Suitability of alternative systems for urban mass transport for indian cities

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In the early stages of growth of any city, the vehicular trips are all road-based and are confined to modes like cycles, personalized cars, two-wheelers, and intermediate public transport (IPT) modes like cycle rickshaws, tongas, taxis, three-wheelers, tempos etc. As the city's population and size grows further, commuter trips tend to get concentrated on particular sections and routes and call for a larger transport unit like a mini-bus or a standard bus, which forms part of the public transport system. In larger cities, public transport system plays an increasingly important role. In cities like Kolkatta, Mumbai, Delhi, and Chennai, suburban rail services carry sizeable volumes of commuter trips. In Kolkatta, tramways also play a noticeable role besides the metro rail operation. With the increase in city complexities and advancement in technology, new systems like Automated Guided Transit (AGT) will soon be visible in metropolitan cities of India, the sign of which can already be seen with the proposal of Skybus system (a suspended type AGT) for Mumbai city [GOM(2000)].

While making selection of a particular mode of mass transport for any Indian City, the criteria should essentially be the volume and pattern of travel demand. But, besides this, the systems should also be judged by their, suitability for Indian conditions; effectiveness and efficiency in dependably performing their designated role(s); flexibility of operation, with wide applicability; capital requirement; energy sources and consumption; environmental impact, from the point of view of pollution and noise; aesthetics, including 'image'; available technology and indigenous capability; proven or non-proven technology; and future potential (especially in technological advancements).

The present paper studies, in detail, the alternative systems of urban mass transit and their system characteristics, and tries to establish their suitability for Indian Cities of various size and form.

1. Introduction

During the second half of the last century, urban population in India had grown enormously. While population of the country increased from 361 million in 1951 to 1.03 billion* in 2001 (in the last 10 year itself i.e. 1991-2001, the population of the country has increased by 21.34%*), the urban population increased from 62 million to 285 million* during the same period. Thus, the percentage of the urban population to the population of the country went up from 17.2% in 1951 to 28%* in 2001.

Also, the number of cities with a population of one million and above has steadily increased from 5 in 1951 to 35* in 2001. This level of urbanisation has brought in its wake its own problems, especially with regard to its impact on the infrastructural facilities. The urban transportation systems have come under heavy strain and this has adversely affected the quality of life of urban dwellers. Public transport facilities provided by buses or suburban trains are grossly inadequate for meeting the increased travel demand and providing a fast, comfortable and convenient travel [Sreedharan (2000)]. This has resulted in a heavy decline of patronage for mass transit facilities and an increased use of private and intermediate transport, which needs to be reversed in order to stop the further degradation of life of urban dwellers.

2. Classification of Mass Transit Modes

Common-carrier urban passenger transport mode is known as *transit, mass transit, or mass transportation.* These are transport systems with fixed routes and schedules, available for use by all persons who pay the established fares. Transit is described as *fixed route, fixed schedule service.* The best known classification of transit modes is into three generic classes based mostly, but not entirely, on right-of-way (R/W) type [Gray et.al.(1979)]. They are street transit or surface transit, semirapid transit, and rapid transit or mass rapid transit systems.

*Census 2001 figures

2.1 Street transit or surface transit

It designates modes operated on streets with mixed traffic (i.e. R/W category C); its reliability is often low because of various interference, and its speed is lower then the speed of traffic flow, owing to the time lost at passenger stops. This class includes the following modes: -

1. *Mini Bus*: These are smaller diesel or petrol driven buses, and have their present use largely in private operation. They are useful for narrow, crowded streets, where large buses have a problem in manoeuvring, and also for low demand routes where provision of large buses may prove to be uneconomical.
2. *Regular Bus (RB)*: It consists of single-decker buses operating along fixed routes on fixed schedules. Buses comprise by far the most widely used transit mode. The more the travel demand is concentrated along corridors, the more advantageous the regular bus becomes. The most typical bus services are street transit routes, which may represent the

entire transit network (small and most medium size cities) or supplementary and feeder services to rail networks.

3. *Double-decker Bus*: This is a higher capacity bus, with a design capacity of about 114 and crush capacity of 130. The bus is of similar size to a regular bus, though of course higher, with a more powerful engine. It is however slower for two reasons, namely power-to-weight ratio and longer stop times. It is not as economical (mainly due to its high capital cost) as regular bus. In addition, it has a disadvantage that all flyovers, elevated rights-of-way, bridges etc. need clearance of 5.5m instead of 4-4.5m.
4. *Articulated Bus*: These buses are usually 55 feet or more in length with two connected passenger compartments that bend at the connecting point when the bus turns a corner. It is not recommended, though it has a higher capacity because its extra length creates its own problems under Indian traffic conditions. The driver can't be as aware of the rear of the bus, and cornering is more difficult. As important is the fact that at stops the driver is not able to pull in correctly even with the standard, and takes up 2 lanes. In addition the bus stop lengths would need to be altered.
5. *Express bus*: service is provided by fast, comfortable buses on long routes with widely spaced stops. Its reliability of service is dependent on traffic conditions along the route.
6. *Trolley buses (TB)* are the same vehicles as buses except that they are propelled by an electric motor and obtain power from two overhead wires along their route. The advantages the trolley bus offers include higher riding quality (smooth vehicle motion) and excellent environmental features (extremely low noise, no exhaust). But, its always more expensive than the standard bus because at low demand levels its infrastructure cost makes it more expensive and at high demand levels, it can't meet the demand, being limited to 2 lanes. However, since these factors are not reflected in the operator's revenues, financial problems of transit agencies have often led to substitution of buses for trolley buses.
7. *Streetcars (SCR) or tramways*: are electrically powered rail transit vehicles operating mostly on streets. Their tracks and distinct vehicles give transit service a strong identification. When compared with buses, the streetcars have: more comfortable ride, quieter and pollution free operation, better vehicle performance, higher labor productivity (large vehicles), higher line capacity, but higher investment cost, less reliable street operation unless transit enjoys priority treatment, less flexible operation, higher maintenance, and greater impedance of other traffic. Tram is by far the most expensive street transit mode, as well as with very low capacity.
8. *Guided buses*: free the driver from the task of steering the bus while operating in a section of route equipped with guided-bus infrastructure. The guidance could be lateral, central, or electronic. The theoretical maximum capacity quoted for guided buses is 12,000 pphpd, but the realized capacity of the guided busway system as observed in Adelaide, Australia, is around half the theoretical capacity just quoted.
9. *Battery Operated Buses*: Battery operated buses have low range and speed capability, and cannot be used on a large scale in a city. However, they offer the following advantages as a low capacity (500-1000 pphpd) people mover in a congested area
   - Economic at low speeds with frequent start/stops.
   - Low noise.
   - Small in size, so easy to manoeuvre.

   They should be considered seriously for short routes and low demand routes in city areas.

Table 1 shows the system characteristics of some selected street transit systems.

		Mini Bus	Standard Bus	Double Decker Bus	Trolley Bus	LRV (Tram)
L*W (m)		6.6*2.3	9.7*2.5	9.1*2.4	11*2.5	11*2.5
Turning Radius (m)		7	11	12	22	15
Vehicle Capacity	Design (Seats)	30(20)	76(35)	114(70)	75(40)	75(40)
	Crush	40	100	130	110	110
PCU		2	3	3.5	4[(1)]	5[(1)]
Acceleration (m/s^2)		0.8	0.5	0.4	1.2	0.6
Cruising Speed (kmph)		60	60	50	60	50
Average Speed (kmph)[(2)]		20	17	15	20	15
Life (yrs.)		8	8	8	18	30
Cost (Rs. Million)- 1986 level		0.2	0.3	0.6	0.7	0.7
Energy Source		D/P	D	D	E	E
Pollution (kg/'000 veh. Kms at avg. speed)		35.0	38.05	38.05	0	0

[(1)]For reasons of length as well as lack of manoeuvrability.
[(2)]At average congestion.

Compiled from GOI (1987), SMART(1998), & INAE(1996)

Table-1: Systems' Parameters for Street Transit

2.2 Semirapid transit

It consists of modes utilising mostly R/W category B [i.e. R/W types which are longitudinally physically separated (by curbs, barriers, grade separation etc.) from other traffic, but with grade crossings for vehicles and pedestrians, including regular street intersections]. This class includes the following modes:

1. *Semirapid buses (SRB)*: are regular or high-performance buses operating on routes that include substantial sections of R/W categories B. Performance of such systems depends greatly on proportion and locations of separated R/W sections, R/W types, types of operation.
2. *Light rail transit (LRT)*: is a mode utilizing predominantly

reserved, but not necessarily grade-separated R/W. Its electrically propelled rail vehicles operate singly or in trains. LRT provides a wide range of Level-of-service (L/S) and performance characteristics. *LRT* compared with *SRB* on the corresponding alignments is characterized by: easier securing of B or A R/W, stronger image and identity of lines (rail technology), more spacious vehicles, higher passenger attraction, low noise, no exhaust, better vehicle performance due to electric traction, higher system performance, ability to operate in tunnels, ability to upgrade into rapid transit, but lower frequency for a given demand due to larger vehicles, a need to introduce new facilities for a different technology in case of a new application, lower ability to branch out and hence requiring more transfers, and a longer implementation period.

2.3 Rapid transit or mass rapid transit system

These modes operate exclusively on category A R/W (i.e. a fully controlled R/W without grade crossings or any legal access by other vehicles or persons) and have high speed, capacity, reliability and safety. All existing rapid transit systems utilize guided technologies (rail or rubber tire), that permit operation of trains (high capacity) and automatic signal control (high safety). This class includes the following modes:

1. *Rubber-tired rapid transit (RTR)*: consists of moderately large vehicles (gross floor areas between 36 and 53 m^2-380 and 570 ft^2) supported and guided by rubber tires, running on wooden, steel, or concrete surfaces in trains of 5 to 9 cars.
2. *Rail rapid transit (RRT)*: typically consists of large four-axle rail vehicles (area up to 70 m^2-750 ft^2) which operate in trains of up to 10 cars on fully controlled (A) R/W which allows high speed, reliability, capacity, rapid boarding, and fail-safe operation (in the case of driver's error or disability, the train is stopped automatically).
3. *Regional rail (RGR)*, usually operated by railroads, has high standards of alignment geometry. It utilizes the largest vehicles of all transit systems (up to 80m^2-860ft^2) which operate in trains, on longer routes, with fewer stations, at higher speeds than typical for RRT. Thus, RGR functionally represents a "large-scale RRT" which serves most efficiently regional and longer urban trips.

2.4 Special Transit

Specialised transport system are those which may have a role to play in a specific part of a city, without in any way forming a substantial part of the urban transport network. These are:

1. *Magnetic Levitation*: In levitation systems the coach is suspended in air by magnetic levitation or by air cushion. The reason for the development of these technologies was to overcome the problems of vibration and resonance, which make it virtually impossible for normal trains to exceed 300 kmph. The air cushion system is still experimental and is not seriously considered. Till now, only small systems have been constructed at low capacities of 2000-5000 pphpd. Under Indian overloading patterns, the magnets may need to be augmented, and may need remagnetising more often.
2. *Monorails*: They have been designed for their low guideway cost, but have three main drawbacks:
   - Low capacity (up to 15-20,000 pphpd).
   - No form of emergency evacuation, so a low safety factor.
   - Complicated guide wheel system.

   Primarily since the monorail is designed for low capacities, and cannot meet the necessary demand levels in India, it has not been seriously considered, till now.
3. *Water Borne Transport*: Water borne transport should be taken more seriously since most cities are either by the sea or on a river, and water transport may be able to take some of the load if traffic demand is across or along water.
4. *Automated Guided Transit (AGT)*: AGT modes are low capacity rail based system of lightweight construction, and totally automated. They consist of two groups: *personal rapid transit (PRT)*, with small vehicles serving individual parties only, and *group rapid transit (GRT)*, also known as *people mover systems (PMS)*, with somewhat larger vehicles (15 to 50 spaces) designed mostly for short-haul medium capacity lines. AGT is classified as *special transit*, together with other proposed and specialized modes. This class of transit contains both *supported* and *suspended* type of technologies. These modes basically provide service in such areas as shopping centres, commercial areas, airports etc. as an enhancement to the area's activities. Table-2 shows the system characteristics of some selected rail based transit systems.

	Heavy Rail			Medium Capacity			Mono rail	Sky Bus
	EMU	Metro	Heavy Rail Recommended	LRT	Purpose Designed Lin. Mtr.	Mag. Lev.		
Gauge (m)	1.667	1.667	1.667	1.435	1.435	1.435	N/A	1.435
Coaches/train	9	8	9	3(articulated)	6	4[1]	4	2/4
Length*Width (m)	20*3.66	20*2.74	20*2.74	29*2.50	16*2.65	12*2.3	10*2.5	8*2.8
Tare Weight (T)	350	300	244	123	99	36	40	N/A
Payload/Tare Ratio	0.50	0.52	0.64	0.585	0.73	0.88	0.75	N/A
Axle Load (T)	19	16.5	16	8	8	N/A[4]	6	N/A
Acc./Dec. (m/s^2)	1.1/1.2	1.1/1.2	1.0/1.3	1.0/1.3	1.0/1.3	1.0/1.3	1.4/1.5	1.3
Max. Speed (kmph)	80	80	80-120	80	80	80	80	100
Min. Radius (m)	200	200	200	20	20	20	20	100
Max. Gradient (%)	2	2	2	7	10	10	10	1.3
Power Supply	25KV AC	750V DC	750 V DC	750 V DC	750 V DC	1 KV AC	750 V DC	750V DC
Energy Consumption (W hr/ Ton. Km)	40[2]	52	40	34[3]	40[3]	35[3]	40 (Est.)	N/A
Min. Headway (Mts)	3	1.5	1.5	1.0	1.0	1.0	1.5	1

[1]Over 4 coaches/train needs design changes to the track power supply system.
[2]On 2 km station spacing.
[3]Assuming Automatic Driverless Operation.
[4] Continuos load distribution.

Compiled from GOI(1987) & GOM(2000)

Table-2: Systems' Parameters for Rail Based Transit

3. Detailed Capacity Assessment of Some Selected Technologies

Certain mass transit systems were excluded from further consideration. Technologies such as rubber tyred rapid transit (RTRT), monorails, automated guided transit (AGT) were rejected on the grounds that they use non-proven technologies or technologies which have experienced operating problems or technologies which don't have the precedence of their application in India. MAGLEV was excluded from further assessment on the ground that it has few successfully operating examples already in existence in the world. Guided bus was not given any further explicit consideration, because it was felt to offer few significant advantages to compensate for the considerable disadvantages, including the capital cost of the guideway structure and the equipment on the buses. Trolleybuses were eliminated for similar reasons (higher capital cost not offset by any substantial advantage) and because- compared with ordinary buses- their operation would be restricted to routes which are equipped with overhead wires.

Hence, the technologies and system which were studied in detail for their capacity ranges are: Standard Bus, Double-decker Bus, Articulated Bus, LRT1 (operating in R/W category B and C), LRT2 (operating in R/W category A), Rapid Rail Transit (RRT or Metro), Regional Rail Transit (Suburban Railway).

For calculating the passenger capacity in the peak direction during peak hour, the following equation has been used:

For Bus

(1)

$$\text{Passengers/hr./dir.} = \frac{\text{Buses}}{\text{hr.}} \left(\frac{\text{Seats}}{\text{Bus}} \times \frac{\text{Passengers}}{\text{Seat}} + \frac{\text{Standing area (m}^2\text{)}}{\text{Bus}} \times \frac{\text{Standees}}{\text{m}^2} \right)$$

For Rail Systems

$$\text{Passengers/hr./dir.} = \frac{\text{Trains}}{\text{hr.}} \times \frac{\text{Cars}}{\text{Train}} \left(\frac{\text{Seats}}{\text{Car}} \times \frac{\text{Passengers}}{\text{Seat}} + \frac{\text{Standing area (m}^2\text{)}}{\text{Car}} \times \frac{\text{Standees}}{\text{m}^2} \right)$$

(2)

Following are the values taken for some general parameters, to be used in capacity calculation:

1. The general space required for one seat for quite a comfortable sitting position = 0.32 m^2.
2. The average seats-to-standees ratio for a single vehicle train unit = 0.35.
   (The ratio was kept a little low, with the aim to maximise the system's capacity)

LOS	Bus		Rail		Comments
	m^2/p	P/seat	m^2/p	P/seat	
A	>1.20	0.00-0.50	>1.85	0.00-0.50	No passenger need sit next to another
B	0.80-1.19	0.51-0.75	1.30-1.85	0.51-0.75	Passengers can choose where to sit
C	0.60-0.79	0.76-1.00	0.95-1.29	0.76-1.00	All passengers can sit
D	0.50-0.59	1.01-1.25	0.50-0.94	1.01-2.00	Comfortable loading for standees
E	0.40-0.49	1.26-1.50	0.30-0.49	2.01-3.00	Maximum schedule load
F	<0.40	>1.50	<0.30	>3.00	Crush loads

Source: HCM(2000)

Table-3: Passenger Load LOS as per HCM 2000

3. Normal load for standees = 5 Standees/m^2.
4. Crush load for standees = 8 Standees/m^2

The Highway Capacity Manual 2000 takes 3 Standees/m^2 as the crush load (Table-3), which can not be thought of in a country like India, hence, based upon some earlier studies done [GOI(1987), SMART(1998)], the above values of normal and crush load has been taken.

3.1 Conventional Bus on Busway

The bus sizes (L*B) taken for capacity calculations are as follows: -

Large Single-decker Bus - 10 m * 2.5 m
Double-decker Bus - 9.1 m * 2.4 m
Articulated Bus - 16 m * 2.5 m

The carrying capacities of buses were obtained for normal and crush load and are shown in the Table-4. The figures shown below are similar to the capacities observed in Mumbai.

Type of Bus	Seats	Normal Load	Crush Load
Single-decker Bus	35	76	100
Double-decker Bus	70	114	130
Articulated Bus	75	118	150

Source: SMART(1998)

Table-4: Carrying Capacities of Conventional Buses

For large urban single-deckers and double-deckers, maximum service frequency on a single-lane busway is determined by operational safety and station/stop capacity, estimated at about 85 buses per hour per direction with normal breaking at bus-stop arrivals. For articulated buses on a single-lane busway, maximum service frequency is estimated at 80 buses per hour per direction with normal breaking standards. Maximum service frequency can be significantly increased if the busway consists of a double lane in each direction of operation- a maximum frequency of 240 buses per hour per direction with normal breaking at stops and stations is possible. Based on these values, and the carrying capacities of buses shown in Table-4, the carrying capacity of different type of busway is calculated and summarised in Table-5.

No. of lanes per direction	1 (Single)	1	1	2(double)	2
Bus type	Large urban single-decker	High capacity double-decker	Articulated	Large urban single-decker	High capacity double-decker
Overtaking possible	No	No	No	Yes	Yes
Buses/hr./dir. (normal breaking)	85 (headway 42 sec.)	85 (headway 42 sec.)	80 (headway 40 sec.)	240 (headway 15 sec.)	240 (headway 15 sec.)
Pphpd (normal load)	6,460	9,690	9,440	18,240	27,360
Pphpd (crush load)	8,500	11,050	12,000	24,000	31,200

Table-5: Capacities of Different Types of Busway

3.2 Light Rail Transit 1 (LRT1)

LRT1 operates in R/W category B or C with some interference from other traffic. The disadvantages are low system capacity and susceptibility to traffic congestion, leading to low service level including low commercial speed and low reliability.
Following are the values taken for capacity calculation: -
Dimensions (L*B) of a light rail vehicle = 25 m * 2.65 m
Effective in-vehicle length, available for passengers after subtracting space for two drivers cabs at each end (approx.) = 21 m.
Effective floor space = 53 m²
No. of seats per rake (assuming longitudinal seating arrangement) = 65
Space needed for 65 seats = 65 * 0.32 m2 = 21 m²
Space for standees = (53 – 21) m2 = 32m²
Normal capacity for standees (5 standees/m²) = 32 * 5 = 160
Crush capacity for standees (8 standees/m²) = 32 * 8 = 256
Two vehicle train is assumed because of interference from other traffic, total length of platform needed (approx.) = 55 m
Minimum headway possible = 60 Sec.
Gauge = Standard gauge (1.435 m)
The capacity for Light Rail Transit 1 (LRT1) for normal and crush load is as shown in the Table-6.

	Normal Load (5 p/m²)	Crush Load (8 p/m²)
Seats	65	65
Standees	160	256
Vehicle Capacity	225	321
2-Vehicle Train Capacity	450	642
Line Capacity (h-60 sec.) in pphpd	27,000	38,520

Table-6: Capacity of Light Rail Transit 1 (LRT1)

3.3 Light Rail Transit 2 (LRT2)

LRT2 operates totally segregated in R/W category A. Headway is only influenced by passenger handling at stations and the signalling and control system. Minimum headway of 90 sec. (1.5 min.) is possible and hence been taken for capacity calculation. The rest of the values are same as taken for LRT1. Table-7 shows the capacity of LRT2 for normal and crush load.

3.4 Rail Rapid Transit (RRT or Metro)

RRT operates with large, long carriages formed into semi-permanent trains with a driving cab at each end to felicitate rapid turnaround at terminals. The gauge used is Broad Gauge (1.667m). It requires Block-Signalling system, trains are electrically powered from overhead catenary via a pantograph on the train roof or from a third rail via collector shoes on the

	Normal Load (5 p/m²)	Crush Load (8 p/m²)
Seats	65	65
Standees	160	256
Vehicle Capacity	225	321
4-Vehicle Train Capacity	900	1,284
Line Capacity (h-90 sec.) in pphpd	36,000	51,360

Table-7: Capacity of Light Rail Transit 2 (LRT2)

train bogies. The disadvantage with RRT is that due to its alignment requirements, the insertion of heavy rail transit into an existing urban area is generally extremely difficult, requiring extensive land and property acquisition, demolition, route elevation or costly underground route location.
Following are the values taken for capacity calculations: -
Dimension (L * B) for a twin-vehicle unit = 37.55 m * 2.90 m
Effective floor space for passengers (approx.) = 92 m²
Necessary platform length for a 6-vehicle train (3 twin-vehicles) = 120 m (approx.)
Minimum headway possible = 1.5 min. (90 Sec.)
Seat arrangement = Back-to-back
Table-8 shows the capacity of RRT for normal and crush load.

	Normal Load	Crush Load
Seats	98	98
Standees	300	480
Vehicle Capacity	398	578
3 Twin-Vehicle Capacity (6 Vehicles)	1,194	1,734
Line Capacity (Headway 90 Sec.)	47,760	69,360

Table-8: Capacity of Rail Rapid Transit (RRT or Metro)

3.5 Regional Rail Transit (RGR) (Suburban Railway)

The operation of RGR could be quite flexible compared to RRT. Track may be shared at certain times of the day with other services, such as inter-city or freight trains. Rolling stock design may be more varied: electric or diesel powered, composed of single or double-deck vehicles. Timetable may be more flexible with some trains not calling at all stations and some trains operating for only part of the route, in accordance with passenger demand. System capacity depends on the capacity of the carriages, the number of carriages per train, the timetable (station stopping pattern) and how many other types of train share the same track (which determines the maximum number of trains per hour). Following are the values taken for capacity calculation: -
Dimension (L * B) of one vehicle unit = 20 m * 3.66 m
Effective floor space for standees (for seat-to-standees ratio 0.35) = (20 * 3.66) / 1.35
= 54 m²
Effective seat area = 0.35 * 54 = 19 m²
No. of seats (for 0.32 m2 area per seat) = 19 / 0.32 = 60
Gauge = Broad Gauge (1.667 m)
Table-9 summarises the capacity of RGR for normal and crush load.
Table-10 shows how line capacity varies with headway and, in the case of rail-based options, the number of cars or units which are coupled together to form a train. The table shows service headway up to 10 minutes. This implies an average passenger wait time of five minutes. Particularly in the peak period, the attractiveness of the transit mode will be increased as headway, and therefore wait times, is reduced. However, at

very short headway the difference in wait times may be imperceptible to the passenger. For example, increasing service headway from two to four minute increases waiting time by only one minute (half the two-minute difference in headway). For rail-based modes, it may be cheaper to operate longer trains at a wider headway and the planner must aim to maximise the financial performance of the transit system by optimising the combination of headway and train length.

	Normal Load	Crush Load
Seats	60	60
Standees	270	432
Vehicle Capacity	330	492
Train Capacity (9 Vehicles)	2970	4428
Line Capacity (Headway- 3 min.)	59,400	88,560

Table-9: Capacity of Regional Rail Transit (RGR)

4. Suitability of Transit Systems for Different Travel Demands for Indian Cities

After doing the detailed capacity assessment of some selected mass transit technologies, their suitability for different travel demands for Indian cities can be ascertained. Hence, based on the analysis done in the previous section, the following travel demand ranges, within which a particular mass transit system is suitable for operation in Indian cities, can be established: -

Street transit system = Up to 12,000 pphpd
(Mini-bus, single decker standard bus, double-decker and articulated)
LRT1 = 12,000 to 36,000 pphpd
LRT2 = 36,000 to 50,000 pphpd
RRT (Metro) = 50,000 to 69,000 pphpd
RGR = 59,000 to 89,000 pphpd

The above ranges can be taken as the basis for determining the suitability of transit systems for Indian cities of different population sizes and forms based on the peak hour passenger per direction (pphpd) count on major corridors within the city.

Headway (minutes)		0.25	0.71	0.75	1	1.5	2	3	4	5	6	8	10
Trains Per Hour		240											
System	Cars/ units per train												
Conventional bus (Single-decker on single-lane busway)		-	8500	8000	6000	4000	3000	2000	1500	1200	1000	750	600
Conventional bus (double-decker on single-lane busway)		-	11050	10400	7800	5200	3900	2600	1950	1560	1300	975	780
Conventional bus (articulated on single-lane busway)		-	-	12000	9000	6000	4500	3000	2250	1800	1500	1125	900
Conventional bus (single-decker on double-lane busway)		24000	8500	8000	6000	4000	3000	2000	1500	1200	1000	750	600
Conventional bus (double-decker on double-lane busway)		31200	11050	10400	7800	5200	3900	2600	1950	1560	1300	975	780
Light Rail Transit-1	1	-	-	-	19260	12840	9630	6420	4815	3852	3210	2408	1926
Light Rail Transit-1	2	-	-	-	38520	25680	19260	12840	9630	7704	6420	4815	3852
Light Rail Transit-2	1	-	-	-	-	12840	9630	6420	4815	3852	3210	2408	1926
Light Rail Transit-2	2	-	-	-	-	25680	19260	12840	9630	7704	6420	4815	3852
Light Rail Transit-2	3	-	-	-	-	38520	28890	19260	14445	11556	9630	7223	5778
Light Rail Transit-2	4	-	-	-	-	51360	38520	25680	19260	15408	12840	9630	7704
Rapid Rail Transit (twin vehicle)	1	-	-	-	-	23120	17340	11560	8670	6936	5780	4335	3468
Rapid Rail Transit (twin vehicle)	2	-	-	-	-	46240	34680	23120	17340	13872	11560	8670	6936
Rapid Rail Transit (twin vehicle)	3	-	-	-	-	69360	52020	34680	26010	20808	17340	13005	10404
Regional Rail Transit	3	-	-	-	-	-	-	29520	22140	17712	14760	11070	8856
Regional Rail Transit	6	-	-	-	-	-	-	59040	44280	35424	29520	22140	17712
Regional Rail Transit	9	-	-	-	-	-	-	88560	66420	53136	44280	33210	26568

Compiled from SMART(1998), GOI(1987)

Table-10: Capacity of MRT Systems by Headway and Cars/Units Per Train (Crush Load: 8 Standees Per Square Metre)

5. Suitability of Transit Systems for Indian Cities of Different Population Sizes and Forms

As discussed in the previous section, to ascertain the suitability of any transit system for any Indian city of a particular population size and city form, the peak hour passenger per direction (pphpd) count on major corridors within the city needs to be determined. Since, its practically very difficult to obtain the peak hour passenger travel demand for every Indian city, a more generalised approach could be, to do a study on hypothetical cities of various population size, urban form, and spatial structure and correspond them with Indian cities, to obtain a fair estimate of the peak hour passenger travel demand, and which can be taken as the basis for ascertaining the suitability of transit system for any Indian city.

Based on the physical

form, cities could be *circular*, *semi-circular*, or *linear/grid*. Also, they could be *mono-nuclear (mono-centric)*, if they are having a single central business district (CBD), or *poly-nuclear (poly-centric)*, if they are having other district business centres (DBCs) along with a CBD. They can also be called *uniform*, if equal employment opportunities exist at CBD and other DBCs, or *non-uniform*, if it has a dominant CBD plus other DBC's with equal employment opportunities [GOI (1987)]. The distribution of population and population density in a model circular city can be suitably assumed as follows:

S.No.	Residential Structure	Population Disposition
1.	Inner Belt 20%	10%@ 600 persons/hectare
2.	Intermediate Belt 60%	60%@ 250 persons/hectare
3.	Outer Belt 20%	30%@ 100 persons/hectare

Table-11: Distribution of population and population density in a model circular city

Circular City Form: For each population range the median population is distributed in three belts, inner, intermediate, and outer, in proportions of 10%:60%:30%, at population densities of 600, 250 and 100 persons per hectare respectively (Table-11). This fixes the dimensions of a hypothetical city of given population range and median population. The three belts are further divided into four quadrants each. Centriods for the twelve population zones so created are computed together with the composite centriods of the three belts in each quadrant. The radial distance of the composite centriods, specifies a ring for 'optimal' location of one DBC each for the four quadrants in addition to the CBD at the centre of the city. For the polynuclear non-uniform circular city structure the CBD has a dominant employment size of 1/2 of the total employment of the city, while the remaining four DBCs have each a uniform share of 1/4 of the remaining half of the total employment. In the case of uniform polynuclear circular city structure, the CBD and four DBCs each have a uniform size of 1/5 of the total employment of the city. In mononuclear activity structure the total employment is concentrated at the CBD.

The structuring of the circular city in the manner described above is based on recognizing four major radial corridors and a ring (peripheral) corridor passing through the four DBCs in the polynuclear structure. The total trip volume in thousands per day can be computed from the basis of the population size of the city by using the following equation:

$$T_v = -395.1118 + 1.2914\,P \qquad (3)$$

$T_{statistics}$ -0.8542 10.3882 $R^2 = 89.91\%$

Confidence level 20.38% 100%

Where, T_v = Trip volume in thousands per day

P = Population in thousands per day

After getting the total trip volume and calibrating the gravity model for each typology of circular city form, the detailed trip assignment on radial and ring corridors can be computed [GOI(1987)].

Semi-Circular City Form: This is again divided into three belts with each belt subdivided into two zones, thereby giving six population zones. The population distribution is similar to the one assumed in the circular case. Accordingly, the various dimensions of the hypothetical city, its population centroids, and work centres can be located in a manner identical to the circular case.

Linear City Form: The hypothetical linear city is assumed to have a width of 5 kms, and a population distribution in the three belts, viz., inner, intermediate, and outer, in proportions of 20% : 60% : 20% at population densities of 600, 250 and 100 persons per hectare, respectively as before. With these assumptions the necessary dimensions of the three belts, each divided into two zones with their respective centroids and activity centres can be worked out for each typology of the classification considered.

Circular

Population (M)	Polynuclear Non-uniform			Polynuclear Uniform			Mononucler		
	Sectional loading on Radial Corridors (M trips/day)		Loading on Ring Corridor (M trips/day)	Sectional loading on Radial Corridors (M trips/day)		Loading on Ring Corridor (M trips/day)	Sectional loading on Radial Corridors (M trips/day)		Loading on Ring Corridor (M trips/day)
	Max	Min		Max	Min		Max	Min	
13	3.35	1.17	0.81	2.4	1.17	1.26	-	-	-
6	1.5	0.52	0.36	1.3	0.5	0.57	-	-	-
3	0.71	0.25	0.17	0.63	0.25	0.27	0.87	0.25	0.0
1.5	0.3	0.11	0.076	0.28	0.11	0.12	0.38	0.1	0.0
0.75	0.12	0.04	0.028	0.1	0.04	0.044	0.14	0.04	0.0
0.375	0.015	0.006	0.0044	0.02	0.006	0.0068	0.022	0.006	0.0

Semi-Circular

Population (M)	Polynuclear Non-uniform			Polynuclear Uniform			Mononucler		
	Sectional loading on Radial Corridors (M trips/day)		Loading on Ring Corridor (M trips/day)	Sectional loading on Radial Corridors (M trips/day)		Loading on Ring Corridor (M trips/day)	Sectional loading on Radial Corridors (M trips/day)		Loading on Ring Corridor (M trips/day)
	Max	Min		Max	Min		Max	Min	
13	5.0	2.3	2.8	5.9	2.3	3.6	-	-	-
6	2.27	1.04	1.3	2.7	1.0	1.6	-	-	-
3	1.0	0.5	0.6	1.3	0.5	0.75	1.7	0.5	-
1.5	0.47	0.22	0.27	0.56	0.22	0.33	0.77	0.22	-
0.75	0.18	0.08	0.1	0.21	0.08	0.12	0.3	0.08	-
0.375	0.027	0.012	0.015	0.03	0.01	0.02	0.04	0.02	-

Linear

Population (M)	Polynuclear Non-uniform Sectional loading on Corridors (M trips/day)		Polynuclear Uniform Sectional loading on Corridors (M trips/day)		Mononucler Sectional loading on Corridors (M trips/day)	
	Max	Min	Max	Min	Max	Min
13	7.7	1.4	7.6	1.5	-	-
6	3.5	0.6	3.4	0.65	-	-
3	1.6	0.31	1.62	0.3	1.7	0.3
1.5	0.7	0.14	0.7	0.14	0.77	0.14
0.75	0.27	0.05	0.27	0.05	0.3	0.05
0.375	0.04	0.007	0.04	0.007	0.04	0.007

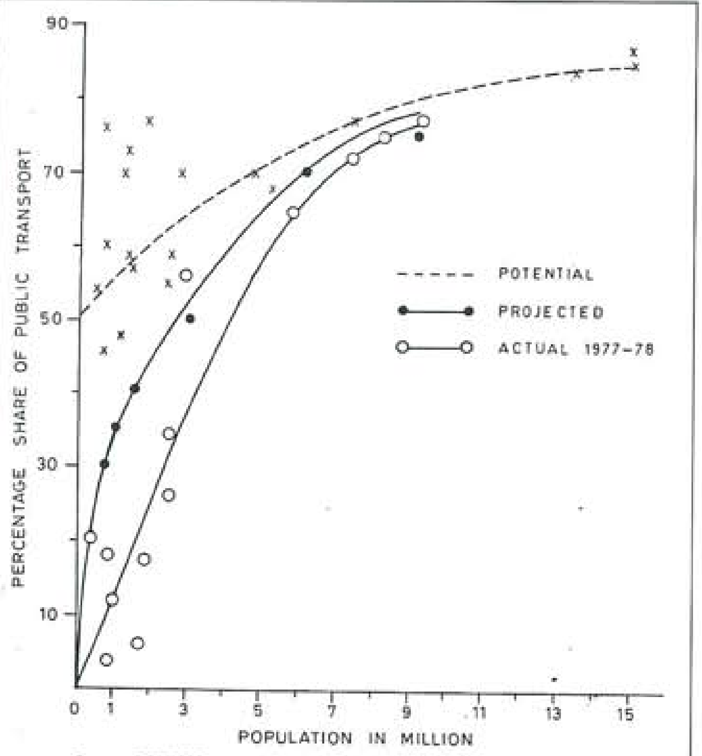
Table-12: Projected Loading for Conceptual Directional and Ring Corridors for Indian Cities [Compiled from GOI(1987)]

The trip assignment data generated by the model for the hypothesized city forms, structures and sizes give a reasonable approximation for the conceptual corridor trip volumes for cities in India, which is as shown in Table-12. The loading for corridors obtained in Table-12 are in terms of million trips per day for all modes, which are required to be converted to peak hour public transport demand in terms of pphpd for the purpose of analysis.

This can be done using the following simple conversion rule:

Peak Hour pphpd = Max. Loading 3 Peak Hour Factor 3 Peak Directional Factor 3 Public Transport Share Factor (4)

Here, Max. Loading can be obtained from Table-12 for the corresponding city population size and form. Peak Hour Factor and Peak Directional Factor can be suitable assumed as 0.1 and 0.6, respectively for Indian conditions [GOI(1987)]. And the Public Transport Share Factor can be obtained from Fig.-1, for the corresponding city population size. To obtain the public transport share factor, it is assumed that the journey lengths beyond which trips by private modes (walk, bicycle, and two-wheeler) will potentially transfer to an attractive public transportation system together with potential percentage transfers in the other modes is as given in Table-13. In accordance with the estimate in Table-13, the potential share of public transport in percentage terms, against the population of a city, are computed through simple and relatively straight forward statistical calculations, and are as shown in Fig-1.



Source: GOI(1987)

Fig.-1: Modal Share of Public Transport for Cities of Different Sizes [Source: GOI(1987)]

Hence, using Eq.4, the maximum peak hour public transport demand in terms of passengers per hour per direction (pphpd) can be computed for various city population size and forms, and is as given in Table-14.

Mode	Assumed distance beyond which 50% trips will transfer to public transport	Potential percentage transfers to public transport
Walk	1 km	50%
Bicycle	3 km	50%
2-Wheeler	7 km	50%
Car	Not applicable	10%
Cycle Rickshaw		25%
3-Wheeler		50%
Institutional Transport		50%
Mini-Bus		100%
Bus		100%
Tram		100%
Train		100%

Table-13: Potential Transfer from Other Modes to Public Transport Modes

After getting the maximum peak hour public transport demand, as shown in Table-14, the suitability of mass transit systems for Indian cities of different population sizes and forms can be ascertained by comparing the pphpd values in Table-14 with the travel demand ranges in Section 4.0. The result is as shown in Table-15. Here, the recommendation of mass transit system for any city is based on the distribution of peak hour demand among the alternative mass transit systems based on their capacity and desired level of service.

Population (M)	Public Transport Share Factor	Activity Structure[1]	Maximum Peak Hour pphpd: Circular City	Semi-Circular City	Linear City
13	0.84	PNU	1,68,840	2,52,000	3,88,080
		PU	1,20,960	2,97,360	3,83,040
		M	-	-	-
6	0.74	PNU	66,600	1,00,788	1,55,400
		PU	57,720	1,19,880	1,50,960
		M	-	-	-
3	0.64	PNU	27,264	38,400	61,440
		PU	24,192	49,920	62,208
		M	33,408	65,280	65,280
1.5	0.58	PNU	10,440	16,356	24,360
		PU	9,744	19,488	24,360
		M	13,224	26,796	26,796
0.75	0.55	PNU	3,960	5,940	8,910
		PU	3,300	6,930	8,910
		M	4,620	9,900	9,900
0.375	0.53	PNU	477	859	1,272
		PU	636	954	1,272
		M	700	1,272	1,272

(1) PNU = Polynuclear Non-Uniform, PU = Polynuclear Uniform, M = Mononuclear

Table-14: Maximum Peak Hour Public Transport Demand in pphpd for Indian Cities

Population (M)	Activity Structure[2]	Recommended Mass Transit System[1]		
		Circular City	Semi-Circular City	Linear City
13	PNU	RGR+LRT1/LRT2+ST	RGR+LRT1/LRT2+ST	RGR+RRT+LRT1/LRT2+ST
	PU	RGR+LRT1+ST	RGR+LRT1/LRT2+ST	RGR+RRT+LRT1/LRT2+ST
	M	-	-	-
6	PNU	RRT+LRT1/LRT2+ST	RRT+LRT1+ST	RGR+LRT1/LRT2+ST
	PU	RRT+LRT1/LRT2+ST	RRT+LRT2+ST	RGR+LRT1/LRT2+ST
	M	-	-	-
3	PNU	LRT1+ST	LRT2+ST	RRT+LRT1/LRT2+ST
	PU	LRT1+ST	LRT2+ST	RRT+LRT1/LRT2+ST
	M	LRT1+ST	RRT+LRT1+ST	RRT+LRT1/LRT2+ST
1.5	PNU	ST	LRT1+ST	LRT1+ST
	PU	ST	LRT1+ST	LRT1+ST
	M	LRT1+ST	LRT1+ST	LRT1+ST
0.75	PNU	ST	ST	ST
	PU	ST	ST	ST
	M	ST	ST	ST
0.375	PNU	ST	ST	ST
	PU	ST	ST	ST
	M	ST	ST	ST

(1) RGR = Regional Rail Transit, RRT = Rail Rapid Transit, LRT1 = Light Rail Transit 1, LRT2 = Light Rail Transit 2, ST = Street Transit.
(2) PNU = Polynuclear Non-Uniform, PU = Polynuclear Uniform, M = Mononuclear.

Table-15: Recommendation of Mass Transit Systems for Indian Cities

A fully integrated mass transit system (as recommended in Table-15) will be most desirable to fully cater the public transport demand in Indian cities.

6. Influence of Other Factors in Selection of Mass Transit Systems

Besides the travel demand criteria, systems are judged by their suitability for Indian conditions on: effectively and cost-effectively performing their designated roles, flexibility of operation with wide applicability, energy sources and consumption, environmental and aesthetic impact, technology including potential spin-off benefits, and export potential. Table-20 shows a detailed comparison between different mass transit systems based on parameters like average life, flexibility of operation, environmental impact, energy input, cost of system, & suitability of operation. The selection of any particular mass transit system for any city can be made with different trade-offs between the parameters mentioned above. Effect of some of the parameters is discussed below: -

Environmental Impact: Urban transport affects the environment in 3 areas, atmospheric pollution, noise pollution, and visual pollution. One fact must be kept in mind throughout that the public transport proportion of pollution accounts for 5% of the total pollution caused by all vehicles. The answer therefore does not lie in worrying greatly about the pollution caused directly by public transport, but rather whether it is controlled effectively, thus reducing the 95% of pollution caused by other vehicles.

Atmospheric Pollution- In India, atmospheric pollution derives mainly from 3 sources i.e. industrial emissions

	Kg of emission (per 1000 vehicle/km)	Percent
Bus	38.05	12.7
Truck	38.05	12.7
Car (Petrol)	49.61	40.0
Car (Diesel)	3.21	1.1
3-wheeler	35.79	25.5
2-wheeler	27.29	17.0

Source: Satsangi(1993)

Table-16: Emissions of Different Vehicles

(especially power stations); smoke from cooking and heating fires; vehicle emissions (estimated to account for 50% of the total emissions). The emissions of different vehicles are shown in Table-16.

In addition, it should be realized that the higher emissions of Carbon Monoxide (CO) from the petrol driven vehicles are much more injurious to the health than those of diesel powered vehicles, which are more visually repellent. This lends further weight to the point made above-namely that it is the personalised vehicles that are the real culprits. However, it would be unreasonable to try and ban or restrict personalised vehicles from being used, unless an alternative is first provided.

Noise Pollution- The average noise levels (at 15m) are as in Table-17. The conclusion is again that a higher level of public transport will be the most effective means of reducing ambient noise levels. This is far more important than the (minor) differences between systems, with the exception of heavy rail. Finally, it needs to be emphasised that the indiscriminate use of the horn in Indian traffic is perhaps the biggest problem.

	Noise Level (avrg. @ 15m high)
Standard Bus	90 dB
Urban Bus	80 dB
Car / 2-wheeler	70 / 80 dB
Heavy Rail	100 dB
Magnetic (Levitated)	55 dB (at 25 m)
Ambient traffic in India	90 dB
Normal office ambient	65 dB

Source: Satsangi(1993)

Table-17: Noise Pollution Levels

Visual Pollution- The worst visual pollution in transport is that of congested, mixed and undisciplined traffic, again the increased public transport share (and especially exclusive grade separated systems) will go far to reducing this problem. Having stated that, two areas of public transport need to be examined: vehicle design; exclusive grade separated right of way.

Cost and Performance Comparisons- Table-20 shows the cost and performance comparison between various mass transit systems. As far as rail systems are considered, it's not always possible in present urban conditions to go for any particular (surface, underground, or elevated) type of construction, hence, a network should not be thought of as solely elevated or surface or underground, but rather the three should complement each other in a network, and fit in with the requirement of each individual section. Table-18 shows the comparison of the cost of constructing medium or heavy rail system on surface, elevated, or underground for 1987 prizes.

	System	Total Cost (Crores/Km.)
Medium Capacity	Surface	9.35
	Elevated	14.9
	Underground	27.95
Heavy Rail	Surface	10.2
	Elevated	18.45
	Underground	31.05

Source: GOI(1987)

Table-18 : Total Cost of different rail based systems for 50,000 pphpd capacity in horizon year (10th year of operation)

7. A Look Ahead in Public Transportation

In the dispersed regional city of future, public transportation will be needed to carry out five essential functions:

1. To guarantee city wise mobility for the growing number of people who are non-drivers by choice or necessity.
2. To supply the exclusive means of travel in high-density areas where cars are prohibited.
3. To complement the services rendered by the automobile on trips that require both methods.
4. To provide local extensions of the intercity and global public transportation networks.
5. To help create a more satisfying, manageable, pollution-free and sustainable urban environment that maximises the ability to move while minimising the necessity for movement.

Harman(1988) outlined the major advances anticipated in the different forms of public transportation. These included:

Buses- There will likely be production of a bus that has two methods of propulsion in one coach, a diesel engine for use on suburban streets and electric power for city streets and in tunnels. Some innovations can be expected in alternative forms of access to the vehicle, in particular for the elderly and handicapped. Although some concepts are currently being developed that would make the bus-road interface much more "intelligent" in terms of navigation and vehicle control, such programs are not likely to see widespread implementation in the early part of the twenty-first century.

Heavy and Light Rail- The major source of innovation will likely come in the means of providing propulsion and in automatic system control.

Commuter and Intercity Rail- There were possible major advances that could be anticipated in the application of linear induction motor, magnetic levitation technology and other forms of providing high-speed passenger transportation.

Automated Guideway- The technology for implementing automated guideway transit, group rapid transit, or personal rapid transit systems is already available. The key issue is now to find the appropriate applications.

Harman then suggested that perhaps the greatest technological innovations will come in the areas of transit user information systems, automatic vehicle monitoring, and in "revisiting" already tested applications such a high-occupancy vehicle facilities.

8.0 Summary

In summary, the procedure for the comparative analysis and selection of transportation modes follows these major steps:

- *Step 1*: Based on urban transportation *policy*, develop *goals* for the transit system.
- *Step 2*: Define *conditions* for the area to be served.
- *Step 3*: Utilizing results from preceding steps, define specific *requirements and standards* for the planned system.
- *Step 4*: Select *ROW type* for candidate modes.
- *Step 5*: Select *technologies* and *type of operation* for candidate modes.
- *Step 6*: Develop *functional designs* for candidate modes.
- *Step 7*: *Evaluate* candidate modes.
- *Step 8*: *Compare* evaluation results (based on capacity, cost, environmental impact etc.) and *select* the optimal mode.

From the results obtained (Table-15), it can be seen that in cities with population up to 0.75 Million (also circular PNU & PU cities of population 1.5 million), the street transit can fully cater to the peak hour passenger travel demand, as the maximum peak hour public transport demand is within the capacity of the street transit, (Table-14). But for cities with population above these values, a rail-based system along with a street transit system is required to cater to increased passenger travel demand. Also, it can be seen from Table-15 that cities with population greater than 6 million probably requires the highest order mass transit systems like regional rail transit to meet the heavy passenger travel demands (Table-14) on major corridors within the city.

Finally, Table-19 shows in tabular form, some of the more frequently encountered relationships involved in translating system goals into design objectives and, in turn, into design methods and technology attributes. For example, to meet the goal of minimizing construction cost, the designer must choose the objective of maximizing the use of shared facilities, seeking to run on HOV lanes and transitways open to carpools and vanpools. In this case, Bus Rapid Transit (BRT) would be the favoured technology, being capable of operation in all types of HOV configurations, LRT would be second choice, being appropriate for limited running in arterial HOV lanes only, and the last choice would be RRT and AGT with their requirements for exclusive guideways.

The authors feel that the paper would strongly help planners in selecting a suitable mass transit system for Indian cities of different sizes and forms.

Goal / Design Objective	Design Method	Technology Suitability Rank			
		RRT	AGT	LRT	BRT
Maximise ridership/ Locate stations within easy walk of many major centers	Locate system underground to allow unobtrusive / nondisruptive high-capacity entry into high-density areas	1	2	2	3
	Locate system in surface streets / malls of major centers, with first-floor-level stops	2	2	1	1
	Use high line mileage and many stations systemwide	1	1	1	1
Provide high-frequency service	Use short trains or single-vehicle trains with short headways	3	1	2	1
Maximize scheduled speed	Provide grade seperation and high-speed alignment for entire system	1	2	3	4
	Provide skip-stop and express service	2	2	2	1
Reorganize transit service systemwide	Remove radial bus service; provide focus to reorient bus route into community / cross-town operation	1	2	3	4
Maximize development impact/ Stress accessibility and permanence	Use fixed-guideway with substantial stations central to areas of potential development / redevelopment	1	2	3	4
Minimize construction cost/ Use of existing ROW to avoid under-Ground / elevated construction	Use freeway medians, railroad / power-line rights-of-way though these may be distant from activity centers	1	1	1	1
	In lower-density areas, let system run on streets / highways mixed with other traffic	3	3	2	1
Maximize use of shared facilities	Run on HOV lanes and other facilities open to carpools / vanpools	2	2	2	1
Reduce total construction required	Reduce system mileage, number of stations	1	1	1	1
	Use shorter, simpler stations, low platforms, etc.	2	2	1	1
	Use smaller horizontal and vertical clearances, lighter structures	2	1	2	2
Reduce system complexity	Eliminate power distribution and control systems	3	3	2	1
Minimize operating cost/ Reduce operating personnel	Use long trains to reduce personnel / passenger ratio	1	2	2	3
	Use more complex systems affording greater automation	2	1	3	4
	Use short trains in off-peak	3	1	2	1
Reduce maintenance personnel	Use simpler systems with less electronics and hardware	3	4	2	1
Maximize public support/ Provide service to widest possible area	Use low cost / mile systems, maximum use of at-grade, nonexclusive right-of-way	4	3	2	1
Fit predispositions of public	Use rail / fixed-guideway systems; avoid bus systems	1	1	1	2

RRT = Rail Rapid Transit, AGT = Automated Guided Transit, LRT = Light Rail Transit, BRT = Bus Rapid Transit

Table-19: Some Relationships Between Design Goals and Technology Attributes [Source: Gray(1979)]

S.no	Factor		Diesel Bus (Street transit)	E.T.B. (Street Transit)	Tram Car (Street Transit)	EMU (Rail Rapid Transit)	O/H system, Monorail	Wuppertal Schwebebahn	U/G Railway, i.e. Metro (Rapid Transit)
1.	Flexibility		Most Flexible	Route-bound System	Route-bound System	Fixed Route	Fixed Route	Fixed Route	Fixed Route
2.	Speed (kmph)	(a) Maximum	60	60-65	50	60-80	80	60	80
		(b) Scheduled	25-27.5	30-32	20-25	40-45	70-80	20-30	45-50
		(c) Average	17-18	18-20	15-16	40-45	70-80	20-30	45-50
3.	Acceleration (m/sec^2)		0.4-0.7	1.2-1.5	0.5-0.6	1.1-1.2	1.4-1.5	1.1-1.2	1.1-1.2
4.	Life (Years)		8	25	30	40	30	40	40
5.	Environmental Impact	(a) Air Pollution	Emits smoke and fumes	Free from smoke and fumes	Pollution free	No air pollution	Non-pollutant	Non-pollutant	Non-pollutant
		(b) Noise and Vibration	Noise by horn and engine	Silent in operation	Far less noise level	Rumbling and whistle sound	Hardly any noise	Hardly any noise	No outside noise and vibration
		(c) Visual Effect	No visual effects	Visual impact by O/H wires	Visual effect by O/H wires	Poor visual impact	Present visual disamenity	Present visual disamenity	None
6.	Energy Input								
	(a) Fuel Source		Diesel oil	Electricity	Electricity	Electricity	Electricity	Electricity	Electricity
	(b) Supply Systems		-	600V, DC	500V, DC	25KV, AC 1500V, DC	455V, 2 Phase 50 cycle AC	600V DC	750V, DC
	(c) Energy Consumption (Watt hrs/passenger)		-	18-20	12-15	8-10	15	14-15	14-15
7.	Cost of System								
	(a) Cost/Unit Coach		Rs. 1.8-2.5 lakhs	Rs. 4 lakhs	Rs. 25-30 lakhs	Rs. 50 lakhs	NA	NA	Rs. 80 lakhs
	(b) Cost of Const./Km		Rs. 1 lakhs	Rs. 5 lakhs	Rs. 10 lakhs	Rs. 50 lakhs	NA	NA	Rs. 700 lakhs
	(c) Maintenance/Km		Rs. 0.4 lakhs	Rs. 0.5 lakhs	NA	Rs. 1 lakhs	NA	NA	Rs. 2.5 lakhs
	(d) Complete System Per Km. route		Rs. 25-30 lakhs	Rs. 40-50 lakhs	Rs. 80-100 lakhs	Rs. 500-700 lakhs	About Rs. 300 lakhs	NA	Rs. 25.30 crores
8.	(a) Suitability of Operation		Varying traffic density	Major movement corridors	Close network of dense traffic	Heavily loaded corridors	High density rapid transit corridors	Low Density corridors	High density rapid transit corridors
	(b) Area of Operation		Any route	Arterial and ring roads	Central and fringe areas	City & suburb areas	Can pass through CBD and arterials without interference to surface traffic	Amusement parks, small stretches serving specific areas.	Can pass through CBD and arterials without interference to surface traffic
	(c) Population of City		Over 3 lakhs	Over 5 lakhs	5-20 lakhs	Above 10 lakhs	Over-grown cities more than 50 lakhs	NA	Over-grown cities more than 50 lakhs
	(d) Trip Length		3-5 km.	5-15 km.	5-10 km.	5-25 km.	Still in experimental stage	5-15 km.	5-15 km.
	(e) Fare Structure		5-7 ps/km	3-5 ps/km.	3-4 ps/km.	4 ps/km.	Over 7 ps/km.	NA	6-8 ps/km.

Source: Verma(2000)

Table-20: Comparison of Various Road and Rail Based Public Transport System

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