Critical Issues Related to Metro Rail Projects in India

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Abstract

Rail-based 'Mass Rapid Transit System' has been widely accepted as a solution for most of the traffic and environmental pollution related problems which major cities throughout the world are facing now. Metro rail construction activities are being undertaken in a big way in India, existing metro rail network of the city of Kolkata and Delhi are being expanded, while it is under various stages of construction in cities like Bengaluru, Chennai, Mumbai and Hyderabad. In the present article, important environmental and other critical issues have been discussed in the Indian context which are equally relevant in other developing counties.

JEL Classification: R—Urban, Rural, Regional, Real Estate and Transportation Economics; R4—Transportation Systems; R42—Government and Private Investment Analysis; Road Maintenance; Transportation Planning

Keywords: Public transportation, Mass Rapid Transit System, urban traffic, passenger ridership, critical issues, emission reduction

1. Introduction

The infrastructure projects are important for development of a nation and are also a mirror of any country's development. However, most of the infrastructure projects on account of their sheer size and nature (namely, type, site/location, urban settling, etc.) are invariably accompanied by significant environmental and social impacts during different phases (namely, pre-construction, construction and operational phase) of the project. The nature of these impacts could be either positive or negative, depending upon their potential to favourably or adversely affect the surrounding environment and also the resident community.

With increasing traffic demand, coupled with increasing number of vehicles on road, the problems related to traffic congestion, road accidents and environmental pollution have also increased significantly over the last few years in various urban centres around the world. One of the most accepted methods of improving traffic and environmental conditions in these cities has been to provide an efficient public transportation system, so that the private vehicle owners are encouraged to shift to public transportation system (Fouracre et al. 2003). In case of developing countries like India, the public transportation system in most of the cities is grossly inadequate and can be considered inefficient as well as insufficient.

In order to improve the public transportation system, the Mass Rapid Transit System (MRTS) have been provided or being planned in various parts of the world. Although most of the developed countries have already provided MRTS in their major cities, the same is lacking in most of the cities in the developing countries, including India. Ideally, as the population of a city grows share of public transportation (road or rail based) should increase for a city. With a population of 1 or 2 million, the share of public transportation should be about 50 per cent–60 per cent. Moreover the percentage share of public transport should progressively increase with the population growth of the city, and should reach about 75 per cent when the population of the city reaches the 5 million mark (Sekar and Karthigeyan 2009).

Selection of a public transportation system on a corridor in the city, whether it should be road based (High Capacity Bus Systems [HCBS]) or rail-based (for example, metro rail, mono rail, etc.) primarily depends on the traffic density during the peak hour(s) on that particular corridor. Experience from Indian cities have shown that under mixed traffic conditions, comprising slow and fast moving vehicles, road-based public transportation system can optimally carry 8,000 persons per hour per direction (phpdt). When traffic density crosses that mark, traffic and environmental pollution related issues/problems increase; under these circumstances provisions of a rail-based mass transit system (that is, a metro rail system) should be considered. However, when the traffic increases beyond 15,000 phpdt on a corridor, introduction of metro rail system becomes unavoidable.

Metro rail is a form of mass transit public transport system employing trains. The metro rail system, unlike conventional rail-based systems is grade separated from the other traffic or provided with separate right of way (ROW) to avoid conflict with other urban transportation networks. In most of the cases, at least a portion of the rails are placed underground (in tunnels), while a major portion remains above ground (elevated). The system is provided in an urban area and is mostly operated by electricity with high capacity and frequency.

In the present article, critical issues related to metro rail projects have been discussed, which directly or indirectly affect its execution, viability (technical as well as financial) and also justification vis-à-vis other public transportation systems. The Delhi metro rail being amongst the fastest growing metro rail networks in the world, these critical issues reflect the experience of the Delhi metro during different phases of the project. Some of these issues discussed in the Indian context are also applicable to other developing as well as developed countries depending upon their unique social, environmental issues and existing land-use pattern.

2. Metro Rail Systems Around the World

At present there are 160 metro rail systems covering a total length of approximately 10,000 km, are operating throughout the world, mostly in Europe and North America. However, such metro rail systems are very few in the African continent which is also an indirect reflection of the development status of the region. The situation is far better in Asia. In fact, Asia is the region in which China and India are two countries where the metro rail network is expanding very fast. In China, the metro rail is under construction in 43 cities where the population is more than 1 million. China is aiming to construct a total of 1,500 km of metro rail corridors by the year 2015. In India also, 15 major cities with a population more than 3 million have already been or are being provided with metro rail (with a total metro rail corridor length of approximately 750 km) and are under different stages of planning and/or construction. Metro rail systems are being provided/introduced in these cities not only to provide an efficient public transportation system, but also to improve the urban traffic conditions, air and noise pollution situations there.

The 'London Underground' (11 lines, ~408 km in length) was the first metro rail system introduced in the year 1853; Shanghai city (China) has the largest passenger metro rail length (~425 km) with the highest passenger ridership of 7.548 million passengers/day in the year 2010; the Delhi metro (India) is the probably the fastest-growing metro rail network in the world (presently, ~190 km, passenger ridership ~2.1 million passenger/day, another ~114 km (Phase III) planned for, to be completed by the year 2017). When all four phases of the Delhi metro construction are completed in the year 2021, it will have a total network length of more than 400 km with 8 lines.

Salient features of some of the important metro rail systems presently operating in different parts of the world are presented in the Table 1 and compared with the Delhi Metro system. Throughout the world, the popularity of metro rail systems as a means of an effective public transportation is increasing. The increasing passenger ridership in these metro rail systems is an indicator of the same. The passenger ridership of some of the important metro rail systems operational in the world has been presented in Table 2. In the context of the length of the metro rail corridor, the world average is that for every 1 million population of a city, there are 19 km of metro lines. Against this world standard, India's corresponding figure (~4 km/million) is very low.

Table 1. Salient Features of Different Metro Rail System around the World[a, b, c]

City	Opening Date	Length (Km)	No. of Stations	Km/ Station	Lines	Km/ Line	Station/ Line
Seoul Metropolitan Subway	15.08.1974	316.3	328	1.0	9.0	35.1	36.4
Barcelona Metro	30.12.1924	125	166	0.8	11.0	11.4	15
Beijing Subway	01.10.1969	372	190	2.0	15	24.8	13
Tokyo Metro	30.12.1927	203.4	168	1.2	9	22.6	19
Moscow Metro	15.05.1935	305.7	185	1.7	12	25.5	15
Shanghai Metro	10.04.1995	434	277	1.6	11	39.5	25
London Underground	10.01.1863	402	270	1.5	11	36.5	25
New York Subway	27.10.1904	337	421	0.8	34	9.9	12
Montreal Metro	14.10.1966	69.2	68	1.0	4	17.3	17
Santiago Metro	15.09.1975	103	108	1.0	5	20.6	22
Cairo Metro	1987	65.5	53	1.2	2	32.8	27
Paris Metro	19.07.1900	214	300	0.7	16	13.4	19
ViennaU-Bahn	08.05.1974	74.5	101	0.7	5	14.9	20

(Table 1 Continued)

(Table 1 Continued)

City	Opening Date	Length (Km)	No. of Stations	Km/ Station	Lines	Km/ Line	Station/ Line
Hong Kong MTR	01.10.1979	211.6	155	1.4	22	9.6	7
Rome Metro	10.02.1955	38	49	0.8	2	19.0	25
Rio de Janeiro Metro	1979	47	35	1.3	2	23.5	18
LA County Metro Rail	30.01.1993	127.27	70	1.8	5	25.5	14
Bangkok MRT	03.07.2004	27	18	1.5	1	27.0	18
Delhi Metro[b] (Ph I +Ph II)	24.12.2002	189.63	142	1.3	6.0	31.6	23.7
Delhi (Ph. III)		114.5	69	1.7	2+3*	—	—
Delhi Metro (Ph I+II+III)		307.74	211	1.5	8.0	38.5	26.4
Kolkata Metro	24.10.1984	25	21	1.2	2.0	12.5	10.5
Bengaluru Metro	20.1.2011	18.1	17	1.1	1	18.1	17.0
Average		**182.06**	**152.9**	**1.2**	**8.9**	**22.8**	**19**

Sources: [a] Complied from www.wikipedia.org.com; [b] Delhi Metro: www.delhimetro.com, Ghosh and Dhingra (2008); [c] *The Hindu* (2011).

Notes: *New lines of Phase III, ** Extension of Phase I and II lines.

Table 2. Passenger Ridership of Some Metro Rail Systems around the World[a]

Country	City	Passenger Ridership (Daily) (million)	Length	Ridership/km (approx.)	Year
	Tokyo	6.33	203.4	31,121	2010
Japan	Osaka	2.24	137.8	16,255	2010
	Kyoto	0.34	28.8	11,806	2008
Russia	Moscow	6.4	305.7	20,936	2010
	St. Petersburg	2.1	110.2	19,056	2010
South Korea	Seoul	6.7	316.3	21,182	2010
	New York	4.39	337	13,027	2010
USA	Washington DC	0.7	171	4,094	2011
	Los Angeles	0.34	127.27	2,671	2011
	San Francisco	0.15	167	898	2010
France	Paris	4.12	214	19,252	2010
Hong Kong	Hong Kong	4.06	211.6	19,187	2010
China	Beijing	5.1	372	13,710	2011
	Shanghai	5.56	434	12,811	2011
UK	London	3.04	402	7,562	2011

(Table 2 Continued)

(Table 2 Continued)

Country	City	Passenger Ridership (Daily) (million)	Length	Ridership/km (approx.)	Year
Brazil	Sao Paulo	3.6	74.3	48,452	2010
	Rio de Janeiro	0.58	47	12,340	2010
Chile	Santiago	2.3	103	22,330	2010
Spain	Madrid	2	300	6,667	2012
	Barcelona	1.04	125	8,320	2010
Ukraine	Kiev	1.38	65.18	21,172	2010
Czech Republic	Prague	1.6	59.3	26,981	2010
Singapore	Singapore	2.22	148.9	14,909	2011
Austria	Vienna	1.39	74.5	18,658	2010
Canada	Toronto	0.94	70	13,429	2010
Iran	Tehran	2	120	16,667	2011
	Delhi	2	189.63	10,547	2012
India**	Kolkata	0.47	25	18,800	2010
	Bengaluru	0.04	18.1	2,210	2012

Sources: [a] Complied from www.wikipedia.org.com, [b] Delhi Metro (www.delhimetro.com).

In India, Kolkata already has a functional metro rail system operating since 1984, which is even older than the Delhi metro rail system. In fact, the Delhi Metro project is considered as the one of the biggest urban intervention in India since independence. Moreover, it is being constructed to world class standards with frontline technologies keeping in view the future requirements for upgradation. Apart from Delhi, Bengaluru and Kolkata, metro rail construction activities are in an advanced stage of construction in cities like Jaipur, Mumbai, Chennai and Hyderabad. From Tables 1 and 2, it is clear that the Delhi metro rail system compares well with other metro rail systems in the world in terms of total length, number of stations, km/station, km/line, station/line and metro ridership.

Feasibility studies including preparation of a Detailed Project Report (DPR) and other technical studies in major cities of India, such as Navi Mumbai, Pune, Chandigarh, Kanpur, Ludhiana, Bhopal, Indore and Ahmadabad have already been completed and are in different stages of planning.

3. Development of Metro Rail Corridors in Delhi

The Delhi Metro Rail Corporation Limited (DMRC) is the body/authority in charge of the construction and operation of the metro rail system for Delhi (the capital city of India) and other National Capital Region (NCR) areas surrounding the city of Delhi. The project is a joint venture with equal equity participation from the Government of India (Ministry of Urban Development) and the Delhi Government. The Master Plan of Delhi Metro (2021) has recommended that the metro rail network for Delhi and other neighbouring areas of the NCR (which includes the neighbouring states of Haryana and UP) be constructed in four phases. Phase-I (65.1 km) and Phase II (~114.5 km) have already been completed with a total cost of ₹30,171 crore (~ US$ 6 billion) (US$1 = ~₹50) and is presently operational. The preparation of DPR and other related technical and feasibility studies for Phase III of the total length of ~114 km have already been completed. Phase III of the project is likely to start from April 2011 and is likely to be completed by the year 2016 (Table 3).

The expected cost of Phase III is likely to be ₹ ~35,242 crore (~7 billion US$). Phase IV (~108.50 km) is likely to be completed by the year 2021. A part of the Delhi metro Phase I and II project cost was financed by the Government of Japan through a soft loan from the Japan Bank of International Cooperation (JBIC) along with the central government of India and state government of Delhi. Also the remaining fund was internally generated by the Delhi metro through property development. The funding pattern for Phase III is likely to be similar to that of Phases I and II.

Table 3. Cost Estimates and Capacity of Different Metro Rail Systems[a]

System	Capacity (Phpdt)**	Cost/km ₹ Cr (US$ million)	
		Underground	Elevated
Heavy capacity	60–90,000	275 (~54)	110 (~22)
Medium capacity	40–50,000	220 (~43)	80–85 (~16.0–17.0)
Light capacity	25–30,000	200 (~40)	70–75 (~14.0–15.0)

Source: [a]Based on DMRC's Experience (Kumar 2011).
Note: ** per hour per direction traffic.

4. Critical Issues

4.1 Underground versus Elevated Corridor

While the requirement for an efficient public transportation system like a metro rail system in Indian cities is no longer a matter of dispute, the question about whether these should be elevated or underground has attracted a lot of attention and has generated spirited debate among various stakeholders, with some even taking this issue to the courts of law. A few organisations representing the Resident Welfare Associations (RWAs) of residential colonies where these metro rail corridors are expected to cross or will be passing, opposed the elevated corridor because of their perceived concerns related to an increase in noise pollution (including vibration) and privacy-related issues affecting their houses which are very close to the proposed/existing metro rail alignment (Chakraborty 2010). Further, the elevated corridors are also opposed by a few town planners and others on plea that these elevated corridors will not only adversely affect the aesthetics of the city, but will also reduce the visibility of various historical monuments by obstructing the line of sight and will further increase concretisation of the whole city which might led to irreversible micro-climatic changes including increased heat-island effects.

The DMRC as well as central government (that is, the government of India) opposed the concept of providing underground corridors throughout the alignment against the elevated corridors, except for the technical reasons such as alignment in Central Business District (CBD), where constructing the elevated corridor may not be feasible because of a large number of properties/buildings which might be affected and due to various technical difficulties which might occur during the construction phase of the project. They also cited various financial and safety related concerns for not going underground, where there is sufficient techno-economical justification for metro rail corridor to go elevated.

Based on DMRC's (based on Delhi's) experience, constructing an underground section is more than twice expensive as constructing an equally long elevated section, their approximate cost in Delhi being ₹275 crore (~55 million US$) and ₹110 crore (~21 million US$) per km respectively (Kumar 2011) (Table 4). Similarly, the cost of construction of per km of underground and elevated corridor in Mumbai has been estimated to be ₹635 crore (~126 million US$) and ₹235 crore (~46 million US$) (CSE 2010).

The higher cost of metro corridors in Mumbai (as against the other Indian cities) is due to higher land acquisition costs and absence of various incentives/tax exemptions which the government has provided to other metro rail projects but not extended the same to Mumbai metro. The second factor in making a choice between an elevated and underground metro rail corridor is technical feasibility. Wherever possible, metro rail planners always prefer the elevated corridor to the underground metro corridor. This is because the engineering complexities and associated risks of cost and time overruns are much less for elevated stretches, as well as the operating costs of Metro rail when they are in operational phase (Sreedharan 2008). Further, many times underground stations and tunnels have to be built by the 'cut and cover' method, this may require far more land than an elevated stretch on road medians which may cause serious practical difficulties during the construction phase. Third, but definitely not the least, is the security aspect. Metro rails throughout the world, are always high on the hit list of terrorists because of the possible collateral damage and its likely psychological impacts. Any attack in the underground portion leading to derailment or collision is likely to cause five times more damage than an elevated one (Sreedharan 2008). Moreover, due to huge costs involved, it is usual to limit underground construction to congested central areas or proximity to archaeological structures or any other restriction which does not permit elevated structures/historical monuments. In Delhi, underground corridors are mostly limited to the Central Business District (CBD) of Delhi or the old Delhi area, where there is no space for an elevated corridor being so congested and having narrow lanes. Thus, despite the high cost, underground metro corridors have been provided only due to technical reasons such as practical difficulties in carrying out above-surface construction activities in busy and congested CBD areas, problems in acquiring

Table 4. Source of Funding of Phases I and II of Delhi Metro[a]

Cost Financed By	Phase I	Phase II	Phase III
Equity (50% each by GOI & GNCTD)	30%	30%	35.74% (by Delhi and Central Govt. of India)
Long Term debt (OECF, Japan) @ 3% P.A. or less	60%	56%	55.6% (JICA & other lending agencies)
Revenues from property development	7%	5% + 5% (Internal Resources)	4.5%
Subordinate debt	3%	4%	4.25% (from Delhi Development Authority)

Source: [a]*The Hindu* (2011).

land/properties along the proposed corridors and their socio-economic impacts due to resettlement and rehabilitation related issues where a significant number of commercial and residential properties would be acquired during the construction and operational phase of the project. Moreover, because of concerns related to obstruction, visibility and aesthetic reasons, underground corridors have been provided near important historical monuments, for example, the Qutab Minar in Delhi.

The extent of underground, elevated and at-grade sections provided/proposed to be provided on various Delhi metro rail projects have been summarised in Table 5.

Table 5. Underground, Elevated and At-Grade Sections on Metro Corridors in India

S. No.	Phase	Length (Km) (%)			
		At Grade	Elevated	Underground	Total
Delhi Metro					
1.	Phase I (Lines 1, 2, 3) (1998–2006)*	4.5 (6.9%)	47.33 (72.81%)	13.17 (20.26%)	65.00 (100%)
2.	Phase II (Lines 3, 4, 5)* (2006–11)	2 (1.6%)	91.49 (73.38%)	31.18 (25.09%)	124.67 (100%)
3.	Phase III (Lines 6, 8)** (2011–17)	0.00 (0%)	76.34 (66.62%)	38.16 (33.30%)	114 (100%)
	Total	**6.5 (2.11%)**	**218.64 (71.04%)**	**82.51 (26.81%)**	**307.74 (100%)**
Jaipur Metro					
1.	Phase I (Corridor I)*	0.00 (0%)	18.004 (78.24%)	5.095 (22.1%)	23.009 (100%)
2.	Phase I (Corridor II)**	0.00 (0%)	9.278 (76.88%)	2.789 (23.1%)	12.067 (100%)
	Total (Phase I)	**0.00 (0%)**	**27.28 (77.5%)**	**7.88 (22.41%)**	**35.17 (100%)**
Mumbai Metro					
1.	Phase I (Lines 1, 2) (2006–11)**	0.00 (0%)	51.80 (81.1%)	12.00 (18.8%)	63.80 (100%)
2.	Phase II (Lines 3, 4, 5) (2011–16)***	0.00 (0%)	19.90 (100%)	0.00 (0%)	19.90 (100%)
3.	Phase III (Lines 6, 7, 8, 9) (2016–21)***	0.00 (0%)	42.30 (67.35%)	20.50 (32.64%)	62.80 (100%)
	Total	**0.00 (0%)**	**114.00 (77.81%)**	**32.50 (22.18%)**	**146.50 (100%)**
Chennai Metro					
1.	Phase I (Corridors 1, 2) (2009–15)**	0.00 (0%)	21.10 (46.66%)	24.00 (53.33%)	45.10 (100%)
	Total	**0.00 (0%)**	**21.10 (46.66%)**	**24.00 (53.33%)**	**45.10 (100%)**

(Table 5 Continued)

(Table 5 Continued)

S. No.	Phase	Length (Km) (%) At Grade	Elevated	Underground	Total
Calcutta/Kolkata Metro					
1.	Line 1 (1973–2009)*	~1.05 (~4.7%)	~5.30 (~23.8%)	~15.95 (~71.4%)	~22.3 (100%)
2.	Line 2 (2009–14)**	0.00 (0%)	5.77 (39.33%)	8.9 (60.66%)	14.67 (100%)
	Total (~)	**1.05 (2.84%)**	**11.07 (29.94%)**	**24.85 (67.21%)**	**~36.97 (100%)**
Bangalore Metro					
1.	Phase I (Line 1)*	0.00 (0%)	13.22 (73.03%)	4.88 (26.91%)	18.10 (100%)
2.	Phase I (Line 2) (2006–13)	0.00 (0%)	20.20 (83.47%)	4 (16.52%)	24.20 (100%)
	Total	**0.00 (0%)**	**33.42 (79 %)**	**8.88 (21.04%)**	**42.30 (100%)**

Source: Developed by the authors.
Notes: *Already operational, **under construction, ***proposed period of completion.

It is not that the proportion of elevated corridors vis-à-vis underground corridors is high in India or any developing countries because the cost of their construction is less. In fact, the figure of underground corridors in the Delhi metro are quite comparable to other metro rail systems operating in other parts of the world, including the London Metro (44 per cent of the 408 km), San Francisco (USA) (29 per cent of 115 km). In metropolitan cities of Asia including Hong Kong (87.7 km), Kuala Lumpur (72 km), Singapore (89.4 km), Dubai (67 km), a substantial portion of the corridor is elevated (Table 5). In some metro rail systems operating in various developed countries, where there is a substantial portion (>60 per cent) of the corridors that are underground (for example, New York (60 per cent of 371 km), Chicago (USA) (66 per cent of 183 km), etc.), the first choice had always been to provide elevated corridors and underground sections/corridors are provided only due to technical reasons (Sreedharan 2008). In India, such as Mumbai, Bangalore, Hyderabad, Ahmadabad, Ludhiana, etc., the proportion of elevated corridors are likely to be significantly more than what has been or is being provided in Delhi due to similar reasons.

Moreover, as these metro rail corridors/projects are mostly public-funded projects, financed by the government, these projects cannot be provided unlimited financial support at the cost of other infrastructure projects. Thus, these metro rail projects always have to work with financial and budget constraints. Providing 1 km of underground section equals 2.5–3.0 km on the surface in terms of cost, which is equal to 1.5–2 km less metro rail corridor for every km of underground section due to budgetary constraints. This may result in a large population of a city still being without a reliable, comfortable and environment-friendly public transport system such as a metro rail system. Thus, elevated versus underground corridor issues can be resolved keeping in view technical considerations only, whereas other issues like availability of funds/resources, safety issues along with socio-economic considerations, although very important, should come later while arriving at the final solution/selection of the corridor.

4.2 Over-estimation of Traffic Demand Forecasts/Ridership Estimation

Financial viability of any transportation projects (road-based, rail-based or a combination of these two) greatly depends upon the accuracy of traffic demand forecasts/ridership estimation. These forecasts not only provide a technical justification for these projects but also a guide and tool for their socio-economic and environmental appraisal vis-à-vis their projected/estimated costs and benefits. However, most of these forecasting/modelling exercises for transportation projects rarely provide a true picture, often leading to inaccurate or sometimes even a misleading picture about the project, forcing the decision/policy makers to take a wrong or flawed decision. In the context of metro rail projects, an over-estimation of the ridership figure leads to over-sizing and underutilisation of the infrastructure/resources leading to over-investing in idle capacity resulting in financial mismanagement or crisis for the project. On the other side, an underestimation of traffic demand/ridership estimation leads to chaos and inefficiency and ultimately a significant further investment as adding capacity to an existing facility is much more costlier than building the whole capacity/infrastructure in one go.

In a significant study carried out by Flyvbjerg et al. (2006), covering 210 transportation projects (including both rail- and road-based) in 14 nations in developed as well as developing countries, indicated a very poor traffic demand forecasting with a very high statistical significance. The study concluded that there is a tendency for traffic forecasts to be overestimated. According to the study, the causes for inaccuracy in forecasts were different for rail and road projects, with political causes playing a greater role in rail projects than road projects. One of the noticeable findings of the study regarding forecasting of rail and road projects was the observation that rail passenger forecasts are highly systematic and significantly misleading and are much more inaccurate and biased (inflated) than road traffic forecasts. The study found that nine out of the 10 rail projects' passenger forecasts are overestimated; the average over-estimation is 106 per cent. For 72 per cent of the rail projects, forecasts are overestimated by more than two-thirds. On the other side, for 50 per cent of the road projects, the difference between actual and forecast traffic is more than ±20 per cent; for 25 per cent of road projects, the difference is larger than ±40 per cent. Since large sums of money and other scarce resources are being invested in creating transport infrastructure, especially in developing economies, it is important to avoid transportation projects, which fail to provide expected benefits in terms of traffic or passenger ridership. Litman (2010) further recommended more appropriate indicators of transit system performance. It says that for reliability of ridership forecasts, ridership should be categorised by year (for example, pre-1990, 1990–99 and 2000+) to see if predictions improved over time.

Demand forecasts for metro rail projects in Indian cities have also not been accurate. In the Kolkata metro rail, the annual passenger volume estimated was 623.7 million trips for the year 2000, however, the actual number of passenger trips on the metro railway during 1999–2000 was only 55.8 million, which is approximately one-eleventh of the estimated traffic 10 years ago in 1990 (Advani and Tiwari 2007). In the case of the Chennai metro rail, according to the MRTS authorities there, it has a capacity to ferry some six hundred thousand commuters daily; however, the service has been attracting only around 25,000 passengers per day, and most of them during peak hours. Similarly, expected ridership of the Delhi metro rail has been modified several times since the commencement of the project in year 2002. The DMRC had initially expected ridership of metro rail to be 1.5 million passenger trips per day (ppd) for 2005, which was further reduced to 0.7 million ppd by March, 2006. Advani and Tiwari (2007) also pointed out that, ridership on Line 1 of the Phase I in April 2004 was 0.12 million ppd and 0.13 million ppd in July 2005. Ridership of Line 2 in July 2005 was 0.24 million ppd indicating that after completion of around 57 per cent of Phase I, ridership was 0.37 million ppd which was only 20 per cent of the estimated ridership. In fact, metro ridership figures were revised, as the feasibility reports (prepared on behalf of DMRC) had actually estimated much higher ridership (RITES 1995) than what was actually observed (*Hindustan Times* 2010) for various years (Table 6). Thus, empirical evidence from Indian cities and a study by Flyvbjerg et al. (2006) make a strong case for critical analyses of the travel demand forecasts.

4.3 Land/Property Acquisition and Resettlement and Rehabilitation (R&R) Related Issues

Metro cities of developing countries throughout the world are densely populated with little availability of land for such mega infrastructure project. Land/property acquisition has always been an integral part of any mega infrastructure developmental project. Efforts are always made to minimise the land/property acquisition as to minimise its socio-economic impacts. The land/property acquisition in some areas along the metro corridors sometimes becomes inevitable no other option related to alternate alignment requiring less R&R impacts is feasible due to technical reasons (including those related to ridership), environmental considerations and financial constraints. The issue of land/property acquisition is a pre-construction phase activity, for which proper socio-economic and R&R surveys need to be carried out to determine the project affected persons/families.

In Delhi, most of the elevated metro corridors are provided along existing roads or the medians of the roads which are mostly owned by the government/government agencies so that the various impacts related to land/property acquisition are the minimum. Providing/suggesting metro rail corridors on the central verge/median and/or at one side of existing road corridors ensures that there is no or very minimum additional land acquired by using the existing ROW of the road for metro rail corridors. In CBD

Table 6. Estimates of Daily Passenger Trips by Metro (million)

	Daily Passenger Trips	
Year	Estimated Ridership[a]	Actual Ridership[b]
2002	12.63	0.035 (December 2002)
2003	20.15	0.035 (February 2003)
2004	23.86	0.11 (April 2004)
2005	31.85	0.25 (July 2005)
2006	33.17	0.40 (February 2006)
		0.50 (December 2006)
2007	34.55	0.61 (December 2007)
2008	35.97	0.70 (June 2008)
2009	37.46	0.81 (June 2009)
2010	39.01	1.09 (June 2010)
		1.30 (September 2010)
2011	40.63	1.65 (January 2011)

Sources: [a]RITES Lt. (1995), [b] HT (4 September 2010).

areas and archeologically sensitive areas the metro rail corridor goes underground. Many times some land is acquired temporarily for material storage or to facilitate safety during the construction phase. In these situations, apart from providing adequate compensation, the acquired land is returned back to the owner/owning agencies after its restoration. The metro rail project implementing agency also ensures rehabilitation of the affected persons by providing them alternate sites/facilities/commercial rehabilitation. Thus, land acquisition for metro rail projects like any other similar transportation-related infrastructure projects is inevitable. However, it should be kept to a minimum by adopting suitable route alignment and by employing the latest construction techniques/methods which reduce the material and land/property requirements/acquisitions, which may not only avoid possible confrontation/social unrest with affected persons but will also result in a reduced overall cost of the project, affecting the financial viability of the project.

4.4 Loss of Trees/Green Cover

During the construction phase of metro rail projects, many times trees have to be cut, resulting in the loss of green cover along the metro rail corridors. Most of these trees are part of roadside/linear plantation on the median and/or on the sides of existing road(s). The loss of tree/green cover may cause micro-climatic changes and affects the aesthetics of the area. As per the estimates, the DMRC has felled 25,507 trees over Phase I and II of its construction in Delhi. The DMRC has carried out compensatory afforestation (10 trees for every tree cut), as per the provisions of the Delhi (Preservation of Trees) Act, 1994. About 30 per cent of the trees on various metro rail corridors have been saved through proper care and planning in route alignment. Department of Forests, Government of Delhi (the nodal agency) is planting trees on behalf of the DMRC on the land allocated on the outskirts of Delhi. It is always debatable that while trees are cut at the project site, their compensatory afforestation has been carried out on the outskirts of Delhi far away from the project site because of the unavailability of land for growing new trees. It is desirable and should be ensured that the afforestation is carried near the project site itself whenever possible in consultation with local authorities/department. Sometimes even underground corridors are also proposed to prevent the loss of trees cover (for example, the Ridge area of Delhi, considered as the lungs of Delhi).

4.5 Noise Pollution and Vibration Issues

Noise and vibration-related issues along the corridor(s) are one of the major issues which may be significant during both the construction as well as the operational phase of the project. During the construction phase, the use of heavy machinery and construction equipment may cause vibrations and also increase the ambient noise levels. Vibrations generated during the construction phase may have several adverse impacts, including cracks developed on the surrounding buildings which can have serious implications on the structural safety.

During the operation of the metro rail, rail–wheel contacts with tracks generate noise and vibration. Engine, cooling fans and generators further increase ambient noise and vibration levels inside the coaches and also outside the metro rail corridor.

Worldwide, several efforts are being made to reduce the impact of noise and vibration generated by the metro rails, both at the source as well as receptor levels. Delhi Metro is using new and advance technology in rails and brake systems, namely, by providing damping wheels and tracks, reducing the roughness of the rails; and noise levels can be further reduced by providing mass spring system technology and noise barriers along the corridor at critical locations along the corridor.

Coaches with advanced sound-absorbing cushions lining on the walls with better buffing have been provided so that the doors will seal perfectly reducing sound filtering in from outside. Apart from controlling the internal noise levels, the Delhi metro runs on a 'ballastless tracks' technology. The integration of turnouts into 'Long Welded Rails (LWR)' further ensures that complete tracks are virtually 'joint less' which, besides lower maintenance cost and higher safety, promises minimal vibration and greater riding comfort for passengers. Various (CRRI 2009a) studies have also highlighted the increased noise levels along the elevated corridors under situations like 'rail-under-a-road' situations, where noise generated by the existing road traffic is further increased (up to 3 dB(A)) due to reflection of noise because of the pillars and canopy of the elevated track. However, this issue is being taken care of by various metro rail agencies including by using noise absorbing construction material, by providing silencers spanning a metro line running over bridges and designing structures in such a way that the reflection of the noise can be minimised.

4.6 Accidents During Construction Phase

Ideally, no accidents during construction should take place. However, during the construction of complex structures such as metro rail corridors, which involve the use of huge machinery and equipment, some freak fatal accidents are always a possibility. The accidents may occur due to human errors/negligence, mechanical failure of machinery, design faults, use of low-quality construction materials and also due to man-made and natural disasters like earthquakes, flooding, fire and deliberate sabotage and terrorist activities. Development of a safety culture at all levels, close monitoring and supervision by trained engineers, proper designing of the structures and its verification by another independent agency, quality checks of the construction materials and 'no tolerance' towards the negligence can ensure a high level of safety during the construction period. Advanced technology should be used so that human exposure and faults arising due to human error can be avoided.

A few accidents have been reported in the Delhi, Mumbai and Bengaluru metros during the ongoing construction phase. Large numbers of workers and machinery are involved in the construction: DMRC had employed 250–300 cranes daily and the numbers of workers engaged in those activities were 35,000–40,000 everyday for Phase II projects. However, a few accidents on DMRC corridors during the construction of Phase II have brought the concerns related to accidents during construction into the limelight. Although, the DMRC accident rate is still very low as compared to International standards (Singapore has 1.1 accidents/million men–hours, the London Underground has 0.32 accidents/million men–hours as compared to DMRC's 0.4 accidents/million men–hours)**.**

In the Delhi metro, 109 construction workers have been killed, since the metro started construction 12 years ago (Pandit 2010). The DMRC argues that though a lot of hype is being created about the 'increased' accidents during construction of Phase II, in fact it was Phase I which witnessed more fatal accidents (55 deaths in 65.1 km against 47 so far in Phase II, ~114 km). In fact, safety during construction is all about ensuring proper project execution through strict compliance to quality norms and formulating a detailed project management strategy including its execution in the field.

4.7 Traffic Issues during Construction Phase

Most of the metro rail corridors (especially elevated corridors) are being built along the existing roads or within the existing ROW of the roads. As a result, traffic needs to be diverted temporarily (or only a narrow width of the existing road is allowed to be used for traffic flow) for carrying out construction activities smoothly and to avoid any accident involving construction machinery/equipment. This diversion of road traffic further from the existing road corridors increases the traffic loads on the adjoining roads leading to congestion and traffic jams during peak hours during the construction phase of the project. The situation may be further aggravated during the monsoon season due to water logging problems at the project site. Traffic diversion plans, including barricading of the project site (that is, the portion of the existing road which needs to be taken over temporarily), needs to be implemented in consultation with traffic police and local authorities before the start of the construction activities. The public should also be made aware of these diversions/closures well in advance to avoid inconvenience. As per the policy of DMRC in Delhi, the road portion taken over by it temporarily, is returned back to the road owning agency and after the completion of the construction activities and after its complete restoration; sometimes in better conditions than the original road conditions, when it was taken over by metro rail agency.

4.8 Metro Rail versus Bus Rapid Transit System (MRTS vs. BRTS)

Metro Rail and Bus Rapid Transit Systems (BRTS) (also known as High Capacity Bus Systems (HCBS)), are the two most popular public transport systems which are increasingly being used successfully throughout the world. Introduction of a BRT system on selected corridors in some selected cities are also being introduced so that travelling by the public transportation buses becomes more attractive as compared to commuting by private vehicles. With the successful implementation of the Bogota (Colombia) BRTS and in different cities of the developed world, the BRT system is also being implemented in different cities in India with a mixed degree of success.

In India, BRT corridors are already present in cities like Pune, Ahmadabad, Delhi, Mumbai and Indore and are being expanded further. Moreover in India, BRTS has been proposed for cities like, Rajkot, Bhopal, Pimpri Chinchwad, Vijaywada, Vizag and Jaipur.

In Delhi, the execution and operation of BRTS on selected corridors have lead to a lot of public criticism and also generated an intense debate between the Metro Rail and Bus Rapid Transit System (that is, MRTS vs BRTS). During the trial run on a selected corridor in Delhi, several technical and operational difficulties such as the malfunctioning of signalling systems, bus operation related issues (that is, low frequency, untrained drivers, slow speed, etc.), undisciplined private vehicular traffic (that is, lack of traffic discipline), jaywalking of pedestrians, absence of supporting infrastructure (for example, parking facilities and foot over-bridges (FOB) or subways, etc., emerged (DIMTS 2009). In fact even before the BRTS was implemented on that particular stretch in Delhi, the road which was divided into six lanes was experiencing very heavy traffic volumes for most part of the day. As a matter of fact, the stretch needed to be widened to handle that traffic volume even before the BRT idea was implemented. But, instead of adding width, two lanes were taken out of the corridor for the purpose of providing separate dedicated lanes for BRTS. As a result, BRTS has taken up almost one-third of the road space leaving very little space for general traffic. While critically evaluating the system in Delhi, it was also pointed out by various experts that the passenger carrying capacity in Bogotá (Columbia) BRTS corridor (which is a success story and is always referred to by various traffic engineers and transportation planners) is higher due to more road space given to cars. However, after a lot of redesigning and traffic management measures, these problems have been controlled to a large extent and a further 15 new BRT corridors, spanning 359.9 km, have been planned.

Worldwide, there is intense debate between BRTS and MRTS in terms of their effectiveness as a public transportation system vis-à-vis cost of their implementation in any urban city. In comparison to BRTS, the metro rail corridor occupies no road space, if underground and only about 2 m width of the road if elevated. Moreover, it carries the same amount of traffic as 9 lanes of bus traffic or 33 lanes of private motor cars (either way) and also consumers approximately 50 per cent less energy/passenger carried as compared to BRTS. Further, metro rail is considered to be more reliable, comfortable and safer than road-based systems and reduces journey time by anything between 50 per cent and 75 per cent depending on road conditions (Kumar 2011). However, metro rail projects are highly capital-intensive projects and cost of per km of the corridor is significantly higher in comparison to per km of a BRTS corridor (that is, ~₹50–100 crores or US$ 1–20 million). However, it is argued that in the case of metro rail, the operator has to bear the entire cost of infrastructure such as the civil cost (electrical and mechanical) and rolling stock cost in addition to the entire (operating and maintenance) cost. On the other hand, in a road-based system, the operator has to bear only the cost of transport vehicles and their operating and maintenance cost. The infrastructure cost of building roads, maintenance of roads, lighting, etc., are mostly borne by the city or city government. Therefore, if the cost of road transportation in a system like BRTS has to be compared vis-à-vis a Metro rail, the road-based system should also include the proportionate cost of infrastructure and its maintenance (Litman 2009, 2010). A comparison between MRTS and BRTS has been summarised in the Table 7.

From the Table 7, it is clear that MRTS has several advantages vis-à-vis BRTS. Critics generally argue that most of the above facts favouring MRTS vis-à-vis BRTS are based on the ‘general perception’ devoid of any real facts, which is strongly opposed by other researchers/proponents arguing in favour of MRTS (Litman 2010).

Table 7. Comparison between Metro Rail System and Bus Rapid Transit System

	Metro Rail System	Bus Rapid Transit System
Commercial speed (km/h)	24–55	25–30
Catchment area	Low	High
Average cost/trip (₹)	45–50	10–15
Required minimum trip length	10–15 km	5 km
Space required	2 lanes for elevated corridor	2–4 lanes
Parking	Needs parking facilities for feeder services	Needs parking facilities for feeder services
Air pollution reductions (along its influence area)	Significantly decreases due to shifting of vehicles to MRTS (particularly private vehicles)	Expected to improve slightly if BRTS is able to shift private vehicle to its system
Noise pollution reductions	Noise levels may slightly increase, if background levels are less than the noise generated by metro rail	No significant improvement in ambient noise levels expected

(Table 7 Continued)

(Table 7 Continued)

	Metro Rail System	Bus Rapid Transit System
Environmental conditions (inside the system)	Noise and vibration levels along with SPM/PM_{10} levels are very low	Noise and Vibration levels comparatively higher, SPM/PM_{10} levels inside generally higher than ambient levels
Road safety	Reduces accidents in urban arterials and in its influence zone	Less safe for pedestrians and NMT movement
Congestion reduction	Reduces the congestion problem in its influence zone and other city arterials	With increase in frequency congestion increases resulting in decrease in LOS (level of services)
Infrastructure cost	Very high	Apparently low
Cost/km of corridor	₹285 crores/km—Underground (~57 million US$) ₹115 crores/km—Elevated (~23 million US$)	Comparatively lower (₹5–7.5 crore/km) (~1–1.5 million US$)
Passenger carrying capacity (PPHPD)	More (30,000–60,000)	Less (15,000–20,000)
Vulnerability to natural and man-made disasters	High	Less
Corridor alignment	Mostly 'Elevated', 'Underground' along the Congested and CBD areas, Very small portion at surface levels	Mostly At-Grade, in some cases Elevated section
Passenger fare	Generally economical in long distances (>10 km)	Economical in short distance travels (3-5km), Comparable with MRT for distances between 5–10 km
USP of the system	Time saving, safe, punctuality, comfortable, environment friendly	Time Saving for Bus commuters, 'Door to Door Service' 'Economical' (travel distance up to 10 km)
Public perception (Indian experience)	Mostly favourable	Mostly apprehensive (bus commuters–mostly favourable)

Source: Developed by the authors.

4.9 Property Development along the Metro Rail Corridors

Property development along the metro rail corridors and metro stations have always been a debatable issue and also generated arguments both in support as well as against it. While, many argue that organisations like DMRC in Delhi and similar organisations in other parts of the country, who have been entrusted the job of construction and operation of metro rail system(s), should not be allowed to venture into property development business like any other real estate agency/developers, when the land to these agencies have been given to them at concessional rates. It is also argued that these implementing agencies, which have been given land/property along the corridors on concessional rates, are focussing more on profit generation by the way of real estate development and commercial use of the land/space at metro stations to earn profiles like any other real estate developers/agency. It is suggested by many to leave this activity to nodal agencies and other private estate developers, who are specifically assigned or doing that particular job.

These metro rail agencies have always argued that the earnings from the property developments have been mandated by the government to finance various on-going projects/activities related to property development/commercial use of property along the metro corridors are not unique for DMRC in Delhi or any other part of India or even in the world. With escalating costs of construction and operation of metro rail corridor projects, coupled with reducing financial support from the government and other international agencies, property development and commercial use of property is the only resource by which the metro rail projects and their operations can be sustained in the long run without compromising the main objective of providing a safe, economical and comfortable mode of public transportation with less dependence on the government for financial help.

In fact, the Delhi metro is amongst the only three metro systems in the world, which does not need any financial subsidy from the government and derives financial support from its property development programmes**.** In fact, Phase-I of the Delhi metro had provided 7 per cent of the project cost upfront and 30 per cent of the recurring income. At present, ~25–30 per cent of the annual revenue of the Delhi metro comes from commercial property developments in the metro station complexes, advertisements and other commercial activities, which is equal to or even less than other metro rail systems operating in different parts of the world. The Hong Kong metro which is one of the few profit-making MRTS in whole world, has (up to) 35–40 per cent of its revenue coming from such non-operating sources. Any efforts to drastically reduce or bring down the share of non-operating revenue sources from the total income would require further rationalisation of passenger fare structures in such a way that it earns more passengers without compromising the metro ridership and thus passenger revenue growth which will further require passenger preference/fare analysis for metro rail vis-à-vis other modes of public transportation.

4.10 Quantification of Benefits Due to Implementation of Metro Rail Projects

In the recent past, there has been a lot of debate and questions have been raised regarding the justification of investment in such capital intensive projects for solving traffic and transportation problems, when there may be other 'less costly systems/options/alternatives' available with similar levels of service (Advani and Tiwari 2005; Cox 2000; Cox and Utt 2010; CRRI 2006, 2009b; Fouracre et al. 2003; Litman 2010; Murty et al. 2006). To justify the huge investment of public money, benefits expected from the metro rail system(s) are quantified vis-à-vis expenditure/investment made on it. In fact, in most of this cost–benefit analysis, benefits accruing due to the proposed metro rail projects/ system are estimated based on various assumptions (related to expected benefits) which are likely to occur after the implementation of the project. Unfortunately, no serious efforts have been made to realistically estimate the expected benefits and validate these expected benefits (theoretical assumptions) vis-à-vis actual field realities (that is, actual benefits accruing after the introduction of metro rail projects). Moreover, it is not always possible (rather difficult) to quantify these impacts/benefits and convert the same into economic terms.

A few studies (CRRI 2006, 2009b; Murty et al. 2006) have been carried out in India, particularly in Delhi (for Phase I of the metro rail system). In a study carried out by CRRI (CRRI 2009b) based on the metro ridership of ~0.85 million passengers (in 2009), has estimated that the introduction of metro rail has resulted in an average of 57,953 vehicles off the road each day and reduced 51 fatal accidents across the metro rail corridor. The study further indicated that the entire cost of Delhi metro's Phase I (that is ₹10,571 crores) (~2 billion US$) will be recovered by 2011, if the social benefits of the project are taken into account along with direct and indirect environmental benefits, including the cost of fuel saving, reduced emissions/pollution levels, value of time saved and reduced expenditure on the maintenance of the roads in the metro influence area.

4.11 Clean Development Mechanism (CDM) Opportunities in MRTS Projects

Transportation projects involving improvement in vehicle fuel efficiency by introducing new technologies, changes in vehicle and/or fuel type, changing to less carbon intensive means of transport and reducing the frequency of transport activities are covered under CDM and are entitled for 'Carbon Credits' as per the Kyoto Protocol.

In fact, CO_2 emission reduction from various MRTS projects like metro rail can also be utilised to earn 'Carbon Credits' by developing countries like India through the Clean Development Mechanism (CDM) as per the provisions of the Kyoto Protocol (1997), which became effective from the year 2005 (Sharma et al. 2010). MRTS projects like Delhi metro provide huge potential of reducing CO_2 emissions along with conventional vehicular emissions like PM, CO, HC, NOx, etc., by shifting of commuters from other modes to a more efficient public transportation system like metro rail system. At present, only a few public transportation projects including metro rail projects have been registered under CDM and the Delhi metro is the only railway/metro railway system in the world which has been awarded 4,00,000 carbon credits for a 10-year period by the United Nations. The DMRC has been certified to have prevented over 90,000 tonnes of carbon dioxide from being released into the atmosphere by reducing its power requirement by adopting regenerative braking system.

The major reasons for the non-registration of more of the transportation sector being unavailability of appropriate approved methodologies for estimation of GHG/CO_2 reductions, difficulty in establishing baselines (that is, what would have happened in the absence of the proposed project, lack of authentic and proper data availability regarding the baseline?), inability to integrate various transportation projects as a part of a larger focus on sustainable development. There is an urgent need to develop appropriate methodologies including that for estimation of CO_2 emissions due to shifting of commuters, getting it as an 'Approved Methodology' from the UNFCC so that the project becomes eligible for CDM. Estimation of emission gains along with the quantification of fuel saving, etc., will have decision makers to take an 'informed policy decision' and to justify the implementation cost of the MRTS and to know how its execution has helped in the reduction of CO_2 due to shifting of commuters from other modes of transportation to MRTS. In this connection a methodology based on the Metro ridership data has been suggested (Sharma et al. 2010) which can be used for estimating CO_2 reduction potential from MRTS projects.

5. Concluding Remarks

Construction of the metro rail system in Delhi and other cities of India (as well as other parts of the world) have brought out several important environmental, social and other related critical issues which need to be studied and addressed carefully to make these mega infrastructure projects not only environmentally and socially acceptable but also technically and financially viable. These metro rail projects are capital intensive projects and mostly implemented in large cities where the high cost of construction can be justified by the accrued, direct and indirect benefits. Moreover, metro rail networks have to be constructed/built in very difficult urban settings so that there is the least inconvenience to the general public. Various structures to be built should be aesthetic and merge with the surroundings.

There is always a debate regarding the justification of introducing a metro rail system vis-à-vis other public transportation system(s) in an urban area (Cox 2000; Cox and Utt 2010; O'Toole 2010). Various critics argue that these metro rail projects are very costly, subsidised, require excessive land use densities, are generally ineffective in solving most of the transportation problems and favour rich people. However, a study carried out by Litman (2010) has concluded that most of these arguments/criticism of rail projects are not based on the actual facts rather based on omissions, errors misrepresentations and intentional bias of data/figure. It was argued that if various benefits (namely, congestion reduction, pollution reduction, vehicle kilometre travelled (VKT), etc.) are considered individually then the cost of the metro rail projects will definitely be higher as compared to other public transportation system but if these benefits are combined together then metro rail projects are least costly vis-à-vis other public transportation project (Litman 2010). Metro rail projects take many years to get operational. During initial years, ridership is small as people take some time to change their transportation preference, thus accrued benefits are generally very small during initial years and as the time passes and various teething problems associated with the operation of metro rail are resolved and the reach (that is, length of the corridor) increases, the ridership also grows resulting in increased benefits vis-à-vis cost of the project.

A public transportation system can only be successful if it encourages the commuters to shift from their private vehicles to this system. A good public transportation system should ideally be a combination of various public transportation systems (for example, metro rail, mono rail, HCBS, etc.). Public transportation systems instead of competing with each other should be complimentary to each other. It requires an integrated approach from the design stage itself. Further, experience gained from similar projects from other countries on various aspects related to construction, operation and environmental management can also be suitably used for any project to ensure that they are environmentally sustainable as well as socially acceptable.

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