both CNG and petrol) due to the diversion of a part of the Delhi road traffic to Metro and reduced congestion to vehicles still operating on the roads. There is an inter-fuel substitution of petrol and CNG to electricity that could result in savings of foreign exchange and a reduction of air pollution. Fuel saved due to traffic diverted to the Metro is estimated given the estimates of diverted traffic described above and the annual run and fuel consumption norms of different vehicles. Table 12 provides information about the annual run and fuel consumption norms of different vehicles in Delhi. RITES (2005a) has estimated the total reduction in CNG due to the traffic of buses diverted to the Metro (Phases I & II) during the year 2011-12 as 39.65 million kg. Similarly, the fuel saved due to the

diverted traffic of cars and two-wheelers is estimated as 138.35 and 25.70 million litres respectively. When these fuel savings are valued at 2004 prices (Rs. 18/kg for CNG and Rs. 38/litre for petrol) the corresponding fuel savings for cars, two-wheelers and buses are Rs. 5260, 9770 and 710 million, respectively.

Table 12: Annual Run and Fuel Consumption Norms

Traffic Mode	Diverted Traffic	Fuel Consumption Norm	Daily Run	Fuel Savings	Value of Fuel savings (million)
Cars	164252	13	30	138350586	5257
two-wheelers	985789	35	25	257009274	9766
Buses	9450	18	209	39651154	714

Notes: For cars and two-wheelers using petrol, price is Rs. 38/ltr
For buses using CNG, price is Rs. 18/kg
Source: Estimated as explained in the text

RITES (1995a) has used the following formula which is also used in a study by the Central Road Research Institute (CRRI) for estimating the fuel savings by residual vehicles due to the reduced congestion on Delhi roads after Metro.

$$F_c = A(\frac{1}{V_c} - \frac{1}{V_d}) + B(V_c^2 - V_d^2)\,.$$

where,

F_c = savings in fuel consumption (cc/km) due to decongestion

V_c = speed of vehicles in a congested situation

V_d = speed of vehicles in a decongested situation

A = 1675.52 for cars and 3904.6445 for buses

B = 0.0133 for cars and 0.0207 for buses

The estimates of savings in fuel consumption for cars and buses calculated by using the above formula are 28.73 cc/km and 91.19 cc/km, respectively. The residual traffic on Delhi roads, in terms of number of cars and buses, for the year 2011-12 are 200752 and 28351 respectively. The total savings in fuel due to decongestion is the product of residual traffic, fuel savings norms given by the above formula, annual run and a conversion factor (cc to litre). The fuel savings during the year 2011-12 due to the decongestion effect for cars and buses are 20714391 ltr and 38510952 ltr, respectively. The RITES study has assumed that the fuel savings of two-wheelers are roughly one-third of cars, which becomes 6835749 ltr.

These savings are valued at 2004 prices as Rs. 390, 130 and 350 million for cars, two-wheelers and buses, respectively.

Fuel savings arising out of the Metro could result in the savings of foreign exchange for the Indian economy given that a very large proportion of domestic demand for petroleum products in India has been met out of imports. A recent study (Murty and Goldar, 2006) on investment planning in India provides an estimate of the shadow price of foreign exchange, which is 10 percent higher than the market exchange rate. Given that there are Rs. 16610 million worth of fuel savings from the Metro in the year 2011-12 valued at market prices or by the dollars spent on the imports of fuels valued at the market exchange rate, the social value of fuels saved at the shadow price of foreign exchange is estimated as Rs. 18271 million.

Reduction in air pollution

Fewer vehicles and the decongestion for the residual traffic on Delhi roads due to Metro could lead to reduced air pollution. The distance saved due to decongestion is estimated by multiplying the time saved with the speed of a vehicle in a decongested situation. An estimate of the pollution reduction by a vehicle in this context could be obtained by multiplying the distance saved by the relevant emission coefficient for different pollutants for each category of vehicle. The emission coefficients for different vehicles as per the Euro II norms are given in Table 13. Estimates of reduction in distance traveled every day due to the decongestion effect are obtained for cars, two-wheelers and buses as 9.18 kms, 7.65 kms and 69.72 kms, respectively. Table 14 reports the estimates of air pollution loads due to decongestion avoided due to Metro. The monetary value of these pollution loads are estimated using the estimates of shadow prices of pollutants made in some recent studies in India (Murty and Gulati, 2005; Murty, Surender Kumar and Dhavala, 2006) which are reported in the same table.

Table 13: Emission Factors of Vehicles as per Euro II Norms (kg/km)

	PM	NO_X	HC	CO
Bus	0.05	0.87	2.75	0.66
Car	0.03	0.2	0.25	1.98
2- wheeler	0.075	0.3	0.7	2.2
3-wheeler	0.08	0.02	1.45	0.29

Source: Chatterjee, Dhavala and Murty (2006)

Table 14: Reduction in Pollution Load due to decongestion and its Monetary Value for the Year 2011-12 with the Assumption that All Vehicles Use EURO II Technology without Metro

Reduction in Pollution Load	HC	PM	NO_X	CO_2
Due to decongestion	643	77	514	8008
Shadow Prices (Rs)	502	4777	6724	448
Value (Rs. Million)	32	0.37	4	4

Source: Estimated as explained in the text.

The vehicular technology complying with Euro II norms or using CNG as a fuel could have similar effects on the air pollution in Delhi as estimated for the Metro. Table 11 above provides estimates of the diverted traffic to the Metro. A major component of the monetary value of reduction in air pollution due to the Metro could be obtained as the savings in the cost of pollution abatement due to the diverted traffic. A recent study by Chatterjee, Dhavala and Murty (2006) provides estimates of the annual cost of Euro II technology for different vehicles.

Table 15: Estimates of Monetary Value of Pollution Reduction in the year 2011-12 due to the Metro

Different Mode of Vehicles	Diverted Traffic	Annualized Cost of Conversion of Technology per vehicle (Rs.)	Annualized Incremental Production Cost of Fuel per vehicle (Rs.)	Monetary Value of Reduction in Pollution Due to fewer vehicle (Rs. million)	Monetary Value of Reduction in Pollution Due to Decongestion (Rs. million)	Monetary Value of Total Reduction in Pollution (Rs. million)
Bus	9450	17212	14790	302	11	314
Car	164252	5312	1876	1181	10	1191
two-wheeler	985789	4622	816	5360	18	5379
Total	1159491	27147	17482	6843	40	6883

Source: Estimated as explained in the text.

Savings in passenger time

The savings of travel time of passengers traveling by the Metro instead of by road are calculated as the product of the number of passengers traveled daily and the time saved on the average passenger lead in Delhi. In the case of residual passenger traffic on road, RITES (1995a) has estimated the daily time saving by the passengers due to decongestion using the following formula:

$$T = \frac{D}{S_c} - \frac{D}{S_d},$$

where,

T: time saving on average daily run

D: daily run of vehicles (in km)

S_c: average speed in congested situation (without Metro).

S_d: average speed in decongested situation (with Metro)

The values of the parameters D, S_c, S_d for cars, buses, taxis, 2- wheelers and 3-wheelers, along with the estimates of T for the first phase of the project are summarized in Table 16. On the basis of these values, the estimates of value of time/person traveling by buses or other vehicles are arrived at (RITES, 1995a). These are Rs. 5.96/hr and Rs. 7.91/hr, respectively. Passenger time saving per annum for mass transport is then calculated as the product of daily passengers carried, time saved on average lead on an annual basis and the value of time of metro passengers. In the case of other vehicles,

the total time saving is given by the product of the total number of passengers on residual vehicles, time saving on average lead on an annual basis and value of time.

Table 16: Values of Parameters D, S_d , S_c and T

Mode	D (km)	S_d (km/hr)	S_c (km/hr)	T (hr)
Bus	209	14	10.5	4.98
Car	30	17	13	0.54
Taxi	80	17	13	1.45
3- wheeler	100	17	13	1.81
2- wheeler	25	17	13	0.45

Source: RITES (1995a)

Table 17: Time Savings and Value of Time for Passengers

	Bus	Metro
Daily passengers carried (million)	3.3	3.2
Time saved on average lead (hours)	0.21	0.31
Value of time per passenger (Rs.)	5.96	5.96
Value of daily time saving (Rs. million)	4.13	5.91

Source: RITES (1995a)

Savings due to fewer accidents

The Road User Cost Study (CRRI, 1982) later updated by Dr. L. R. Kadiyali et. al. in association with the Loss Prevention Association of India provides estimates of the cost of various accidents on road. Components like gross loss of future output due to death/major injury, medical treatment expenses, legal expenses, administrative expenses on police, insurance companies and the intangible psychosomatic cost of pain were included in the estimation. In the case of buses and other public vehicles, the loss due to lay off period and unproductive wages paid to the crew are also included. The costs (at 2004 prices) under different heads are reported in the Table 18.

These studies have found that the following relationships exist between the number of vehicles affected and the number of persons killed and injured in road accidents.

$Y_1 = 49.43X + 750.42$ $R^2 = 0.89$

$Y_2 = 257.04X + 3181.41$ $R^2 = 0.90$

where,

X: number of vehicles affected in lakhs

Y_1: number of persons killed in road accidents in a particular year

Y_2: number of persons injured in road accidents in a particular year

Table 18: Compensation Values

Cost Component	Value (Rs.)	Reduction in injuries, fatalities and damage to vehicles	Compensation for 2011-12 (Rs. million)
Cost of fatal accident	437342	573	250
Cost of major accident	64256	2980	190
Cost of damage to cars in road accidents	9763	236	2.3
Cost of damage to two wheelers in road accidents	2286	1416	3.2
Cost of damage to buses in road accidents	32818	14	0.4

Source: RITES (1995a)

Assuming that the above relationships hold and given the number of vehicles that are expected to go off the road (diverted traffic) due to the Metro, the reduction in fatalities and accidents is estimated. For instance, in the year 2011-12, the diverted traffic for cars equals 164252, while the corresponding values for two-wheelers and buses are 985789 and 9450 respectively. The values of reduction in fatalities and injuries, as derived from the above equation are reported in Table 18. The total benefit owing to the lesser number of fatalities and injuries is reflected in the total savings in compensation paid. Next, the study also reports the estimated relationship between the number of accidents resulting in damage to property and number of vehicles on road as,

$Y = 143.63X + 3345$ $R^2 = 0.84$

where,

X: number of vehicles on road

Y: number of vehicles causing damage to property

Given the above relationship and the data on the mode wise distribution of accidents in Delhi over the years, the reduction in accidents for different types of vehicles is estimated and reported in Table 18. The estimates of cost of damage to cars, buses and two-wheelers in road accidents, as reported in the above table are used to estimate the total savings in compensation paid due to damage caused vehicles.

Savings in vehicular operating costs due to the decongestion effect

Annual vehicle operating cost is substantially reduced due to the higher speed of vehicles and consequently lesser hours on road. It is estimated as the product of the residual traffic, time saved on average lead per vehicle annually and the vehicle operating cost per hour. According to RITES (2005b), the value of this component for the year 2011-12 is Rs. 15040 million.

Savings in Capital and Operating Cost of Diverted vehicles

Reduction in the capital and operating cost of vehicles due to the introduction of the MRTS is given by the product of the diverted traffic stream, the annual run and the VOC/V-km. The estimated value of this component for the year 2011-12 is Rs. 17677 million.

V. Economic Evaluation of Metro

The methodology described in Section III is used for the economic evaluation of the Metro. Two approaches are used for the analysis. One approach maintains that there is a sub-optimal level of savings in the Indian economy and therefore the social time preference rate is lower than the rate of return on investment and there is a social premium on investment. This approach is similar to the standard UNIDO method (Dasgupta, Sen and Marglin, 1972) for investment project evaluation. Another approach assumes that the level of savings in the Indian economy is optimal and there are no distortions in the capital market so that the rate of return on investment or the market rate of interest could be taken as the social time preference rate. Both the approaches recognize that distortions still exist in the markets for unskilled labour and foreign exchange so that their market prices are different from the shadow prices. However, in the case of unskilled labour, its shadow price consists of the direct and

indirect opportunity cost of unskilled labour employment on investment projects in the first approach while it constitutes only the direct opportunity cost in the case of the second approach. The direct opportunity cost constitutes the marginal productivity of unskilled labour in the alternative employment say in agriculture while the indirect opportunity cost is due to the social value of loss in savings or investment due to labour employment. A recent study commissioned by the Planning Commission, Government of India (Murty and Goldar, 2006) has obtained estimates of the social time preference rate and the rate of return on investment for the Indian economy as 8 and 10 percent, respectively. It has also made the estimates of 36 percent and 10 percent social premium on investment and foreign exchange respectively. It provides an estimate of the marginal productivity of unskilled labour in agriculture as Rs. 48 per day and an estimate of the shadow wage rate consisting of the direct and indirect cost of unskilled labour employment as Rs. 60 for the Indian economy. This study also provides some estimates of the income distributional weights pertaining to incomes of people belonging to different income groups in the Indian economy. These estimates of national parameters for the investment project evaluation in India are used for the economic evaluation of the Metro.

The economic agents affected by having the Metro operational in Delhi could be identified as government, passengers, general public, private transporters and unskilled labour. As explained in Section III these agents get incremental benefits and incur incremental costs due to Metro.

The **Government** gets fare box revenues, revenues from property development and advertisements and tax revenue on the goods and services bought for the investments and operation and maintenance of the Metro while it suffers revenue losses due to the displaced public buses. It incurs the investment and operation and maintenance cost of the Metro while it saves the cost on road infrastructure and the capital and operating cost of displaced public buses. The net benefits for the government during the year 2011-12 are estimated as Rs. 31760 million at 2004 prices.

The **Passengers** gain to the extent of the difference between the fares paid to buses in the absence of the Metro and the fares charged by the Metro. For instance, during the

year 2011-12, the fare box revenue to the displaced buses should have been Rs. 10460 million while that of the Metro is estimated at Rs. 35280 million. Therefore, passengers have incurred an additional cost of Rs. 24830 million due to these fare differences. However, there is a time saving for the passengers due to the Metro. As explained in Section IV, there is both time saving travelling on the Metro as also time saving to the residual traffic on the roads due to the reduced congestion. During the year 2011-12, these savings are together estimated as Rs. 22090 million. There are also benefits due to a reduction in accidents to the passengers due to the functioning of the Metro, which are estimated as Rs 448 million during the year 2011-12. The net benefits to the passengers from the Metro are estimated as Rs.22440 million during the year 2011-12.

The **Private transporters** lose the revenue from displaced private buses but at the same time save on their capital and operating costs. These are estimated as Rs. 9410 and Rs. 6550 million, respectively resulting in a net loss of Rs. 2860 million to the private transporters during the year 2011-12.

The **Unskilled labour** employed on the construction and maintenance of Metro gain to the extent of the difference between the project wage rate and the wage rate in an alternative employment in India. Murty and Goldar (2006) provide an estimate of the marginal productivity of unskilled labour in agriculture as Rs. 48 while on the average, the industrial wage for unskilled labour in India is Rs. 120 per day at 2004-05 prices. Assuming that the unskilled labour cost constitutes 10 percent of investment cost and 5 percent of operation and maintenance cost of the Metro, the benefit to unskilled labour is estimated as Rs. 316.4 million during the year 2011-12.

The **General public** representing the Indian society receives the benefits of social premium on investment and foreign exchange and the environmental benefits of reduced pollution due to the Metro. There are foreign exchange costs and foreign exchange benefits from the Metro. Foreign exchange cost accounts for 60 percent of the investment cost of the Metro. There are foreign exchange benefits to the extent of reduced fossil fuel consumption due to a change in the mode of transport. Murty and

Goldar (2006) have estimated a 10 percent social premium on foreign exchange for the Indian economy. The net benefits to the general public from the Metro arising out of the social premium on foreign exchange is estimated as Rs. 1203.3 crores during the year 2011-12. There could be incremental benefits or losses of savings due to the Metro in the Indian economy depending upon the propensity to save of different agents affected by the project. Without accounting for the social premium on savings, the government, passengers, private transporters and the public get total net benefits worth Rs. 52550 million in the year 2011-12. Assuming a savings rate of 29.10 percent on an aggregate in the Indian economy in 2011-12, the incremental savings due to the Metro in the Indian economy works out to be Rs. 15290 million in the same year. Given an estimate of the social premium on investment as 36 percent (Murty and Goldar, 2006), the public receives benefits worth Rs. 5500 million on this account. It is assumed that the propensity to save of unskilled labour is zero in this estimation. Also the public receives benefits from the reduced air pollution due to the Metro. Section IV describes a method of estimating these benefits and provides an estimate of these as Rs. 6883 million in the year 2011-12. Therefore, public receives net benefits worth of Rs. 14260 million in the year 2011-12 due to Metro.

Table 19: Net Benefit to Various Agents during the year 2011-12

(Rs. Million)

Agents	1st approach	2nd approach
Govt	31764	31767
Public	14260	8086
Unskilled labour	316	316
Passenger	22441	22441
Transporter	-2859	-2859

Source: Estimated as explained in the text

Table 20: Estimation of NPEB for Different Agents

(Rs. Million)

Agents	1st approach	2nd approach
Govt	225483	124502
Public	159458	67643
Unskilled labour	7049	5508
Passenger	79553	55615
Transporter	-39155	-21217

Source: Estimated as explained in the text

Net Present Economic Benefits and Economic Rate of Return of Metro

The net present economic benefits (NPEB) and the economic rate of return of the Metro are estimated after taking into account all the flows of benefits and costs described above for the time period 1995-2041 during the life of the project. An estimate of NPEB of the Metro using the first approach and an 8 percent rate of discount is Rs. 432387.5 million while the estimate using the second approach and a 10 percent rate of discount is Rs. 232050.7 million. The estimates of the economic internal rate of return (IRR) corresponding to the first and second approaches are 23.86 and 23.88 percent, respectively. Table 21 provides the estimates of NPEB and the economic rate of return of the Metro at different levels of approximation to the social benefits.

Table 21: Estimation of NPEB and IRR

	1st approach		2nd approach	
With different scenarios	**NPB (Rs. Million)**	**IRR (%)**	**NPB (Rs. Million)**	**IRR (%)**
At market prices	265880	21.51	158900	21.51
With shadow price of unskilled labour only	272929	22.30	164408	22.30
With shadow prices of unskilled labour and	294358	22.56	176330	22.56
foreign exchange only				
With shadow prices of unskilled labour, foreign exchange	324155	22.54	176330	22.56
and investment				
With shadow prices of unskilled labour, foreign exchange	432387	23.85	232051	23.88
and investment and environment services				

Source: Estimated as explained in the text

VI. Equity and Social Benefits of Metro

The Metro in Delhi has resulted in significant income distribution among various economic agents affected by it. As shown in Table 20, while on the one hand, the government, unskilled labour, public and the passengers have gained, on the other private transporters have suffered substantial losses. The social benefits of the Metro could be estimated by assigning the appropriate income distributional weights to the incremental changes in incomes of these agents due to the project. Murty and Goldar (2006) describe a method of estimating these weights and provide their estimates for the incomes of people belonging to different income classes in the economy. Table 21

provides estimates of the income distributional weights used in the estimation of the social benefits of the Metro which are computed as follows:

$$D = (Y_i / \bar{Y})^v$$

where,

Y_i: income of the i^{th} economic agent

$\bar{Y}$: per capita gross domestic product of India

v: elasticity of social marginal utility of income with respect to income.

Distributional weights are computed assuming that the public and government are assigned to the income class having a per capita income equal to the per capita GDP of India. Passengers are assigned to the income class having a per capita income equal to the Delhi state per capita GDP while transporters are assigned to the income class having a per capita income equal to twice the Delhi per capita GDP. Unskilled labour is assigned to the income class having a per capita income equal to the per capita income of an unskilled labourer's family. Murty and Goldar (2006) provide an estimate of "v "for the Indian economy as 1.4. The gross domestic per capita income for All India and Delhi state are Rs. 23484 and Rs. 50991 in the year 2002-04, respectively.

Table 21: Income Distributional Weights

Agents	Income distributional weights (D_i)
Govt of India	1
General public	1
Passengers	0.34
Private Transporters,	0.13
Unskilled labour	1.87

Source: Estimated as explained in the text.

The estimated NPSB of the Metro after accounting for the income distributional effects is Rs 419979.6 million using the first approach while it is Rs. 218512.4 million using the second approach. The corresponding IRR is approximately 22.70 percent for the first approach, while it is 22.60 percent for the second approach.

VII Conclusion

The Delhi Metro planned in four phases is part of an Integrated Multi Mode Mass Rapid Transport System (MRTS) planned for dealing with the fast growing passenger traffic demand in Delhi. It provides an alternative safe and comfortable mode of transport by rail to a large fraction of passengers using the road transport in Delhi. It reduces the travel time of people using the road and Metro, number of accidents on roads and the atmospheric pollution.

The financial cost-benefit ratio of the Metro is estimated as 2.30 and 1.92 at 8 percent and 10 percent discount rates respectively while its financial internal rate of return is estimated as 17 percent. The financial evaluation of the Metro is done considering the financial flows of the project comprising the annual revenue earned and flows of investments and operation and maintenance costs. The shares of debt, equity and internal resource mobilization in investments made on Metro are 60, 30 and 10 percent, respectively.

The social cost-benefit analysis of the Metro requires the identification of benefits and the economic agents affected by it. The incremental changes in the incomes of various economic agents: passengers, transporters, public and government and unskilled labour due to the Metro could be estimated by considering the Delhi economy with and without the Metro. It is found that there are income gains to the government, public, passengers and unskilled labour while there are substantial income losses to the transporters because of the Metro.

The estimated NPSB of the Metro at 2004-05 prices and the 8 percent social time preference rate for the Indian economy is Rs. 419979.6 million. The social rate of return on investment in the Metro is as high as 22.7 percent.

The economic rate of return on investments in the Metro is 21.5 percent at market prices while the financial rate of return is only 17 percent. These rates are much higher than the recommended social time preference rate of 8 percent and 10 percent cut of rate of return for the investment in the Indian economy by a recent study commissioned by the Planning Commission, Government of India. There is a one percent increase in

the economic rate of return on investment in the Metro, pegged at 22.5 percent after accounting for the differences between shadow prices and market prices of unskilled labour, foreign exchange and investment in the Indian economy in the measurement of economic benefits and cost of the Metro. Accounting for the benefits from the reduction in urban air pollution in Delhi due to the Metro has further increased the economic rate of return to 23.9 percent. This means that the benefits to the Delhi public from reduced air pollution due to the Metro increases its economic rate of return by 1.4 percent.

Delhi Metro provides incremental income to the Delhi public which has a per capita income more than two times the national per capita income. Therefore, accounting for income distributional effects of the Metro has resulted in the reduction of the social rate of return to 22.7 percent.

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