

# Urban Transportation

Planning, Operation and Management



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## Planning, Operation and Management

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*This work is dedicated to the memory of the first author*

***Late Prof. D. Johnson Victor***

*who passed away a few days before the book went for print*



# Foreword

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It gives me great pleasure to write a foreword for this book on *Urban Transportation*. In this age of globalization and urbanization, the subject of Urban Transportation has gained critical importance. The growth of population is a major factor in increasing urbanization. In India the high ratio of population below 25 years of age will further push the urbanization process. There are few books written on the subject with the background of cities in the Developing World, and as I can see it, this book would be of high value to both students and practicing engineers, as well as those in the fields of economics, environmental studies and demographics.

The authors have covered the subject quite comprehensively, starting with the basic principles of urbanization and the planning requirements for an efficient urban transport system. They have rightly laid emphasis on public transport systems and their planning.

Prof. Johnson Victor had started the Transportation Engineering Division in the Indian Institute of Technology, Madras and was heading it for about two decades. He was considered an outstanding expert in the field. Dr. Ponnuswamy, after serving the railways and its consultancy undertaking for over 34 years, took up his academic pursuits and specialized in urban transport. The two of them have pooled their knowledge and experience together in bringing out this book.

I am sure this will be a valuable contribution to the analysis and planning of the growing infrastructure development.

**M. Anandakrishnan**  
Chairman,  
Indian Institute of Technology,  
Kanpur.





# Preface

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Urbanization has been a continuing process world over since the onset of industrial revolution. About 50% of world population lives in urban areas. India has been a late starter in this respect, but urbanization in the country has been rapid since independence. The growth of urbanization is considered fastest in the world. The urban population in India has grown from 17.29% in 1951 to 27.78% in 2001. It is expected to reach 42.5 % by 2041. There is a tendency for larger cities attracting more settlers.

Urban economy very much depends on the mobility provided by the city. With inadequate public transport system in many cities, there has been rapid growth in number of private vehicles in the cities. An analysis made by the urban planners in connection with evolving urban transport policy for the country indicates that the rate of growth is over 10% per annum in most cities. For example the vehicle population in Delhi grew from a mere 5.4 lakhs in 1981 to 18.12 lakhs in 1991 and nearly 40 lakhs in 2005 and in Bangalore from 1.68 lakhs in 1980 to 22.72 lakhs in 2005, of which 16.91 lakhs are motorized two wheelers, perhaps highest for any city. Such growth in most cities has led to proliferation of vehicles on road leading to congestion, low speeds and high pollution. The problem calls for proper study of demand and supply of transport and plan for an optimal mix of transport and systems for different cities. Transportation problems call for a good understanding of the subject by those involved in planning and implementation and management of surface transport systems. The need for dissemination of such knowledge has led to growth in number of institutes of planning, engineering and technology to offer courses on Transportation Engineering/Systems.

Urban Transportation has thus become a subject of major interest for students, academia and practicing engineers in the government and private sector. So far, there is hardly any book available on the subject written by Indian authors covering the subject in the context of a developing country. In order to meet the demand, the authors have come together to pool their knowledge gained as a teacher and a practicing engineer respectively and write this book.

This book has been prepared to fit in with the syllabus on Urban Transport and Public Transport taught at graduate level in various universities and Indian Institutes of Technology as well as Schools of Planning. At the same time, the book can be used as a reference book by practicing engineers

and consultants. It covers the subject of planning for transportation in an urban area including basic principles and current practices. Special emphasis has been given to conditions in India and developing countries.

The importance of urbanization and different aspects of urban growth and structure of the city and impact of transportation infrastructure on city growth has been brought out in the first two chapters. Factors influencing the demand for transport and characteristics of different modes are an important aspect of planning. National urban transport policy has to ensure balanced and cost effective and environment friendly transport solutions. Conducting different surveys and data collection is a pre-requisite to any planning process. These aspects are covered in next two chapters. Chapter 5 deals with Demand Forecasting and presents different steps involved in the analysis of data, development of transportation models for designing and developing urban transportation network.

The role of public transport in an urban area requires priority attention. The most common and affordable public transport is the bus transport. Its role, characteristics and infrastructure requirement for their operation on roads and their maintenance has been covered comprehensively. The chapter on the bus transport covers various steps involved in their route planning and design and scheduling. Management aspects of a bus transportation organization are another important detail covered. Bus transport has its own limitations in terms of capacity and speed as it has to compete with other modes for street space. Some innovative measures are being developed. When the city size and population go above certain limits, provision of rail based modes on some corridors becomes necessary.

In addition to conventional suburban rail and metro rail modes, there are some newer developments like LRT, Monorail, etc., which are available for less dense corridors and at more economical costs. Chapter 7 is devoted for a study of the characteristics of different rail based systems. Rail transit is a high cost solution and can be thought of only for most essential corridors. These modes have gained importance in South and South East Asian cities in last thirty years only. A few case studies are included to illustrate how they have been planned and implemented and also to what extent they have served the purpose.

Design and development of rail transit is a complicated subject requiring deeper understanding of its different components, like structure, track, traction, signaling and control, and vehicles including their maintenance requirements. A full chapter is devoted for this. When there are two or more major public transport systems in a city, co-ordination between them becomes important in order for them to function optimally.

One of the major problems of increase of vehicles on roads is the provision and management of space for their storing when not on move, i.e., the parking. Assessing demand for parking in different areas and design has become a major task for urban transport planners. Non-motorized transport like cycling and walking together still comprise 30–35 per cent of trips made in cities. Their requirements need greater attention than what they receive presently and they are discussed in detail.

Intermediate Public Transport has a major role as an access mode for public transport and serves as an alternative mode for main trips for some non-vehicle owners. Their role in Indian cities and also in cities in other countries forms an interesting study. Impact of goods transport on city roads and their special requirements have also been briefly touched upon.

The final chapter briefly covers different innovations made of late in alternative systems like Bus Rapid Transit and new modes like Maglev and also use of Information Technology and **GPS** in assisting commuters and in traffic Management.

The bulk of the basic information for the book has been taken from many sources including those mentioned under References at end of each chapter. The information and corresponding illustrations on many case studies have been collected from the Internet, either from the organizations' web pages or sources like Wikipedia free Encyclopedia and Urban Rail sites. Most illustrations and information pertaining to Delhi Metro, Chennai Metro, Bangalore Metro and Mumbai transport studies have been kindly furnished by DMRC, CMRL, BMRL and MMRDA respectively. Authors are grateful to these organizations for the same and record their gratitude towards Dr. E. Sreedharan, M/s V. Somasundarm, B. Sudhir Chandra, P.R.K. Murthy and A. Aiyaswamy for their kind help and co-operation. They are grateful to Mr. R. Balasubramanian and Dr. M.S. Srinivasan for their kind help in going through some portions of the text and suggestions for improving the contents. The authors are thankful to Mr V. Dinesh for his help in preparation of some of the illustrations and Ms. V. Srividhya for secretarial help.

The authors are grateful to Dr. M. Anandakrishnan, Chairman, Indian Institute of Technology Kanpur, for writing the Foreword for the book.

The authors are grateful to the publishers, Tata McGraw-Hill, for agreeing to publish the book and for their excellent co-operation.

**D. Johnson Victor (Late)**  
**S. Ponnuswamy**



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# Abbreviations

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ATC	Automatic Train Control
ATO	Automatic Train Operation
ATS	Automatic Train Supervision
AWS	Automatic Warning system
BEML	Bharath Earth Movers Ltd.
BMRCL	Bangalore Metro Rail Corporation Ltd.
BRT	Bus Rapid Transit
CATC	Continuous Automatic Train Control
CBD	Central Business District
CMRL	Chennai Metro Rail Ltd.
CPKM	Cost per Passenger Kilometre
CTC	Centralised Automatic Control
CTTS	Comprehensive Traffic and Transportation Study
DLS	Dockland Rail System
DMRC	Delhi Metro Rail Corporation
DMU	Diesel Multiple Unit
DOT	Department of Transport
EMU	Electrical Multiple Unit
EPKM	Earning per Passenger Kilometre
FHWA	Federal Highway Administration
GIS	Geographic Information system
GVW	Gross Vehicle weight
HGV	Heavy Goods Vehicle
HHIS	Household Interview Survey

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HOV	High Occupancy Vehicle
ICF	Integral Coach Factory
IPT	Intermediate Public Transport
IRC	Indian Roads Congress
ITS	Intelligent Transport System
IUT	Institute of Urban Transport
LCV	Light Commercial Vehicle
LIM	Linear Induction Motor
LRT	Light Rail Transit
MLR	Multiple Linear Regression
MMRDA	Mumbai Metropolitan Regional Transport Authority
MNL	Multi-nomial Logit
MORTH	Ministry of Road Transport and Highways
MOUD	Ministry of Urban Development
MRTS	Mass Rapid Transit System
NMT	Non-Mechanised Transport
O-D	Origin Destination
OH	Over head
PCU	Passenger Car Unit
PHPDT	Peak Hour Peak Direction Traffic (Trips)
PRT	Personal Rapid Transit
PT	Public Transport
RGR	Regional Rail (system)
ROW	Right of Way
RRT	Rail Rapid Transit
RTS	Rapid/Rail Transit System
SCR	Suburban Commuter Rail
SMRT	Singapore Mass Rapid Transit
TR	Third rail
TSM	Transport System Management
TW	Two Wheeler (Mechanised)
UGM	Urban Goods Movement
UMTA	Unified Multiple Transit Authority
UT	Urban Transit
WAAS	Wide Area Augmented System

## 1.1 IMPORTANCE OF TRANSPORTATION

Transportation is essential for providing mobility to the people, and for movement of goods. Transportation facilitates a broad spectrum of opportunities for an individual for desired activities. Though transport is not an end in itself, it is the means to many ends. Efficient transportation results in economic, social and political advantages. The economic advantages include: expanded market for goods; stabilization of prices in different markets; and economy of scale by concentration of activities in certain localities and subsequent distribution. The social benefits comprise: opportunities for travel for intellectual pursuits and pleasure; access to medical facilities; and choice of location for home and work. The political effects result from promotion of national integration, uniform extension of government services to various communities, and strengthening of the security of the country. Thus transportation is important for the progress of any nation. Government is associated with transportation both as a provider of facilities and a regulator of operations.

Transportation furnishes the fabric on which the cities depend for existence. Transportation contributes to the best geographical distribution of people and their activities by facilitating possibilities of exchange adapted to actual needs and safe-guarding future developments. The nature and efficiency of the transportation system determine the magnitude and distribution of economic activity in an urban area. Conversely, a wide variety of social, economic, demographic, and political factors interact to affect the type, nature and configuration of urban transportation systems as well as the urban form. Transportation engineering involves comprehensive planning, analysis, and design of the various components of transportation, such as the roadway or rail track with its nodes referred as fixed facilities, the vehicles, the signals and the geometric features required to secure safety in operation.

The desires of the people and their needs for goods create the demand for transportation. People travel primarily to earn a living, conduct family business, and engage in social and recreational activities. The sustenance of their activities requires the transport of goods within and among communities. The supply of transportation is in the form of travel by different modes, such as trains, buses, cars, motorized two-wheelers, cycle rickshaws, bicycles, and other vehicles, besides walking. The choice of the mode depends on the individual's preference in terms of time, cost,

comfort, and convenience. The aim of transportation management is to serve the people’s needs for transport with maximum safety within the constraints of time, space, and available resources.

In order to achieve optimum utilization of available resources and to ensure maximum productivity, transportation management should be treated as a system with interactive capacity. It is not adequate to plan for independent systems towards satisfying the same objective, as currently practiced in operating components of private and public transportation as separate entities. They must be properly coordinated as an integrated system with management towards the common goal. Each city has its own unique transportation needs. A densely populated city may need an underground rail rapid transit, while another city with low density housing may be able to manage with an efficient bus system. Balanced transportation for any particular city has to be evolved for its local setting.

1.2 BRIEF HISTORY OF TRANSPORTATION

1.2.1 Transportation

The history of transportation has been characterized by several innovations, most of them being influenced by some changes in human knowledge and progress. It is debatable whether transport is a catalyst of progress in civilization or whether it is a consequence of it. It is probably both. An abridged chronology of the history of transport development<sup>1</sup> is listed in Table 1.1.

Table 1.1 Chronology of Transport Development

Year	Development
B.C.	
6000	Sails used on rafts and canoes
5000	Ox and ass tamed and ox-yokes invented
3500	Horse tamed in Asia and the bit and bridle invented
3200	Wheel invented - “the world’s greatest invention”
1800	The horse and the spoked wheel appeared in Egypt
530	Persian empire, “the first road empire”, established
---	Iron shoe invented
100	Roman empire, “the second road empire”, established
---	Stirrup invented in Central Asia
A.D.	
450	Modern stirrup used in Roman Empire
900	Modern horse-harness appears in France
1000	Lief Ericcson discovers America
1200	Modern type of ship rudder developed

(Contd.)

**Table 1.1** (Contd.)

Year	Development
1450	Three-masted ship invented
1486	Diaz reaches the Cape of Good Hope
1492	Columbus rediscovers America
1498	Vasco da Gama reaches India by sea
1550	Coaches and wagons appear on roads in England
1620	The <i>Mayflower</i> and the Pilgrim Fathers reach America
----	Dutch sailors reach the Australian coast
1776	James Watt invents steam engine
1786	Wilkinson builds the first iron boat
1788	William Symington builds steamboat
1801	Richard Trevithick's steam carriage
1807	Robert Fulton's steamboat
1811	Steamboats on the Mississippi
1822	First iron steamboat, the <i>Aaron Manby</i> , built
1825	Stockton-Darlington Railway opened, world's first public railway service
1829	Stephenson's Rocket
1832	Stage Carriage Act in England regulates local transport services
1832	Horse-drawn street railway service in New York
1838	First suburban railway service in London
1841	Thomas Brassey builds the first French railway
1849	First ocean cable across the English Channel
1853	First railway line in India from Mumbai to Thane
1856	First railway line in South India between Royapuram (Chennai) and Arcot
1858	First ocean cable across the Atlantic
1863	London subway opened
1868	New York metro started with elevated line
1869	First American transcontinental railway completed
1878	Horse-drawn tram service in Kolkata
1885	Daimler makes the first motor cycle
1885	Daimler and Benz make their first motor car
1888	J.B. Dunlop invents the pneumatic bicycle tyre
1890	Electric traction for London underground
1893	Henry Ford builds his first car

(Contd.)

Table 1.1 (Contd.)

Year	Development
1896	Diesel engine is developed
1897	Electric Multiple Unit train system for urban transit in USA
1903	Wright Brothers fly their first aeroplane
1909	Bleriot flies the English Channel
1912	Motor Bus developed
1912	Diesel locomotive introduced in Germany
1913	Ford's assembly line
1919	Alcock and Brown fly the Atlantic
1941	Whittle's jet engine
1941	Modern diesel bus introduced
1984	Kolkata metro starts operation
1994	Rail services started through Channel Tunnel connecting UK and France
2002	First line on Delhi Metro rail started service
2006	Railway line between Lhasa, Tibet and other Chinese cities inaugurated

If we examine the chronology in Table 1.1, we can see that recent transport inventions have occurred fast compared with those of earlier times. It took men thousands of years to learn how to harness horses properly. Hundreds of years more elapsed before men could develop a system of good roads and coaches in order to make the best use of the correct horse-harness. But the last great transport inventions — the railway, the motor car, the motor bus, and the airplane — all took place in less than one hundred years.

The fastest speed at which men were ever able to travel till about 1829 was about 20 km per hour (kph), the speed at which a horse could trot. In Roman times, men had traveled long distances at that speed, and in 1800 they could go no faster. With the invention of the railway, man’s traveling speed began to rise. By about 1850, railway trains in England were already traveling at about 90 kph. The advent of the aeroplane pushed up the speed in excess of 500 kph. Technology has advanced so much that trains capable of running at speeds in excess of 500 kph and planes which can fly at supersonic speeds have been developed.

Better roads and railways have helped to develop great nations of the world. People began to feel more patriotic towards their nation, which railways had helped to develop, than they had felt towards their own town or city in the earlier years.

1.2.2 Urban Transportation

A brief history of development of urban transportation is indicated in Table 1.2<sup>2</sup>. With early urbanization, pedestrian and animal drawn traffic was increasing in the central areas. Since streets were unpaved and sidewalks were narrow or non-existent, movement in the downtown areas was



**Table 1.2** Development of Urban Transportation

Year	Development
1819	Horse-drawn omnibus (Diligences) in Paris
1827	12-passenger horse-drawn stage coach in New York
1832	Horse-drawn street railway in New York Stage Carriage Act in England introduced regulation
1838	First suburban railway service in London
1863	London Subway opened
1868	Elevated rapid transit in New York
1873	Cable car introduced in San Francisco
1878	Horse-drawn tram service in Kolkata
1886	Electric street railway in Montgomery, Alabama
1890	Electric elevated railways in New York
1897	Subway built in Boston
1900	Paris subway opened
1901	Wupertal Schwebebahn monorail established in Germany
1904	First subway line in New York
1905	Motor bus introduced in New York
1910	Jitneys started operation in USA
1925	India's first electric train service between Bombay V.T. and Kurla
1927	Tokyo subway opened
1931	Madras Beach-Tambaram: India's first electrical suburban service on M.G.
1935	Moscow subway started operation
1956	Rubber-tyred rapid transit in Paris
1972	BART, a modern Metro rail system inaugurated in Bay Area, reviving the concept of elevated rail over median of road for major length
1975	Unmanned automated transit in Morgantown, West Virginia
1984	Hong Kong Metro opened
1984	Kolkata Metro started operation
1997	First elevated RTS in India opened in Chennai
2002	Opening of Delhi Metro Rail Service

hazardous, inconvenient, and unpleasant. Horse-drawn coaches for public carriage, called omnibuses, were introduced in 1819 in Paris and in 1827 in New York. The Stage Carriage Act passed in England in 1832 was the first regulation of public transport service requiring drivers and conductors to take out licences for operating the service. Since the ride was bumpy and slow, tracks were laid on the road on which the vehicles were pulled. This enabled the use of less number of horses to pull the vehicles

and permitted a smoother ride at speeds up to 10 kph. But the solid waste generated by the horses and left uncleared made the streets unsightly, unsanitary, and odoriferous. Calcutta Tramways Company started operation in Kolkata in 1878 with horse-drawn trams, and later improved the service. In spite of its drawbacks, the service is still patronized by about 300,000 commuters daily.

London subway opened in 1863. Steam powered elevated trains were introduced in New York in 1868 followed by Chicago in 1892. Electric tram was commissioned in 1886 in Montgomery, Alabama. New York City's first subway line was opened in 1904.

Gasoline powered motor bus was introduced in 1905 in New York as a 24-passenger double deck bus. During the 1920's, trams began to lose popularity, and buses having one or two decks came to be used predominantly for intracity public transport. Trams disappeared in most British, Canaan, US and French cities by middle of 20<sup>th</sup> century, with buses replacing them. Though they are noisier, less efficient and more polluting, the buses have been preferred over the tram and the trolley bus, because buses can use any assigned route and need no sophisticated infrastructure like substations, supply cables and rail track and stations.

### 1.3 VALUES, GOALS AND OBJECTIVES

The planning of urban transportation should be in accordance with the society's values, goals and objectives with reference to urban transportation. In view of the semantic difficulties attached to the concepts such as values, goals, objectives, criteria and standards, their meanings are briefly discussed in this section<sup>3</sup>.

**Values** are irreducible qualities which form the basic desires and drives governing human behaviour. Examples of societal values include: (a) the desire to survive and preserve traditions and culture; and (b) the need for order, security, equity, freedom, and justice. It can be seen that values are abstractions, which are not measurable, and that it is extremely difficult to explain transport facilities in terms of these values.

**Goals** are idealized end states of the total environment toward which planners strive while planning an urban system. Examples of goals may be stated as: (a) To provide equal opportunities to all members of the society to travel, regardless of income, age or health condition; (This goal reflects societal values such as equity and social justice.); and (b) To improve the urban environment. (This goal is in consonance with the societal value to preserve cultural heritage and the need to maintain the harmony between man and his environment.) Goals are less abstract than values, but are not stated in measurable terms.

**Objectives** are specific statements which arise from one or more goals and are truly attainable. An objective is stated in such a way that the degree of its achievement can be expressed through the use of criteria. For example, for the goal of improving the urban environment, the following objectives can be developed: (a) To ensure that all residents of the metropolitan area experience air pollution levels which are within acceptable limits; and (b) To minimise social disruption resulting from construction of new transport facilities.

**Criteria** are specific measures or tests which reflect the degree of attainment of particular objectives. At least one criterion must be associated with each objective. A criterion specifies a

range of values within which the performance of the system must lie for the objectives to be met. As an illustration, for the objective on air pollution, the criteria may be: (a) The number of days per year on which the acceptable limit is exceeded; and (b) The maximum annual concentration averaged over the time period specified in air quality regulations.

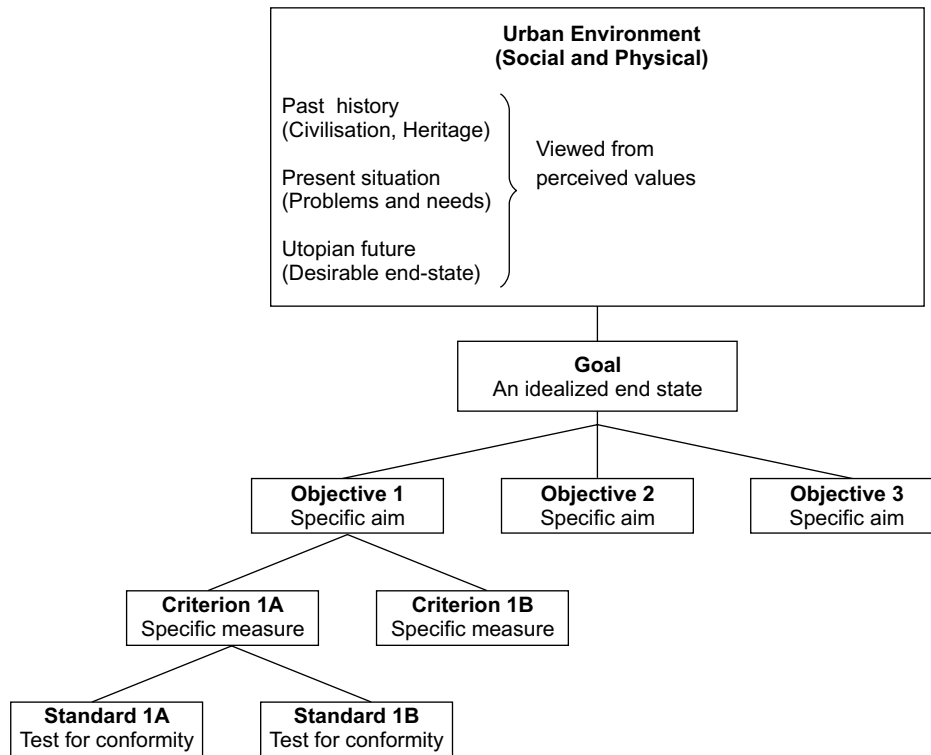
**Standards** specify the method of measurement to determine conformity to the criterion prescribed. For example, in the criterion “at least 85% of the elderly and handicapped must have access to social services”, the value of 85% sets a standard.

In the transportation planning process, goals serve as guide for system planning (long term strategic planning) and they also lead to the development of objectives which indicate the type of projects needed. Objectives are associated with project planning (short term action planning) and these relate to the development of criteria for evaluating the alternative plans at the project level. The relationships among the urban environment, values, goals, objectives, criteria and standards are shown in Fig. 1.1. Typical goals and objectives for urban transportation are indicated in Table 1.3. It is important that the selected goals for transportation planning should be realistic with respect to the needs of the population and be compatible with the resources that the society can mobilize.

**Table 1.3** Typical Transportation Goals and Objectives

Serial No.	Goal	Objectives
1.	Provide maximum personal mobility	Provide reliable, affordable and safe public transport to all citizens, and particularly to the urban poor, the aged, and the children. Improve level of service of urban travel. Improve facilities to pedestrians and cyclists.
2.	Improve the urban environment	Reduce air pollution due to vehicles. Reduce noise and vibrations due to traffic. Minimize disruption to community and problems of rehabilitation due to new projects. Enhance esthetic qualities of the urban environment.
3.	Enhance the economic efficiency of transportation	Increase the capacity of existing facilities for goods and person movement. Reduce personal cost for urban travel. Reduce public cost of urban transportation systems. Reduce costs of urban goods movement. Maximize the positive impacts of urban transportation.
4.	Conserve energy resources	Reduce consumption of electricity in urban public transportation. Reduce fuel consumption for urban travel.
5.	Improve traffic safety	Reduce traffic accidents. Reduce injuries and deaths due to traffic accidents. Improve personal safety of road users.

Goals can be achieved only if they are accompanied by supportive policies and strategies. Policies are guidelines in the form of operational objectives designed to determine how to achieve the pre-set goals. Strategies relate to the arrangement of policies and goals in a sequence of time, place and priorities<sup>4</sup>.



**Figure 1.1** Relationships among the Urban Environment, Values, Goals, Objectives, Criteria and Standards

## 1.4 CLASSIFICATION OF TRANSPORTATION

The scope of transportation may be broadly classified with reference to the area of operation as urban transportation and regional transportation. Urban transportation concentrates on planning and operation of transportation with emphasis on the spatial requirements in an urban area. The trips are essentially intra-city trips with short trip lengths. Regional transportation deals with the aspects relating to inter-city and long distance trips.

Transportation can also be classified into three categories as private transportation, public transportation, and intermediate public transportation. When the vehicles are owned by the passengers and used for their exclusive conveyance, the transportation is referred as Private Transportation; e.g., cars, motorized two-wheelers, and bicycles. Public transportation involves

the use of common carriers not owned by the passengers, e.g., buses and trains. Transportation, using hired vehicles such as taxi, auto-rickshaw, and cycle rickshaw, is called Intermediate Public Transportation (IPT).

Though the major aspects of regional transportation are included in the discussion, this text is primarily directed towards a detailed discussion of the planning, operation and management of urban transportation.

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## 2.1 URBANIZATION

### 2.1.1 Hierarchy of Human Settlements

Areas of human settlements are broadly classified as (i) Rural areas and (ii) Urban areas. Rural areas are those which are predominantly agricultural, whereas urban areas are those which are predominantly non-agricultural.

Human settlements can also be classified as: (a) Hamlet; (b) Village; (c) Town; (d) City; (e) Metropolis; and (f) Megalopolis. Hamlet denotes a cluster of a few single family hutments, with population less than 2000, and without any clear provision of streets. A village consists of a number of dwelling units with definite street pattern, usually with a population between 2000 and 20000, and with basic amenities like primary school. A town has a population in excess of 20000 but less than 50000, and has civic facilities like post office, police station, and high schools. A city has a population between 50000 and 100000, and will have most of the civic amenities such as hospital, educational institutions, post offices, and police stations. A metropolis is a large city with population in excess of 1 million, and may consist of a number of suburban areas attached to a core city centre. The metropolitan city is a centre of administration, commerce and higher education. Megalopolis occurs when two or more metropolitan cities lie adjacent to each other forming a continuous urban agglomeration.

Census of India classifies the urban areas into six classes based on population. Class I cities have population greater than 100000; Class II cities have population between 50000 and 99999; Class III towns are urban areas with population between 20000 and 49999; and Classes IV, V and VI urban areas have population of 10000 to 19999, 5000 to 9999 and less than 5000, respectively. According to the 2001 census, India has 423 urban centres which have population exceeding 100000. Currently, there are 35 metropolitan cities with population more than one million. About 30% of the population now lives in urban areas.

### 2.1.2 Growth of Urbanization

Urban areas as permanent places of habitation started with the agricultural development. Their later growth, development and shaping were closely related to the availability of transportation.

Before mechanical means of transportation became available, land travel was difficult and slow. So the early cities were located on the waterfront near the mouth of a river at the sea coast to facilitate movement of goods by water transportation. With the development of railways, highways and airplanes, water transportation ceased to be a prerequisite for the development of large cities. The growth of cities is affected not only by transportation, but also by other economic, social, cultural and geographic factors. Over time, the means of internal transportation influences the growth of the urban area.

A typical pattern of urban growth<sup>1</sup> is shown in Fig. 2.1. The settlement is initially pedestrian oriented with streets in primitive stage, with the urban area being limited by the distance one could walk in a reasonable period of time. With increase in population, the urban area expands and radial suburban rail corridors are developed, along with a few streets. These rail corridors may initially be parts of intercity rail tracks. Tram (street railway) lines develop and extend service along certain corridors, shaping the city into a better organised and developed urban area, with concentration of activities at the city centre. Commuter rail traffic grows and fosters an outward spread of population. Further concentration of population occurs along these rail corridors, and new roadway arterials form radially between the radial railway lines. When a city matures into a metropolis, radial and circumferential grid forms with some of the traffic corridors being rail-based and the rest road-based. Thus enhancement of connectivity accelerates the expansion and growth of the city.

As a result of increasing industrialisation of the country, the proportion of the population living in urban areas increases. There is a strong correlation between a country's economic growth and the level of urbanization. Developing countries typically have urbanization less than 30%, compared with 35% to 70% for moderately developed countries, and over 70% for developed countries. For example, Japan and USA have urbanization in excess of 77%, whereas urbanization in India is about 28% (grown to 31.16% in 2011). Though the overall percentage of urbanization in India is low, the increase in urban population is steep in a few metropolitan cities, while medium sized and smaller cities grow more gradually. This aggravates the problems of shelter, infrastructure and sanitation in these cities. For example, Kolkata has a population of 13.2 million, with a density of about 10350 persons per km<sup>2</sup>. Urbanization in India is likely to increase to 40% by 2021. The number of metropolitan cities in India has increased from 5 in 1951 to 12 in 1981, and further to 23 in 1991 and 35 in 2001. This number may probably rise to 75 by 2021. Population growth in 20 metropolitan cities in India is shown in Table 2.1.

Cities with population in excess of 5 million are known as large cities, while those cities having population more than 10 million are referred as megacities. There were 41 large cities in the world in 2000, of which 19 were megacities. By 2015, the number of large cities is expected to increase to 59, while there will be 23 megacities. Most of the heavily populated cities of the world are located in developing countries, as can be seen from Table 2.2, which shows the top 10 urban areas in the world based on the estimated population in 2015<sup>2</sup>. In terms of population, Tokyo is currently the largest urban agglomeration in the world, followed by Mexico and Mumbai. By 2015, Mumbai is expected to become the second largest city followed by Lagos and Dhaka.

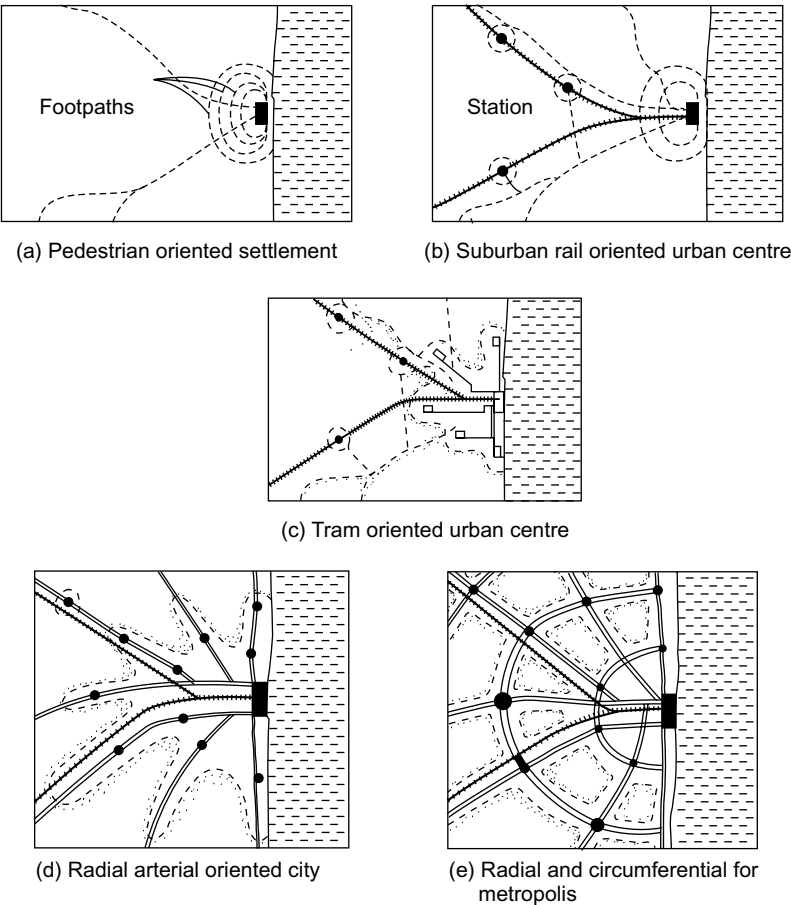


Figure 2.1 Typical Pattern of Urban Growth

Table 2.1 Population Growth in 20 Metropolitan Cities in India

Serial No.	City	Population, in Million					
		1951	1961	1971	1981	1991	2001
1.	Greater Mumbai	2.96	4.15	5.97	8.24	12.57	16.37
2.	Kolkata	4.66	5.98	7.42	9.19	10.91	13.22
3.	Delhi	1.43	2.35	3.64	5.72	8.37	12.79
4.	Chennai	1.54	1.94	3.16	4.28	5.36	6.42

(Contd.)



**Table 2.1** (Contd.)

Serial No.	City	Population, in Million					
		0.78	1.20	1.66	2.92	4.08	5.69
5.	Bangalore	0.78	1.20	1.66	2.92	4.08	5.69
6.	Hyderabad	1.13	1.24	1.79	2.54	4.28	5.53
7.	Ahmedabad	0.87	1.20	1.75	2.54	3.29	4.52
8.	Pune	0.60	0.79	1.13	1.68	2.48	3.76
9.	Surat	0.23	0.31	0.49	0.91	1.51	2.81
10.	Kanpur	0.70	0.97	1.27	1.63	2.11	2.69
11.	Jaipur	0.30	0.41	0.63	1.01	1.51	2.32
12.	Lucknow	0.49	0.65	0.81	1.00	1.64	2.27
13.	Nagpur	0.48	0.69	0.93	1.30	1.66	2.12
14.	Patna	0.32	0.41	0.55	0.91	1.09	1.71
15.	Indore	0.31	0.39	0.56	0.82	1.10	1.64
16.	Vadodara	0.21	0.30	0.46	0.74	1.11	1.49
17.	Bhopal	0.10	0.22	0.38	0.67	1.06	1.45
18.	Coimbatore	0.28	0.44	0.73	0.92	1.13	1.45
19.	Ludhiana	0.15	0.24	0.40	0.60	1.01	1.40
20.	Kochi	0.17	0.29	0.50	0.68	1.13	1.36

**Source:** Adapted from Census of India 2001

Urbanization is a result of continuous economic development accompanied by emphasis on the development of both human resources and urban infrastructure. The rapid growth of cities has outpaced the government's resources to meet the increasing demand for the provision of basic infrastructure. The key areas of public infrastructure development include: land development; urban transport strategy; environmental quality; and affordable housing. Deficiencies in infrastructure development exact considerable macro-economic and social costs.

One major cause for increase in urban population is the rural-urban migration of people in search of better employment opportunities. Further, the larger cities also attract in-migration of population from smaller cities. The migrants settle in available open land close to their job sites, despite often unsatisfactory living conditions. Concerted efforts should be made by the government to disperse industries throughout the country and to create employment opportunities in many medium sized cities. The urban poor constitute a significant proportion of the urban population in developing countries, i.e., their household income is below the poverty level appropriate to the concerned country. Due to resource constraints, developing countries find it difficult to provide adequate amenities such as housing, roads, water supply, drainage, and transport. The shortage of housing in India is of the order of 40 million dwelling units.

**Table 2.2** World's Top 10 Urban Areas in 2015

Serial No.	Urban Agglomeration	Estimated Population, Million
1.	Tokyo, Japan	26.4
2.	Mumbai, India	26.1
3.	Lagos, Nigeria	23.2
4.	Dhaka, Bangladesh	21.1
5.	Sao Paulo, Brazil	20.4
6.	Karachi, Pakistan	19.2
7.	Mexico City, Mexico	19.2
8.	New York, USA	17.4
9.	Jakarta, Indonesia	17.3
10.	Kolkata, India	17.3

**Source:** UN, "World Urbanization Prospects, 1999"

A major part of the urban poor lives in slums and squatter or illegal settlements. For example, over 50% of Mumbai's inhabitants live in slums. A slum is defined as a predominantly residential area of blight, chaotically occupied, and unsystematically developed, generally neglected, over-populated and ill-repaired. Squatter settlements are habitations of poor people in land not owned or legally leased to them. While it is increasingly recognised that the slums cannot be cleared by rehousing the existing population, state governments make efforts to improve the existing slums by providing a few amenities like water supply, sanitation, and electricity.

### 2.1.3 Impacts of Urbanization

Urbanization causes the following impacts:

- The housing shortage becomes more acute.
- The urban sprawl increases. For example, the area of Chennai city expanded from 70 sq. km in 1923 to 130 sq. km in 1970 and further to 172 sq. km in 1980. (426 sq. km in 2011).
- As a consequence of urban sprawl, the average trip length and the total passenger-km of trips increase.
- The cost of living for the inhabitants rises.
- The number of trips in the urban area increases.
- The roads become congested, increasing the level of air pollution.
- The availability of infrastructural facilities such as water supply, drainage, schools, playgrounds, and hospitals fall short of the requirements.
- The number of registered vehicles and also the incidence of traffic accidents rise. For example, the vehicular population in Delhi increased from 0.5 million in 1980 to 4.0 million in 2001, while the number of road accidents rose from 7697 in 1990 to 10217 in 1998.

- (i) The public transport vehicles become overcrowded during the peak periods.
- (j) New forms of transport such as rail rapid transit are difficult to accommodate due to high density build up and space constraints.

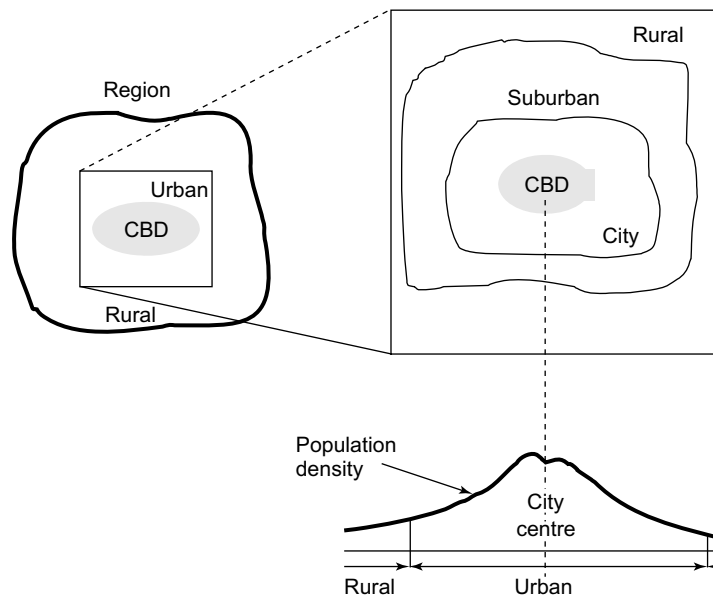
In any developing society, the process of urbanization is unending and is accompanied by many adverse impacts. By enlightened management of urban centres, the urbanization process can be channeled to achieve all-round prosperity and growth.

## 2.2 IMPORTANCE OF URBAN AREAS

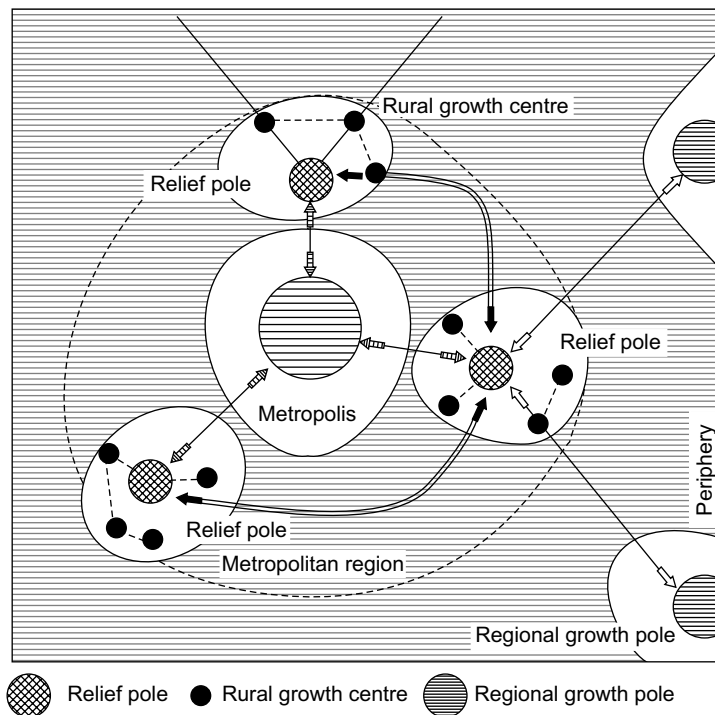
Cities function as the locus of commerce, invention and creativity, and have become the engines of economic development. Urban centers act as catalysts for growth, providing avenues for employment for the masses and improved standard of living. The major part (about 60%) of the country's Gross Domestic Product (GDP) comes from the urban areas. Also the centres of learning and culture, the seat of administration and financial institutions are concentrated in urban areas. Hence it is important to devote special attention to the development of the urban areas. An effective urban transportation system helps to maximize the economic efficiency of the city, while an inferior system retards economic progress.

## 2.3 STRUCTURE OF URBAN AREAS

The structure of an urban area in a regional setting can be shown schematically as in Fig. 2.2. The density of population is maximum near the centre of the Central Business District (CBD). The density reduces as the distance from the CBD increases.



**Figure 2.2** Schematic Diagram of Urban Area in Regional Setting



**Figure 2.3** Relief Pole Strategy

**Source:** Adapted from Reference 3

The pressure of population in a metropolitan city can be reduced if a few urban nodes are developed outside the city but within the metropolitan region as indicated in Fig. 2.3. Such urban nodes are referred as relief poles and the strategy is known as the relief pole strategy<sup>3</sup>.

## 2.4 URBAN DESIGN

The urban system can be visualised as composed of five components<sup>4</sup>:

- Moving objects : People, Goods, Vehicles, Services
- Activities : Residences, Jobs, Production of Goods and Services, Movement
- Infrastructure : Buildings, Roads, Railways, Power Plants
- Land : Land under varied uses
- Policy : Goals, Decisions, Plans

Urban design is a way of interpreting and improving people's perceptions of the final form of the city<sup>5</sup>. The following three aspects of the design are important:

- (a) City Form—the physical organization of the city reflecting the pattern of developments and the corridors used for transportation systems.
- (b) Transportation Architecture—the physical appearance and qualities of open and closed public spaces or buildings, which include transportation facilities.

(c) Human Factors—design for pedestrian and rider comfort, social contact, and stimulation of the senses by light, sound, visibility and weather.

Secondly, transportation architecture should be given attention in ensuring spatial organization, old/new continuity and surfaces needing minimum maintenance. The different buildings, roads, bridges, pedestrian ways, open spaces, gardens and trees should be effectively integrated to form aesthetically pleasing overall composition. The modern pedestrian malls in shopping areas of new towns contribute to enhanced aesthetics of city centres.

The third aspect to be considered is the quality of the personal environment in transportation, involving image, microclimate, social distance, human engineering and information/communications. Image is a sense of being in a space, visual impact and environment. The ideal microclimate has clean air, low noise and vibration, moderate temperature, and good lighting. Transportation information should be legible and easy to understand. In a country with many languages and low literacy, directions and orientation could be communicated in graphics to the possible extent. Letters must be of appropriate size to enable reading from a distance. To be effective, physical planning of the urban area should be accompanied by social planning. Our challenge is to devise ways to promote the amenities of life in the midst of urban development, so as to make urban life more fulfilling than frustrating.

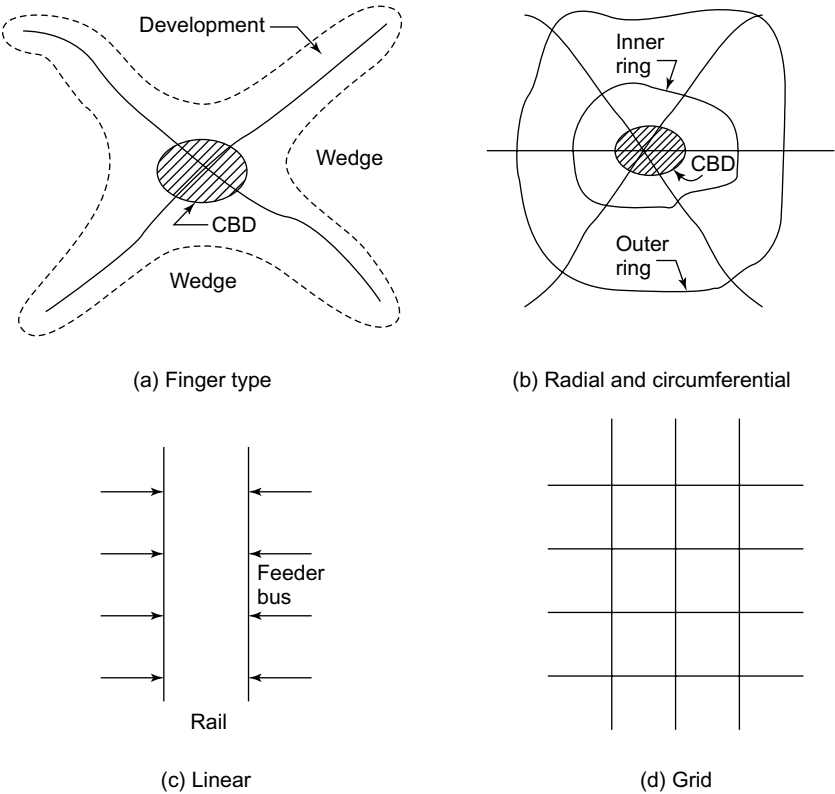
## 2.5 TRANSPORTATION AND URBAN FORMS

The function of urban transportation is to provide linkages between points of residence and employment, besides facilitating large scale industrial and commercial activities which lead to development of the urban area. Transportation affects the urban form and geographical growth of the urban area. Many cities in developing countries are at a crucial point in their evolution. Uncontrolled growth due to increased urbanization without the benefit of planned expansion of housing, transport and other needed infrastructure has led to declining quality of life in many urban areas. Crowded buses and trains, narrow streets choking with a variety of vehicles, pedestrians spilling on to the carriageway, and confusing assortment of signs constitute the common scene.

Transportation is a major element in the design of the total urban environment. With appropriate design, transportation may introduce delight rather than blight, as dramatic and visually delightful, non-polluting new modes of travel connect residences to workplaces, shops and recreation centres, in a planned urban milieu. The new modes, however, need investment of resources and efforts, over a timeframe suitable to the scale of development envisaged. The investment on urban transportation should be so planned as to be cost effective, and should establish operationally efficient transport systems consistent with an appropriate intermodal mix. Urban transportation is increasing in importance for the economy and the social welfare. For enhancing the effectiveness of movement in major cities, it is necessary to provide public transport in preference to private transport.

Transportation corridors influence the formation of the urban form as shown in Fig. 2.4. Transportation decisions are often irreversible, and the decisions made now will influence the future form of the city. Policy decisions on the use of public transportation centers and on joint

development of urban area and transport should be framed so that the alternatives are studied carefully by an interdisciplinary team as part of urban design. The team may consist of experts from professions such as economics, social science, public administration, private sector organizations, technology, and urban design, besides transportation. Each profession brings its own special field of expertise, and interacts with other fields by discussion of impacts, so that a synthesis of all factors may yield a single coherent development proposal. Whenever a major transportation facility is planned, the planner must take into account the various physical, social, economic, political, human, aesthetic, and technological factors that are encountered. To significantly improve the physical quality of urban environment, the planner must consider both the visible form and the hidden forces that accompany change<sup>4</sup>. Public policies for urban transport should be aimed at freedom of choice of mode for the citizen, social equity and maintenance of environmental quality at an acceptable level.



**Figure 2.4** Urban Forms and Transportation

The travel patterns and the alignment of travel corridors in an urban area are determined by the distribution and the density of urban activities. This, in turn, establishes the economic feasibility

of the various modes of transportation for specific point-to-point movements. The alternatives for an urban area involve choices among the various possible arrangements of residential, commercial, and industrial development together with the appropriate interconnected transportation.

As shown in Fig. 2.4, the pattern of transportation corridors may include: (a) Finger type; (b) Radial and circumferential; (c) Linear; and (d) Grid pattern. The finger type denotes the formation of major traffic corridors (possibly rail) radially from the CBD, and intense development along these corridors. The wedge areas between the radial corridors get filled gradually. The radial and circumferential pattern is more suitable for bus operation as routing can be flexible. The radials form the major arterials which can be served by rail or bus. The circumferential routes can function as feeder to the main radial arterials. Chennai is an example for this pattern. A linear city, like Mumbai, can develop main traffic rail corridors along the length with feeder routes by bus. Orthogonal road system, usually for buses, is developed in planned cities in advanced countries, e.g., New York. Urban form changes with development and with the evolution of new traffic corridors. Planners should ensure easy access to transport.

A significant proportion of urban land is occupied by transportation facilities. In some metropolitan cities, nearly one-third of all land is taken up by roads, fuel filling stations, bus, truck and railway terminals, railway yards, and airports, resulting in serious diminution of green areas and unused land. The desired nature, character and life style of the era are the principal determinants in regard to urban development, on which would depend the compatible land development and transportation policies to be implemented. Growing cities might avoid major transportation problems in the future if the relationships among the urban size, form and compatible transportation systems are considered in the early stages of urban development plans.

## 2.6 USE OF ROAD SPACE

The operational planning for transport in urban areas will require a consideration of planning the use of the road space. The activities which compete for the road space are many; and these also vary with time. Some of the uses of road space are<sup>6</sup>: (a) Passage of vehicles along the road; (b) Access to property; (c) Parking of vehicles; (d) Pedestrian traffic along the road; (e) Pedestrian crossing; (f) Carriage of goods along the road; (g) Collection and delivery of goods; (h) Window shopping; (i) Appreciation of views, works of art, buildings; (j) Admission of light and air to buildings; (k) Passage of gas, sewage, water mains and electrical cables below ground; (l) Selling from shops, eating and drinking from cafes; (m) Exercising pets; (n) Hawking; (o) Advertising; (p) Play; (q) Courtship; and (r) Gossip.

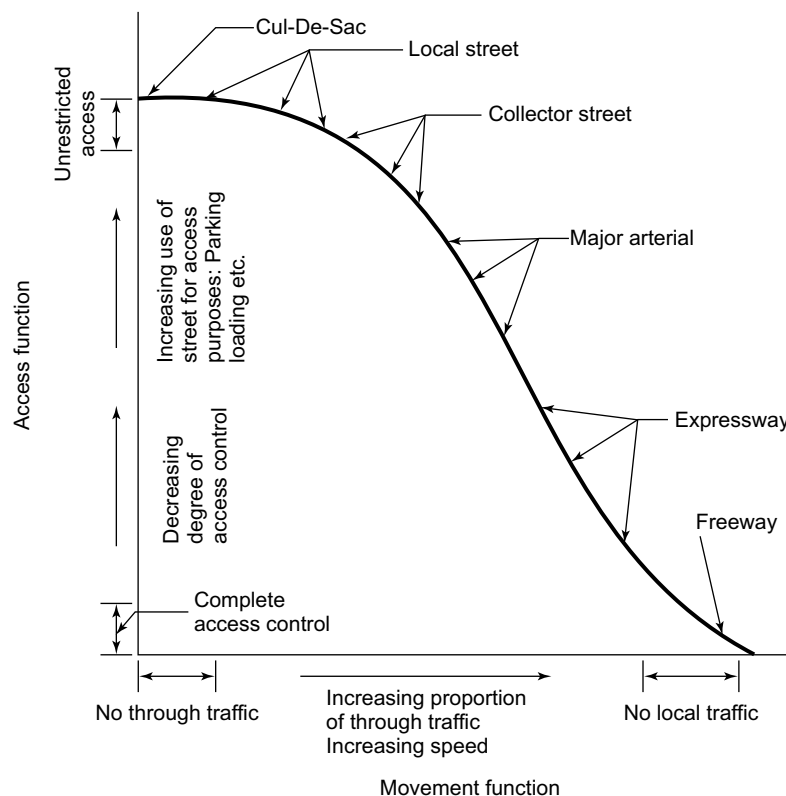
All these activities have their place in life. For a smooth life in general, it is necessary for us to set up priorities between them. The priorities so desired will also vary with the hours of the day and the location. Most of the roads will have more than one use, though the functions are predominantly to serve for movement and access. The transport plan should take cognisance of this fact, modify the priorities and control some of them. It should be dynamic to respond to changing priorities and technologies.

## 2.7 FUNCTIONAL CLASSIFICATION OF URBAN ROADS

Urban roads cater to the following functions:

- (a) movement function—facilitating smooth movement of motorized vehicles, bicycles and pedestrians;
- (b) access function—providing access to land, buildings and roadside facilities;
- (c) promotion of urban area formation—to induce an urban structure and form a framework for urban area; and
- (d) spatial function—to accommodate public utilities such as electricity, water supply, drainage, underground railways, etc.

The design of an urban road will depend heavily on the relative importance given to its various functions, particularly the functions of access and mobility. A local street whose function is strictly land service must be designed with frequent access points, whereas a freeway emphasizes high speed movement. The traffic characteristics to be considered are: average trip length, average travel speed, access control, spacing between streets of the same category, traffic volume and type of control used.



**Figure 2.5** Classification of Urban Roads with Reference to Movement and Access Functions



Based on the geometric and traffic characteristics, the urban roads may be classified as freeway, expressway, arterial, collector street, local street, or cul-de-sac. Cul-de-sac is a short discontinuous street giving access to dwelling units (DU). Local street separates individual DUs and integrates a cluster of DUs. Collector street separates clusters of DUs and integrates a neighbourhood. Arterial separates neighbourhoods and integrates a community. Expressway/Freeway separates communities. The classification of the various types of urban roads with reference to movement and access functions is shown in Fig. 2.5. The urban roads have to be organized into an efficient road network system consisting of the various types of roads, incorporating measures to harmonize traffic and the environment in the urban area.

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# Urban Transportation Characteristics

# 3

## 3.1 FACTORS INFLUENCING TRANSPORTATION NEEDS

Transportation needs of an urban area are affected by a wide variety of factors including: total population, population distribution, geography, income levels, and government policy on urban development.

- (a) *Total population* The greater the total population of the area, the more extensive the transportation system that will be needed to serve the large number of intra-city trips made by the population. For example, the large metropolitan centers of the world such as Mumbai, Tokyo and New York depend very heavily on mass transit, generally fixed rail transport. On the other hand, small cities like Mathura, Kancheepuram and Chengalpattu are totally dependent on the street system and private transport. In the middle range of population, e.g. cities such as Madurai and Vadodara, there can be effective utilization of public bus transit on a well planned street system that also serves private transport.
- (b) *Population distribution* When the density of population is low, private transportation is economical and the energy efficient mode. However, at high levels of density, private transportation is inefficient, and rail and bus transit become economical and financially feasible.
- (c) *Geography* Rivers and hills in the urban area create restrictions to transport systems. Bridges and tunnels may be required. Capacity addition can be achieved by maximum utilization of existing facilities.
- (d) *Income levels* Increased per capita income leads to proliferation of private transport and reduction in the use of public transport.
- (e) *Government policy* A government policy that encourages ownership of detached housing units leads to low density travel patterns and reliance on private transport. Encouragement to high density residential patterns will be conducive to effective operation of public transport, especially rail rapid transit.

## 3.2 TRANSPORTATION DEMAND

Transportation demand is concentrated at specific times that are related to the current activity pattern of the society. The demand is temporal as well as spatial. In some cases, e.g. trips to work

and school, the demand has a certain amount of regularity which allows detailed estimates to be made. In other instances, e.g., social and recreational trips, there is a great amount of uncertainty, and in these cases the reliability of demand forecasts will be poor.

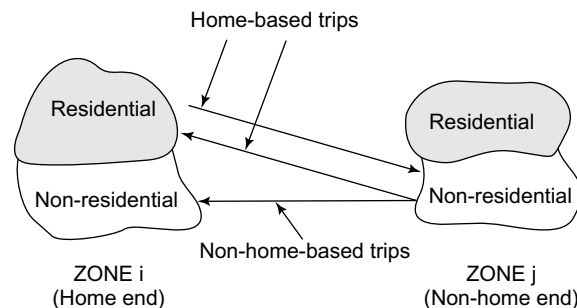
### 3.3 TYPES OF TRIPS

A trip is a movement from an origin to a destination. The distance between the origin and the destination is called the trip length. The time taken to go from the origin to the destination is known as the travel time or journey time. The expenditure in money terms to perform the trip is referred to as travel cost. The origin and the destination constitute the two trip ends.

Trips may be broadly classified as Home-based trips and Non-home-based trips, as shown in Fig. 3.1. A trip which has one end of the trip at the home of the trip maker is called a Home-based trip. If the trip does not have the home as a trip end, e.g., a trip from workplace to a shop, such a trip is called a Non-home-based trip. In most urban areas, home-based trips constitute 85 to 90% of the total trips.

Depending on the purpose of the trip, trips can also be classified as work trips, school trips, shopping trips, and social-recreational trips. Of these, the work trips and school trips are performed at regular timings on every working day, and these trips are called commuter trips.

The shopping trips and the social-recreational trips do not have regular schedule. Usually, the commuter trips constitute about two-thirds of the total home-based trips.



**Figure 3.1** Broad Classification of Trips

### 3.4 MODES OF TRAVEL

In urban areas, the movements from and to places of residence (home-based trips) form the major portion of the total trips. For example, in Chennai, home-based work trips constituted 42.9 % and home-based education trips 37.6 % in 1992. A large part of the trips will continue to involve walking. Planning and design of pedestrian movements should be accorded equal attention as for mechanized person transport. The mix and use of the various modes of travel are determined by a complex interaction among factors such as the city size, shape, geography, demographic and economic characteristics, and the available technology.

The modes of travel can be broadly classified into three categories as Private Transport, Public Transport, and Intermediate Public Transport. Private transport modes comprise walk, bicycle, motorized two-wheeler and car. The vehicles are privately owned and operated by users for their own use, usually on publicly provided and maintained roads. Bus, tram, and railway train constitute the public transport modes. Public transport is also known as transit, mass transit, or mass transportation. The service is available for use by all persons who pay the established fare. Intermediate public transport (also known as paratransit) modes include hired vehicles such as taxi, autorickshaw, jeepney, and dial-a-ride. In some transport planning reports, intermediate public transport modes are treated as part of private transport. These basic transportation modes are not likely to be replaced in the near future; but the share of the market available to each mode may be modified with changes in economic and demographic characteristics of the region.

The route and schedule are fixed for public transport, whereas they are flexible for private transport. For intermediate public transport, the schedule is flexible; but the route is flexible for hired vehicles like taxi and autorickshaw, while it is fixed for jeepneys and similar paratransit services and is essentially fixed for dial-a-ride.

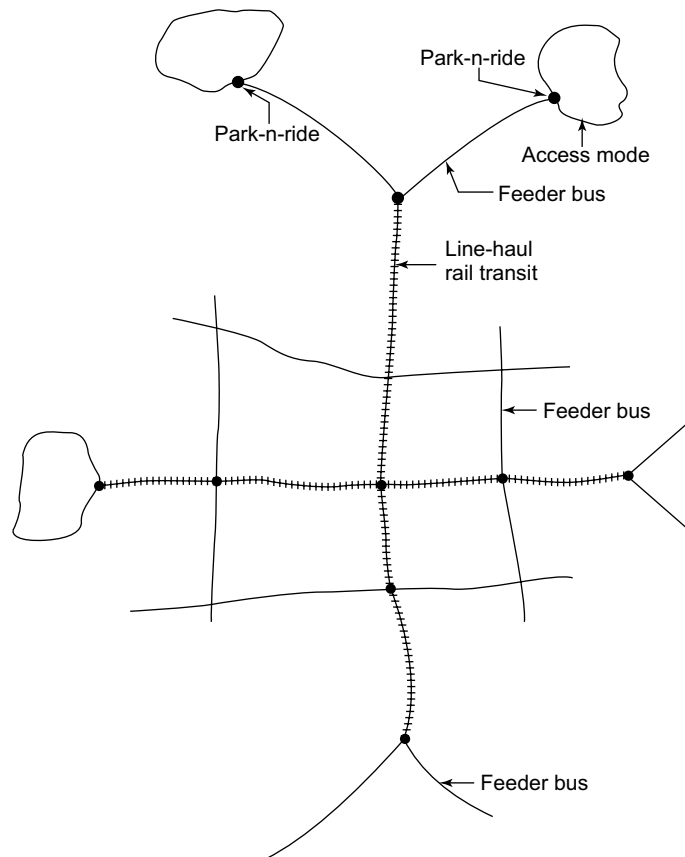
Transit refers to urban public transportation with emphasis on capacity and frequency of services. Mass transit is transit with emphasis on high capacity and energy efficiency, e.g., bus and suburban railway. Rapid transit is mass transit with emphasis on high speed, e.g., rapid rail transit (RRT). Transit can also be classified as: (a) Bus transit; and (b) Rail-based transit. The latter includes rapid rail transit, light rail transit, suburban rail, monorail and tram.

A hypothetical integrated system involving different modes is shown in Fig. 3.2. The total mass transportation system may be composed of circulation system, feeder system, and line haul system. A circulation system transports people within a CBD or a major activity centre. A line haul system is the long fast movement from the collection point to the distribution point, and may extend bothways. It is usually in the form of rapid rail transit with exclusive right-of-way. A feeder system carries passengers between the residence/workplace/park-and-ride lot and the nearest station/transit stop of the line haul system. Park-and-ride facilities may be provided at convenient locations, either at transit stops or at other locations from where a feeder bus is made available to connect to a transit stop.

The aim of urban mass transit is to provide a quick transport service for its ridership in a safe, economical, reliable and comfortable manner. For the community, the objectives include: freedom from air pollution and noise pollution, and better space utilization. The objectives for the transport agencies are: meeting the demand at minimum cost, optimum utilization of infrastructure, and customer satisfaction.

Passengers exercise choice of the mode of transport and class of service. Their choice is influenced by consideration of five factors: (a) travel cost; (b) reliability of service; (c) travel time; (d) convenience of access; and (e) travel comfort. For patrons from low income group, the travel cost is the most important consideration. In developing countries, urban households spend about 8 to 10 % of the household income on transport. People may avoid a bus taking a long zigzag route and may opt for a route having less travel time. Easy accessibility from home to a bus stop or

railway station may influence the choice. In developing countries, the riders normally have limited choice and they become captive riders.



**Figure 3.2** Integrated System Involving Different Modes

### 3.5 URBAN TRANSPORTATION SCENE IN INDIA

The urban population in India is in excess of 286 million (2001). Over 60% of the urban residents live in about 300 cities with a population exceeding 100000. There are 35 metropolitan cities having a population of one million and above. The general lack of adequate public transportation has resulted in a disproportionate growth of private transport vehicles leading to chronic congestion on the city roads. The number of vehicles increases rapidly without corresponding expansion of the road space. Pressure on the road network and consequent levels of road congestion are expected to become more acute in future with increase in road traffic.

**Table 3.1** Mixed Traffic on Indian Roads

Motorised Vehicles	Animal Drawn Vehicles	Human Powered Vehicles
Two-wheeler	Horse Cart	Hand Cart
Car/Jeep	Bullock Cart	Tricycle
Auto-rickshaw	Camel Cart	Cycle-rickshaw
Taxi		Bicycle
Van		
Bus		
Light Commercial Vehicle (LCV)		
Truck, Heavy Goods Vehicle (HGV)		

A wide variety of vehicles are operating on the roads as shown in Table 3.1. These include: personal vehicles such as cars/jeeps, motorized two-wheelers and bicycles; public vehicles comprising buses and mini-buses; intermediate public transport (hired) vehicles such as taxis, auto-rickshaws, cycle-rickshaws and tongas; goods vehicles such as trucks (HGV) and light commercial vehicles (LCV); and animal drawn carts and handcarts. Motorized two-wheelers constitute almost 70% of the total motor vehicles in India. The mixed traffic poses peculiar problems to smooth and safe operation of traffic, resulting in serious traffic congestion, inordinate delays, increased accidents, environmental pollution and a deteriorating quality of life.

The number of motor vehicles registered in the NCT of Delhi<sup>1</sup> as on 1<sup>st</sup> April of the years 1981, 1991, 1994 and 2005 are indicated in Table 3.2. It can be seen that the motorised two-wheelers constitute about 64 % of the total vehicle population. The predominance of two-wheelers contributes to the road congestion, and also leads to increase in road accidents. In 1997, out of 33.8 million motor vehicles in India, 7.7% were in Delhi, the corresponding figures for Mumbai, Kolkata and Chennai being 2.1%, 1.5% and 2.3%, respectively<sup>2</sup>.

**Table 3.2** Registration of Motor Vehicles in NCT of Delhi

Vehicle Type	1981	1991	1994	2005
Car/Jeep/Van	119495	398479	522264	1471858
M.Cycle/Scooter	345109	1220640	1492201	3078660
Taxi	6385	10157	11846	20646
Autorickshaw	20379	63005	72102	74188
Bus	8044	18858	24211	25511
Truck	36599	101828	116379	128193
<b>Total</b>	<b>536011</b>	<b>1812967</b>	<b>2239003</b>	<b>4799056</b>

**Source:** Various Study Reports

### 3.6 GROWTH OF URBAN TRANSPORT DEMAND

Transport demand in urban areas is dynamic and has many dimensions such as size, physical characteristics, technology and management. The travel demand is already high in Indian cities and is continually increasing with regard to the number of trips, per capita trip rate and average trip length. The increase in population contributes directly to the increase in the number of trips. Economic improvement of the community leads to increased activity and mobility, i.e. increase in the number of trips per person. The average trip length tends to increase with time as population and activities result in expansion of the city size. For example, the number of trips per day in Chennai has been estimated to have increased from 2.65 million in 1970 to 6.75 million in 1984, 7.45 million in 1991 and to 9.15 million in 2001. The corresponding per capita daily trip rate<sup>3</sup> increased from 0.80 in 1970 to 0.88 in 1984, to 1.29 in 1991 and to 1.30 in 2001.

### 3.7 ROAD CONGESTION

Congestion on the road is the most frequent manifestation of the urban transport problem. Congestion increases vehicle operating costs, requiring higher fuel consumption, and also leads to environmental pollution. Road congestion is bad for the economy as it imposes high costs on industry and other users. Several solutions have been advocated and attempted such as: restrictions on on-street parking, one-way operation, banning of turns, priority traffic control, and provision of grade-separated pedestrian crossings. Other measures include effective exclusion of stray cattle on the road and carrying maintenance work at night. The more effective approach would be to encourage high capacity public transport vehicles which are more efficient in use of energy and utilisation of road space, besides intraurban and suburban rail service in all metropolitan cities.

### 3.8 CAPACITY, SPACE UTILIZATION AND ENERGY CONSUMPTION OF MODES

The efficiency of a transport mode may be determined by its unit space requirement for movement ( $\text{m}^2$  per passenger) and its unit energy consumption (expressed as  $\text{kwh/passenger-km}$ ). The maximum capacity of a mode depends on the maximum capacity of a unit vehicle and the maximum vehicular flow per lane per hour. The practical capacity will be much less than (about one-half of) the maximum capacity. The energy consumption of any urban transport mode per passenger is computed as the sum of the proportionate value of the energy for manufacture of the vehicle, fabrication of the guideway and operation of the vehicle, divided by the occupancy of the vehicle. Table 3.3 gives the typical values of the above parameters<sup>4,5</sup>. It is seen that mechanized private modes consume many times the space and energy required by public transport modes.

### 3.9 IMPACT OF TRANSPORT ON ENVIRONMENT

The impacts of transport on the environment include the following: (a) Air pollution; (b) Noise pollution; (c) Impact on communities by way of severance and visual intrusion; and (d) Accidents and damage to human health.

Table 3.3 Typical Mode Characteristics

Vehicle	Space Required for Movement Per Passenger m <sup>2</sup>	Estimated Total Energy Consumption Per Passenger-km kwh
Car	40.0	1.12
Two-wheeler	17.5	0.29
Bus	4.5	0.12
Rail	2.5	0.09
Bicycle	8.5	0.06
Walk	0.7	0.04

Source: References 4, 5

Transport causes air pollution due to various emissions from the vehicles as indicated in Table 3.4. Carbon monoxide (CO) causes greenhouse effect, and even low dosage impairs vision and causes headaches and drowsiness. Nitrogen oxide (NO<sub>x</sub>) at high doses leads to respiratory irritation, acid rain and damage to vegetation. Sulphur dioxide (SO<sub>2</sub>) causes respiratory problems. Particulate matters (PM) cause respiratory problems and damage buildings. Ozone (O<sub>3</sub>) causes acid rain, photochemical smog and leads to respiratory problems. Increase of Carbon dioxide (CO<sub>2</sub>) in the atmosphere will lead to increase in global warming. It is estimated that vehicles contribute about 70% of the air pollution in Delhi<sup>1</sup>.

Serious transport noise disturbs sleep, affects performance of school children and reduces quality of life. Reduction in walking and cycling has contributed to greater incidence of heart ailments, obesity and diabetes. Provision of roads and rail lines severs communities and results in visual intrusion. Traffic related accidents are on the increase in urban areas and these lead to health hazards and human suffering. For example, the number of fatalities from road accidents<sup>6</sup> in Delhi increased from 694 in 1977 to 1878 in 1991 and to about 2000 in 1998.

The adverse effects of transport on the environment can be reduced if the share of public transport in the overall use of vehicles is increased and use of private transport is reduced. Typical emissions of different vehicles are shown in Table 3.4. It is evident that the emission of carbon monoxide is higher from petrol cars than from diesel buses. The noise level at 15 m from the source is about 90 dBA for a bus and is about 70 dBA for a car. If more people take to bus instead of using private vehicles, the ambient noise level can be reduced.

Table 3.4 Typical Emissions from Vehicles

Vehicle	Emission, kg per 1000 Vehicle-km	
	Total Emission	Carbon Monoxide
Bus	38.1	12.7
Truck	38.1	12.7
Car (Petrol)	49.6	40.0

(Contd.)



Table 3.4 (Contd.)

Vehicle	Emission, kg per 1000 Vehicle-km	
	Total Emission	Carbon Monoxide
Car (Diesel)	3.2	1.1
Three-wheeler	35.8	25.5
Two-wheeler	27.3	17.0

Source: Reference 7

3.10 URBAN TRANSPORT POLICY

3.10.1 Components of Comprehensive Transport Policy

There are five major components forming part of a comprehensive transport policy in a metropolitan area. The components and issues involved under each component are indicated in Table 3.5 below:

Table 3.5 Essentials of Comprehensive Transportation Policy

Harmonisation with allied sectors	<ul style="list-style-type: none"><li>• Land use</li><li>• Environment</li><li>• Economics</li></ul>
Comprehensive planning	<ul style="list-style-type: none"><li>• Comprehensive use of traffic data</li><li>• Appropriate use of demand analysis techniques</li><li>• Co-ordinated implementation of construction and traffic control</li></ul>
Multi-modal transport system	<ul style="list-style-type: none"><li>• Different Transit systems</li><li>• Terminals</li><li>• Fare co-ordination</li></ul>
Implementation of transport systems	<ul style="list-style-type: none"><li>• Co-ordination in Investment</li><li>• Construction of transit facilities</li></ul>
Managing competition	<ul style="list-style-type: none"><li>• Regulation</li><li>• Financing</li><li>• Fare systems</li></ul>

A study of transport development in the developed countries would show that they have been providing a number of modes for passenger transport within their cities keeping pace with the city development and technological advancement. Large cities like London, New York, Paris, Tokyo and Chicago introduced underground or elevated Rail Rapid system for intra-city travel within about three decades of invention of steam locomotives and railway as a mode of travel for passenger movement. Simultaneously, they introduced trams or street cars and horse-drawn coaches as modes of travel on roads. With the introduction of automobiles and buses in post world war era, the bus transport replaced coaches and supplemented other modes. It later became a competitive

mode. Most of these services were planned by the city governments and built and operated initially as private enterprises under the control of city governments. When the car ownership started increasing and the bus transport became a major competing mode, the state had to take over the urban rail and tram systems so as to avoid their closure. They also went in for city specific co-ordinating bodies to ensure that the public transport systems function as complementary to one another. Such bodies have a say in expansion of the different public transport systems. As the cities grew, these cities have been introducing new mass transit modes like RRT, LRT or BRT on corridors with heavy traffic, complemented by already existing bus transit on other roads, as a policy in the advanced countries. Some typical examples are: BART in San Francisco, and RRT and LRT in Los Angeles, Hong Kong and Singapore. The Federal or central governments and regional/state governments in those countries have been providing capital support for such projects.

The continued growth of personal vehicles and their increased presence on roads resulted in congestion on many roads in most cities with consequent increase in pollution, especially in central areas and major arterials. In order to combat this, some of the cities like Singapore resorted to levy of congestion charges and provide some disincentives for private vehicle acquisition. In the recent past, cities like London and Stockholm introduced congestion pricing in central areas. It is reported that this step has resulted in reduction of traffic in central areas to an extent of 15% in London and 20% in Stockholm. All these cities have been following a parking policy which helps in controlling parking on roads, unlike in cities in developing countries. Thus in those cities, urban transport policy has been a continuously evolving phenomenon. On the other hand, in the countries which are facing the problem of rapid urbanization now, planned urban development, especially with regard to mobility, has become a major problem. A number of agencies are involved in providing and managing different forms of urban transport and related issues. Transport infrastructure calls for heavy investment and the demand arises simultaneously from a number of cities. Hence optimal utilization of resources and assets in urban transport, calls for a uniform policy at national level in countries like India.

The aim of such a policy is to provide a safe, affordable and efficient transportation in the city, increasing energy efficiency, reducing pollution, congestion and adverse health effects and also limiting urban sprawl. The policy, to be effective, should encompass land use, infrastructure, and public transport systems and goods delivery networks<sup>8</sup>.

### **3.10.2 National Urban Transport Policy in India**

Government of India early in 2007 approved and notified the transport policy to be followed in Indian cities<sup>8</sup>. The objective of the policy, as stated in the policy document, is 'to ensure safe, quick, comfortable, reliable and sustainable access for the growing number of city residents to jobs, education, recreation and such other needs within our cities'. Different actions proposed in the policy document are discussed here.

The policy proposes to achieve the stated objective by adopting an integrated land use-transport planning approach in urban planning and incorporating urban transportation as an important

component at urban planning stage itself. Such planning will aim at minimizing travel distance for the citizens for their work places, education and other social needs, particularly so for the marginalized (poor) segment of urban population. It encourages greater use of public transport and non-motorised modes like cycles, with Central financial assistance forthcoming for such projects. The road space allocation and distribution is to be made more equitable to suit the objective of keeping movement of people rather than vehicles as the main focus. It has spelled out an appropriate parking policy including pricing and also congestion pricing in the long run.

The policy focuses on establishment of high quality multi-modal public transport systems well integrated so as to provide seamless transfer and travel across different modes. The fare policy would aim at being made affordable. It envisages establishment of appropriate regulatory and enforcement mechanisms so as to ensure level playing field for all operators of transport services and also have institutional mechanisms for enhanced co-ordination in planning and management of different transport systems. The policy also lays down guidelines on types of public transport, extent of financial assistance the central government would provide for studies and project preparation and also their participation in implementation stage.

Road safety and trauma care find important place in the policy formulation. Change in travelling practices, enforcement of stricter norms and technological improvements will focus on reducing pollution. It envisages use of ITS (Intelligent Transport System) in traffic management and use of cleaner technologies wherever required/appropriate. Apart from strengthening institutional mechanism and manpower to plan for and implement various measures for sustainable urban transport, the policy envisages establishment of required knowledge management systems. Innovative methods of raising finance like tapping land as a resource and private sector participation where their strength can be beneficially applied and taking up pilot projects that would demonstrate potential for providing sustainable urban transport are other thrust areas of the policy.

### 3.11 COMPONENTS OF URBAN TRANSPORTATION SYSTEM

The urban transportation system can be shown schematically<sup>9</sup> as in Fig. 3.3. The system can be divided into four levels. At the regional level, the analysis is restricted to urban transportation, i.e. short distance transport. The sectoral level is divided into the transportation and non-transportation sectors. Depending on the purpose of transport, there may be further subdivision of the transportation sector into passenger transport and goods transport. The passenger transport consists of public transport, private transport, and intermediate public transport (paratransit). The subsystems are the individual modes satisfying the transportation needs within the overall transportation function for the city. Subsystems consist of a number of elements. In combination, the elements of the various subsystems contribute to the quality of the transportation system as a whole, satisfying the transportation needs within the overall transportation function for the people according to local, operating and technical conditions. The proper maintenance and better utilization of the various transportation facilities is vital to the economic health of the nation.

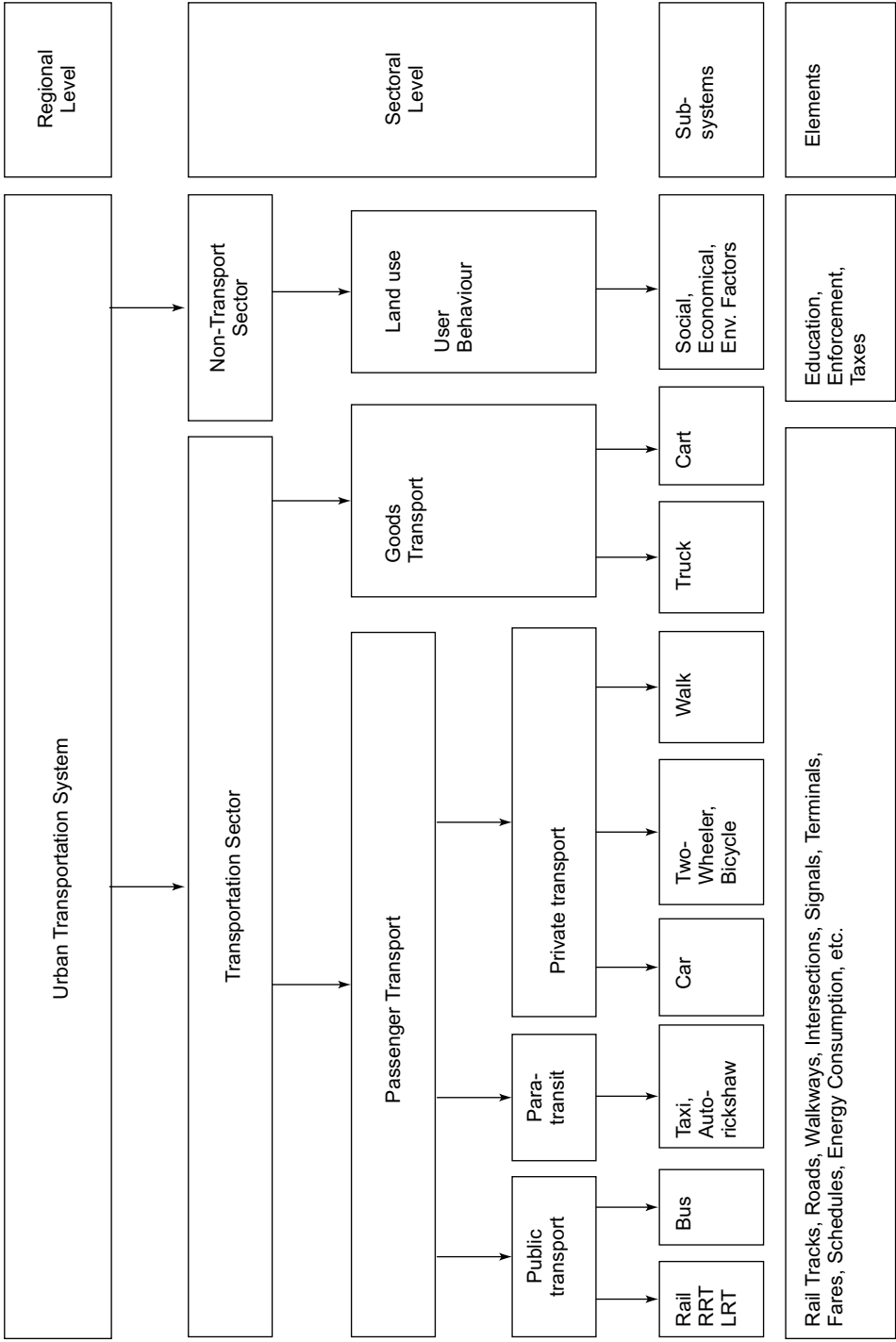


Figure 3.3 Components of the Urban Transportation System

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# Urban Transportation Planning Process

# 4

## 4.1 URBAN TRANSPORTATION PLANNING OBJECTIVES

The urban areas contribute to the generation of over 60% of the nation's GDP through various economic activities. This generation is dependant very much on the mobility provided by the transportation facilities available to different segments of its population. Hence, the need for availability of an efficient transportation system in the cities and suburbs constituting the urban area cannot be over-emphasized. The road network acts as the arteries of the city for people and goods to move.

Urban transportation planning comprises all activities for the analysis of the problems associated with the demand for the movement of the people and goods and for the identification of appropriate solutions to secure sustainable accessibility in conformity with the aspirations of the concerned society. The main objectives of the urban transportation planning include: (a) Provision of efficient, economic, environmentally acceptable transportation facilities which would form a cohesive system for the metropolitan area, improving the quality of life; (b) Evolving an efficient mechanism for operating different components of the system in a coordinated manner; and (c) Ensuring that the plan provides for the long term needs of the area, while at the same time it caters to the short and medium term components.

The transportation planning process is based on following assumptions:

- (i) Travel pattern is tangible, predictable and stable;
- (ii) Transportation system influences the development of an area and in turn is affected by the development in the area;
- (iii) Decisive relationships exist between one another of all modes of transport. Hence the future role of any mode in the area cannot be considered in isolation;
- (iv) Areas of contiguous urbanization require consideration of problems on a regional basis; and
- (v) Transportation planning is a continuous process involving designing, implementing, monitoring, updating, validating and taking corrective measures.

The land use in a zone very much influences travel pattern, thus influencing demand for transportation facilities and at the same time, availability of transport infrastructure affects the land use pattern. Hence, transportation planning has to form an integral part of the overall planning process for the area.

4.2 HIERARCHY OF URBAN TRANSPORTATION SYSTEMS

The hierarchy of urban transportation systems can be shown schematically as in Fig. 4.1. The system can be broadly classified as motorized transport and non-motorised transport (NMT). Motorised transport may be further divided as passenger transport and goods transport. Passenger transport consists of public transport, private transport, and intermediate public transport (IPT) or paratransit. Goods transport uses vehicles such as trucks, trucks with trailers, vans, carts, and tempos. Non-motorised transport comprises passenger movement by walk, bicycles and cycle-rickshaws, and goods movement using handcarts and animal-drawn carts.

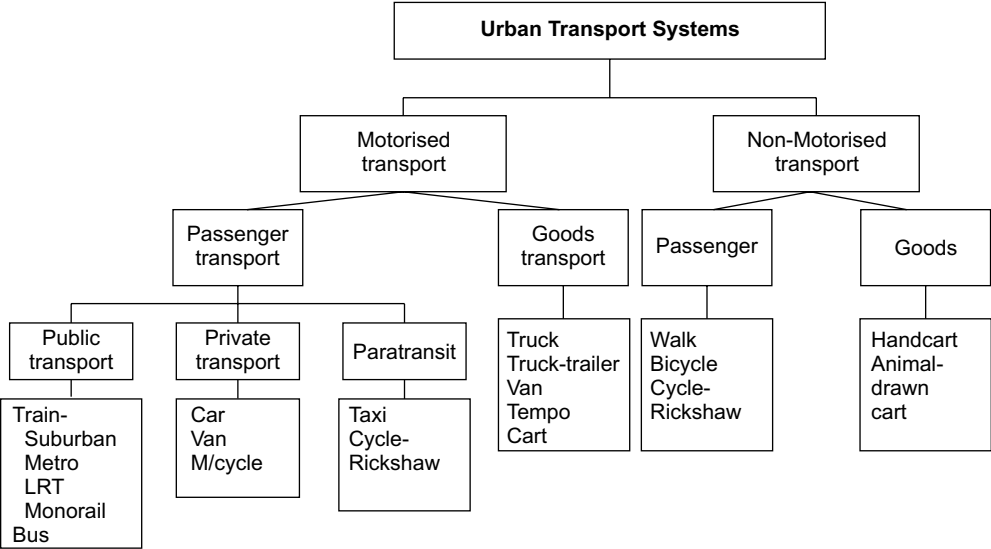


Figure 4.1 Hierarchy of Urban Transport Systems

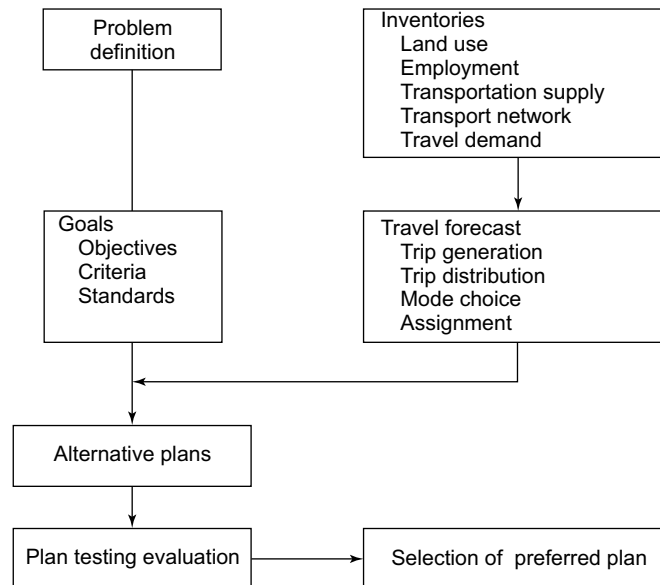
The urban transportation planning process involves a series of interconnected steps, which are indicated briefly in Fig. 4.2. The problem definition phase identifies the problem intended to be solved. This leads to the formulation of goals, objectives, criteria and standards to be adopted for the project. Inventory information is gathered regarding the population, land use, socio-economic characteristics, existing transportation supply and the existing travel demand. Using suitable models, horizon year land use pattern and travel demand are derived. Alternative transportation plans are prepared to satisfy the conditions in the horizon year. By testing each alternative and evaluating its least adverse impacts most cost effective one is selected for implementation.

4.3 URBAN TRANSPORTATION PLANNING SEQUENCE

The planning process involves the following steps:

- Identification of problem
- Collection of data and analysis

- Study including model building and simulation
- Forecasting requirements
- Designing and evaluation including consultation with stake holders
- Final choice of facilities, and formulation of plan.



**Figure 4.2** Urban Transportation Planning Process

This chapter covers the first two aspects. In order to understand the problem of transportation in an urban area, the planner has to study the existing structure of the urban area, the transportation network, the present pattern of traffic, and the demographic and socio-economic characteristics of the citizens, which influence the travel pattern.

The study area has to be defined first. In urban transportation study, the study area should cover the entire conurbation covering the present and potential contiguous built-up areas forming the conglomeration. In Indian context, this generally covers the areas delineated as metropolitan areas for planning and development or regions, e.g., Chennai Metropolitan area (1189 sq. km), and Mumbai Metropolitan Region (4354 sq. km). The boundary of the study area will be an imaginary line running on geographical boundary of such an area and it is considered the 'outer cordon'. The travel pattern of people within that cordon is studied in detail. The travel pattern from and to the areas outside are also studied at a macro level as external trips which will add to locally generated trips. The study area covered should be such that they are built up and are likely to grow along with the city which forms the core area; and the people living within have some dependency towards the city area and commute often in that direction. To the extent possible, the area should be compatible in spread with that of previous such study.



## 4.4 DATA COLLECTION

Data collection involves a number of surveys and basic studies as listed below:

- Household (or Home) Interview survey
- Mid-block volume count
- Roadside Interview or Origin-Destination (O-D) survey
- Cordon survey
- Screen line survey
- Speed and delay study
- Parking survey
- Pedestrian survey
- Commercial vehicle survey
- IPT survey
- Public transport survey including Terminals survey
- Transport network inventory survey.

For the purpose of any planning study, the city and suburbs forming the study area have to be divided into a number of contiguous zones, just as a city is divided into a number of wards for administrative purposes. For example, in a recent study 786 km<sup>2</sup> area of Bangalore metropolitan area was divided into 174 zones comprising 128 in the corporation area; 34 covering other municipalities and 12 covering the villages on the fringe<sup>2</sup>. The delineation of zones for traffic study should be such that: (i) each zone is homogeneous in character, i.e., of distinct land use pattern; (ii) Each zone is not too large or not too small, the travel time between adjacent zones being in the range of about 3 to 5 minutes by fast modes and to 10 minutes by slow modes; (iii) the optimum population of the zone should be 5000 – 10000 in medium dense areas and may go even upto 50000 in densely populated areas (as in core area of Bangalore, Delhi, Mumbai and Chennai); (iv) the zone should be bounded by well defined physical boundaries, such as a canal, stream, or railway line; (v) to the extent possible it should be co-terminous with administrative units or other planning units; and (vi) the zones should preferably be water-sheds of trip making.

## 4.5 TRANSPORTATION NETWORK

The transportation network in an urban area will consist of the roads and railway lines and in some cases, the rivers and canals if some trips are being made by inland water transport (IWT) across or along such canals and rivers, e.g., case of Kolkata. The rail tracks providing intra-urban transport facilities are essential in cities with 3 million population and more. The road system or hierarchy of roads in a city comprises expressways, arterials, sub-arterials, collectors/distributors and local streets.

*Local streets* as the name suggests are primarily intended for direct access to the residents and commercial establishments abutting the street. They do not usually carry large volumes of traffic

and the trips originate or terminate on them. No parking or loading/unloading restrictions are imposed on such streets.

*Collector streets* connect a number of local streets and primarily serve the purpose of collecting and distributing traffic from local streets and provide access to next higher level of sub-arterials or arterial streets/roads. Normally free access is provided from them to abutting properties. Few parking restrictions are imposed on collector streets, except for some during peak hours.

*Sub-arterials*, at the next higher level provide for better level of mobility and they provide linkage between collector streets and arterials. They should have minimum width to accommodate at least two lanes for fast vehicles, some space for cycles and SMVs and footpaths for pedestrians. Traffic in opposing directions is generally separated by yellow line marking and in some cases medians. Parking, and loading/unloading are usually restricted. Pedestrian crossings are restricted to crossings at intersections. Spacing of sub-arterials varies from 0.5 km to 3 km.

*Arterial roads* on top of hierarchy in smaller and medium size cities are primarily intended for through traffic. It should be a continuous highway for connecting CBD to outlying residential areas and urban nodes or connecting urban nodes and industrial units in orbital direction. They may form part of major (National or State Highways) passing through or emanating from the city. Parking and loading/unloading operations are prohibited on arterial streets. They, along with any expressway provided, will form the primary road network of the city/metropolitan area. They are generally spaced at 1.5 km in densely populated areas to 4 km in sparsely developed (outer/fringe) areas. They will be minimum four lane divided carriageways. Pedestrian footpaths and cycle tracks should be available and their crossings will be restricted to intersections with other roads.

*Expressways* or *Freeways* are provided in larger metropolitan areas, with the primary objective of providing for heavy volume of motor traffic at free flow conditions. They are defined as 'arterial highways for motor traffic with full or partial control of access.' They will have grade separators at intersections. They connect major points of traffic generation en route and may connect with the CBD also. They serve predominantly medium and long length traffic. Parking and loading/unloading operations are strictly prohibited on expressways. Even pedestrian traffic is not permitted on them.

Figure 4.3 shows the ideal carriageway configuration of different classes of roads, as suggested by the Indian Roads Congress<sup>3</sup>. The road network covering the expressways, arterials and sub-arterials assume importance in respect of providing mobility in the city and hence in any transportation planning study. All rail and tram lines are also equally important. In addition, the collector streets through which public transport buses ply have to be included in the study. For example, Fig. 4.4 shows city road network which was considered in the comprehensive traffic and transportation study of Chennai in 1991. As part of the study, an inventory has to be made for all these roads/streets covering classification of the street, length, cross-sectional dimensions, type and condition of road surface and footpaths if any, capacity, intersections, any structures and control devices, and street furniture.

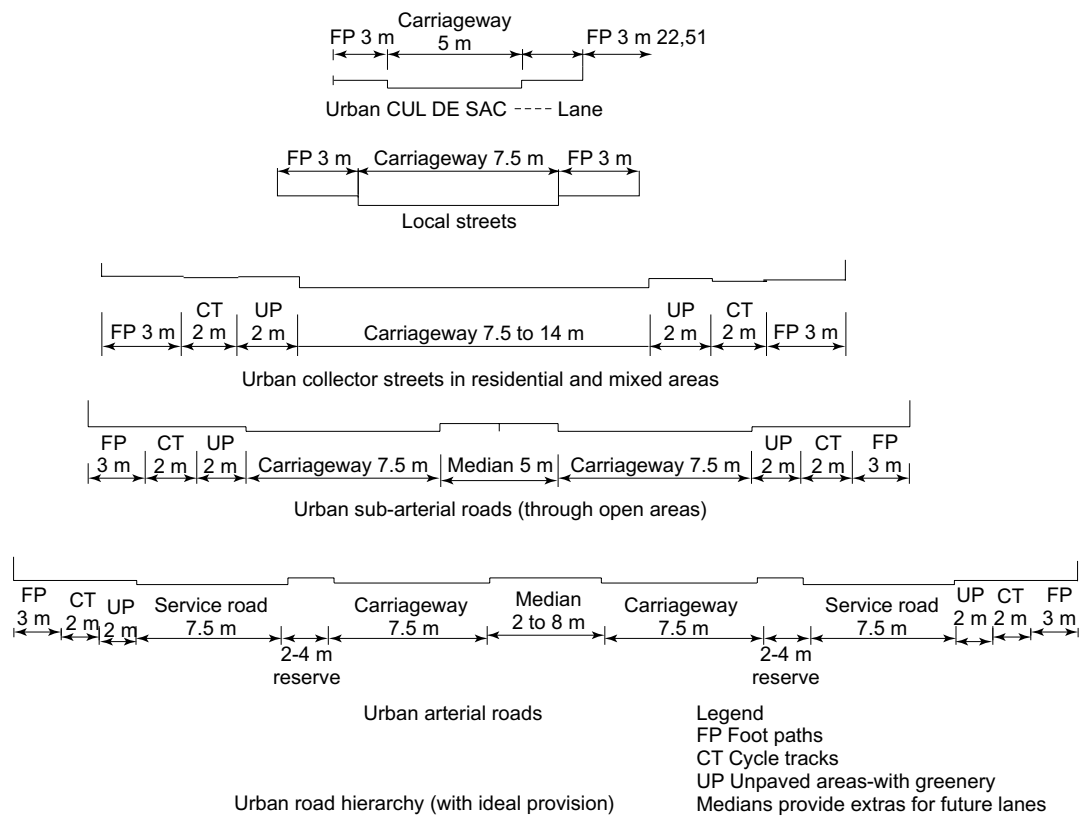
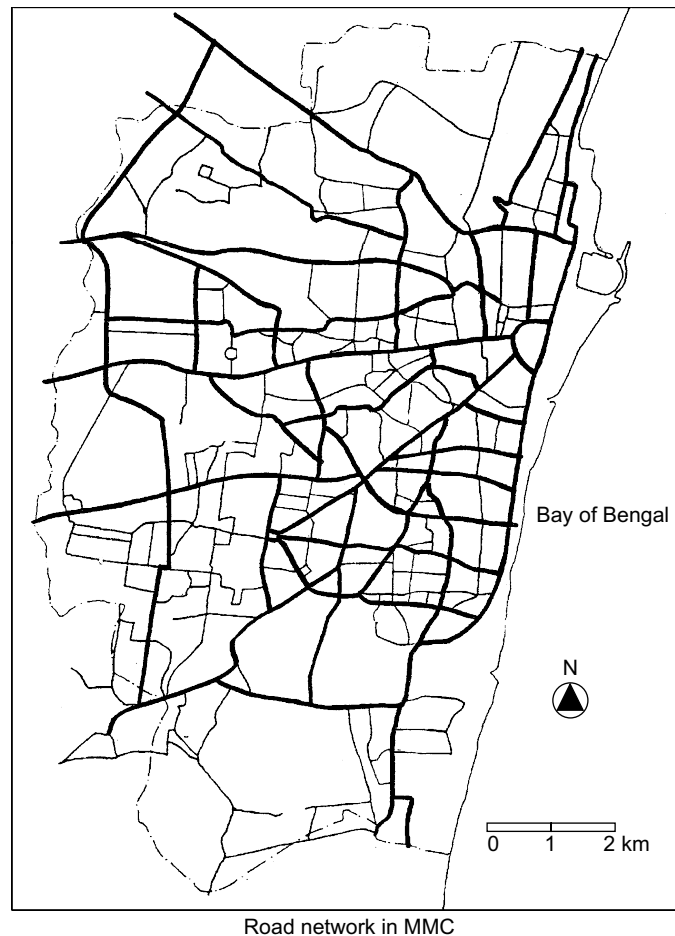


Figure 4.3 Carriageway Configuration of Different Classes of Roads

4.6 SURVEYS FOR DATA COLLECTION

4.6.1 Household Interview Survey (HHI)

The household or home interview survey is aimed at collection of data on: (i) composition of the household; (ii) socio-economic characteristics of each member of the household, including age, sex, occupation, income, vehicle ownership, driving status, literacy level; and (iii) the trip record for a working day, preferably the day (which should have been a working day) before the day of the survey for each member. In addition, opinion survey is conducted amongst some randomly chosen percentage of the traveling members on different aspects of their trips/travel and alternative policies like introduction of new modes, fare structure and various aspects of service provided and transport management measures. Full particulars of the outward trip starting from the residence till reaching the destination and vice versa for return trip shall be recorded. Even if the trip would have been made by more than one mode, the details of each leg of travel will be recorded and the trip itself will be treated as single one and the mode used for the longest leg will be treated as the



**Source:** CMDA – Comprehensive Traffic and Transportation Study 1994

**Note:** Thicker lines indicate arterials and sub-arterials; thinner lines indicate collector streets.

**Figure 4.4** Road Network in Chennai City

principal mode. The details will cover purpose of trip, mode used, access times, waiting time and in-vehicle time and out of pocket expenses for each component. If any member of the household would have made any other trip (for business or shopping, etc.) during the day, similar particulars will be recorded as separate trip in the same manner. Only inter-zonal trips are to be recorded and taken into consideration for analysis.

The time taken for conducting such survey per household can be about 30 to 45 minutes depending on the number of trip makers in the house. It has to be done on holidays or evenings when the head of the household and most trip makers will be available. If number of enumerators is less, alternatively the enumerator would collect the socio economic particulars and leave the sheets

for recording trip details with the head of family requesting him to have it filled for being collected a day or two later. In this manner an enumerator can cover 4 to 5 households per hour. There is, however, some risk of the trip particulars not being complete and correct. Suitable expansion factors will have to be used, depending on the percentage of households covered in each zone while analysing the data.

4.6.2 Traffic Surveys—Mid-Block Counts

Mid-block counts are done on a weekday on all busy roads in order to study the density of traffic continuously for about 16 hours in order to assess the total daily volume and their composition and peaking pattern as well as their direction. Mode-wise vehicle counts are generally made and recorded at 15 minute intervals. The Volume/Capacity (V/C) ratio of road stretches can be obtained from these data in order to help in planning long term strategies for easing traffic. Accident-prone stretches will also be identified. Simultaneously, occupancy of vehicles is also noted on a sample basis.

Different types of vehicles ply on the roads and the space occupied by them per unit of time are quite different from one another. In order to assess the volume of flow and capacity of a road, it is necessary to use a standard unit for vehicles. The general practice is to adopt a unit known as Passenger Car Unit (PCU). It is measured based on the interference it causes to other traffic. If the addition of one vehicle of the type per hour in a traffic stream causes reduction in the average speed of the remaining vehicles in the stream by the same amount of reduction of speed as would have been caused by addition of one passenger car in the stream, the PCU of such a vehicle is treated as 1. This value depends on the size and speed of the vehicle and also the type of road (urban, rural) and location on the road (roundabout, signal, mid section). Many academic institutions in India have been doing research on the values to be adopted for the heterogeneous traffic conditions in Indian cities. In UK, they follow four different standards, one each for urban roads, rural roads, roundabouts and traffic signals. In India, the PCU equivalents as per IRC: 70-1977 in urban areas shown in Table 4.1 and for comparison, values adopted in UK are also given.

Table 4.1 Passenger Car Unit Equivalent

Type of Vehicle	PCU Equivalent for Urban Roads in UK <sup>2</sup>	PCU Equivalent for Urban Roads in India <sup>3</sup>
Passenger car, tempo, tractor, auto-rickshaw	1.00	1.00 (1.00)
Motor cycle, Scooter	0.75	0.50 (0.33)
Lorry, bus, tractor-trailer	2.00 bus 3.00	3.00 (1.75 to 2.25)
Cycle rickshaw	-	1.50
Horse-drawn vehicle	Coach, tram 3.00	4.00
Bullock cart	-	6.00 to 8.00
Bicycle	0.33	0.50 (0.20)

**Note:** Figures in brackets are figures suggested for design of signals at intersections.

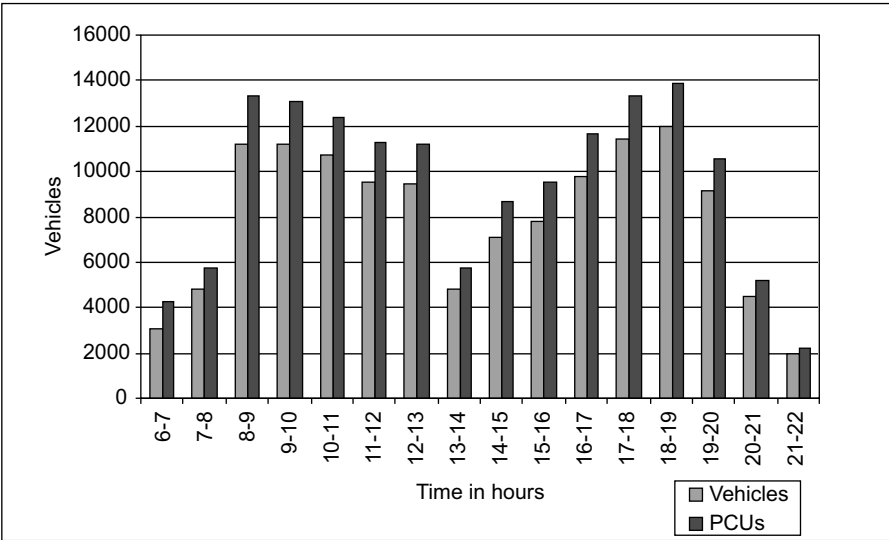
### 4.6.3 Roadside Interview (RSI) Survey

RSI survey is generally combined with traffic counts at the peripheral cordon of the study area. In small towns and cities, a single cordon at outer periphery is chosen and survey points fixed on all radial roads entering the city. In larger metropolitan areas more than one cordon is chosen. The outer cordon will be at the boundary of the study area and the inner cordon at entry into the city proper or the core area (CBD). At these points, the vehicular counts are made for 24 hours in the same manner as for mid-block survey. In addition, O-D survey is conducted by stopping some vehicles and making enquiries on a percentage basis. Generally, 10% of the vehicles are stopped and the interview conducted, selecting one in every 10<sup>th</sup> vehicle. It should cover all types of vehicles. Sample size can be reduced in busier hours. An alternative method is for a surveyor to stop and interview one vehicle and as soon as he completes it, stop next vehicle coming and interview it. In busy times, more than one interviewer can be engaged. Another alternative is to stop every n<sup>th</sup> vehicle and give a prepaid questionnaire to the commuter requesting him to complete and mail the same to the survey office. But this latter method is not recommended since many of the recipients of the questionnaire do not respond. In order to avoid delay to other vehicles, generally bays are created at the counting point for diverting the sample vehicle into it and interviewing the occupant. Each interview will take about 10 minutes. The questionnaire covers the location, type and registration number of vehicle, number of occupants, origin and destination with their land use classification, trip purpose of occupants and stoppages en route and selection of route in onward direction. This survey data will help in cross checking the results of HHI survey and calibration of different models. While the vehicle count should be done for 24 hours, the O-D survey may be restricted to 16 hours (0600 hours to 2200 hours) on a working day.

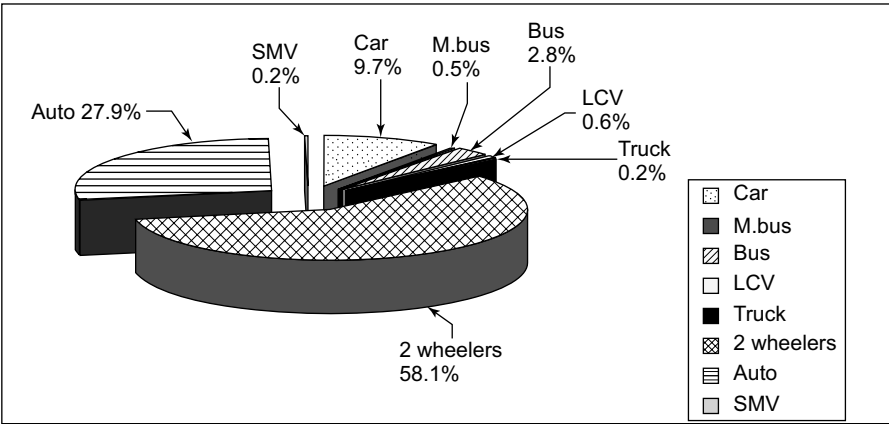
Analyzed data will give the volume of traffic, its composition, its hourly distribution and origin destination pattern of traffic. The O-D data collected helps in understanding the present pattern of traffic and extrapolation for future in order to do scientific planning of transportation system and mass transit facilities of a metropolitan area. In fact, some planners have tried to develop quick response models for such planning using only O-D and traffic count data, dispensing with HHI survey.

### 4.6.4 Screen Line Survey

Screen line survey refers to similar volume count conducted at different locations in the study area at crossings along natural barriers like rivers, canals and railway lines. Basic purpose of this survey is for validation of models developed. Based on the HHI survey, trip assignments are made, which would give the volume of traffic on different routes, from which trips going across the screen lines can be determined. This is cross checked with the data on counts made at the screen line locations and any adjustments in calibration of the model can be made. For example, for a study done for Chennai, the Adyar and Cooum Rivers and the three rail corridors formed the screen lines and the survey was done at all major road crossings across these barriers. Figures 4.5 (a) and (b) show the diurnal variation in vehicular traffic and their modal split in morning peak hour at a Cordon survey point in Bangalore.



(a) Diurnal Variation



(b) Modal Split at Cordon Point in Morning Peak hour

Source: Adapted from a RITES study for Bangalore

Figure 4.5 Hourly Variations in Traffic at a Cordon Point

4.6.5 Speed-Flow Studies

The time taken to traverse a length of road is a function of speed and delay on the same. This will be different for peak hours and off-peak hours as the speed itself is dependant on the volume *vis-à-vis* capacity of the link. The present conditions will thus change when volume of traffic goes up in future. In order to assess future capacity on different roads with and without improvements, models are developed for different classes of roads, as it is not possible to do so for individual roads.

This is done by conducting speed-flow surveys by a moving observer method. The objective is to determine the journey speed or travel time on a stretch of road. The surveyor travels in a vehicle with the traffic and notes time of travel from end to end and at the same time notes down the number of vehicles he crosses and the number of vehicles which overtake his vehicle. He does so by making a number of trips up and down on the road. In order to have a better estimate, he will make a number of such return trips and average out the results.

The journey speed is calculated as follows:

Let  $t_s$  and  $t_n$  be the times taken for south bound and north bound trips respectively;  $x_s$  and  $y_n$  are opposing traffic count of overtaking vehicle met with during the trips.

Then the north bound flow  $q_n = (x_s + y_n) / (t_s + t_n)$

Similarly,  $q_s = (x_n + y_s) / (t_s + t_n)$

Mean travel time for north bound trips  $t_n' = t_n - (y_n / q_n)$ , and

Mean travel time for south bound trips  $t_s' = t_s - (y_s / q_s)$

If  $L$  is length of the road, journey speed =  $L / t_n'$  north bound and  $L / t_s'$  south bound.

While computing these, it is desirable to convert the different type of vehicles met with in terms of PCU (Passenger Car equivalent).

Of late use of GPS (Global Positioning System) to derive journey speeds on different sections by remote observations of the moving vehicle is also being adopted on such studies.

#### 4.6.6 Parking Survey

With the rapid growth of personal vehicle ownership in Indian cities, parking has become a major problem in the cities and even suburbs. Parking surveys have to be conducted on different roads and parts of the city to assess the demand for parking and to see how best the demand can be controlled/regulated and how the demand can be met with. It requires collection of basic data like locations, inventory of parking spaces available in each location, demand for parking space and duration. In order to identify the locations, a general reconnaissance of study area is done. Major shopping areas, commercial centres, railway stations and terminals and major institutional areas have to be covered in parking survey. In addition, locations where buses and commercial vehicles are likely to be parked for short and long duration and other streets where kerb parking is done have to be covered. It is usually done from 8:00 AM to 8:00 PM. The survey comprises of noting down the number of spaces available, type of parking (parallel or saw tooth), registration number of vehicles parked in those slots every half hour or closer intervals and it is done on a typical working day.

#### 4.6.7 Pedestrian Survey

Pedestrian survey is conducted at important locations where there is heavy flow of pedestrians for 12 hours on a working day and also on holidays. Width and type of sidewalks available and any encroachments on them are noted. The volume of pedestrians walking along and across the road is counted every half hour or less during peak hours.



4.6.8 Commercial Vehicle Survey

The pattern of loading, unloading, commodities conveyed, origin, destination and details of movement during the day of commercial vehicles is collected through a questionnaire distributed to different transport operators, apart from the counts done as part of cordon and screen line survey. This information is required for future projection of such traffic likely and their impact on movement on city roads.

4.6.9 IPT Survey

Similar survey is conducted amongst the IPT operators, (taxis, auto-rickshaws and vans) and individual drivers. The questionnaire will be such as to elicit information of all trips made by the driver during 24 hours in a log form detailing timings of trips, origin destination, and number of passengers carried.

4.6.10 Public Transport Survey

This covers inventory of public transport vehicles, capacity, their routing pattern, schedules, and fare structure. These are to be collected from the operators. Occupancy survey is conducted by head counting as well as by an enumerator traveling in some buses on major routes for studying the loading pattern. Similar data is collected for rail transit modes and loading pattern can also be studied from the ticketing data collected from the operator.

4.6.11 Sampling

None of the surveys mentioned above can be done covering the entire population or all roads. The surveys have to be on a sample basis. The selection of sample has to be such that it covers the entire area and be quite representative. The representative nature should cover different size of families, different income levels and occupations and vehicle ownership types. It has been found that sample size is based on the principle ‘smaller the population, larger has the sample to be’. The Bureau of Public Roads in USA<sup>3</sup> has laid down the following standards for HHI surveys:

Population in Study Area	Sample size % of Households
Below 50,000	20%
50,000 to 150,000	12.5%
150,000 to 300,000	10%
300,000 to 500,000	6.7%
500,000 to 1 million	5%
Over 1 million	4%

Minimum sample size for a comprehensive survey is 2% and maximum 5%. In case of updating surveys in large cities of population 5 million and above even 1% sample size has been found adequate.

Different types of sampling adopted are:

- Random sampling
- Stratified sampling
- Cluster sampling, and
- Quota sampling

*Random sampling*, as the name suggests, involves choosing the household to be surveyed in a random manner. It ensures that every individual or household has an equal chance of being included in the survey. One method is to write out the door numbers of the houses in a street on slips of paper, put them in a box and selecting the required numbers of slips as in a raffle. The selected door numbers are given to the surveyor to do the interview survey or opinion survey. Another method is to run the random number list and based on that choose the households in accordance with that list. Usually details of the streets and door number lists are obtained from the municipal or corporation offices. Alternatively voter list can be used and sample home to be interviewed selected by using random number. HHI surveys are conducted using this method.

*Stratified sampling* is done by dividing the population into different groups based on a specific characteristic like age, sex, income, vehicle ownership. Income grouping can, for example be BPL (below poverty line), low income, middle income, high income, or based on vehicle ownership (no vehicle owner, cycle owner, motorized two wheeler owner, car owner), etc. In order to use this method, the basic demographic details in zone will have to be available before start of survey. For example, census reports can form the basis. The samples are chosen by proportionate representation, on a percentage basis. This methodology is more useful for conducting opinion surveys and for studying the behaviour of the population in respect of travel habits and choice of mode.

*Cluster method* refers to collection of samples by grouping different areas/ zones into homogeneous groups like slums, tenements, independent houses or areas with low level of development, normal development and well developed.

*Quota sampling* is used when it is proposed to restrict the number of samples. In this method, the number of households to be surveyed in each zone is fixed and same adopted for all zones. Within this number, the investigator should choose households to represent different socio-economic levels and vehicle owners.

## 4.7 ENVIRONMENTAL IMPACT ANALYSIS

### 4.7.1 When Required

Urban transportation planning study will invariably lead to the need for improvement of the transport system in the city in order to keep pace with the growth in demand for transport. This improvement may pertain to transport network calling for widening of roads, construction of new roads like ring roads, bypasses and flyovers, intersection improvements with rotaries or signalization and even introduction new mass transit systems like BRT, LRT, RRT and Monorail. All these works will have some impact or other on the environmental balance in the city. The environmental impact caused by major new road works and new system introduction will be quite significant and will call for a detailed analysis. One major objective in transport and urban planning, presently, is to aim

at a sustainable development. Hence most of the countries have made it mandatory that any major infrastructure planning study covering new roads or rail systems should be accompanied by an Environmental Impact Analysis (EIA) report.

#### 4.7.2 Coverage of EIA

Indian Roads Congress special publication IRC:104-1989<sup>5</sup> lays down the requirements of an EIA for new road projects in India. It involves three steps viz., base line data collection, holding consultations with people likely to be affected, analysis and identifying mitigation measures and evolving strategies during construction and operation. Any EIA has to cover the perceived impact on the following aspects:

- Any local geological/geomorphologic feature of importance
- Any heritage structure or structure of religious/historical significance
- Topography including natural formations and water bodies
- Interference with any water supply source/drainage pattern
- Land use changes and effect of severance
- Air quality and atmospheric pollution
- Likely discharges and waste and their disposal
- Noise
- Forestry, trees and green coverage
- Ecology and nature conservation
- Visual impacts and landscape
- Socio-economic changes
- Effect of construction operations like noise, pollution, etc.

The analysis should cover both positive and negative impacts. Mitigation measures have to cover action to be taken during implementation and periodically thereafter. It has to identify the monitoring mechanism also.

#### 4.7.3 Objectives of Mitigation Measures

Geologically or geomorphologically fragile zones which fall on the alignment or vicinity of the facility will need to be protected against degeneration. Possibility of triggering or aggravating soil erosion problems should be avoided.

It is important that no structure of historical or architectural importance or those of major religious significance is disturbed for locating the facility and not marred or disfigured due to pollution or vibration caused by the traffic using the facility.

If the road or rail line runs across the natural slope blocking free flow of rain water, adequate cross drainage openings should be provided and water logging avoided. Water bodies of importance for local drainage or as source of water should be preserved and also protected against encroachment and pollution. The leakage of oil, diesel, etc., from passing vehicles on the new road or terminals and bus depots can be washed by rain or wash water and may pollute streams, water bodies and even percolate down and cause pollution in ground water. Regulations call for base line tests and

studies of water resources at the time of investigations and fixing of standards to be maintained and also devise a monitoring mechanism.

Any transport facility will have a major impact on the land use pattern on either side. Its area of influence which can extend upto 3 to 4 km on either side depending on nature of road or rail line. It will also interfere with free movement across the facility in case of works like major arterials and expressways and rail lines at grade. The impact of such constraint needs to be studied and adequate crossing facilities provided.

Air quality on the corridor will be affected by pollution due to emission of gases like CO, CO<sub>2</sub>, NOX, HC and particulate matter from the passing vehicles as well as dust raised by them. They will affect the breathing of other road users and residents and also mar the buildings. Their impact on sensitive buildings housing hospitals, schools and research establishments and heritage structures is of high significance. Similarly there will be adverse impact on residents and such facilities caused by higher level of noise and vibration that will be caused by passing vehicles, more particularly by rail vehicles. Such impact will have to be studied over an area of influence extending for about 200 m on either side. Base line measurements are called for in cases of both air quality and noise at specified locations, which can be monitored periodically after facility is built and comes into operation.

Ecology is defined as a 'scientific study of interrelationship between the living organisms and their environment, e.g., climate, soils and topography'. Nature preservation, on the other hand refers to maintenance of a balance in the diversity of and character of the area's wild life. This also includes rare species of birds and reptiles and seasonal migrating birds. Though there will be no case for wild life protection and major problem affecting ecology in urban areas, there can be exceptional cases in coastal areas and peri-urban areas on the fringe of forests and hill towns. For example, Adyar Creek area in Chennai has a fragile ecology being one of locations attracting migrating birds and also having some marine vegetation. Any major development in such areas calls for care to preserve their basic structure and balance. Even in other areas, it is important to maintain the green cover and enhance the same, which will also help in absorption of some CO<sub>2</sub> emissions. The regulations call for replacement of any tree cut by two new ones, if not more. This aspect of EIA is considered very important by most approval authorities.

Socio-economic impact studies call for detailed local consultations with the people living along the corridor and specially those whose properties will be directly affected and/or who will need to be relocated/ rehabilitated. Needs of inter communication between the groups who will be separated and will have to live on either side of the road or rail line, which may pass through a habitat has to be given special attention.

There will be disturbance in the form of dust, noise and other disturbance to residents in immediate vicinity on either side caused by men and machinery during construction operation. In case of improvement works or construction of new bridges, etc., existing users may have to take diversions, which will be dusty and have rough surface, causing discomfort and delays. Mitigation measures to minimize such discomfort and inconvenience have to be specified.

#### 4.7.4 Air Pollution

Air pollution is the major environmental hazard in cities. Urban planning has to aim at providing infrastructure that facilitate reduction in overall pollution level and also ensure that in any location it does not reach dangerous levels.

**Table 4.2** Ambient Air Quality Standards (National)

Pollutants	Time-weighted Average	Concentration in Ambient Air			Method of Measurement
		Industrial Areas	Residential, Rural & Other Areas Sensitive Areas	Sensitive Area	
Sulphur Dioxide (SO <sub>2</sub> )	Annual Average*	80 µg/m <sup>3</sup>	60 µg/m <sup>3</sup>	15 µg/m <sup>3</sup>	- Improved West and Geake Method - Ultraviolet Fluorescence
	24 hours**	120 µg/m <sup>3</sup>	80 µg/m <sup>3</sup>	30 µg/m <sup>3</sup>	
Oxides of Nitrogen as (NO <sub>2</sub> )	Annual Average*	80 µg/m <sup>3</sup>	60 µg/m <sup>3</sup>	15 µg/m <sup>3</sup>	- Jacob & Hochheiser Modified (Na-Arsenite) Method
	24 hours**	120 µg/m <sup>3</sup>	80 µg/m <sup>3</sup>	30 µg/m <sup>3</sup>	- Gas Phase Chemiluminescence
Suspended Particulate Matter (SPM)	Annual Average*	360 µg/m <sup>3</sup>	140 µg/m <sup>3</sup>	70 µg/m <sup>3</sup>	- High Volume Sampling, (Average flow rate not less than 1.1 m <sup>3</sup> /minute).
	24 hours**	500 µg/m <sup>3</sup>	200 µg/m <sup>3</sup>	100 µg/m <sup>3</sup>	
Respirable Particulate Matter (RPM) (size less than 10 microns)	Annual Average*	120 µg/m <sup>3</sup>	60 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	- Respirable Particulate matter sampler
	24 hours**	150 µg/m <sup>3</sup>	100 µg/m <sup>3</sup>	75 µg/m <sup>3</sup>	
Lead (Pb)	Annual Average*	1.0 µg/m <sup>3</sup>	0.75 µg/m <sup>3</sup>	0.50 µg/m <sup>3</sup>	- ASS Method after sampling using EPM 2000 or equivalent Filter paper
	24 hours**	1.5 µg/m <sup>3</sup>	1.00 µg/m <sup>3</sup>	0.75 µg/m <sup>3</sup>	
Ammonia	Annual Average*	0.1 µg/ m <sup>3</sup>	0.1 µg/ m <sup>3</sup>	0.1 µg/m <sup>3</sup>	
	24 hours**	0.4 mg/ m <sup>3</sup>	0.4 mg/m <sup>3</sup>	0.4 mg/m <sup>3</sup>	
Carbon Monoxide (CO)	8 hours**	5.0 mg/m <sup>3</sup>	2.0 mg/m <sup>3</sup>	1.0 mg/ m <sup>3</sup>	- Non Dispersive Infra Red (NDIR)
	1 hour	10.0 mg/m <sup>3</sup>	4.0 mg/m <sup>3</sup>	2.0 mg/m <sup>3</sup>	Spectroscopy

\* Annual Arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval.

\*\* 24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.

**Source:** Central Pollution Control Board website ([www.cpcb.nic.in](http://www.cpcb.nic.in))

Any new proposal has to be examined in the light of likely impact on pollution levels. In order to ensure this, it will be necessary to check the level of pollution at critical locations along the proposed corridor and establish monitoring mechanism for continuous check. For this purpose, the Central Pollution Control Board<sup>6</sup> has laid down the standards applicable in different areas and the same is reproduced in Table 4.2.

Air pollution on urban roads is caused by the increasing number of gasoline driven and diesel driven vehicles. The former emits more of CO and CO<sub>2</sub>, while diesel vehicles emit more of particle matter (smoke) and NO<sub>x</sub>. In order to control these, all countries have laid down stringent emission standards for the vehicles at manufacturing stage itself. In India, special attention to this aspect has been given since 1989 when the rapid growth in vehicle population started in India. The norms have been introduced in stages as Euro I, Euro II, Euro III, etc. in western countries. India has been following them and has issued Bharat 1, Bharat 2, etc., Currently, Bharat 2 is enforced since 2005, especially in 11 selected cities. Bharat III corresponding to Euro III is to come into force in 2010. The norms followed currently are given in Table 4.3.

**Table 4.3** Emission Standards for Vehicles in g/kwh

Vehicle Type	Year From	Reference Standard	CO	HC	NO <sub>x</sub>	PM- Particle Matter
Heavy diesel	2005	Euro II	4.00	1.1	7.0	0.15
	2010	Euro III	2.10	0.66	5.0	0.10
Light diesel	2005	Euro II	1 – 1.50	0.70 – 1.20		0.08 – 0.17
Gasoline 4 wheeler	2005	Euro II	2.2 – 5.0	0.5 – 0.7	-	
Gasoline 3 wheeler	2005	Bharat 2	2.25	2.00	-	
Gasoline 2 wheeler	2005	Bharat 2	1.50	1.50	-	

**Source:** Compiled from Reference 7

Periodic checking of vehicles for the emission levels has been made mandatory. Planners have to assess likely air pollution levels based on estimated volumes at critical locations.

#### 4.7.5 Noise Pollution

Noise beyond a level causes discomfort to the residents and road users as well. In general terms, it causes annoyance and disturbance. It interferes with one's normal sleep, disturbs concentration on work or study, and would even affect the listening to each other in conversation by the noise produced by vehicles close by. An extremely high level of noise and for long periods can lead to physical discomfort and possibly deafness. Noise level is measured in terms of decibels or dBA, which is a logarithmic function of sound pressure. Zero dB marks the threshold of hearing the lowest sound pressure that can be made on that scale. Whisper is supposed to produce noise of 20

dBa, noise in a quiet office being 40 dBA. A person's normal concentration is likely to be disturbed at 60 dBA and the noise becomes painful at the level of 80 dBA. Comfort level for noise is based on a subjective judgment. While a level of 60 dBA is considered as quiet, any level above 90 dBA would be considered extremely noisy by many.

Noise emanates from the working of the engine in the vehicle and it is heightened at higher speeds and/or when a vehicle hauls heavier loads, especially on a road with a steep gradient. Motor cycles by nature and heavy diesel trucks make higher noise than automobiles and light vans. The tyre-road interaction is a major producer of noise on roads. Rail-wheel interaction of trains causes still higher level of noise. Trains also produce higher noise at joints when the wheels pass over the rail joints. A train on move can produce a noise of level 92 dB, a truck of 90 to 100. The effect of noise in tunnels and narrow roads with high building on either side is more accentuated. For example, New York subway is reported to experience a noise level of 95 dBA which is considered annoying.

Traffic noise felt in Central London<sup>8</sup> is reported to range from 80 to 95 dBA. The same study reported that, in the same location, the cumulative graph of noise level 10 percentile of time the noise was above 76 dBA, 50% time above 69 dBA and 90% time above 64 dBA. In Indian cities, studies indicated the following levels during peak hours: Delhi 80 dBA; Kolkata 87 dBA; Mumbai 85 dBA; and Chennai 89 dBA.

In India, IS: 4954-1965 'Noise abatement in town planning-recommendations' and IS: 3098-1980 'Noise emitted by moving road vehicles-measurement' deal with the subject in relation to traffic noise. The ambient noise level as specified in India for different areas are as in Table 4.4.

**Table 4.4** Acceptable Ambient Noise Levels

Area	Noise Levels $L_{eq}$ dBA	
	Day time	At night
Silence zone	50	45
Residential zone	55	45
Commercial zone	65	55
Industrial zone	75	65

**Source:** Adapted from Reference 8

Checking for noise pollution becomes important especially when new elevated roads and rail facilities are proposed on any corridor in the city. If such a facility passes by any sensitive locations like schools, hospitals, zoos and research establishments, the issue gains more importance. In case the project is unavoidable, special measures will have to be taken to reduce the impact like provision of dampeners and % or tubular covering over the structure at such locations. Ballasting on rail tracks and welding of joints on railways dampen the noise to a large extent. In urban areas, the railways provide suitably shaped parapet walls to reduce the impact of the noise on neighbourhoods where ballast-less track is used. Provision of rubber pads below rails and between bearing pads and sleepers may also be tried to reduce the noise levels.

On the roads, steps taken to reduce noise levels include the following:

- (i) Changes in design of vehicles;
- (ii) Banning use of older vehicles (say over 8 to 10 years old), specially on city roads;
- (iii) Changes in design of tires and road surfacing;
- (iv) Modification in traffic operation like;
  - rerouting buses and heavy vehicles away from predominantly residential localities and sensitive areas
  - prohibition of blowing of horns in sensitive areas like hospitals, and schools
  - provision of synchronized traffic signals on arterial roads
  - bypassing through traffic not having any work in the city through ring roads or bypasses, and
  - providing properly designed sound barriers on flyovers within the city.

Provisions of IRC: 104-1989<sup>5</sup> giving guidelines for preparation of EIA (Environmental Impact Analysis) are applicable equally to road and rail projects within the city.

Another aspect which has gained some importance in urban areas is the 'visual pollution' due to a new infrastructure like flyover and elevated rail with overhead electric catenary. Local consultations will be called for in such cases, especially if the structure passes through business localities, on beach front or in front of any heritage or prestigious structures.

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## 5.1 TRAVEL DEMAND FORECASTING PROCESS

Development of transportation as an integral part of the urban milieu promotes the expansion of urban areas with better distribution of goods and services and higher density of urban activities. The expansion of the urban area is accompanied by population growth and continuous increase of passenger travel and freight movement, necessitating the provision of more public services and urban facilities. The process of urban transportation planning is influenced by the total range of human activities in an urban area. Strategies have to be evolved and planning measures have to be initiated to secure balanced transportation, to facilitate which the transportation demand has to be estimated realistically. Travel demand forecasting has thus become an essential ingredient of the overall transportation planning process.

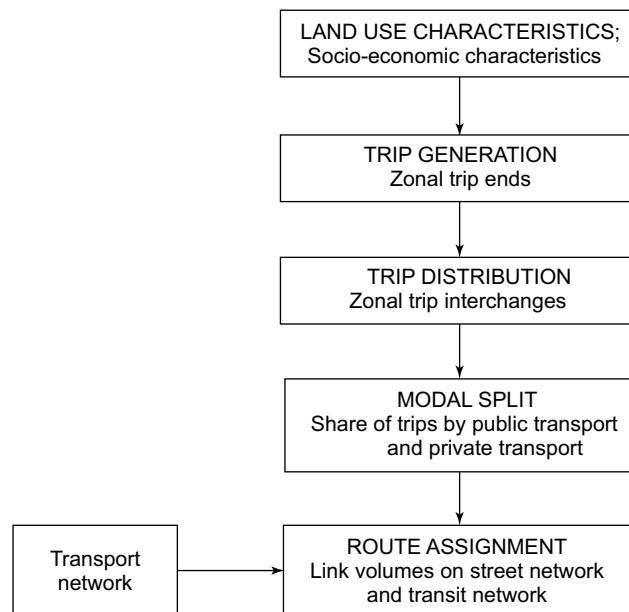
Travel demand is influenced by national economic policy formulation, which is based on inadequate philosophical assumptions and unpredictable extent of inflation and employment. Though sophisticated dynamic and stochastic models are applied, their reliability is limited because of uncertainties relating to the assumption that future is similar to the present condition. Still we try to arrive at a realistic estimate of future travel demand to facilitate acceptable transportation planning.

As indicated in Section 3.3, the trips may be broadly classified as home-based trips and non-home-based trips. Depending on the purpose, the trips may be stratified as: home-to-work trips; school trips; business trips; shopping trips; and social and recreational trips. By mode of travel, trips may be classified further as: public transport trips (bus, tram and rail); private transport trips (car, motorized two-wheeler, bicycle and walk); and intermediate public transport trips (taxi, hired vehicles, auto-rickshaw and cycle rickshaw).

For the purpose of urban planning, the year of investigation is taken as the base year, and the future year for which planning is performed is called the horizon year. The interval between the base year and the horizon year is called the plan period, which may be 20 years for long term planning and about 5 years for short term planning.

For the existing base year conditions of urban form, transportation models are developed relating travel demand to different socio-economic and demographic variables. These models are applied to predict the probable travel demand for a horizon year using reasonable assumptions

regarding the probable future land use allocations and socio-economic characteristics. Predictive and estimating models are designed to explain real world phenomena and the patterns that may be expected over time. The duration between the base year and the horizon year has been adopted as 20 years in earlier plans. However, the predictions made in the 1960s were found to be inaccurate in the 1980s due to various drastic changes in social and economic aspects of travel. Hence in recent years, the horizon year is being shifted from the distant future to a reasonably shorter period in some cities.



**Figure 5.1** Travel Demand Forecasting Process

The traditional travel demand forecasting process consists of four stages: (a) Trip generation; (b) Trip distribution; (c) Modal split; and (d) Route assignment. The process is depicted in Fig. 5.1. In the trip generation phase, relationships are established to estimate the number of trips produced by or attracted to a given zone. These trips are distributed as trip interchanges to the various zones in the trip distribution stage. The modal split phase determines trips by mode. The route assignment process allocates the zonal trip interchanges to the various links of the network. The four phases of the travel demand forecasting process are explained in detail in the following sections.

## 5.2 TRIP GENERATION AND ATTRACTION ANALYSIS

### 5.2.1 Introduction

The trip generation analysis phase relates the extent of trip making to and from land use parcels to measures of the type and intensity of land use. Relationships between existing land use and travel

demand are derived, and models are developed for the prediction of travel demand in a future year based on the forecast change in land use and trip making characteristics.

There are two types of trip generation: (a) Trip production, which covers trips generated by residential zones where these trips may have home as origin or destination; and (b) Trip attraction, which denotes the trips generated by activities at the non-home-end of a home-based trip.

5.2.2 Factors Influencing Trip Generation

Factors affecting trip generation in an urban area include: Household income, car ownership, household size, distance from the central business district (CBD), residential density, floor space of business and industry, number of jobs available, and accessibility of the workforce. These are shown in Table 5.1.

Trip frequency increases with increase in persons per household, household income and ownership of private vehicles. The degree of urbanization influences the number of trips, and the distance of the zone from the CBD is related to the degree of urbanization. Improved accessibility to public transport with enhanced efficiency or level of service will result in increased number of trips. The trip making capability is also influenced by the level of employment opportunities, industrial activity, and commercial activities which are often measured in terms of floor space occupied by different concerns.

Table 5.1 Factors Affecting Trip Production and Attraction

Trip Production	Trip Attraction
Household income	Employment available
Vehicle/Car ownership	Commercial floor space
Household size	Industrial floor space
Distance from CBD	Accessibility of workspace
Residential density	Educational institutions/Enrolment spaces

5.2.3 Models for Trip Generation

In the trip generation analysis phase of the travel demand forecasting process, models are developed to estimate the trips generated by a zone for each trip purpose, depending on the future land use developments, socio-economic characteristics and nature of transportation facility in the zone. The earlier technique of extrapolation of the past trends has given way to more rational methods requiring a clearer understanding of the relationships between the transportation system and the travel behaviour of the individual. The models are evolved on the assumption that there is a measurable relationship between the land use and the intensity and distribution of travel.

Three types of models have been developed to analyse trip generation: (a) Growth Factor Method; (b) Multiple Linear Regression Technique; and (c) Category Analysis. These methods are discussed briefly in the following sections.

### 5.2.4 Growth Factor Method

Growth factor method uses a simple model which defines a growth ratio linking the base year and the horizon year trip generation for a zone as in Equation (5.1).

$$T_i^h = a_i \cdot T_i^b \quad \dots(5.1)$$

where  $T_i^h$  is trips produced at zone  $i$  in horizon year  $h$   
 $T_i^b$  is trips produced at zone  $i$  in base year  $b$   
 $a_i$  is growth factor for zone  $i$

Though this model has the merit of simplicity, it does not take into account the various socio-economic and demographic factors that affect trip generation. It uses an approximate factor to reflect the anticipated changes in the future land use characteristics of the zone. This model is used only for short-term projections in stable areas in a rural-urban interface context such as external-internal and through trips.

### 5.2.5 Multiple Linear Regression Technique

The multiple linear regression (MLR) technique is the most widely used method for the analysis of trip generation. This is a statistical technique in which the influence of different independent factors in association with other independent factors on the dependent variable is estimated. The independent variables can be the planning factors such as total population, number of households, family size, car ownership, etc. The dependent variable can be the number of zonal trip ends (productions and attractions) by mode and trip purpose.

The functional form is of the type

$$Y_p = a_0 + a_1X_1 + a_2X_2 + \dots + a_kX_k + U \quad \dots(5.2)$$

where  $Y_p$  is trips generated for purpose  $p$   
 $a_i$  is partial regression coefficients  
 $X_i$  is planning factors  
 $U$  is disturbance term.

The multiple linear regression analysis technique for evolving trip generation models is based on the following assumptions:

- (i) Each of the independent variables is linearly related to the dependent variable.
- (ii) All the variables are normally distributed and continuous.
- (iii) The independent variables are not highly correlated between themselves.
- (iv) The influence of each independent variable is additive, i.e., the inclusion of each independent variable would explain part of the variation of the dependent variable.

The regression models are derived using present values of the dependent and independent variables for the zone under study using the technique of least squares. It is assumed that the coefficients and other parameters thus established will be valid for the future situation. Knowing the future values of the zonal characteristics which are derived from the land use development models, the number of trips for the horizon year for the different trip purposes is estimated.

The goodness of fit of the derived regression line is measured by the regression coefficient

$$R^2 = \frac{(\sum Y_e - \bar{Y})^2}{(\sum Y - \bar{Y})^2} \quad \dots(5.3)$$

where  $R^2$  is coefficient of multiple regression

$R$  is multiple correlation coefficient

$Y_e$  is estimate of dependent variable

$\bar{Y}$  is mean of  $Y$  values

$Y$  is observed value.

$R^2$  measures the percentage of variations in the dependent variable that can be explained by changes in the independent variables. The choice of the variables that appear in the equation is made by a step-wise multiple regression analysis.

The regression models derived should satisfy the following three criteria:

- (i) The regression equation should be statistically valid; i.e., a low non-negative value for the  $a_0$  term, and a high value for  $R^2$  (nearer to unity), and the equation should pass the F- and t-tests.
- (ii) The equation should be logical.
- (iii) The independent variables should be non-collinear.

The concept of regression analysis is based on zonally aggregated measures of travel characteristics. The traffic zone is taken as the unit of trip making. Unless the zones are homogeneous internally, important variations in the zonal characteristics will be submerged by the aggregation. A further shortcoming of the regression model is that continuous variation of land use characteristics is assumed, while household size and car ownership are stepped functions. While these models are useful tools in planning analysis, they should be applied with caution in view of their inherent limitations.

### 5.2.6 Typical Examples of Trip End Models

Planners tend to develop a number of trip end models for a large city, since the variables influencing the choice are different for different types of trips like work, education and other purpose trips. Two examples are indicated here.

#### (a) Models for City A

Models developed for a major metropolis in 1992 are quoted below to illustrate how different factors influence trip generation and attraction of home based trips in different cases during peak periods. An approximately equal number can be expected to make the return trips. The return trips related to work and education trips will be in the after-noon peak period.

*Trip Generation*

$$\text{Work trips} = 109 + 0.446 * V + 0.375 * W \quad R^2 = 0.83$$

$$\text{Education trips} = 95 + 0.165 * V + 0.203 * S \quad R^2 = 0.62$$

$$\text{Other trips} = 56 + 0.0165*P + 0.048*V \quad R^2 = 0.36$$

*Trip Attraction*

$$\text{Work trips} = -366 + 0.4955*WP \quad R^2 = 0.64$$

$$\text{Education trips} = -136 + 0.309*SE \quad R^2 = 0.51$$

$$\text{Other trips} = 215 + 19.99*CA + 0.006*P \quad R^2 = 0.16$$

where  $P$  is Population in zone

$V$  is Motorized vehicles in zone

$W$  is Number of workers in zone

$S$  is Number of students in zone

$CA$  is Commercial area in zone in hectares

$WP$  is Number of work places in zone

$SE$  is Student enrolment in zone

$R^2$  is Coefficient of multiple correlation.

### (b) Models for City B

In a recent study made for another large city, models were developed for trip generation using only population as the influencing factor for all trips generated.

*Trip generation*

$$\text{Work trips} = 7092 + 0.230*P \quad R^2 = 0.83$$

$$\text{Education trips} = 3287 + 0.881*P \quad R^2 = 0.76$$

$$\text{Other trips} = 2734 + 0.108*P \quad R^2 = 0.72$$

*Trip Attraction*

$$\text{Work trips} = 4904 + 0.686*W \quad R^2 = 0.77$$

$$\text{Education trips} = 2469 + 0.416*S \quad R^2 = 0.70$$

$$\text{Other trips} = 8989 + 401.10*CA \quad R^2 = 0.73$$

[Note: It is often seen that in several *study* reports, the constant terms are indicated to a number of decimal places, with the coefficients shown to an unrealistic number of decimal places, presumably because they are copied from computer print-outs. Noting that a value less than one for the number of trips is meaningless, the use of decimal places in these equations may be adopted realistically.]

### 5.2.7 Category Analysis

In this method, the household is used as the fundamental unit of trip making. The basic household data is classified into relatively homogeneous separate categories according to household characteristics, and the analysis is known as cross classification or category analysis. For each

category, the average trip generation rate is calculated from the survey data collected for the existing trip generation from each category of households, and is used in the estimation of trips, assuming that the trip generation rate remains constant into the future.

The following assumptions are made in the analysis:

- (a) A dwelling unit or household forms the fundamental unit in which trips can originate or end to satisfy the travel needs of the members of the household.
- (b) Trip making in a household depends on the characteristics of the household and its spatial relationship with the destinations of the trips generated.
- (c) Households of different sets of characteristics produce trips at different rates.
- (d) Trip generation rates in a horizon year will be the same as in the base year as long as the conditions external to the households are same as in the base year for each category of household.

For purpose of illustration, a simple zone may be assumed. The significant causal factors of trip production for work trips may be taken as the number of persons per household (1 to 6+) and car ownership (0, 1, 2). Thus there are 18 categories for which trip rates have to be determined from survey. A typical hypothetical set of data for this simple example is shown in Table 5.2. Knowing the future residential intensity according to the causal factors which are again categorized into subgroups, the zonal trip production estimates can be computed by estimating the households in each category and multiplying with the appropriate trip rate from the above analysis and then summing over all categories of people.

**Table 5.2** Example of Trip Rates by Category Analysis for Work Trips Production in Zone  $t$  per Household

Cars per HH	Persons per Household					
	1	2	3	4	5	6+
0	0.41	0.83	1.50	2.10	2.52	2.8
1	0.90	1.95	2.62	2.85	3.10	3.27
2	1.65	2.80	3.15	3.32	3.52	3.65

Productions

$$T_i = \sum_c h_i(c).t_p(c) \quad \dots(5.4)$$

Attractions

$$T_j = \sum_c b_j(c).t_a(c) \quad \dots(5.5)$$

where  $T_i$  is number of trips produced by zone  $i$   
 $h_i(c)$  is number of households in zone  $i$  in category  $c$   
 $t_p(c)$  is trip production rate of household category  $c$   
 $T_j$  is number of trips attracted to zone  $j$   
 $b_j(c)$  is number of employment opportunities in category  $c$   
 $t_a(c)$  is trip attraction rate of employment category  $c$ .

The model is calibrated with actual data obtained from household surveys. The number of observations for each category should be statistically adequate. The sample size may vary from 2% to 20% depending on the rarity of the category.

5.3 TRIP DISTRIBUTION MODELS

5.3.1 Distribution Matrix

The purpose of a trip distribution model is to “distribute” the zonal trip ends in order to predict the flow of trips,  $T_{ij}$ , from each production zone  $i$  to each attraction zone,  $j$ .

Destination zones →

	1	2	3	4	5	$n$	$\Sigma$
1	$t_{11}$	$T_{12}$	$T_{13}$			$T_{1n}$	$P_1$
2	$t_{21}$						$P_2$ $P_3$
3							
$n$	$t_{n1}$					$t_{nn}$	$P_n$
$\Sigma$	$A_1$	$A_2$	$A_3$			$A_n$	

Origin zones ↓

$$\sum_{i=1}^n t_{ij} = A_i$$

$$\sum_{j=1}^n t_{ij} = P_i$$

Figure 5.2 Properties of Synthesized Distribution Matrix

The trip distribution is a function of: (a) zonal socio-economic and demographic characteristics; (b) the level of service, type and nature of transportation facilities in the zone; and (c) spatial pattern, distribution and intensity of land use.

The properties of synthesized distribution matrix are depicted in Fig. 5.2. There are  $n$  zones in the urban area, resulting in  $n^2$  possible movements. From the matrix, it is clear that the trip distribution model has to satisfy the following two criteria.

$$\sum_{j=1}^n t_{ij} = P_i$$

...(5.6)



$$\sum_{i=1}^n t_{ij} = A_j \quad \dots(5.7)$$

where  $t_{ij}$  is trip movement from zone  $i$  to zone  $j$   
 $P_i$  is total trip production at zone  $i$   
 $A_j$  is total trip attraction to zone  $j$ .

### 5.3.2 Trip Distribution Models

There are several approaches to trip distribution. These can be broadly classified into two groups: (a) Growth factor methods; and (b) Stochastic models. Both the above methods are based on the principle that the trip movement increases with increase in attractiveness of the particular type of travel and decreases with increase in impedance to travel. In the growth factor methods, the base year trip interchanges are multiplied by growth factors to yield horizon year trip interchanges. In the stochastic model methods, the model is calibrated or made to fit the base year trip pattern, and then the calibrated model is applied to the horizon year conditions.

**Table 5.3** Trip Distribution Models

Growth Factor Models	Stochastic Models
Average Growth Factor Method	Gravity Model
Detroit Model	Intervening Opportunities Model
Fratar Model	Competing Opportunities Model

The types of models used for trip distribution are shown in Table 5.3. The growth factor models are now used only for short term updating of trip tables. Gravity model is the most widely used model for trip distribution. The opportunities models are based on the theory of probability. These models are briefly described in the following sections.

### 5.3.3 Average Growth Factor Method

This is the simplest growth factor method. The symbolic representation is given by Equation (5.8).

$$T_{ij}^h = T_{ij}^b \frac{F_i + F_j}{2} \quad \dots(5.8)$$

where  $T_{ij}^h$  is trip interchange for horizon year  
 $T_{ij}^b$  is trip interchange for base year  
 $F_i$  is growth factor for zone  $i$   
 $F_j$  is growth factor for zone  $j$ .

The trip production constraint is

$$T_i = \sum_{j=1}^n T_{ij} \quad \dots(5.9)$$

where  $T_i$  is total trip production in zone  $i$ .

### 5.3.4 Detroit Method

This method was developed in Detroit Metropolitan Area Traffic Study (1956). The method assumes that the zonal trips predicted by taking into account, the growth factor of the zone are distributed to other zones in proportion to the ratio of the growth factor of the attracted zone to the growth factor of the entire urban area. The computation is represented as in Equation (5.10).

$$T_{ij}^h = T_{ij}^b \frac{F_i \cdot F_j}{F} \quad \dots(5.10)$$

where  $F$  is growth factor for the area as a whole.

### 5.3.5 Fratar Method

Fratar developed a method of trip distribution based on the assumption that the distribution of the horizon year trips from a zone is proportional to the existing trip distribution pattern from that zone modified by the growth factors of all the zones under study. The modification considers the spatial configuration of the zones and the locational factors are defined as the reciprocal of the average attracting factors of all the zones. The mathematical representation is given in Equation (5.11).

$$T_{ij}^h = T_{ij}^b F_i F_j \frac{L_i + L_j}{2} \quad \dots(5.11)$$

where  $L_i$  and  $L_j$  are locational factors for zones  $i$  and  $j$ .

$$L_i = \frac{T_i^b}{\sum_{j=1}^n T_{ij}^b F_j} \quad \dots(5.12)$$

Fratar model is used for short term extrapolation in urban areas and for prediction of intercity and rural traffic.

### 5.3.6 Gravity Model

The basic premise of the gravity model is that the magnitude of the trip interchange between zones  $i$  and  $j$  is directly proportional to the number of trips produced in zone  $i$  and the number of trips attracted to zone  $j$ , and inversely proportional to some function of the spatial separation of the two zones. The relationship can be expressed as in Equation (5.13).

$$T_{ij} \propto T_i \cdot A_j \cdot \left[ \frac{1}{f(d_{ij})} \right] \quad \dots(5.13)$$

or

$$T_{ij} = T_i \cdot A_j \cdot \left[ \frac{f_{ij}}{\sum A_j \cdot f_{ij}} \right] \quad \dots(5.14)$$

where  $f_{ij}$  is friction factor.

The friction factor is an inverse function of the “cost” of travel (travel time, distance, out-of-pocket expenses, etc.) between zones  $i$  and  $j$ . Factor  $f_{ij}$  is some polynomial function of distance between zones  $d_{ij}$  and is to be evaluated by calibration with observed data for any given area.

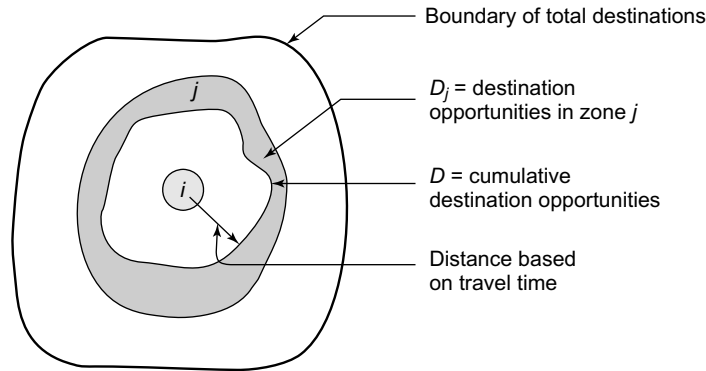
### 5.3.7 Intervening Opportunities Model

The basic hypothesis of the model is that the trip interchange  $T_{ij}$  is directly proportional to the number of opportunities at the destination zone and inversely proportional to the number of intervening opportunities. Schneider<sup>9</sup> proposed that trips remain as short as possible, becoming longer only when suitable destinations are not found at shorter distances. The probability of finding an acceptable destination is assumed to be a constant  $L$ .

The general form is given by Equation (5.15).

$$T_{ij} = T_i P_r(S_j) \quad \dots(5.15)$$

where  $P_r(S_j)$  is the probability of trip ending in zone  $j$ .



**Figure 5.3** Intervening Opportunities Model

Consider an urban area with destinations in order of travel time from origin zone  $I$  as shown in Fig. 5.3. Let  $D$  be the cumulative destination opportunities upto zone  $j$  and  $D_j$  be the destination opportunities in zone  $j$ .  $P_r(S_j)$  will decrease as distance of  $j$  from  $I$  increases and can be represented as in Equation (5.16).

$$P_r(S_j) = e^{-LD} - e^{-(D+D_j)} \quad \dots(5.16)$$

Hence

$$T_{ij} = T_i [e^{-LD} - e^{-(D+D_j)}] \quad \dots(5.17)$$

Trips are stratified into short trips, long-residential trips and long non-residential trips, and different  $L$  factors are used. The disadvantage of this method is that future values of  $L$  are difficult to evaluate satisfactorily.

### 5.3.8 Competing Opportunities Model

In this model, the probability that a trip chosen at random from zone  $i$  will have its destination in zone  $j$  will depend on the ratio of the trip opportunities in zone  $j$  to the total number of competing opportunities within a given time boundary. See Fig. 5.4.

The general form of the relationship is the same as in Equation (5.15).

$$T_{ij} = T_i \cdot P_r(S_j) \quad \dots(5.15)$$

$$P_r(S_j) = P_r(A_j) \cdot P_r(s_j) \quad \dots(5.18)$$

where  $P_r(A_j)$  is the probability of attraction to zone  $j$

$$= D_j/D_k$$

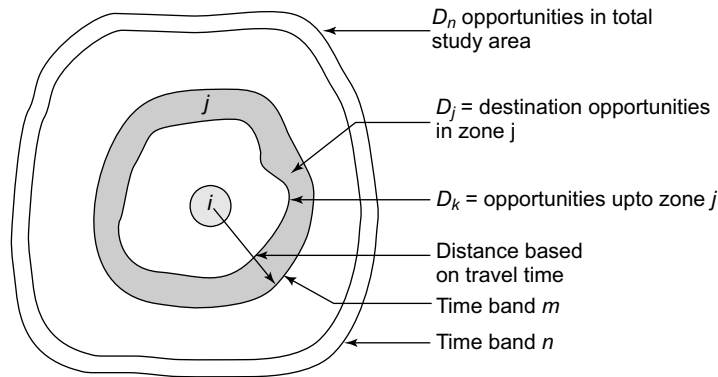
$D_k$  is opportunities up to time band  $m$  (up to zone  $j$ )

$D_j$  is opportunities in zone  $j$

$P_r(s_j)$  is probability of trip end allocation satisfaction in zone  $j$

$$= (1 - D_k/D_n)$$

$D_n$  is the opportunities up to time band  $n$  for total study area.



**Figure. 5.4** Competing Opportunities Model

This model is difficult to calibrate due to difficulties associated with selection of time bands.

## 5.4 MODAL SPLIT ANALYSIS

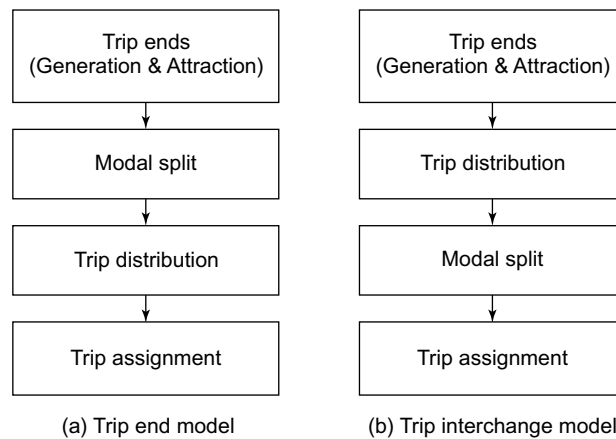
### 5.4.1 Definitions

Captive riders are those trip makers who do not have access to private vehicles, and hence are dependent on public transport, e.g., children, the poor and the elderly.

Choice riders are those trip makers who may chose freely between public transport and private transport for a particular journey.

The difference between the terms mode choice and modal split needs to be noted. Mode choice refers to the process by which the trip maker chooses a particular mode for his trip. Modal split deals with the procedure developed by the transportation analyst to simulate the mode choice process of the trip maker.

Modal split can be placed either prior to trip distribution or after trip distribution as shown in Fig. 5.5. If it is employed immediately after trip generation, no account will be taken of the route characteristics. The model is called Trip End Model, and the model emphasizes captive riders. On the other hand, if modal split is performed after distribution, the effect of modal choice on distribution is neglected. The model is then called Trip Interchange model and it focuses on choice riders. As a compromise, captive modal split is placed after distribution.



**Figure 5.5** Alternative Sequencing of Planning Models

Modal split is considered normally between the two predominant modes: private vehicles and public transport (transit). Planning models in Indian Cities consider split amongst car, motorized two wheeler, IPT and Public Transport. In cities where train plays a major role as in Mumbai, Chennai and Kolkata they consider between car, two wheeler, IPT, bus and train.

#### 5.4.2 Factors Affecting Modal Split

The major determinants of modal split are: (a) human elements - the socio-economic characteristics of the trip makers; (b) system elements and the relative costs and service properties of trips by private vehicles and by transit.

The human elements affecting the modal choice of the trip makers are: vehicle ownership, household income, size of household, age, sex, and purpose of trip. The system factors influencing the modal choice decision are: travel time, difference in travel time between transit and private mode, out-of-pocket costs, congestion costs, reliability of service, and comfort and convenience.

### 5.4.3 Types of Modal Split Models

Modal split models are used to predict the percentage of trips using each of the modes available to the given group of trip makers. The modal split models can be broadly classified as: (a) Multiple Linear Regression (MLR) models; (b) Statistical models; and (c) Probabilistic models. Statistical models are empirically derived. These synthesize a relationship between causal variables and are developed at a city level. Most common of these models is the diversion curves model. Probabilistic models, on the other hand, are based on the premise that a consumer chooses an alternative which has higher utility than another. In recent approaches, the modal split models represent utility as a linear function of disutilities associated with each competing mode. These are also known as disaggregate models.

### 5.4.4 Multiple Linear Regression Models (MLR)

Multiple linear regression models for modal split have been used in the past for estimating trips on a corridor by specific modes. They have been used more often for estimating Public Transport trips on a corridor and, many times, specifically for share of trips by transit or train.

A typical MLR model developed for Delhi in 1977 by Sarna<sup>8</sup> is given as Equation (5.19):

$$y_1 = 22.0 - 0.559 x_1 + 0.732 x_2 + 0.11 x_3 \quad \dots(5.19)$$

where  $y_1$  is estimated percentage of transit users from the zone

$x_1$  is percentage of high income households in the zone (dividing the population into high, medium and low income households)

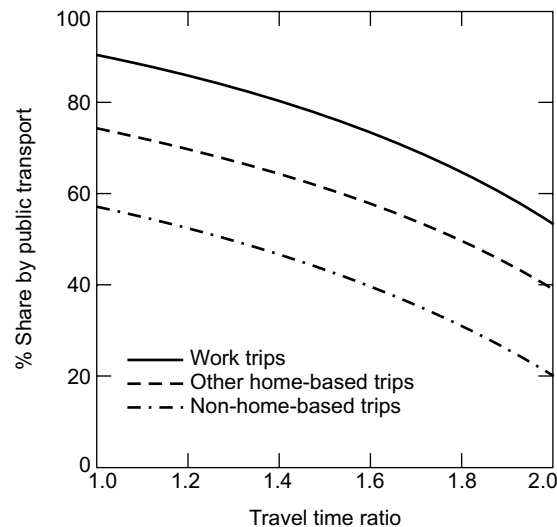
$x_2$  is distance to CBD in km from zone centroid

$x_3$  is residential density in persons per acre

However, such empirical relationships have limited applicability. They were used in studies done in Indian cities in 1970s for estimating modewise trip generation from zones. In Chennai and Kolkata comprehensive traffic and transportation studies, MLR model form was used for estimating mode wise trips but they were found to over estimate the public transport trips. MLR models are seldom used now for modal split analysis on city wide basis. They can, however, be used to develop quick response models in preliminary studies on specific corridors when a new mode is proposed to be introduced. For example a model can be derived for estimating proportion of trips on rail facility to be introduced on a specific corridor by conducting a limited survey covering the zones in the area of influence of the proposed rail transit line.

### 5.4.5 Diversion Curves for Modal Split

Diversion curves model uses empirically derived two-dimensional curves which relate the percentage share of transit (or private vehicles) in the overall transit trips with one or more explanatory variables, such as ratio of travel time by transit to that by car, cost ratio or income range. A typical set of diversion curves for trips stratified by trip purpose relating travel time ratio and public transport share is shown in Fig. 5.6. These curves are to be derived for particular regions, and are not universally applicable.



**Figure 5.6** Typical Diversion Curves for Modal Split

#### 5.4.6 Disaggregate Travel Demand Models for Modal Split

The limitations and deficiencies in using MLR models for choice of an alternative mode led planners and researchers to develop disaggregate travel demand models based on discrete choice analysis. They have adopted statistical probability approach in developing such models. They attempt to estimate the statistical probability of choice of a commodity or service by an individual, based on his perception of 'utility' of an alternative as compared to the 'utility' of the alternative choice. The data collection and analysis is done at individual level.

Such choice models are calibrated using observations made on individual choice behaviour and hence have the following advantages:

- They are more data efficient, and hence call for less sample size than for other conventional methods.
- While in other methods, the variation in perception between individuals is lost sight of when the data is aggregated at zonal level, in these models such variations are accounted for in the calibration.
- They can be applied at any level of aggregation.
- They are less likely to be biased than in methods using correlations using aggregate units.

They are developed as binary choice models considering the two modes: Public Transport ( $M = 0$ ) and private vehicles. These models being probabilistic, one can make use of different probability concepts. The models reflect the individual choice behaviour while choosing the mode of travel. During application of the model, different forms and levels of aggregation can be used. For example, a summation concept can be used to get total number of people choosing a mode from an area as sum of the individual choice possibilities in the sample population.

According to the theory on which this discrete choice model is based, an individual is assumed to have complete information about the alternatives. He evaluates each alternative based on its utility to him and would choose the one giving him maximum utility. The explanatory variables are included in the model by means of a linear 'utility' expression. It is possible to include policy variables also as pseudo variables or using weighted parameters.

They were first private transport ( $M = 1$ ). Amongst the binary choice stochastic models, the popular models are Logit model and Probit models. Both use random utility functions in the form

$$U(i) = V(i) + e(i) \quad \dots(5.20)$$

where  $V(i)$  is a deterministic component; and  $e(i)$  is the stochastic component and the problem is to find the probability of choosing ( $i$ ) over ( $j$ ) for all ( $j$ ) not equal to ( $i$ )

The approach is different in the two cases. The ease of mathematical computations and iterative process in logit modeling approach has made it more popular.

A mode choice index ( $y$ ), also known as utility function, which is a function of different characteristics of travel by mode 1 and mode 2, is computed as in Equation (5.21).

$$y = a_0 + a_1X_1 + a_2X_2 + \dots + a_nX_n \quad \dots(5.21)$$

where  $X_1, X_2, \dots$  denote user and system characteristics, and

$a_0, a_1, a_2, \dots$  denote model parameters.

Typical variables ( $X_i$ ) used in analysis include: car ownership; difference in costs; travel time; gender; and home to work distance.

$$P(M = 1/ij) = e^y / (1 + e^y) \quad \dots(5.22)$$

(a) *Logit Model* Logit model, in its elementary *binary* form, is represented as below:

$$P(M = 0/ij) = 1 / (1 + e^y) \quad \dots(5.23)$$

where  $P(M=1/ij)$  = probability of using mode 1 (private vehicle) for trip interchange  $ij$ .

and  $P(M=0/ij)$  = probability of using mode 0 (public transport) for trip interchange  $ij$ .

$Y$  is the utility function

Equation (5.22) gives a logistic form. Alternatively it is possible to adopt an approximate linear form as in Equation (5.24).

$$P(M=1/ij) = a(c_1 - c_2) + b(t_1 - t_2) + d \quad \dots(5.24)$$

where  $c_1, c_2$  are out-of-pocket costs by mode 1 and mode 2

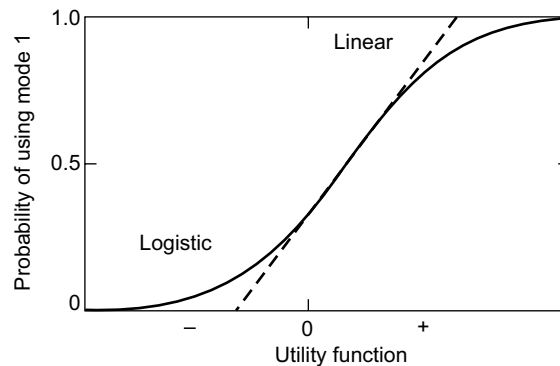
$t_1, t_2$  are travel times by mode 1 and mode 2

$a, b$  are parameters to be determined empirically

$d$  is a constant.

Typical logistic and linear forms for modal split are shown in Fig. 5.7.



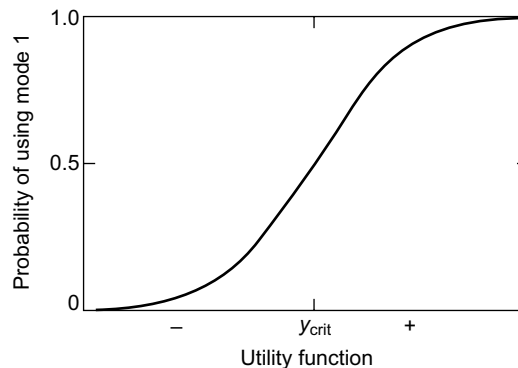


**Figure 5.7** Typical Logit Analysis for Modal Split

It will be seen the logistic form provides a better fit.

(b) *Probit Model* The basic premise of the model is that choice trip makers will choose mode 1 if  $y \geq y_{\text{crit}}$ , and mode 2 if  $y < y_{\text{crit}}$ , where  $y$  is the value of utility function for the chosen mode and  $y_{\text{crit}}$  is to be determined. The form of the relationship is as shown in Fig. 5.8.  $y_{\text{crit}}$  is normally assumed to be zero.

Both logit and probit models are acceptable. Logit model is usually preferred as it is easier to calibrate.



**Figure 5.8** Typical Probit Analysis for Modal Split

### 5.4.7 Multinomial Logit Models

Though in initial stages, logit models were developed as binomial models, later the principle was extended to cover choice amongst a number of modes i.e., multiple choice situation as MNL (Multinomial Logit) models. The multinomial form of the model is expressed as in the equation 5.25 A.

$$P(i/m) = e^{G(x_i)} / \sum_{i=1}^m e^{G(x_i)} \quad \dots(5.25a)$$

The utility term or function  $e^{G(x_i)}$  is made of two parts, a measurable part and a random error term to take care of the effects of left over influences of that alternative.

$$G(x_i) = a_1x_1 + a_2x_2 + \dots + a_nx_n + a_1x_1 + \varepsilon$$

Where  $a_1x_1$ ,  $a_2x_2$  are deterministic components of the function, representing different parameters and  $\varepsilon$  is the stochastic component (or a random variable).  $\varepsilon$  can other wise be called an error term and by some as a bias term. In case of modal choice, higher the value of the variable factors like cost, time taken, distance of travel etc. lower will be the utility of that mode to the chooser. In such circumstances, the term  $G(x_i)$  really becomes a disutility function. The choice probability equation for mode choice can, alternatively be written as in 5.25 B.

$$P(i/m) = e^{-G(x_i)} / \sum_{i=1}^m e^{-G(x_i)} \quad \dots(5.25b)$$

in which

$e^{-G(Xi)}$ , the disutility function =  $a + b x_{1i} + cx_{2i} + d x_{3i} + \dots$

$x_{1i}$ ,  $x_{2i}$ ,  $x_{3i}$  ... are different attributes (variables) of mode  $i$  like, time of travel, cost of trip, waiting time, access distance, etc.

$b, c, d$  are coefficients/parameters

$a$  is error term, and  $a$  constant known as modal bias

The calibration of the bias value and coefficients for all alternatives is done using Maximum likelihood method. 'Maximum likelihood estimator is the value of the parameters for which the observed sample is most likely to have occurred'. A number of standard statistical analysis programmes like ULOGIT, ALOGIT and BLOGIT are available for doing model calibration.

Validity of the model is tested through Log likelihood test and a parameter known as Pseudo R square value. Fitness test parameter is expressed as

$$\rho^2 = 1 - L^*(\theta) / L^*(O) \quad \dots(5.26)$$

where  $L^*(O)$  is initial log likelihood value for estimated coefficient and  $L^*(\theta)$  is value for estimated coefficient.  $\theta$  standing for vector of coefficients.

This is the equivalent of  $R^2$  value used for validating multiple linear regression equation.

$-2 \log \lambda$  is a parameter considered equivalent to Chi-square test value where

$$2 \log \lambda = -2 [L^*(0) - L^*(\theta)]$$

Since MNL models are based on data collected at disaggregate level, they are considered more reliable. Hence they are more commonly used by planners now.

When applied at local level, such as choice of access mode to a metro rail station or choice of a route or a mode in a specific corridor, a number of variables like cost, walking time, waiting time, accessibility, comfort, etc., are considered. But when applied at a city level study, using so many variables can make the model unwieldy for applying. In such cases, general practice is use a single variable known as generalized cost to represent the utility or disutility of mode  $i$ . Such generalised

cost for each competing mode is computed by considering out of pocket expenses and value of time taken for the journey.

For example, a set of MNL models developed in a study<sup>11</sup> done in an area in Chennai for the modal choice preferences for work trips by vehicle owning commuters are quoted below.

$$P(i) = e^{-G(Xi)} / \sum e^{-G(Xi)}$$

$$\text{For } G(X_{mv}) = -0.8786 + 0.1357 c + 0.0391 \text{ i.v.t} \\ (-1.48) \quad (2.67) \quad (5.30)$$

$$G(X_{tr}) = -0.3606 + 0.1357 c + 0.0255 \text{ o.v.t} + 0.0391 \text{ i.v.t} \\ (-0.48) \quad (2.67) \quad (2.99) \quad (5.30)$$

$$G(X_{bs}) = -1.6481 + 0.1357 c + 0.0255 \text{ o.v.t} + 0.0391 \text{ i.v.t} \\ (-2.69) \quad (2.67) \quad (2.99) \quad (5.30)$$

$$G(X_{cy}) = -1.4827 + 0.0391 \text{ i.v.t} \\ (-2.79) \quad (5.30)$$

Figures in brackets indicate t-statistic for the respective parameter.

In these expressions:

mv stands for car or scooter/motor cycle or taxi/auto rickshaw,

tr for suburban train,

bs for bus, and

cy for cycle or cycle rickshaw.

c for out of pocket expenses in paise,

o.v.t is access and waiting time, i.v.t. is in-vehicle time all in minutes.

The pseudo R square value for the equation was 0.23.

## 5.5 ROUTE ASSIGNMENT ANALYSIS

The fourth and final step in the transport demand analysis is to assign the trips to different routes. The aim at this stage is to allocate the transit and private transit trip interchanges to the various links of their respective networks. Since Public Transport links are fixed, only private transport trips are to be allocated to the links. These will include direct trips by the private vehicle and access trips by private vehicles to use the transit for part journey. This phase is known as the traffic assignment. Traffic assignment is useful to both the transport planner and the traffic engineer. It helps the former to know the required capacity augmentation on existing links and for the various links proposed for the future such as expressways. It also helps the planner in designing new Public transport systems and provides data for testing alternative system proposals. For the latter, a knowledge of the expected traffic will also help in geometric design of the links and intersections including signaling needs.

The inputs required for traffic assignment analysis are: (i) transport network (ii) trip distance and travel time matrix (iii) O-D matrix for different modes.

Early efforts in this area were concerned with the estimation of the proportion of traffic that would divert to a freeway when constructed. The choice in that case was limited to two paths. The assignment methods were (a) Diversion curves or (b) All-or-nothing method. Recently methods have been developed for multi-path assignment and capacity restrained assignment.

### 5.5.1 Diversion Curve Method

The diversion curves method is similar to that described in Section 5.4.5 for modal split. This is the oldest method. Typically the model predicts the percentage of trips that is likely to use a proposed freeway depending on distance saved, or time saved, or cost saved, or a combination of these. Different other parameters that have been used are: (i) distance ratio, (ii) cost ratio, and (iii) travel time ratio. Among these, travel time ratio curves have been most popular. American Association of State Highway Official (AASHO) has found that when such alternative is developed, not all trips shift to it based on such differences since they are not significant. They have evolved an empirical relationship of percentage of people shifting as follows:

$$P = 50 + 250 \times (B - A/B + A) \quad \dots(5.27)$$

where  $A$  is the time taken on the route under study and  $B$  is the time taken on the alternate route.

California Division of Highways, based on their observations on freeway in California in 1956, developed the following equation for arriving at percentage use of Freeway<sup>12</sup>:

$$P = 50 + \{[50 (d + 0.5 t)] / \{(d - 0.5t)^2 + 4.5\}0.5\} \quad \dots(5.28)$$

where  $d$  is the distance saved in miles on route under study and  $t$  is the time in minutes saved by the route. This technique can be used only for assigning trips to two competing paths and not applicable to networks with more than two routes between the O-D pairs.

### 5.5.2 All-or-Nothing Assignment

Under this method, all trips for a zone pair are assigned to the minimum path connecting them. The minimum path is the route which has the least journey time, distance or other impedance factors. The fallacy of this type of assignment is that in a network with two or more parallel and close links, the link which is only marginally quicker will be allocated all the trips. The resulting flow pattern may lead to an unrealistic situation, especially when capacity restraints and congestion effects are present. As the traffic volume increases, the speeds will fall, travel time will increase and the route may no longer be the shortest.

This method has been found to give satisfactory results for small urban areas. This method can be used successfully if the planner can use his judgment to moderate the behavioural pattern of the commuters/road users. The computations are simpler and it can be applied at a low cost and has been advantageously used for planning studies in most cities in India in the past, e.g., Delhi in 1969, Chennai in 1972, Pune in 1985 and Hyderabad in 1988.

### 5.5.3 Multi-Path Assignment

A number of different paths are identified for each zone pair, and different proportions are assigned to each path such that the traffic flow to each is a function of impedance of the route to that of the shortest route. The techniques used in arriving at the function have to incorporate the travel behaviour of the road users. There are five different techniques possible viz., (i) Diversion curve approach; (ii) diversion factor approach; (iii) stochastic models; (iv) linear graph method, and (v) probabilistic models.

In the diversion curve approach, trips are apportioned to two routes in proportion with or according to travel time ratios of alternative routes. Similarly, in the diversion factor method, a number of paths are chosen and trips are allocated in proportion to the overall speeds of the alternative routes. Stochastic models use random choice procedures for obtaining alternative paths and then allocate trips in proportion to overall travel speeds of the routes. Linear graph method of assignment uses the analogy of current flow in electrical circuits to the alternative paths while deriving the linear graph for use in apportioning the trips. Probabilistic method is still in a theoretical study stage. All these methods are very much dependant on the judgment of the person using the method. They are approximate, based on random choice and may not be realistic.

### 5.5.4 Capacity-Restrained Assignment

The capacity-restrained assignment technique involves a sequence of all-or-nothing minimum path assignments where the sequence is iterated until the traffic volumes assigned to each link are comparable with the link travel time assumed in the minimum path tree building phase. The link travel time used in assignment is a function of speed on that link, which again is dependant on the traffic flow being assigned. This is a better method than the all-or-nothing method. But the solution convergence, requiring a number of iterations, had been difficult and hence not used earlier. But with the easier availability of more powerful computers, this task has been made easier.

The capacity constrained assignment process involves the following steps:

- (i) Practical capacity on each link in the network along with the speed at which traffic will flow on each at full capacity is worked out and stored. A tree of minimum path links is built up along with a list of speeds and volumes for each link of the network. Network is then loaded with the traffic assessed.
- (ii) Volume loaded is compared with the capacities on each link. Where  $V/C$  ratio is over unity, the speed on link will be affected. With the help of speed capacity functions, new speed on each link in the network is calculated which will result in a different travel time. This will result in some inverse change in loading. While doing so, some moderation is made in computation of link speed.
- (iii) A new set of trees is built up with the modified speeds on each link and the modified network is loaded and volume capacity ratio on each link examined. Process in step (ii) is repeated till required convergence is reached.

Some of the methods used for moderation of the capacity constraint are given below:

(a) Smock method<sup>13</sup>

After first loading the links using all-or-nothing principle, the link travel time for next step is worked out using the following function.

$$T_a = T_0 e^{(V/C-1)}$$

Where  $T_0$  is travel time on the link when volume equals capacity

$T_a$  is modified travel time on the link, and

$V$  and  $C$  are volumes and capacities of the link.

(b) Bureau of Public Roads (BPR) method

The equation used by the Bureau of Public Roads<sup>14</sup> to arrive at the capacity of a link reduces to the form given below.

$$T_a = T_0 \{0.87 + 0.13 (V/C)^4\}$$

(c) Current approach

Current approach for the assignment is not to rely on travel time or distance only but to take into consideration cost. In order to simplify the computation a concept of Generalised cost has been introduced. This takes into consideration the actual cost of travel which will cover the vehicle operating cost (indirectly taking care of distance) and the user's perception of value of time spent in terms of cost. In these methods, assignment is done for public transport and private vehicles separately for each link and they are added. Since commercial vehicles and cycles normally have fixed paths based on distances, they are normally preloaded on the links and added to the volumes of assigned public transport and private vehicles on the links.

## 5.6 SUMMARY

The travel demand forecasting process yields the total number of trips generated in each zone, the travel characteristics between any pair of zones, the trips catered by public transport and private transport, and the intensity of trip making in any link of the network. The procedure generally adopted involves four steps. Chapter discusses the basics and different approaches used in forecasting demand and their assignment to the transport net-work in an urban area.

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# Public Transportation – Bus Transport

# 6

## 6.1 BUS TRANSPORT CHARACTERISTICS

Bus transport systems refer to bus systems that serve populated areas on fixed routes and schedules, available to all interested users and charging a published set of fares. When the bus services cater to the needs of urban areas on a regular basis, they are referred as bus transit.

Though the total transport systems are composed of many modes such as walk, bicycles, cars, bus, train and boats, buses form the predominant mode in most urban transport systems for trip lengths in excess of 3 to 8 km but below 200 km. Buses are an affordable means of transportation, and provide flexibility and convenience when compared with other modes. They are relatively easy to plan and implement, and are amenable to operation by the private sector. They also play a major role in facilitating access to and integration with high volume transportation modes such as suburban trains and rapid rail transit.

Buses are non-tracked large cabin systems. The bus is driven by a driver with the assistance of one or two conductors to handle passengers, the crew being employed by the organization operating the service. These buses run on street networks as intra-urban as well as commuter urban systems. There are no guideway costs as for rail based transit. Because they share the carriageway with other traffic, their operating speeds are relatively low. Average speeds are 16 to 20 km per hour (kph) during peak periods on normal urban roads, and can even be 8 to 16 kph in highly congested Central Business District (CBD) areas. Bus headways depend on traffic demand, and may vary between 5 and 60 minutes on a typical urban route. The noise level for a bus at a speed of about 50 kph may typically be 80 dBA inside the bus and 84 dBA outside at a distance of 15 m from the bus on plain ground.

The advantages of bus transport include:

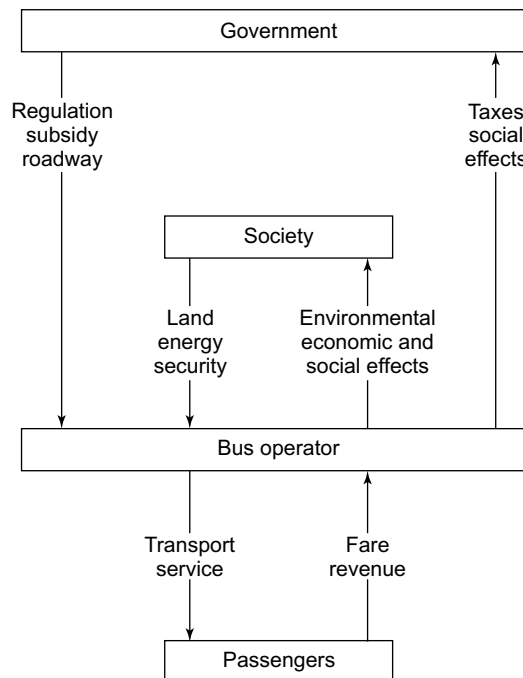
- (a) Buses can operate over the existing road system. Hence bus systems can be implemented and expanded in a relatively short period of time.
- (b) The bus routes can be modified easily, facilitating a wider reach for the user.
- (c) The schedule can be varied easily to suit the demand.
- (d) Buses can be used for charter and other services when not needed in the scheduled service.
- (d) A relatively small number of passengers would suffice to justify dispatching a bus. Hence buses can serve more diverse, low density travel patterns than fixed way systems.



- (e) The undepreciated investment at anytime is salvageable to a large extent if the service needs to be terminated.

Depending on the route coverage, bus services may be of the following types: (a) City services; (b) Intercity services; (c) Rural services; and (d) Minibus operation. City services cover the major routes within the city limits. Intercity services connect the concerned city with other nearby cities, and have a central terminal in the CBD. Rural services connect nearby villages with cities and towns; and in these services, additional provision should be made for carrying luggage. Minibus operation is resorted to when it is necessary to provide bus connectivity on routes with less traffic demand and on routes passing through narrow city streets and in some cases as feeder services to Metro rail stations.

City bus services can be broadly classified into two categories: local bus service and express bus service. The latter can be further subdivided into limited stop service, Point-to-point service and Bus Rapid Transit. Local bus service consists of buses which stop at every bus stop on the route to service passengers. Limited stop service buses stop at selected stops only. Point-to-point service buses follow the route of the local bus service, but the buses travel from the origin to the destination without stopping at any of the intermediate bus stops. Bus Rapid Transit, if available, operates on exclusive busway and hence is capable of higher speeds.



**Figure 6.1** Role of Four Agencies in Bus Transport System

Bus system capacities depend on the type of bus, the seating configuration, the type of operation and the road facility. As the bus stops and the operational conflicts increase, the speeds and the bus route capacities decrease. The bus system capacities in terms of passengers per lane per hour would normally range between 8000 per conventional bus in city traffic to close to 20000 for articulated bus in exclusive busway.

The four agencies involved in bus transport operation are: (a) the passengers; (b) the operator; (c) the society; and (d) the government. A schematic diagram showing the inter-relationships among the four agencies is given in Fig. 6.1. The operator for the urban bus transit is generally the State Transport Undertaking, responsible for transit operation for the concerned city. The operator receives input in the form of fare revenue and delivers the transport service to the passengers and indirectly contributes to the welfare of the community and to the objectives of the government. The society supplies land, energy and resources to the operator, and gets back economic and environmental impacts from the transport operation. The government levies taxes on the society and receives taxes and social and political effects from the operator, while supporting the transport operation through regulations, subsidies and provision of the roadway on which the buses operate. Thus the overall transportation function is performed in a closed system.

## 6.2 TYPES OF BUSES

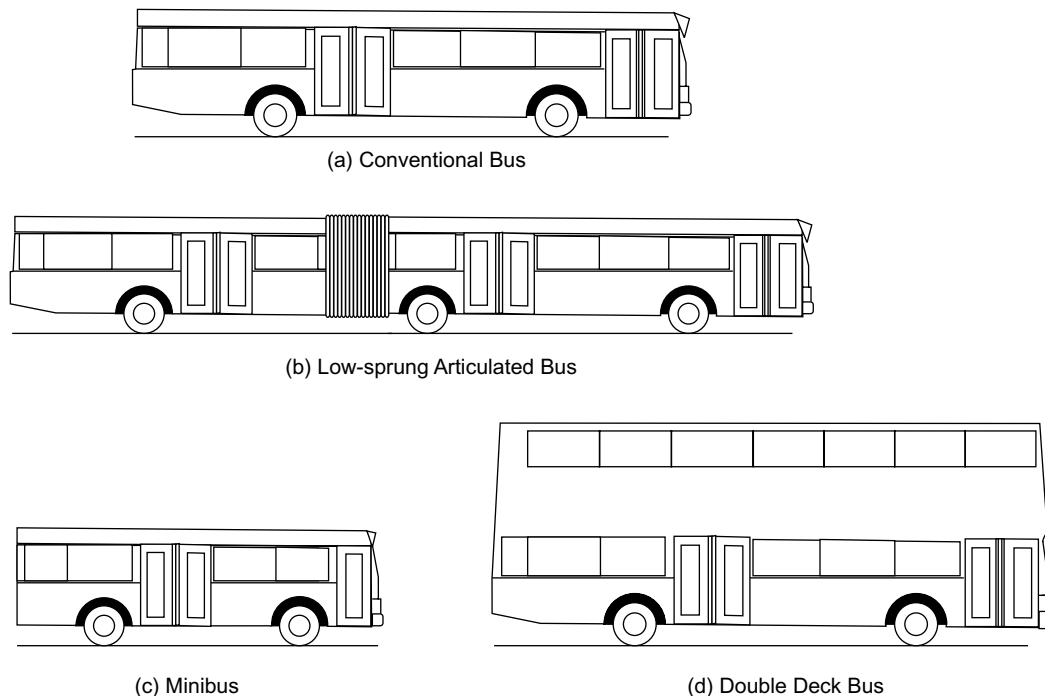
The types of buses used in urban transportation are: (a) Conventional bus; (b) Articulated bus; (c) Minibus; and (d) Double deck bus. These are shown in Fig. 6.2. The conventional bus is about 11.7 m long, and is most commonly used. An articulated bus is about 18 m long and is hinged in the middle for easy turning. Its width varies but generally is 2.67 m. Minibus is a shorter bus, and is used on routes with lower traffic demand. Double deck bus carries passengers at two levels and has higher capacity than the conventional bus. It is possible to adopt articulated double deck buses on routes with heavy patronage.

The individual bus capacities depend on the size of the vehicle, the seating arrangement and the regulation regarding standees. For a local bus, the area allowed is about  $0.3 \text{ m}^2$  per seated passenger and about  $0.2 \text{ m}^2$  per standee. Typical capacity ranges are indicated in Table 6.1.

**Table 6.1** Passenger Capacity for City Buses

	Seats	Standees	Total Passengers
Minibus	16–24	12–16	28–40
Conventional Bus	35–54	19–40	45–94
Articulated Bus	35–70	30–60	80–120
Double deck bus	50–90	15–30	65–120

There is considerable scope to develop standardization of buses in India, somewhat on the lines of the designs developed by the Federation of Public Transport Undertakings (VoV) in Germany<sup>1</sup>.



**Figure 6.2** Types of Buses

The primary aim of the design of the bus is to enhance cost-effectiveness in operation and to improve the comfort and convenience of the passengers. Special attention in design may be paid to: Information display regarding destination and route; Wide doors for boarding and alighting; Steps, such that the lowest step is about 200 mm above the road surface; and Ergonomically designed seats for the driver and the passengers. Design and development of high capacity low floor buses suitable for BRT (Bus Rapid Transit Systems) is receiving attention from many bus manufacturers. Air Conditioned express buses are being introduced on normal routes for attracting private vehicle users to the public transport in many cities in India. From the point of view of passenger comfort, the acceleration and deceleration rates of buses should not exceed 5 kmph per second. The speed of the bus depends on the traffic volume and geometric features of the road. One more concern is design of the buses and bus stops suitable for wheel chair users. Buses operate with different fuels such as diesel oil, petrol or compressed natural gas, and also on electricity.

Another type of bus which has been used in a few cities abroad but is now not in wide use is the trolley bus. Trolley bus enjoys the quiet power of electric traction, while at the same time traveling on pneumatic tyres, thus obviating the need for rail track on the street as for trams. The current (usually 600 V DC) is collected with twin pulley poles from overhead wires. Since it is free to move

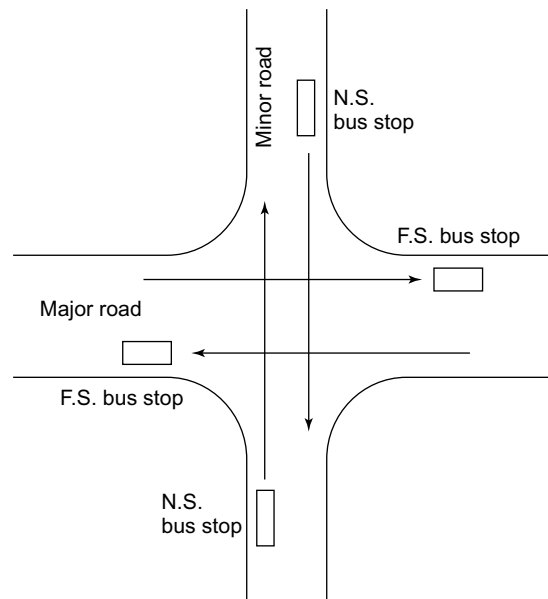
at some distance from under the centre line of the wires, the trolley bus can get round obstacles on the street that would block the conventional tram. The electric components are designed to have compact dimensions. However, trolley buses require a system of overhead power wires, which tend to restrict routing and cause visual obstruction. While the trolley bus is environmentally attractive due to its non-polluting operation, the diesel bus is still the mode preferred by the operators due to its flexibility and lower operating cost.

### 6.3 BUS STOPS

The effectiveness of a bus system is greatly influenced by bus stop spacing, location and design. Considering time and limited mobility of small children, the elderly, and the infirm, bus stops are to be available at short distances, preferably within a five-minute walk. Spacing of bus stops ranges from 400 m to 800 m for a local bus route, 800 m to 1.5 km for a limited stop bus route and 1.5 km to 3.0 km for an urban express bus route. The in-bus travel time increases and the access time to the stop decreases, as the bus stop spacing decreases. The bus stop spacing may be arranged in such a manner that the sum of the access time and the in-bus travel time is minimized. Preferably, the bus stops should be located at major traffic generators and at major road intersections. The simplest bus stop has only a sign. For heavily used stops, additional provisions needed include shelter, benches, schedule information, a coin-operated telephone and possibly an automatic ticket vending machine.

The bus stop may be located either near an intersection or at a midblock location. The midblock stops are desirable in a CBD area at locations where bus routes require right turn at the next intersection, and when the bus stop has to cater to multiple routes, so that stopped buses may not interfere with the turning traffic. The bus stop near an intersection can be at a location ahead of the crossing in which case it is called a near-side (N.S.) bus stop. This location is convenient for the driver as he can negotiate the intersection at a lower speed; the location is also convenient for the passengers, as the stop is normally close to the pedestrian crossing. Far-side (F.S.) bus stop, i.e., stop beyond the intersection, is convenient when the bus has to make a right turn because a longer distance is available for maneuvering. However, a longer queue length may obstruct traffic. The two types are shown conceptually in Fig. 6.3.

The bus stop may be one of three types: (a) Curbside stop, (b) Stop at a lay-by, and (c) Bus bay. Curbside stop is easy to arrange, and does not involve any change to the road or pedestrian crossing. But it obstructs traffic and inconveniences pedestrians. Using a lay-by reduces obstruction to traffic, but it needs more space from the sidewalks. If the drivers observe the road rules, the lay-by enhances safety. Bus bay (Fig. 6.4) is a bus stopping space physically separated from the main stream traffic by islands. It is best in terms of safety and does not cause delay to other traffic. When the number of passengers is large or at transfer stations, bus bays are recommended. A bus bay also facilitates an express bus to overtake an ordinary bus by skipping the stop, thus increasing the journey speed.



**Figure 6.3** Locations of Bus Stops at an Intersection

## 6.4 BUS STOP SHELTERS

A bus stop is a primary interface between the user and the bus system. A well designed bus shelter at a stop enhances the attraction of the bus system in encouraging ridership and providing comfort, security, information and a place to rest for the users, while waiting for the bus. Bus stop shelters are provided to protect the waiting passengers from sun, rain and wind. The shelters may also be provided with benches for the elderly to sit on while waiting for the bus. Bus shelters are installed at terminals and at stops having a minimum of 10 passengers at any bus operating time. A shelter can be built only when adequate space for the same is available. The environment of the bus stop and shelter should be designed to provide a sense of security. The shelter area should be well lighted at night, and should enable the bus driver to see the waiting patrons.

Considerable ingenuity can be applied in the design of simple, functional and at the same time architecturally pleasing bus shelter. The shelter can typically be of rectangular shape in plan and elevation. It can be of size  $4.0 \text{ m} \times 1.6 \text{ m}$ , with aluminum skeletal structure. The sides may be glazed, and provided with openings for access on the curbside. The size of the shelter should be adequate to accommodate the required number of passengers at about  $0.4 \text{ m}^2$  per passenger. The shelter should be so aligned on the sidewalk that there should be a space of at least  $0.8 \text{ m}$  in front and at the rear of the shelter. By providing glazed advertising space on one short side of the enclosed space, the cost of the installation and maintenance of the shelter can be arranged to be underwritten by the advertiser, as done in German cities. Figure 6.5 shows a typical modern bus shelter in use in Chennai.





**Figure 6.5** Typical Bus Shelter

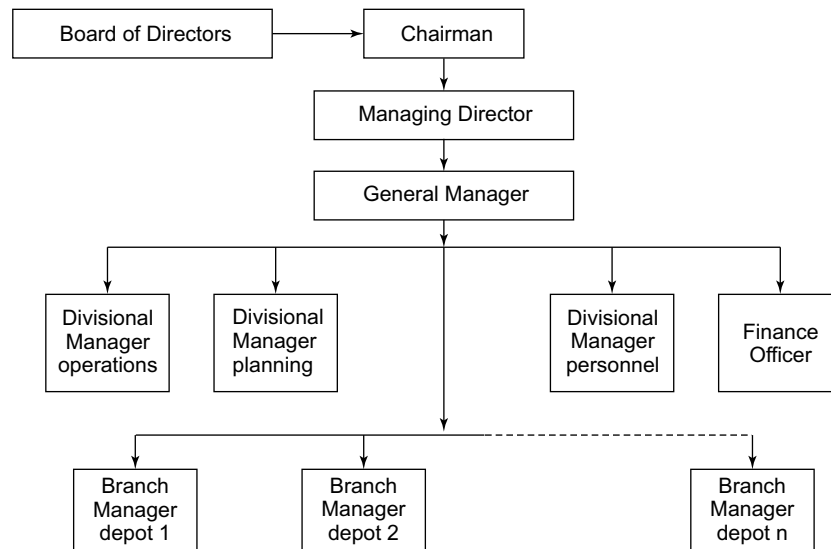
of standards and regulating compliance. The actual operation of the services should be entrusted to separate autonomous (public sector or private) entities operating under commercial conditions. In other words, the government's role should change from one of service provider to a regulatory body responsible for system administration and planning.

Transit management involves the acquisition, allocation, and control of resources (human, physical, financial, and informational) to achieve given standards and objectives of transit service<sup>2</sup>. In recent years, the forms and orientation of transit has acquired a public service dimension that has, in turn, introduced new complexities and demands for transit management. The transit manager has to balance the need for efficiency and productivity in bus transit with the growing social obligations to serve the totality of urban mobility needs of the various segments of the urban population. The transit management should ensure that the public is getting the quality of transit service that it needs, and that this service is being provided in a manner that efficiently utilizes the resources at its disposal.

Bus transit management can be entrusted to a government company or to a private company. In India, the nationalized bus public transport in cities is managed by State Transport Undertakings (STU), functioning as autonomous, commercially operated, government owned companies. Each STU consists of a Board of Directors composed of government-nominated Chairman and members, who are responsible for policy making and goal setting. The Board of Directors makes basic decisions regarding budget, grants, loans, recruitment of key personnel, general policies regarding the services by the system, fare structures, acquisition of new buses and facilities, and financial and legal matters. The policies are to be carried out by a Chief Executive Officer, often called the Managing Director.

The Managing Director is assisted in day-to-day operations by Managers of functional divisions such as: Transportation (Operations), Traffic Planning, Vehicle Maintenance, Personnel, Accounts, Stores Purchase, Legal and Public Relations. Depending on the magnitude of the transit operation,

these functional divisions may be separate entities or may be combined. Depots are headed by Branch Managers. The general organizational chart for a typical STU is shown in Fig. 6.6.



**Figure 6.6** Organizational Structure of STU

There are potential benefits in licensing private companies to operate bus services. The benefits primarily arise from the private sector's incentive to maximize profit by reducing costs and increasing income, and its access to private capital. Experience in London has shown that, consequent on deregulation in 1984, all routes are publicly planned and operated privately. Under this regime, the operated bus-km increased, while the cost per bus-km and the total network costs reduced substantially. Similar successful operation by private sector has also been reported in case of bus transit in Singapore and Hong Kong. Competitive franchising is thus shown to reduce costs of operation and fiscal burden without losing the benefits of network integrity and intermodal coordination in large metropolitan systems. Transit management should concentrate on clear-cut consumer oriented objectives, which are attainable, measurable and time-bound. While private operators would focus on profit, the publicly owned firms should have service as the primary goal, aiming to achieve a significant increase in the ridership. In Kolkata and Delhi, and a number of Tier-II level cities and towns, private bus operators have been permitted to provide services side by side with the STUs. In such cases, the routing, frequency of services and fares are regulated by the Government through their regional transport officers.

Bus transit management is the harmonious blend of traffic management, engineering (depot) management, and finance management, which supported by effective administration calls for mutual cooperation and accommodation to keep the transport undertaking in effective operation. The components of bus transit management are shown in Fig. 6.7.



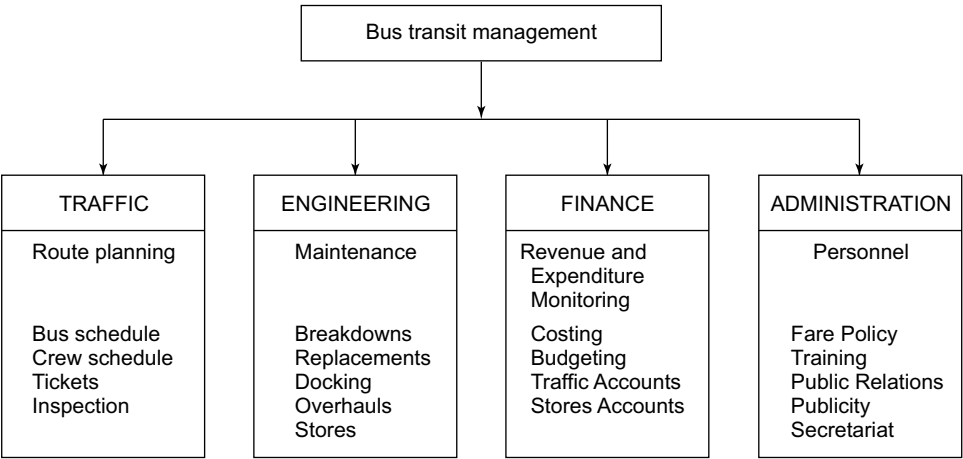


Figure 6.7 Components of Bus Transit Management

6.6 ESTIMATION OF THE REQUIRED FLEET STRENGTH

The number of buses required to cater to urban routes of a major city depends on many factors: (a) Population of the city; (b) Standard of living; (c) Travel habits of the residents; (d) Availability and utilization of other modes; (e) Condition of road infrastructure; and (f) Degree of congestion on the roads. No satisfactory equation is available to calculate the number of buses required. As a rough rule of thumb, the minimum requirement of buses may be taken as one per 2000 inhabitants. One possible method of estimation is indicated here, with illustrative calculations suitable for a metropolitan city.

The steps involved in the method are evident from the sample calculations shown below.

Data of the city and travel characteristics:

These data are obtained from surveys.

Population = 4.28 million

Per capita trip rate = 1.5

Share of bus trips in overall trips = 50%

Average trip length = 8.2 km

Distance travelled by bus per day = 230 km

Capacity of bus = 67 passengers

Average occupancy = 0.8

Expected fleet utilization = 85%

Calculation

Total trips per day = 4.28 × 1.5 = 6.42 million

Bus trips = 6.42 × 0.5 = 3.21 million

Average daily passenger-km =  $3.21 \times 8.2 = 26.32$  million

Passenger-km per bus =  $67 \times 230 \times 0.8 = 12328$

Number of buses required =  $26320000/12328 = 2135$

Providing for 85% fleet utilization,

Total number of buses required =  $2135/0.85 = 2512$

## 6.7 BUS ROUTE PLANNING

### 6.7.1 Need and Functions

Transport by bus is the predominant mode of public transport in many Indian cities, and this situation is likely to continue in the near future. In Chennai metropolitan area, over 80% of public transport trips are carried by buses because of inadequate rail transit facilities. The obligation of the bus operator is to carry the passengers from where they are to where they want to be without questioning the reason. Planning of bus routes plays a pivotal role in the efficient operation of a city bus system. The aim of route planning is to determine an acceptable alignment for an efficient, reliable, fast and profitable bus operation between two trip ends. An additional aim is to form a network of such routes for an urban area, which network will lead to an optimal use of the buses and other resources.

The need for route planning may arise under the following situations: (a) To maximize the utility of the existing fleet; (b) To enhance the efficiency of the existing route network; (c) For extension or modification of the existing routes due to additional development; and (d) For a new town under development<sup>3</sup>.

The functions of bus routes are: (a) Collection of passengers from dispersed residential areas, shopping areas, and work places; (b) Provision of suitable alignment for line haul between origin and destination; and (c) Dispersal of passengers to work places, shopping areas, and residential areas. For an urban bus service to be feasible, the town should have a minimum population of 30000.

Passenger travel characteristics influencing bus route planning are:

- (a) The passenger demand stabilizes over a period; the onward and return journeys are nearly equal.
- (b) Passengers handle themselves, unlike goods which require handling and delivery.
- (c) Passengers exercise choice of mode based on their perceived utility.
- (d) Passengers tend to form travel habits; and they do not change their travel patterns easily.

City bus route planning is a complex task, as the supply of bus facility has to match the dynamically varying traffic demand<sup>4</sup>. In recent years, the complexity of routing of buses has increased manifold due to unwieldy physical extension of cities and haphazard development of the various activity centers and residential areas in an environment of inadequate road development, rapid rise in the number of vehicles on the road, and the steep growth of population. It would be ideal to attempt the integrated planning of the entire network of bus routes for a city at one time. However, this is not always practical. The city undergoes changes with time, and the traffic demand also alters.

The individual bus routes of an existing network are often improved by adopting the optimal route courses for the current conditions. An STU is expected to service both profitable and unprofitable routes, and still operate the system without financial loss.

6.7.2 Types of Routes

City bus routes can be classified functionally and conceptually as: (a) Grid type; (b) Radial and ring type; (c) Linear routes; and (d) Linear type with spurs and loops<sup>6</sup>. These are shown diagrammatically in Fig. 6.8.

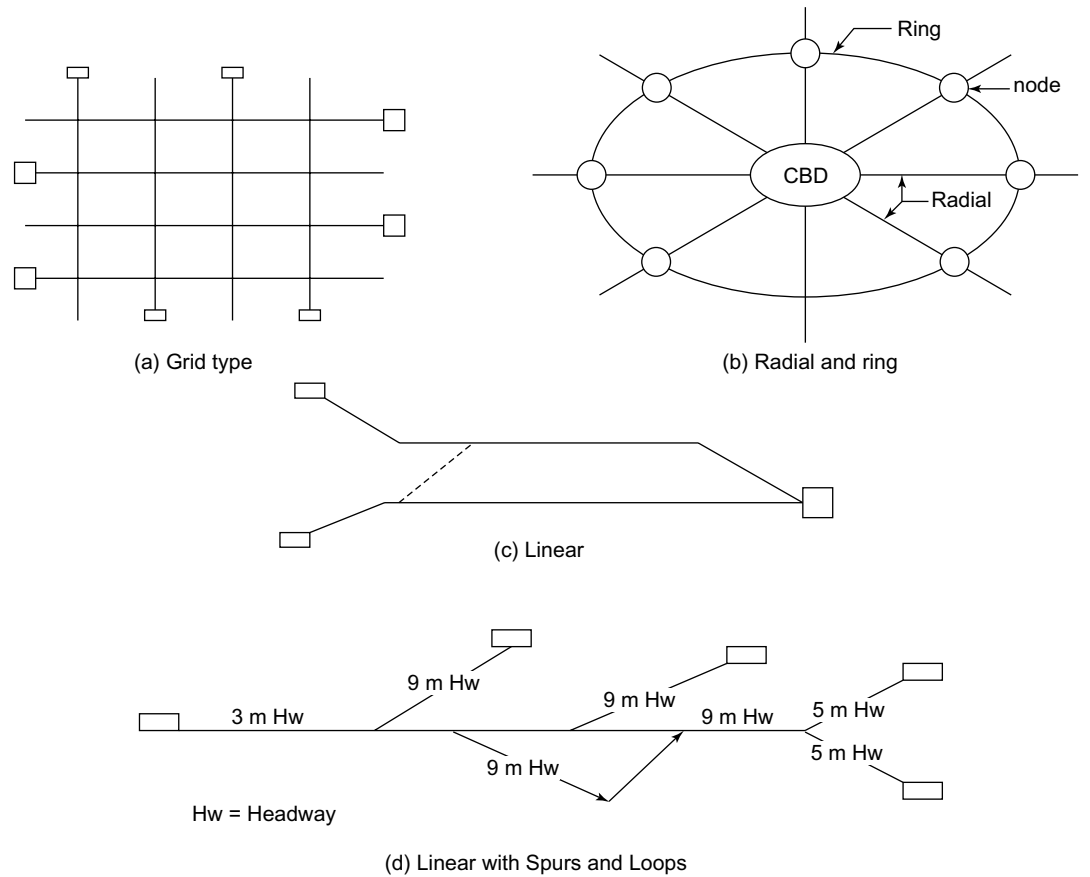


Figure 6.8 Different Types of Bus Routes

City bus routes can also be classified as: (a) traditional routes; (b) circular routes; (c) serpentine routes; and (d) direction-oriented routes. The traditional routes are the routes which have evolved over a period of time in response to traffic demand. The route courses attempt to cover as many activity centers as possible, resulting in heavy detour to the direct passengers and overlaps among

the routes. Circular routes originate and terminate at the same terminal, and are suitable for routes along ring roads. A serpentine route has its route course connecting many residential areas, and in the process involves considerable meandering. In the case of direction oriented routes, the passengers may move in the desired direction on one route and may have to transfer to another route to reach their destination, e.g., radial and circumferential route pattern.

6.7.3 Route Planning Process

The route planning process involves three basic studies: (a) Inventory of existing route network; (b) Changes in road network and future road building and land use form; and (c) Origin-destination pairs of the present and projected routes. In addition, the planner may conduct a questionnaire survey to assess the accessibility to bus services and road conditions, and perform a traffic census to study variations in demand.

The outcome of the studies should include conclusions on: (i) Demand for route, bus stops, and origin-destination of each route; (ii) Supply in terms of number of buses including spare buses and their capacities; (iii) Temporal variation of demand; (iv) Demand with reference to locations; (v) Expected overcrowding along certain stretches; (vi) Waiting time and unserved passengers at various bus stops; and (vii) Characteristics of passengers.

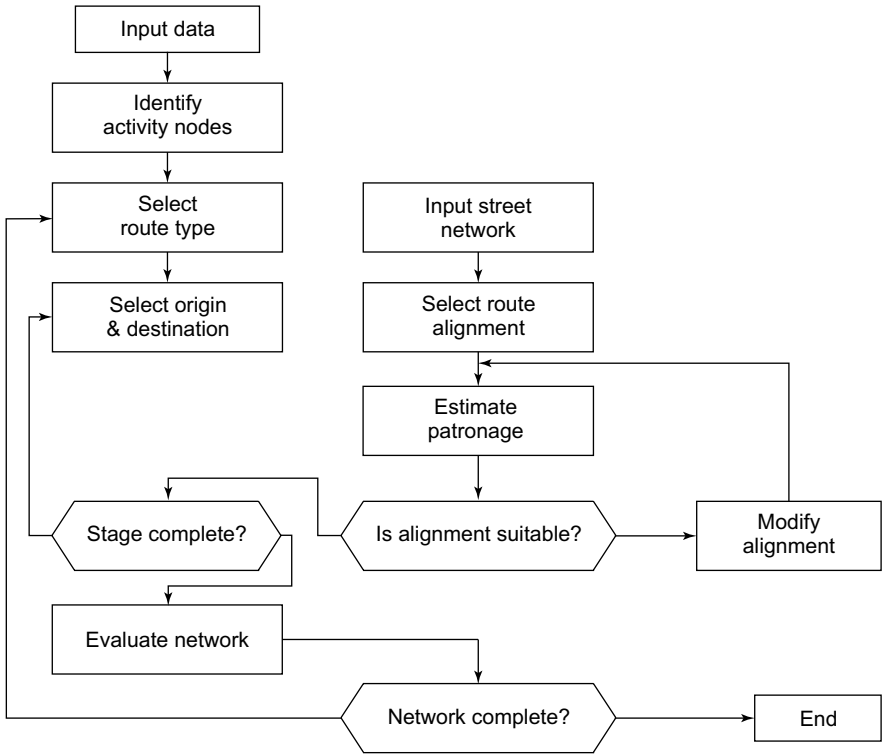


Figure 6.9 Procedure for Planning City Bus Routes

The procedure for planning city bus route is indicated in Fig. 6.9. While deciding on route alignment, the following general principles may be taken into account:

- (a) A direct bus route along the shortest distance may be desirable, but may not necessarily be the best. Deviations may be necessary, to accommodate the desired origins and destinations of passengers and to facilitate even loading throughout the route.
- (b) For the passengers, the distance from residence to the nearest bus stop should be less than 500 m or corresponding to 5-minute walk.
- (c) Each route should connect more than one land use.
- (d) Terminals should be sited near points of convergence of passengers. Railway stations should be chosen as terminals for important bus routes to aid proper road-rail coordination.
- (e) Interchange point from one bus to another should be planned in such a manner that the passengers alighting from one bus can board the other at the same bus stop.
- (f) The bus depots should be so located that the dead-km is minimum.
- (g) A direction oriented routing pattern is likely to be more efficient for operation than a destination oriented system.
- (h) Once a route is planned and operated, changes are difficult, as passengers get used to the route and may resist change.
- (i) Stops should also be provided close to major activity centers and suburban/metro railway stations.

#### 6.7.4 Route Length

The distribution of the trip length of bus passengers is city specific and hence will vary for each city. The distribution of trip length and fare revenue for city bus transit as observed for a metropolitan city in India is shown in Table 6.2. For this city, the average trip length per passenger was computed as 8.2 km. nearly 76% of the passengers and 64% of the fare revenue related to trips within 10 km. About 96% of the passengers accounting for 92% of daily fare revenue covered journeys less than 20 km. Only 0.5% of the passengers, 2.1% of passenger-km and 1.2% of the daily revenue pertained to trips beyond 30 km. For this city, the bus route length was less than 20 km for 55% of the routes and 35% of the routes had route length between 20 and 30 km.

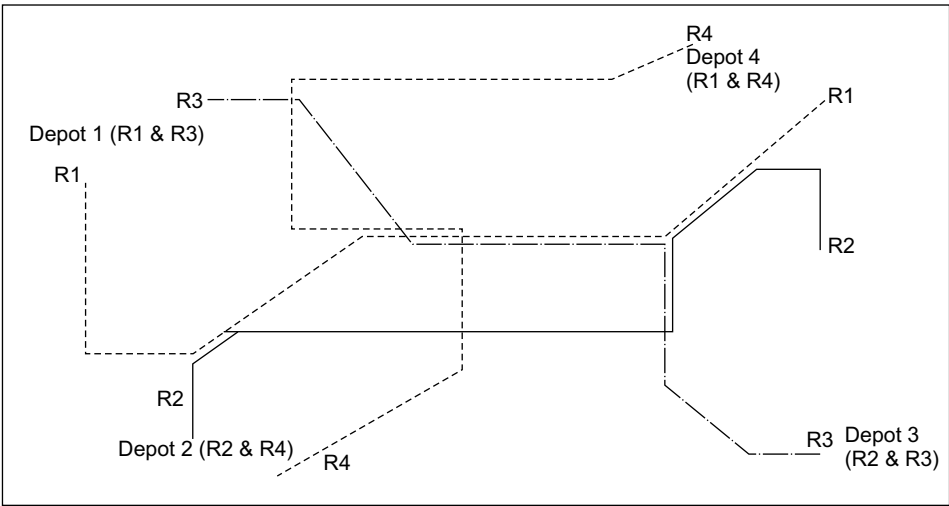
When the route length is long, say over 20 km, difficulties arise with regard to turn-around time, bus and crew scheduling and dislocations in the event of a breakdown. Too short a route length is also undesirable, as that would involve inconvenience to passengers due to transfers and result in reduced bus productivity due to loss of time at terminals. Hence from the point of view of efficient operation, the individual bus route (including a circular route) should have its route length below 30 km, and possibly not less than 15 km for the city considered. For any given city, similar analysis may be performed to determine the desirable limit for the route length. The termination of a route may be arranged at a terminal suitable for the route length, making sure that a smooth transfer is available.

**Table 6.2** Distribution of Bus Transit Trips in an Indian Metropolis

Trip Length in km	Cumulative Percentage of		
	Tickets Sold	Revenue	Passenger-km
2	12.3	7.6	3.0
5	44.0	30.1	20.5
10	76.6	60.6	52.5
15	89.9	80.0	74.0
20	95.6	90.4	86.1
25	98.4	96.2	93.9
30	99.4	98.4	97.4
40	99.9	99.8	99.7
44	100	100	100

**6.7.5 Overlapping of Route Pairs**

One of the characteristics of a city bus route network is that several bus routes have overlapping sections, with a few common bus stops. It may not be possible to eliminate the overlaps especially near the major terminals. However, the overall percentage of overlapping in the network should be minimized, in order to achieve efficient coverage by proper route planning and to reduce traffic congestion on the road. When two routes have a long overlap, say in excess of 30% of the route length, the alignment of the routes should be examined carefully to explore the possibility of reducing the extent of overlap by realignment or curtailment of one of the routes. Figure 6.10 shows a typical operation of such overlapping routes in part of a major city.



**Figure 6.10** Example of Overlapping Routes

## 6.8 EXPANSION/CURTAILMENT OF SERVICES

During the operation of a bus service, there will be public demand for expansion of services. The management should limit expansion to the capacity of the bus company such that the quality of maintenance does not suffer. Before expansion, one should consider the requirements of staff, training, equipment and terminals. Consolidation of operation should accompany expansion, such that the number of buses to be maintained by a depot is limited to about 100.

Curtailement of some services may sometimes become necessary due to various reasons such as fuel crisis, delays in procurement of new buses, or rationalization of routes. When a new route is planned to be introduced, or when alterations including curtailment of routes is contemplated, wide publicity should be given in advance. After the implementation of the change, the progress of the service should be closely monitored. When new buses are procured, priority in allotment should be regulated such as, restoration of suspended routes and services; augmentation of services on remunerative routes; and operation of new routes.

## 6.9 PERFORMANCE INDICATORS

The overall performance of a bus transit is assessed by various indicators, which are classified as: (a) Operational performance indicators; (b) Financial performance indicators; and (c) Quality of service indicators.

### 6.9.1 Operational Performance Indicators

The operating performance of a bus company is evaluated using the appropriate key performance indicators such as passenger volume, fleet utilization, and average distance traveled per bus, breakdowns in service, fuel consumption, staff-bus ratio, accident rate and dead-km. The numerical values of the above indicators for the company under review are compared against a range of values usually expected from a well-operated bus company. Deficiencies, if any, should be investigated with a view to improve the performance.

Passenger volume gives the total number of passengers served per bus per day. This would depend also on the capacity of the bus operated. A better measure of the capacity utilization is the occupancy ratio, which is the ratio of the passenger-km actually realized to the seat-km offered during a day. An average occupancy ratio of about 0.8 is desirable.

Fleet utilization is expressed as percentage of buses operated during the peak period with reference to the total fleet. Well-run companies register fleet utilization of about 90%.

The average distance traveled per bus per day is the average of the total revenue journey distances traveled by all the buses on one day divided by the total number of buses in service on that day. The total revenue journey distance (passenger-km) may suffer reduction due to various reasons such as bus breakdown, crew absenteeism, frequent late running of buses, frequent traffic diversions due to political disturbances and road blocks and accidents. Ineffective management of the street system is often the cause of unacceptable delays for bus operations. Freight movements, uncontrolled access to roads, frequent turning movements, unrestricted parking, poorly timed traffic signals, deficient

geometric features of roads and conflicts between fast and slow moving traffic, pedestrians and occasional stray cattle all contribute to congestion, low bus speeds, and consequent poor utilization of buses. The average revenue distance performed per bus per day should preferably be in the range of 230 to 260 km.

Breakdowns should be minimized by proper preventive maintenance of the vehicles and by driver training. The breakdowns should be less than 5% of the fleet strength. Adequate spare buses should be retained to cater to breakdowns. An efficient unit should be able to achieve a rate of less than 1 per 100,000 bus-km.

Fuel consumption by a bus depends on the age and condition of the bus, and also on the nature of roads and terrain. For normal city service, the fuel consumption will be of the order of 24 to 26 liters of diesel per 100 km.

The total staff per operating bus is of the order of 5 to 7. Out of this number, the administrative staff may be 0.3 to 0.4, and the maintenance staff may be 1.0 to 1.5.

The operation should ideally be free of accidents. But practically, the accident rate for a well-maintained urban bus transit company may be in the range of less than 1 per 100000 bus-km. For example, BMTC in Bangalore could achieve a figure of 0.16 in 2005–06 and 0.15 in 2007–08.

Dead-km refers to the distance traveled by a bus without earning revenue. Usually this distance pertains to the journeys between the bus depot and the starting bus terminal. By properly arranging depot-terminal bus allocation, the dead-km can be minimised<sup>5</sup>. Dead-km should be limited to be less than 2.0% of the total distance traveled.

### 6.9.2 Financial Performance Indicators

The overall financial performance of the bus transit company is measured by Operating Ratio, which is the ratio of the total revenue to the total costs (cost of capital, operating costs, wages, interest and depreciation). The operating ratio should be over 1.0 and preferably be about 1.05 to 1.08. The motto of the transit company could be: “service without financial loss”. Fare box ratio, on the other hand, refers to the ratio of revenue through sale of tickets to the total cost of operation of the buses. This should always be over 1.0.

The financial performance is also assessed by measures such as Earning per km of bus operation (EPKM), Cost per km of bus operation (CPKM) and Cost per passenger-km (CPPKM). For a satisfactory performance, EPKM should be greater than CPKM. Also the average earning per passenger-km should be higher than CPPKM.

Since conventional bus transit uses the existing streets, there are no direct costs due to guideway as in rail transit. The major components of the total cost of operation of an urban bus transit are Personnel costs and Fuel costs. The share of these costs is likely to be of the order of 55% for Personnel, 20% for Fuel and 25% for ‘Other’ costs. Since bus transit is a labor intensive enterprise, special care needs to be exercised over efficient management of personnel.

Operating costs per bus-km vary inversely with operating speed, i.e., the higher the operating speed, the lower will be the operating cost. This situation results because for the same wages of crew, the bus performs a larger bus-km with increased speed. Thus, measures aimed at increasing



the operating speed such as better bus stop spacing and bus priority scheme, not only attract more passengers but also reduce operating costs.

### 6.9.3 Quality of Service Indicators

These indicators permit the evaluation of the service provided by the bus company to the public. The key quality indicators are: passenger waiting time, walking distance to the bus stops, passenger journey time, the need to interchange between routes and services (transfer), reliability as evidenced by punctuality of service, and passenger travel expenditure and affordability.

The passenger waiting time at the bus stops depends on the frequency of service and varies from place to place. An acceptable waiting time may have a range of 5 to 15 minutes. Punctuality of arrival of buses at any stop is an important indicator of quality of service. A bus is said to be punctual if it arrives within  $\pm 5$  minutes of the scheduled time of arrival. Punctuality should be within 90% for frequencies of less than one bus per 30 minutes and above 90% for frequencies of more than one bus per 30 minutes.

Overcrowding is to be expected for short periods in any bus transit system. If more than two buses or 15 minutes pass before boarding is possible, the system is overcrowded at that location at that time. If this situation extends over many adjacent stops along a route, serious overcrowding arises.

The walking distance to the bus stops depends on the catchment area. The desirable maximum walking distance should be between 300 m and 500 m in densely populated urban areas and between 400 m and 900 m in low density urban areas. The journey time from home to work one way should be less than one hour for almost 90% of the commuters.

Travel time can be considered excessive when door-to-door trip of 6 km consistently takes over 40 minutes, a 10 km trip takes 60 minutes, and a 16 km trip needs 90 minutes. The travel time is assumed to include walking and waiting time, as well as time spent on board the vehicle. The journey speeds of buses range from about 12 kph in dense areas with mixed traffic to about 18 kph in areas with bus-only lanes.

Passengers would prefer direct bus service from origin to destination of their trips. This is not generally possible. It is desirable to limit the number of transfers for commuter trips to one for about 90% of the passengers. The fare structure should preferably be such that the expenditure on travel is limited to about 10% of the household income.

## 6.10 TIME TABLE, BUS SCHEDULE AND CREW SCHEDULE

The efficiency of a city bus operation depends to a large extent on a properly designed time table which satisfies the traffic demand and at the same time avoids unnecessary journeys. The preparation of bus time tables requires the determination of the bus frequencies based on the demand. Even if there is inadequate demand, a minimum frequency should be maintained on a route in order to provide minimum accessibility to any given area. A Time Table is a schedule of timings indicated in a chronological order at which buses start from, or pass through, or arrive at the terminus or bus stop on a route during the day. The time table is for the use of the passengers.

A bus schedule gives the services to be performed by the concerned bus so as to conform to the timings in the time table. There will be one schedule for each bus. The aim of bus scheduling is to maximize the utilization of vehicles (thus maximizing revenue generation) and to minimize dead-km and avoid wasteful expenditure (hence minimizing the operating cost). The bus schedule should allow a minimum layover time at the terminal to enable the desired schedule reliability to be adhered to.

The crew for a bus normally consists of one driver and one conductor. In case of a double-deck bus, there may be two conductors. The crew schedule need not be identical with the bus schedule. The crew have to be allowed rest periods as per labor (hours of work) regulations. The crew should also be given weekly rest besides other leave. Hence spare crew (normally one for every six regular crew) should be maintained. The crew schedule should be prepared carefully to satisfy the various requirements including labor rules.

Time table compilation is governed by the following factors: (a) Required frequency of service during the different periods of the day; (b) The timings of the first bus and the last bus; (c) Running time from one terminus to the other terminus of the route; (d) Dwell time at the end of each service; and (e) The timings and locations for change of shifts for the crew. Dwell time is the period of halt at the end of a service. The dwell time facilitates correction of any delays in the previous service and boarding/alighting of passengers. It also gives a short rest period to the driver, who may quickly check for obvious defects in the bus.

Preparation of Time Table, Bus Schedule and Crew Schedule is a skilled operation and should be undertaken by experienced staff. A time table should be simple and realistic. It should allow for correction of minor delays due to traffic congestion or delay at a level crossing. To the extent possible, bunching of buses on overlapped stretches should be minimized by effective time tabling. While a time table with uniform headway throughout the day may be relatively simple, a practical situation will require varied headways during the day. Bus schedule and crew schedule should be drawn based on the time table and requirements to conform to duty period, rest period and other labor laws pertaining to the crew.

The number of buses required for a route depends on the peak hour demand, the capacity of bus at normal maximum load (crowd load) conditions and time taken by the bus to make a round trip. The time taken depends on the average speed at which the bus covers the distance and minimum time required at terminals between trips. The frequency of bus can be reduced in the off peak hours in the morning, mid-day and evening. Minimum desirable headway for any city bus service is 30 minutes even in off-peak hours.

### 6.11 EXAMPLE OF CONSTRUCTION OF A SIMPLE TIME-TABLE<sup>7</sup>

It is proposed to draw up a Time Table for a bus route of 12 km length.

Average speed of bus in traffic	18 kph
Peak hour trips in one direction	4000
Peak period	7 to 10 AM and 5 to 8 PM (17 to 20 hrs)

Capacity of bus in crowd load condition 90

Number of buses required in peak hour  $4000/90 = 4.44$  say 5

Minimum 5 trips are required per peak hour

Minimum peak hour headway =  $60/5 = 12$  minutes

Being an important route 20 minute headway is proposed for non-peak hours.

Journey time for a single trip =  $12 \times 60/18 = 40$  minutes

Shed/terminal time = 5% of 40 minutes = 2 minutes

Turn round time =  $2 \times 40 + 2 + 2 = 84$  minutes

Number of buses required during peak hours =  $84/12 = 7$  numbers

Number of buses required during off-peak hours =  $84/20 = 4.2$  Say minimum 5 buses.

With 5 buses available and turn round time of 84 minutes, extra shed/terminal time will be available.

=  $(5 \times 60 - 3 \times 84)/3 = 16$  minutes which can be suitably distributed at either end.

(Total 20 minutes can be distributed as 15 minutes at one end and 5 minutes at the other end)

Also 2 out of 7 buses will be garaged or used on any special charter duty during off-peak hours.

The work of preparation of time schedule is done in three steps: (i) morning peak; (ii) pre-peak build-up; and (iii) for mid-day off peak. Using these as skeleton, full day time table can be prepared.

Morning peak frequency schedule with terminal times of 2 minutes at each end is given below:

Vehicle number	A-depart	B-arrive	B-depart	A-arrive
1	7-00	7-40	7-42	8-22
2	7-12	7-52	7-54	8-34
3	7-24	8-04	8-06	8-46
4	7-36	8-16	8-18	8-58
5	7-48	8-28	8-30	9-10
6	8-00	8-40	8-42	9-22
7	8-12	8-52	8-54	9-34
1	8-24	9-04	9-06	9-46
2	8-36	9-16	9-18	9-58

Pre-peak period schedule includes 'build-up' period for service from the other end and supply from garage. Minimum 20' headway is proposed till 7 AM. Changes of frequencies are to be effected at the time of departure from A without reducing minimum stand time at the other end. Such adjustment may require some head ways to be less than 20 minutes. Gradually headway should be reduced to 12 minutes. In one or two services from other end this may be exceeded marginally for initial services. Table below shows the build-up.

Vehicle number	A-depart	B-arrive	B-depart	A-arrive	A-depart
1	From garage				7-00*
2	5-30	6-10	6-20	7-00	7-12
3	From garage				
4	6-00	6-40	6-50	7-30	7-36
5	From garage				7-48
6	6-20	7-00	7-10	7-50	8-00
7	6-40	7-20	7-25	8-05	8-12
1*	7-00	7-40	7-42	8-22	8-24

\* Peak regular service

Vehicles 4, 6 and 7 are used for build up

Scheduling for mid-day off peak period involves reducing service frequency from 5 to 3 buses per hour and number of buses to be used will be 5 instead of 7. It means two vehicles are to be returned to garage/depot or for use elsewhere. The tailing off can commence a little earlier, so as to withdraw the said vehicle when it returns to A after service. Scheduling done at transition stage is tabulated below:

Vehicle number	A –arrival after peak service	A-depart	B-arrive	B-depart	A-arrive	Remarks
4	8-58	9-00	9-40	9-42	10-22	To depot
5	9-10	9-12	9-52	9-54	10-34	
6	9-22	9-24	10-04	10-06	10-46	
7	9-34	9-36	10-16	10-18	10-58	To depot
1	9-46	9-48	10-28	10-30	11-10	
2	9-58	10-00	10-40	10-42	11-22	
3	10-10	10-20	11-00	11-10	11-50	
5	10-34	10-40	11-20	11-30	12-10	
6	10-46	11-00	11-40	11-50	12-30	
1	11-10	11-20	12-00	12-10	12-50	
2	11-22	11-40	12-20	12-30	13-10	
3	11-50	12-00	12-40	12-50	13-30	
5	12-10	12-20	13-00	13-10	13-50	
6	12- 30	12-40	13-20	13-30	14-10	

The cycle will continue till about 17 hours when vehicles numbers 4 and 7 will be re-inducted into service and service frequency increased to 5 per hour. It will be again tailed off after 20 hrs, and frequency decreased to 3 per hour, reversing the process used in the morning.

## **6.12 BUS INVOLVEMENT IN ACCIDENTS**

Accidents may cause property damage, injuries or fatalities. An accident involving a bus causes a heavy burden to the operator. It results in interruption to service and a poor image to the bus company, and may often involve heavy monetary compensation to be paid to the victims of the accident. Accidents occur due to several causes such as negligent driving, poor maintenance of the vehicles, fault of other road users or even defective road maintenance. The bus transit company can minimize the accidents by ensuring that the drivers are trained in defensive driving and the vehicles are properly maintained. A small number of accidents may occur as normal. This may be limited to 1.0 per 1000,000 vehicle-km.

## **6.13 BREAKDOWNS**

A breakdown is an occurrence which causes detention of a vehicle in service for more than 10 minutes due to any reason. Breakdown is annoying to the passengers and it brings a bad reputation to the transit company. Breakdowns occur due to overage of buses, poor quality of parts and engine components, inadequate level of maintenance and poor driving techniques. Breakdowns should be minimized by attention to proper preventive maintenance of vehicles.

## **6.14 VANDALISM**

Vandalism is a major scourge in developing countries, and is also seen in some developed countries. Various forms of vandalism are encountered, ranging from graffiti on bus bodies to burning, stoning and breaking of buses during political and other disturbances. Conditions leading to vandalism are beyond the control of the bus transit operators, who can only hope to minimize damages with the timely intervention of police authorities.

## **6.15 INSPECTION**

Good inspection is an essential component of bus transit operation. Inspectors are the eyes of the administration. They should be honest, alert and be capable of dealing with situations with utmost tact. Besides routine inspection, special inspection during festival periods and terminus inspection to ensure proper boarding/alighting of passengers should be taken up. Special squads may take up surprise checks on routes with passenger complaints.

## **6.16 PERSONNEL MANAGEMENT**

Bus transit is a labor intensive operation. The personnel cost is generally about 50% of the operating cost. Hence substantial economy can be achieved by exercising control over personnel cost. The efficiency of a transport undertaking depends on the efficiency of the personnel. For example, an incompetent driver may damage a bus; an inexperienced mechanic may spoil equipment; and an inefficient traffic supervisor may implement deficient bus schedules. Hence staff requirement should be planned correctly and recruitment should be done carefully to ensure the right type of staff in adequate numbers. Excess staff may also lead to inefficiency. Besides technical qualifications

required for each category, staff should also possess good attitudes, smartness and politeness towards the clients. It has been observed that in a city bus company in a medium size US city, they had achieved a staff-bus ratio of 3.5 by dispensing with the need for a conductor and by outsourcing routine jobs like cleaning buses and depots. Major repairs are done by unit replacement method. The buses are provided with automatic ticket vending machine at entry to bus, which is located near the driver thus having no conductor.

Effective training procedures should be introduced and followed in bus transit administration for all categories of staff. The training may be initial training and periodical in-service training. Effective training would lead to enhancement of efficiency and would inculcate in staff a better sense of service and courteous behavior towards the passengers.

The bus driver has an important role in ensuring satisfactory performance of his vehicle and that of the company and road safety. By diligent driving, a good driver can minimize the costs on fuel consumption and also repair costs due to wear and tear of the vehicle. Punctuality practiced by him would improve service to passengers and result in better utilization of the vehicle. Training of drivers thus becomes an essential requirement. Special tracks and simulation equipment are used as part of driver training by many institutions run by some state governments and bus manufacturers.

Crew absenteeism is a major problem in any transport company. This can be minimized by devoting special attention to management-staff relations.

Incentive schemes may be tried to enthuse the staff towards higher productivity. However, these schemes should be introduced carefully, as once given, incentives cannot easily be withdrawn. They should be linked to productivity.

## 6.17 FLEET MANAGEMENT

Fleet composition needs serious consideration. With a large fleet, the transit company can have a variety of bus sizes to match the size with the traffic demand on any route. For the same size of bus, it is desirable to have less variety of makes so as to keep the inventory of spare parts to the minimum. At the same time, restricting to a single make is risky, as any industrial disturbance in that manufacturing company may affect availability of replacement parts. A judicious mix is desirable.

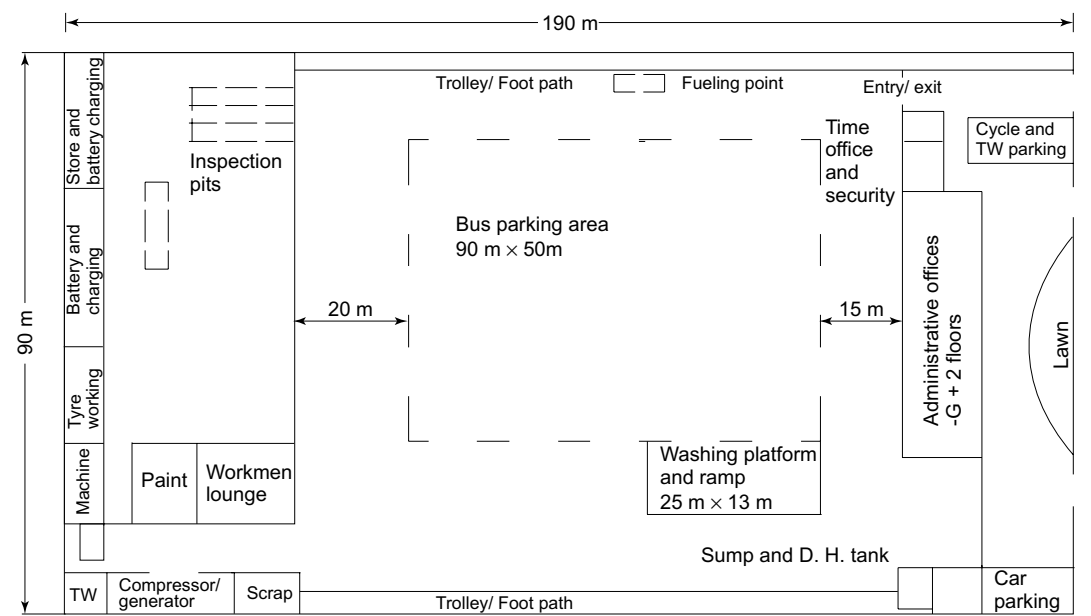
The useful life of a bus under Indian conditions varies from 6 to 10 years. For an old bus, the vehicle operating cost (VOC) is high, but the depreciation cost is low. For a new vehicle, on the other hand, the reverse is true. It is not easy to conclude that a new vehicle will necessarily give a higher return on investment. However, it is desirable to limit the age of buses in urban transport to about 6 years, with a view to maintain low rates of breakdown.

An efficiently run bus operation should be able to schedule 90% of its fleet strength. The scheduling can be demand based or policy based. The demand based scheduling aims at varying the number of buses on a route at different times of the day to suit the demand. Policy based scheduling, on the other hand, adopts fixed frequency based on market conditions and social objectives. The major factors influencing the scheduling include: headway, vehicle occupancy and area coverage.

6.18 BUS DEPOTS

A bus depot is a place where the buses get the required housing, maintenance and care. The basic requirements of a depot are: parking space for buses; fuel and lubrication station; washing bays; routine maintenance facilities; and major overhaul facilities. It is desirable to locate a number of depots at different places in the city, each depot being close to a major terminal so that the dead-km may be minimised<sup>5</sup>. Quite often, the location is governed by the availability of land.

The capacity of a depot for city operation should not normally exceed 100 buses, so that the depot manager could know the drivers personally. This system has been practiced successfully in bus transport corporations in Tamil Nadu. The depot should have adequate area to house buses at the rate of 40 m<sup>2</sup> per bus plus covered area for offices, repairs and stores. Washing area and fuel station in the depot should preferably be located near the entrance. The depot should have adequate lighting, as the vehicles are cleaned, serviced and repaired at night. The lighting should be by flood lights in the parking area and by fluorescent lamps in the pits with reflecting walls. The area for stores should be at 0.4 m<sup>2</sup> per bus. In addition, adequate space should be available for offices, staff canteen and security. A typical layout for a bus depot suitable for 100 buses including an attached workshop is indicated in Fig. 6.11.



Source: Adapted from an IRT Study

Figure 6.11 Typical Layout for a 100-bus Depot

6.19 METHODS OF FINANCING

The sources of funds for bus transit operation include the following: (a) Share capital; (b) Internal funds; (c) Revenue from fares and other concessions; (d) Loans from government; (e) Loans from

financial institutions, e.g., Transport Development Finance Corporation in Tamil Nadu; (f) Bonds and debentures; (g) Subsidies from government; and (h) Public deposits.

While loans, bonds and public deposits may be availed for capital expenditure like procurement of buses, the operating costs should preferably be met out of revenues from fares, i.e., fare box. Government subsidies may be received as compensation for discharging social obligations imposed by government, e.g., free passes to students.

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# Public Transportation – Rail Transport

# 7

## 7.1 GENERAL

Rail transport is an attractive choice for any heavily traveled corridor, as it is the mode of urban travel which could best move people consistent with the local requirements. When the requirements of passenger travel in a major city are served by rail transport on a regular basis, the service is referred to as rail transit. With a rail line introduced in a travel corridor, a rider trades the flexibility of a private vehicle for the speed and efficiency of rail transit. Trains run frequently and reliably and are not adversely affected by traffic congestion or bad weather. By lengthening or shortening trains and/or changing frequency of service, the carrying capacity can be easily manipulated to meet passenger flows without additional construction and without any additional impact on the environment. For better effectiveness, the rail transit in a major city should be planned as the major component of an integrated network covering the entire city.

Rail transit network for any city is developed to achieve one or more of the following objectives: (a) To secure for public transport a larger share of the total transportation market; (b) To provide a faster, more reliable higher capacity transport system than could be provided by bus system; (c) To reduce the need for private transport and construction of new highway facilities; (d) To reduce the potential negative impacts of air and noise pollution due to increased road based transport; (e) To use the transport network to guide the future development of the urban area; (f) To improve the image of the city with a view to attract investment and industry to the area, as in Lille, France for example; and (g) To support national fuel conservation and environmental goals.

While planning transit networks, the effect of stop spacing, time for access to stations and connectivity should be considered. With closer stops, the operating speed will be reduced, but will be convenient for the rider, as the access time will be reduced. Such close spacing may be desirable for densely populated areas. If the stop spacing is increased, the operating speed can be increased, but the increased access time will make the overall travel by transit less attractive to the rider. There should also be facilities to transfer from one transit line to another at some selected stations to facilitate easy mobility from one location to another in the urban area.

## 7.2 TYPES OF RAIL TRANSIT

Rail based urban public transportation systems can be classified into four types:

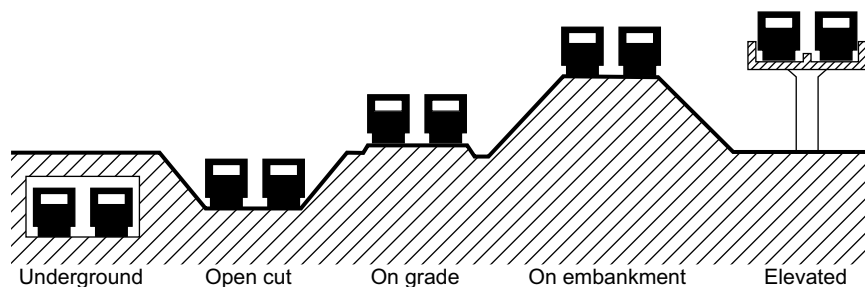
- (a) Suburban commuter rail (SCR)
- (b) Rapid Rail transit (RRT) or Metro Rail
- (c) Light rail transit (LRT)
- (d) Monorail systems.

Suburban commuter rail refers to railway facility operating on the normal intercity tracks with the special purpose of providing mobility to commuters to travel to the city centre from suburban areas. It is sometimes called Regional Rail System (RGR) or commuter rail service. The frequency of service is limited depending on the number of intercity trains using the same line. The speeds of trains are comparable with those of the RRT though their acceleration/deceleration capabilities are slightly lower. The service may be operated with diesel locomotives or with electric power, and in multiple units. The tracks are mostly at grade.

Rapid rail transit refers to electric trains operating on completely controlled grade separated exclusive right-of-way (ROW). This system is also referred as metro rail, subway or underground. Trains are made up of Electric Multiple Units.

Light rail transit refers to an urban electric railway using articulated vehicles and having private but not necessarily exclusive right-of-way. It can be at grade on exclusive or shared ROW and may be elevated or underground. The term LRT embraces a variety of rail-based vehicle systems ranging from tramways to those approaching rapid transit vehicles.

Possible track positions for rail transport are shown schematically in Fig. 7.1. The on-grade position is the commonest and often the most economical. On rural sections, the track can be taken in open cut or on embankment depending on the topography. For urban transit passing through built-up areas, it may be necessary to have elevated tracks or to carry the track underground.



**Figure 7.1** Possible Track Positions

Monorail systems use a relatively narrow “monobeam” for support or suspension. Different systems are in use or are under development. The Alweg system uses a car or a number of cars straddling over a concrete beam. Examples of this type are the revenue service between Tokyo

and Haneda, and the local application in Disneyland, Orlando, Florida, USA. The type with a suspended vehicle has been in use in Wuppertal, Germany since 1901, and currently the system—known as Schwebebahn or H-bahn—carries around 50,000 passengers per day on a 13.3 km line. Innovative versions with small capacities on a personal scale (typically to carry 3 persons in one cabin) are under development, and these systems are known as Personal Rapid Transit (PRT) systems. Examples of PRT systems are Cabintaxi (German), SIPEM (Dortmund, Germany) and Skycar (Korean, under development).

The physical and operating characteristics of RRT and LRT are summarized in Table 7.1. These are discussed in greater detail in the following sections.

### 7.3 SUBURBAN COMMUTER RAIL

Suburban commuter rail (SCR) lines were built as radiating from major cities, forming part of inter-city lines, to help people settle in spacious suburban locations and to commute to the cities for employment and for schooling. The first such suburban line was built in London in 1838. SCR lines have helped the development of satellite towns and urban nodes, relieving overcrowding in city centers. With the availability of faster trains with improved coaches and with electric traction over better track beds, it is now common for people to commute to work even for long distances: e.g., Pune to Mumbai 198 km; Aligarh to Delhi 126 km; Kharagpur to Calcutta 116 km; and Chengalpattu to Chennai 61 km. The suburban railways generally use electricity from overhead lines at 25 kV sharing tracks with intercity routes as in Mumbai and Chennai.

Good SCR systems (also called RGR or commuter rail in USA) radiating from the CBD area are found in many cities such as London, New York, Chicago, Sydney and Zurich. The Regional Express Rail (RER) system operating in Paris may also be considered under this category. The present trend in some cities (e.g., Paris) is to develop SCR and RRT systems integrated in alignment, station spacing and speed similar to commuter rail within the city areas and more distant spacing for stations for the portion of the system outside the urban area. A typical SCR that shares its tracks with intercity passenger and freight traffic can have a capacity of about 20,000 to 40,000 passengers per hour in one direction. Typical examples are the suburban rail systems operating in Mumbai, Kolkata and Chennai. An upgraded suburban railway in Porto Megre in Brazil, which has station spacing of 2 km and exclusive use of its tracks, has a capacity of 48,000 passengers per hour in one direction<sup>2</sup>.

### 7.4 RAPID RAIL TRANSIT

Variously known as metro, subway or underground, Rapid Rail Transit (RRT) is an optional mode for high capacity network service to serve an urban area. The route length may extend 10 to 25 km depending on the spread of the city. It has an exclusive right-of-way, and is free from interference by any other traffic. It has a simple duo-rail for guidance, electric traction and fail-safe signaling for movement control. It can be operated in trains up to 10 coaches (4-axle cars) by one person (or even by remote control without manning the train), thus resulting in a capacity and operational labor productivity much higher than in any other mode. However, this requires separate stations,

efficient signaling systems, fast fare collection facilities, high platforms, boarding and alighting facilities, and automatic closing of doors to prevent passengers falling out especially when operating through tunnels. Train headway can be as low as 90 seconds with automatic train operation and control.

**Table 7.1** Physical and Operating Characteristics of Urban RRT and LRT Systems

	Rapid Rail Transit	Light Rail Transit
<b>Fixed Facilities</b>		
Right of way category	Exclusive	Exclusive, semi-exclusive or shared
Control	Signal	Visual/signal
Fare collection	At station	On board/at station
Power supply	Overhead/third rail	Overhead/third rail
Stations: Platform height	High level	Low or high level
Access control	Fully controlled	Control optional
Station spacing, km	0.5 to 3.0	0.3 to 0.8
Ruling Gradient, %	3.0 to 4.0	4.0 to 7.0
<b>Vehicle/Train Characteristics</b>		
Minimum operational unit	1–2	1
Typical number of vehicles	2–10	2–4
Vehicle length, m	15–23	14–23( <i>mostly articulated</i> )
Vehicle capacity (seats/vehicle)	32–86	22–93
Vehicle capacity (total/vehicle)	100–300	74–200 ( <i>Double articulated 300</i> )
(for 0.25 sq. m per standee)		
<b>Operating Characteristics</b>		
Operating speed, kmph	25–80	15–45
Typical peak period frequency, per hour	Up to 30	Up to 40
Capacity (passengers per hour)	Up to 50000	Up to 20000 ( <i>30000 exceptional</i> )
Reliability	High	Moderate to high
<b>System Aspects</b>		
Network and Area coverage	Predominantly radial,	Good CBD coverage,
	some CBD coverage	branching capability
Average trip length, km	15–25	10–25
Interface with other modes	Pedestrian, car, bus and other transit modes	Pedestrian, car, bus and other transit modes

**Source:** Adapted from Reference 1

The main advantage of RRT is its capability for high speeds, about 110 kmph, the operating speed being in the range of 25 to 60 kmph. The average operating speed depends on the station

spacing and the station dwell time. As the average station spacing increases and the average station dwell time decreases, higher average operating speeds can be attained. With modern signaling arrangements, the peak period frequency can be in the range of 20 to 30 trains per hour. The typical RRT vehicle is 16 to 23 m long, 2.7 to 3.2 m wide with vehicle capacity varying from 150 to 250. The train capacity with crush load can go up to 60,000 (even up to 80,000 in special cases) passengers per hour as in Sao Paulo, Brazil, and Hong Kong. Train capacity is a function of several variables such as average speed, train size, train occupancy, and headways. RRT system has to be placed in tunnels or on elevated structures in central urban areas, while it can operate at surface level in suburban and adjacent rural stretches. In the latter case, suitable grade separations for the crossing traffic should be provided and tracks should be fenced to prevent trespassing. For example, the London RRT is entirely underground in central London area, the remaining network being on surface. Similarly, Paris Metro has open and elevated sections apart from tunnels. The RRT network in Manhattan is mostly in tunnel. Substantial lengths of metro in New York and Chicago are elevated. So also is the case with modern systems in Singapore, BART and Bangkok. Underground systems have the advantage that they cause low levels of noise and air pollution, but are the most expensive for construction and maintenance.

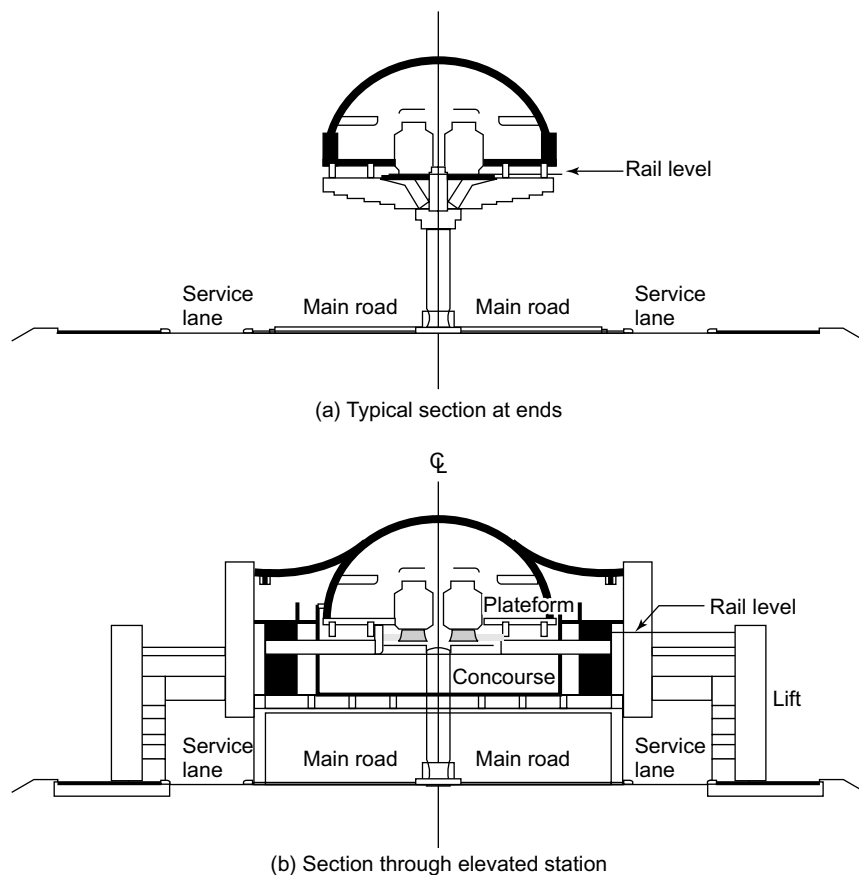
RRT is predominantly suburban radial service for medium to long trips (line-haul) with some CBD coverage. The patronage to the system should be strengthened by possible intermodal transfer of passengers from pedestrian, private transport and bus feeder systems at transit terminals. The need for RRT in a particular city depends on the population, travel patterns, topographical constraints, and size and character of the city. A RRT system is normally needed only in metropolitan cities. The train length (number of coaches per train) is usually constrained by the platform length for passenger boarding and alighting. A general global standard is that a city deserves a metro or light rail system when its population exceeds one million. From cost and economy considerations, planners recommend that in developing countries, cities with population over 3 million should plan for RRT. At micro level planning, LRT or Monorail and RRT may be considered for any corridor with traffic of 15,000 and 25,000 passengers per hour per direction, respectively.

Surface system is the most common form of construction for a railway. The gauge adopted on most metro systems abroad is the standard gauge (1435 mm). In India, the broad gauge (1676 mm) had been used in Kolkata and Delhi (part) with a view to keep in line with the intercity network. New urban transit lines are now being proposed using the standard gauge as for example, the new metro lines coming up in Delhi, Bangalore, Chennai and Mumbai. Steeper gradients (of the order of up to 2% for RGR and 4% for RRT) are manageable on urban transit lines. The surface line is simple to construct and the major costs are due to cross drainage works and crossings over busy roads. The major constraint of the surface line is that it divides the city and hampers easy communications between communities living on either side of the railway line. To avoid nuisance due to stray cattle and trespassing pedestrians, the line may have to be fenced right through. All crossings will have to be grade separated.

Elevated construction can be used in locations presenting difficulties in acquiring sufficient land to have surface operation. It can follow street alignments for the major part of the length. The cost of elevated track is likely to be over five times that of surface track. The structures should be

designed esthetically to suit the surroundings. Typical details of an elevated RRT system are shown in Fig. 7.2. Underground construction permits faster operating speeds, but is very expensive in capital cost and in maintenance.

One disadvantage of the rail transit system is noise pollution. The average operating noise for RRT systems is in the range of 63 to 80 dBA for car interior and 78 to 90 dBA for outside at 15 m from the track. The construction cost of the RRT system is high because the system has to be carried either underground in tunnel or on elevated structures. Since high speed is necessary to increase frequency and augment capacity, the station spacing should be at least 1.0 to 1.5 km. This is a disadvantage in a CBD area as the passengers will suffer less accessibility as compared to systems operating at the street level.



**Figure 7.2** Typical Elevated RRT System

The high capital cost of setting up a RRT system has been a major deterrent for developing countries. The costs of structural works for two tracks for different forms of RRT as estimated for Chennai RRT at 2007 prices are approximately as below:

	Cost/km Rs (Million)
Surface level	40
Elevated	300
Tunnel, cut-and-cover	900
Tunnel, bored	1300

While the absolute magnitude of costs may vary with location and time, the relative ratios of costs for the different forms are likely to be valid for purposes of preliminary planning. For an underground metro, the structural cost typically constitutes about 60% of the overall cost. The balance cost is taken up for rolling stock, installations for traction, electrical and signaling (33%) and for land acquisition (6%), the preliminary expenses covering the rest (1%).

Apart from the cost involved, there are major difficulties associated with the laying of underground lines in a heavily built-up metropolitan area. These include traffic dislocation, diversion of underground services connected with electricity supply, water supply, drainage and telephone cables. On the other hand, elevated structures cause visual intrusion and entail noise pollution. Unless the roads over which aerial structures are taken are very wide, there will be difficulty in quick dispersal of the gases and smoke emitted by the road vehicles passing under the elevated structures. Hence, a grade separated RTS can only be justified when the intensity of traffic is likely to reach the level of about 40,000 passengers per hour per direction.

**Table 7.2** Countries with Major Heavy Metro Rail Systems as in 2008

Sl. No.	Country	Number of Cities	Total Length of RTS km	Total Number of Stations	Gauge mm	Year First Opened
1	USA	11	1224.9	953	1435	1870
2	China	10	801.3	485	1435	1969
3	Japan	11	781.0	692	1435	1933
4	United Kingdom	3	527.1	383	1435	1863
5	South Korea	6	495.5	474	1435	1974
6	Spain	5	476.0	436	1435	1919
7	Russia	6	453.3	282	1520	1935
8	Germany	4	385.6	398	1435	1902
9	France	6	354.0	473	1435	1900
10	Brazil	6	237.3	173	1435,	1900
11	Mexico	3	223.3	201	1435	1969
12	Canada	3	183.8	170	1435	1954
13	Italy	6	162.5	190	1435	1955
14	Chile	2	147.5	125	1435	1975
15	Singapore	1	109.4	64	1435	1987

(Contd.)

**Table 7.2 (Contd.)**

Sl. No.	Country	Number of Cities	Total Length of RTS km	Total Number of Stations	Gauge mm	Year First Opened
16	India	3	108.6	93	1676	1984
17	Sweden	1	105.7	100	1435	1950
18	Taiwan	2	102.7	90	1435	1996
19	Ukraine	1	102.4	70	1520	1960
20	Turkey	4	97.9	98	1435	1989
21	Netherlands	2	88.0	71	1435	1968
22	Norway	1	84.2	104	1435	1966
23	Greece	1	72.2	52	1435	2000
24	Austria	1	69.5	84	1435	1976
25	Venezuela	4	68.8	56	1435	1983
26	Egypt	1	65.5	53	1435	1987
27	Romania	1	62.2	45	1435	1979
28	Czech Republic	2	59.3	57	1435	1979
29	Malaysia	1	56.0	49	1435	1996
30	Argentina	1	52.3	74	1435	1913
31	Belgium	1	50.0	68	1435	1969
32	Iran	1	48.5	40	1435	2000
33	Philippines	1	45.8	42	1435	1984
34	Thailand	1	44.0	41	1435	1999

**Source:** Adapted from different sources on Internet.

The most common form of traction for rail transit is electric traction. It has three distinct advantages: (a) It is energy efficient, with no need to carry fuel in the vehicle; (b) The high acceleration, deceleration and braking capabilities aid in reducing the travel time between stations; and (c) Auxiliary operations like lighting, ventilation and door closing can be performed with the same electricity. Different voltages of electricity are being used in different cities, sometimes based on technical advantages and at other instances due to historical compulsions. Chennai RTS uses 25 kV AC with overhead current collection to conform to the main line electrification on the Indian Railways. Mumbai suburban trains operate on 1500 V DC to continue with the system first adopted, but they are also being converted to 25 kV AC so as to be in conformity with the system prevalent in adjacent sections. Kolkata RTS has opted for 750 V DC with third rail collection. DMRC has adopted 25 kV overhead traction for their elevated and tunnel sections in Delhi. They have used special type of catenary system for the underground sections in Delhi, similar to those used in Shanghai Metro. This aspect is discussed in greater detail in Chapter 8.



Over 51 countries have RRT systems, Israel having the shortest length of 1.8 km and USA having the length of 1224.9 km spread over 11 cities. A list of countries having significant presence of RRT systems as in 2008 is presented in Table 7.2.

## 7.5 LIGHT RAIL TRANSIT

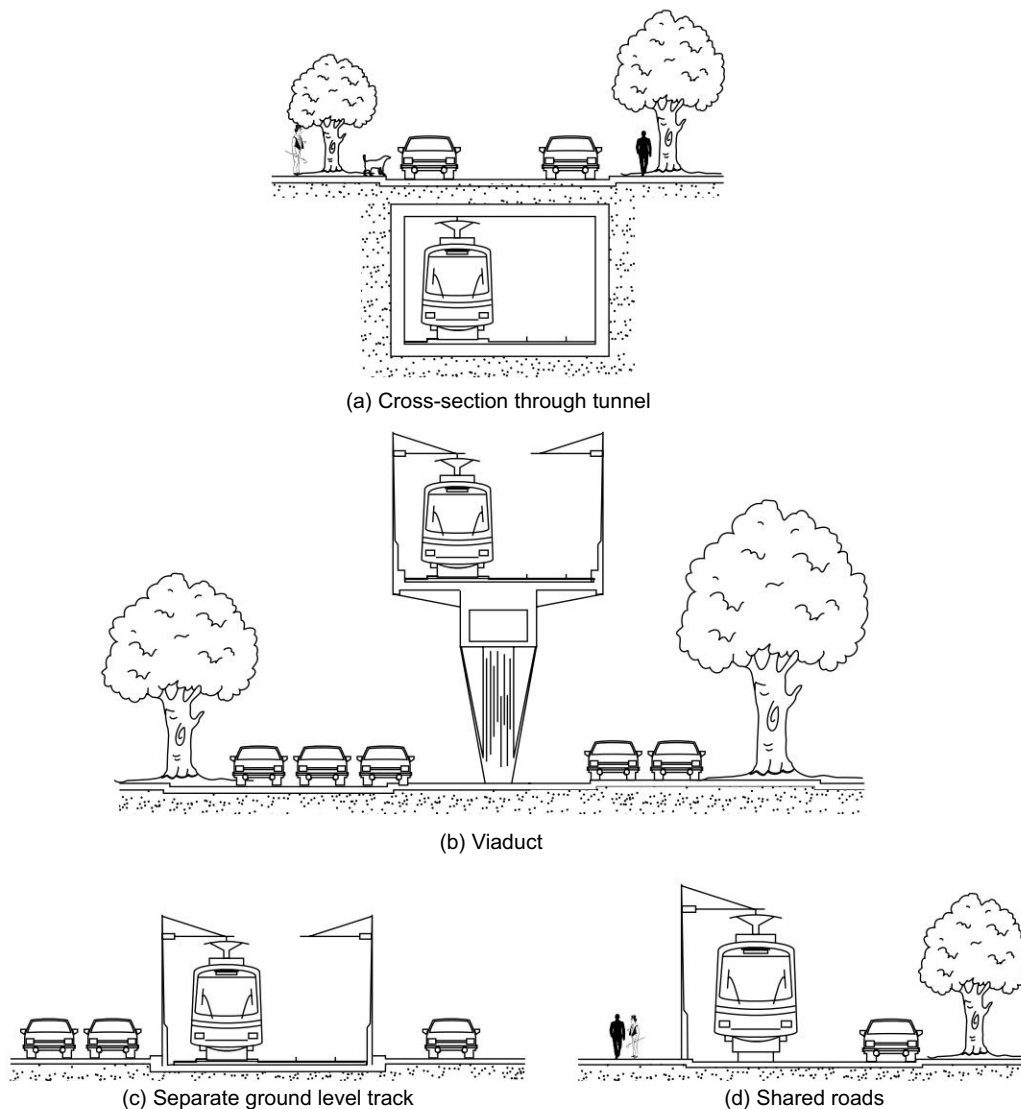
### 7.5.1 System Characteristics

The Light Rail Transit (LRT) systems are being used increasingly in urban areas all over the world as a mode of rail based public transport. As the name implies, LRT uses relatively lighter vehicles (maximum axle load of the light vehicles being 100 kN) and lighter track and covers different forms of modern urban passenger transport running on rails other than long distance railways<sup>2</sup>. It can be developed in stages from a modern tramway that shares its right-of-way with other traffic to a rapid transit system operating on its own exclusive right-of-way, underground, on embankments or viaducts. Each stage of development can be chosen as the operating stage; but it should also permit development to the next higher stage.

There are some specific criteria which distinguish LRT from a normal long distance railway. These are: (a) The track is partly on the road, necessitating special measures for its operation and for shielding it from other road traffic; (b) It uses light articulated vehicles (like trams) varying in length from 25 m to 35 m, a train consisting of single vehicle or two or three vehicles; (c) The capacity of LRT can be higher than the bus system, but is lower than that of a normal railway; and (d) The capital costs of a LRT system are lower than those of a normal railway. The major strength of the LRT system is the possibility to start as a tram and upgrade to RRT standards as the traffic and the available resources rise. This stage extension of a LRT network has a great advantage over new construction of a RRT system, in as much as the completion of each new stage of work improves the transport quality of the network as a whole, enabling improvement of public transport with a predictable period of time at a predictable cost. LRT can negotiate sharp curves of about 75 m radius and can follow city street alignments. Still steeper slopes can be used in depots.

The physical and operating characteristics of a LRT system are included in Table 7.1. The major components of a LRT system include: (a) Infrastructure consisting of the right-of-way, superstructure, stations, signal and power system; (b) vehicles; and (c) operation. Normally, the right-of-way used for LRT systems fall into three different categories: (i) Shared right-of-way, where the track area lies within the regular traffic area shared with other road users; (ii) Separate right-of-way, where the track area is outside the regular road traffic area, though signal controlled level crossings for pedestrians and vehicles remain possible; and (iii) Exclusive right-of-way, which is fully controlled, without any legal access for other traffic, as in underground or elevated track operation. The special feature of LRT is its capacity to operate on all three of the above types of right-of-way. Depending on the type of right-of-way and intersections, LRT systems can carry about 20,000 passengers per hour in one direction. Manila LRT has carried up to 30,000 passengers per hour per direction.

The installation and maintenance of the trackway is a major factor in total system cost. The LRT track can be designed for lower axle loads relevant to LRT instead of the freight train standards of the main line. The track structure required will depend on the type of right-of-way. On exclusive right-of-way, the track structure is exposed with the assembled components (rails, ties and fastenings), and is held in place by a bed of ballast, usually crushed stone, similar to any main line railway. In shared right-of-way, the track is embedded in the street pavement. The cross ties may be of timber or concrete. Good drainage of the track structure must be ensured.



**Figure 7.3** Different Forms of Light Rail Transit Right-of-Way

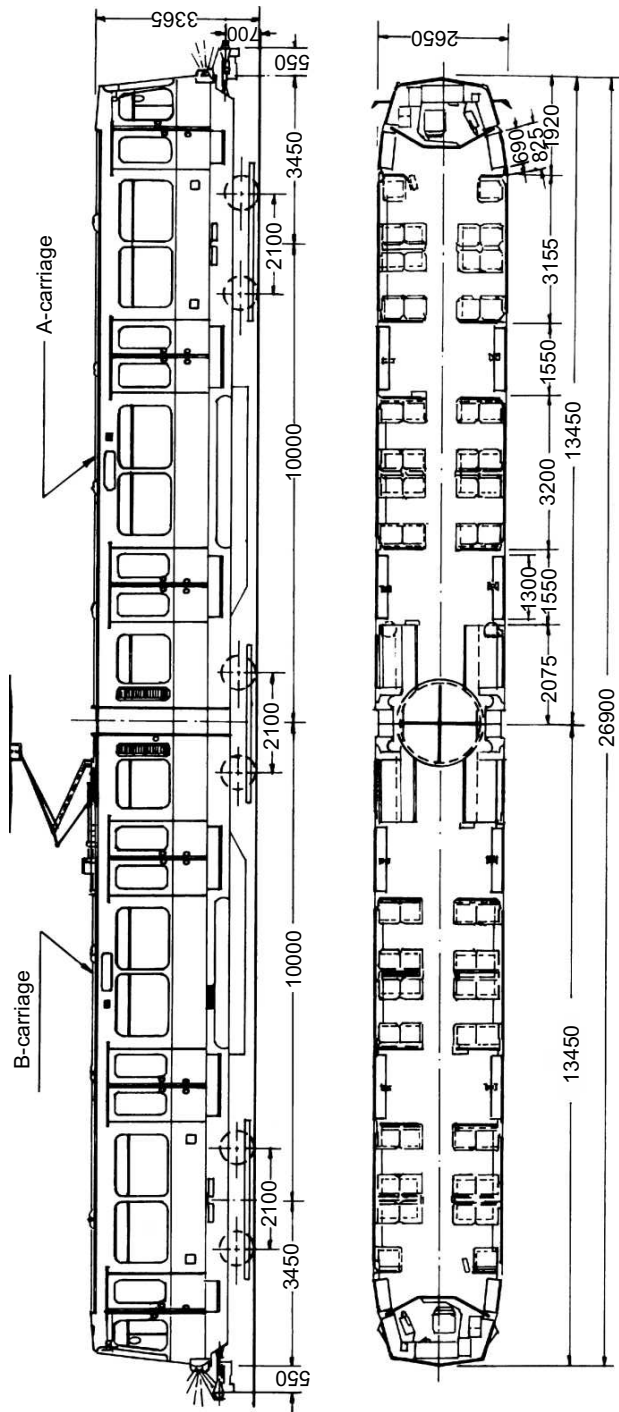


Figure 7.4 Typical Details of a LRT Vehicle

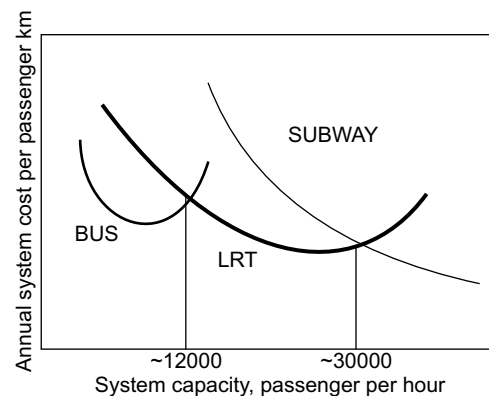
The light rail vehicles are powered by 600 V or 750 V DC electrical drive units, the current collection being through pantographs contacting overhead catenary wires. Typical details of a LRT vehicle with twelve wheels and single articulated coupling as used in Cologne are shown in Fig. 7.4. LRT in Manila uses double-articulated 8-axle vehicles. The vehicles are equipped with the most advanced technical features so as to meet high standards of comfort, i.e., noise-free and vibration-free running, joltless stopping and starting, safe braking and attractive design with low floors. The noise levels of about 70 dBA for the interior of LRT and about 70 to 80 dBA at 15 m from the track are attainable.

The features that distinguish LRT most strongly from conventional RRT are the flexibility with which it can be adapted to a variety of urban settings, and its potentially lower cost. In congested CBD areas, LRT can be operated in tunnels. In lower density areas, it can be operated at grade in existing roadway medians or other exclusive rights-of-way. At heavily traveled intersections and in busy arterials, grade separation can be achieved through underpasses or elevated structures. With preemptive signals and barriers, surface level crossings and operation in mixed traffic might be tolerated in some situations. Substantial cost reduction can be realized by laying a significant portion of the track on surface and adopting tunnels and elevated structures to the minimum extent. The effectiveness of LRT in improving the quality of service in the city can be enhanced by extending it at grade with shared ROW into suburbs and/ or providing efficient transfer stations at the outskirts of the city, which serve to link the rail network with the regional bus service.

Another major advantage is that the length of the train can be easily modified. During peak hours, the LRT train can be run as formation of two or three units; and during the mid-day non-peak hours, the train can be run as a single unit at similar frequency, thus economizing on power.

LRT is a technologically proven concept that can be introduced into a community without much disruption and can be operated with minimum intrusion in residential areas. It requires a road with minimum ROW of 20 m so as to co-exist with the other modes of transportation. Some cities have adapted even narrow intervening roads linking wider roads by constructing at grade LRT through them and prohibiting other vehicular traffic in them. Hong Kong and Singapore, which have recently built extensive RRT networks, have since introduced LRT lines on corridors with medium traffic. London has now reintroduced a few LRT tracks in places where it had removed then existing tram tracks during the 1950s. LRT on exclusive ROW may offer a capability for conversion to higher capacity service, thus allowing a city to match its initial investment to existing and near-term demand and to stage subsequent investment as required. If used properly, LRT can ensure a safe, convenient and popular transit service.

The purpose of any transit mode is to offer the intended ridership transport service with sufficient speed, comfort and capacity at an acceptable fare.



**Figure 7.5** Average Cost per Passenger-km in Relation to System Capacity

Figure 7.5 demonstrates qualitatively the cost effectiveness of the LRT system as bounded by the bus system at the lower end and the RRT system at the upper end, i.e., in the approximate range of 12,000 to 30,000 passengers per hour<sup>3</sup>. Table 7.3 contains a list of selected major LRT systems in the world.

**Table 7.3** Characteristics of Selected LRT Systems

Sl. No.	City	Gauge mm	Route Length km	Under-ground km	Elevated km	No. of Stations	Traction	Signal Control	Users per Day
1	Baltimore	1435	29.00			33	NA	ABS	27000
2	Boston	1435	56.00	2, 10	8.0	46	600 OH	ABS	267000
3	Brussels	1435	11.40			18	600-700 OH	CTC	
4	Buffalo	1435	10.30	8.37		NA	650 OH	CTC	64000
5	Calgary	1435	44.80	3.60	2, 29	37	600 OH	ABS	270000
6	Charleroi	1000	25.00			26	600 OH		
7	Cleveland	1435	24.60			27	600 OH	ABS	9000
8	Cologne	1435	43.60	1.00		28	750 OH	ATS	
9	Dallas	1435	38.40			46	600 OH	ABS	
10	Detroit	1435	14.10			22	NA	ABS	67000
11	Edmonton	1435	12.90	5.30		12	750 OH		9000
12	Frankfurt	1435	51.00			77	750 OH		137500
13	Gothenburg (incl. tram)	1435	44.90				600 and 750 OH	ABS	
14	Hanover (incl. tram)	1435	69.00	13.00		122	600 OH & TR	CTC/ ABS	
15	Los Angeles	1435	55.70			32	750 OH	ABS	90500
16	Karlschrut (Berlin)	1435	46.00			46	750 OH		
17	Manilla	1435	28.80			29	750 OH	ABS	255000
	Mexico City	1435	17.76			18			
18	New Castle	1435	77.70	6.40		60	1500 OH	ATS	129000
19	Philadelphia (incl. tram)	1435	21.90			22	600 TR	ATS	
20	Pittsburg	1435	16.84	2.40			600 OH	ATC	
21	Portland (incl. tram)	1435	44.00			47	600& 700 OH		163000
22	San Diego	1435	54.80			49	600 OH	ABS	84000

(Contd.)

**Table 7.3** (Contd.)

Sl. No.	City	Gauge mm	Route Length km	Under-ground km	Elevated km	No. of Stations	Traction	Signal Control	Users per Day
23	San Francisco	1435	51.50			54	600 OH	ABS	83000
24	Sacramento	1435	32.90			NA	750 OH		30000
25	San Jose	1435	42.20			34	750 OH	ATC	
26	Stuttgart (Incl. tram)	1000 1435	87.00 26.00			164 41	750 OH		252000

**Note:** OH—Over head; TR—Third Rail; ABS—Automatic Block; CTC—Centralized Traffic Control; ATS—Automatic Train Supervision; ATC—Automatic Train Control

**Source:** Compiled from different sources.

### 7.5.2 Example of Cologne LRT

Cologne, Germany, has been most active in the development and application of light rail transit<sup>4</sup>. The LRT (Stadtbahn) system, operated by the Kolner-Verkehrs-Betriebe (KVB), has developed from a basic tram system to a high performance LRT network. Routes comprised sections of any one of the three types of right-of-way: (a) Type A - fully separated (U-bahn); (b) Type B - partially separated, with longitudinal physical separation from other traffic, but with a few signalized grade crossings; and (c) Type C - surface streets with mixed traffic and no separation. The allowable maximum speed for the Type A section is 70 kmph. The track had a limiting gradient of 4%, maximum radius of 120 m and maximum superelevation of 165 mm.

The new design vehicles have the flexibility to operate on all the three types of right-of-way. They have retractable steps to allow boarding from high or low platforms. A typical 6-axle articulated LRT vehicle is shown in Fig. 7.3. The rail used in U-bahn sections is T-rail S41 (41 kg/m). Girder rail, as used in tram operation, is used on much of the surface track.

The KVB has been a leader in concrete slab track, which does not use ties or ballast. The advantages of this type of track over ballasted track are: tunnel height reduction by about 200 mm; reduced weight on bridges; reduced maintenance costs; and reduction in noise level. The KVB has developed a special type of fastener, known as “Cologne Egg” after its oval shape. In this type of fastener, the rail rests on a base plate permanently attached to a rubber collar through vulcanization. The bolts for the fastener are secured to the concrete slab by first concreting the space around the bolts and then finishing the base slab. The special fasteners have reduced the noise and they perform the energy- and vibration-absorbing function of the ballast.

Buses operated by KVB serve as feeders to the LRT network. Fare collection is by self service. Tickets are available from automatic vending machines in most of the stations/stops and from manned booths in heavily patronized U-bahn stations. Passengers insert the ticket into a cancelling machine in the vehicle, which marks a code to indicate date, time and location of boarding.

Multiride tickets and season tickets are encouraged with reduced fares. Since school children use the LRT, separate school fleet is not maintained by the city administration. Roving ticket examiners conduct surprise checks and ticketless passengers (usually less than 1.5%) are fined heavily.

## 7.6 MONORAIL SYSTEM

Monorail system (MRS) comprises a single rail serving as the guide way (track) with the vehicles suspended from or straddling the guide way. Monorail vehicles are wider than the supporting guideway structure. In most cases, the rail is elevated, but it can also be at grade, below grade or in subway tunnels. The major advantage of the MRS is that it requires a smaller structure than the duorail track, involving lower infrastructure cost and lower maintenance costs.

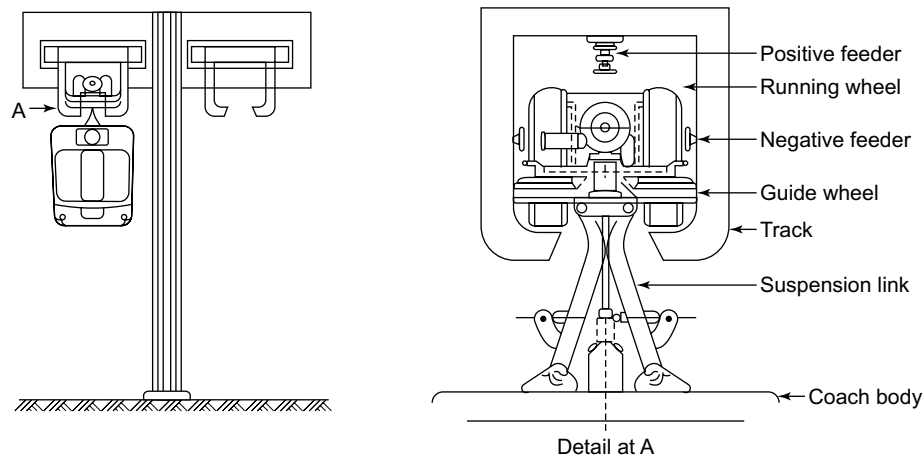
The first monorail for public transport was the Wuppertal Schwebebahn opened in 1901 in Wuppertal, Germany. Since then many monorail systems have been introduced in several countries. The Alweg monorail design adopted for the Tokyo-Haneda monorail line in 1964 is a noteworthy example of a successful application.

The monorail and allied technology can be classified under five categories<sup>6</sup>. These technologies with examples in parentheses are: the straddle type (Haneda Monorail), the suspended type (Wuppertal), Hybrid – inverted T-monorail (not in popular use), Maglev (Shanghai Maglev), and PRT- Personal Rapid Transit (small vehicles, still under experimentation, e.g., Singapore Airport PRT).

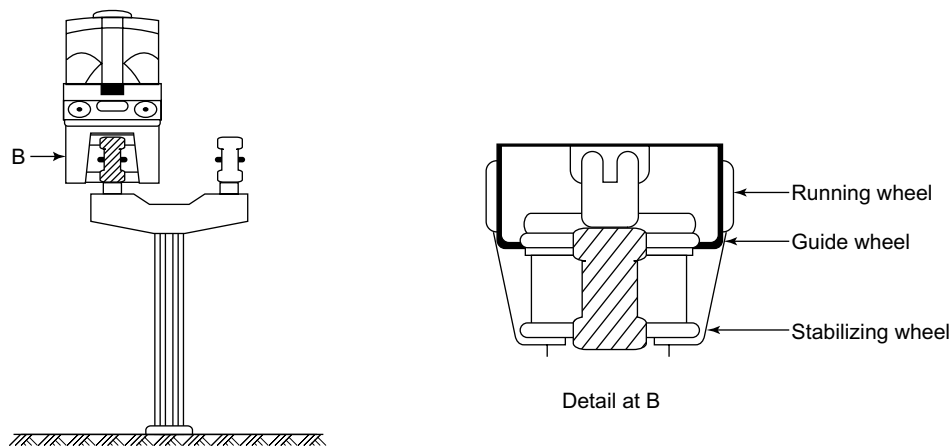
The monorail system has proven to be an option as a public transportation mode which is safe, cost-effective, aesthetically attractive and environmentally friendly. However, special design and operational procedures are needed for switching of tracks. Special arrangements are required for evacuation of passengers in case of breakdowns/accidents. The design of the track profile and vehicle design are inter-related, limiting the choice during extension of any line already built. The capacity of the mode can be in the range of 10,000 to 20,000 passengers per hour per direction (PHPDT).

### (a) SAFEGE System

In this system, the train works on the suspension principle based on the idea that the suspended trains would run in both directions from a single line. If increased capacity is needed, double line may be provided. A single rail suspension arrangement would be needed for each train. The track for this system is installed within a hollow beam with a slit opening in its bottom flange. The wheels carrying the vehicle and providing motion pass on the bottom flanges of the beam fitted inside the hollow beam. Lateral guidance is provided by horizontal wheels and guided. Switching arrangements at stations or between lines are complicated and costly and they have to be actuated by electro-pneumatic equipment or hydraulic equipment. Where the trains can be run in a closed circuit in uni-direction, such a switching system can be avoided. Special platform arrangement for boarding and alighting will have to be provided at stations as in case of LRT, width of which can be comparatively less.



(a) Monorail – SAFEGE System



(b) Monorail – ALWEG System

**Figure 7.6** Monorail Systems

Figures 7.6 (a) and (b) show two of the mostly used monorail systems, SAFEGE and ALWEG systems.

### (b) ALWEG System

In this system, the vehicle moves over the way which is formed of a prestressed concrete beam of I Section with a flat surface on the top for supporting and passage of the wheels of the coaches. Restraint and guidance are provided by two additional horizontal wheels on either side bearing against the sides of the rail beam. They also ensure stability and provide directional guidance. In this case also, special type of switches will have to be provided for changing the routes, but the



operation of switches is faster on this system than in the Safege system. The trains are provided with pneumatic wheels for both traction and guidance. The vehicle is smaller than the other railway vehicles and the length of the vehicle has to be limited to suit the permissible curvature of the track. One disadvantage is that because of the supporting system arrangement about 30% of the vehicle cross sectional area cannot be used for accommodating passengers. In view of its bottom support, the vehicle can be modified to be carried over surface as well as through tunnels without the need for providing larger vertical clearance. But larger side clearances are needed.

## **7.7 GROWTH OF RAIL BASED TRANSIT SYSTEMS**

### **7.7.1 RRT or Metro Rail Systems Growth**

Just as the first railway was built in London, the development of metro rail system also was started in London. The initial development of railways in that city was done by a number of companies who started building lines from different terminals radiating into the countryside. These were started serving the commuters in and around the city in form of suburban railways since 1838. Within the city, horse drawn coaches and trams plying on streets served the needs of commuters, but this was not adequate and fast enough. This led to the development of rail lines within the city following road alignments in cuttings or tunnels. Where depth of cutting was not much or the area was not too busy or where line was not following street alignments, the line was in cutting open to sky with deep retaining walls protecting the sides. Where there were construction difficulties in deep cuttings in clayey strata or where alignment had to deviate from street alignments, they were taken through tunnels formed by cut and cover method and the first such line was commissioned in 1863. Where space would not permit cut and cover such tunneling was done using circular cutters in shape of a tubes, e.g., across River Thames. It gave the name ‘tube railway’ to the system in London.

Initially vehicles were hauled by steam locomotives. Ventilation was provided by shafts built at frequent intervals. Such construction by private entrepreneurs continued till 1880 when due to fund constraints it had a setback. With the invention of electricity and its use as motive power for trains by the end of 19<sup>th</sup> century electric locomotives were used. Thereafter, the development of metro railway system accelerated in not only London but also in many other cities in Europe and North America. In fact American financiers were investing in the metro rail lines in London. London’s first line using electric locomotive was commissioned in 1890. In order to fit within the tube, third rail current collection system at 550 V DC was adopted. The trains were hauled by camel back type locomotives till 1904 when the EMU (Electric Multiple Unit) form of trains were introduced.

In America, the urban rail system was introduced in 1868 both on surface and elevated alignments. New York introduced such combination first and Chicago followed the suit the same year. It was not till the turn of the nineteenth century that the underground railway system idea was taken up in New York where the first ‘underground’ was opened in 1904. Other cities followed suit. Chicago continues to retain most part of its elevated lines even in city centre, while New York developed more of underground lengths even replacing good proportion of elevated lines within

the city retaining elevated lines in fringe and outer areas. European countries followed suit, with Paris in the lead with their first underground line in 1900. Moscow was a late starter with its first metro line opened only in 1983.

### 7.7.2 Decline and Revival and New Developments

Almost all of those railways were built by private entrepreneurs. While the intra urban transport systems were controlled by city governments, the suburban services extending from the city outwards were controlled by the Central governments. They grew at a rapid pace till the First World War and at a slower pace in the interim period between the two World Wars. The development of road transport with its advantage of flexibility in routing and its competitive profile retarded the growth of rail transit. Personal vehicles and buses for public carriage were introduced. The post second world war period saw fast growth of cars due to affluence and surplus money with people; and increase of buses on city roads. The buses could offer lower fares since bus operators did not have to construct or maintain roads but only pay a tax and reach different parts of cities, i.e., closer to origins and destinations of commuters. This, in turn, resulted in lower patronage of rail transit adversely affecting their viability. The private operators of rail lines started looking forward to their being taken over by city authorities. Closure of trams and no expansion of metro rail resulted in more use of road vehicles with consequent congestion on the roads and pollution.

The faster depletion of non-renewable energy in form of fossil fuels since later half of last century caused revival of the interest of the Governments in rail transit form. Many of the existing ones were taken over by the governments who had to subsidise them even for day to day operation. They also started funding extensions and development of new corridors. A new concept of testing the viability of such projects on the basis of socio-economic benefits, they would bring in was brought in and the two resulted in construction of more lines, notable ones being the Victoria line extension in London and the new systems like BART (Bay Area Rapid Transit) in San Francisco in USA and Dockland Light Rail system in London. Many technological developments in design and construction of structures, design of coaches and use of IT in operation and control helped making the metros safer, faster and more attractive to passengers. They also helped in developing alternative less expensive, but lower capacity, rail based transits like LRT, Monorail, etc., for less dense corridors. New modes of financing and management of rail transit have been evolved with the Governments taking keen interest in them.

Increased congestion and pollution caused by road transport induced major cities in Asia to think of rail based transit lines in the latter half of last century. A few cases are presented here to show the trend.

## 7.8 SOME CASE STUDIES

### Hong Kong<sup>7</sup>

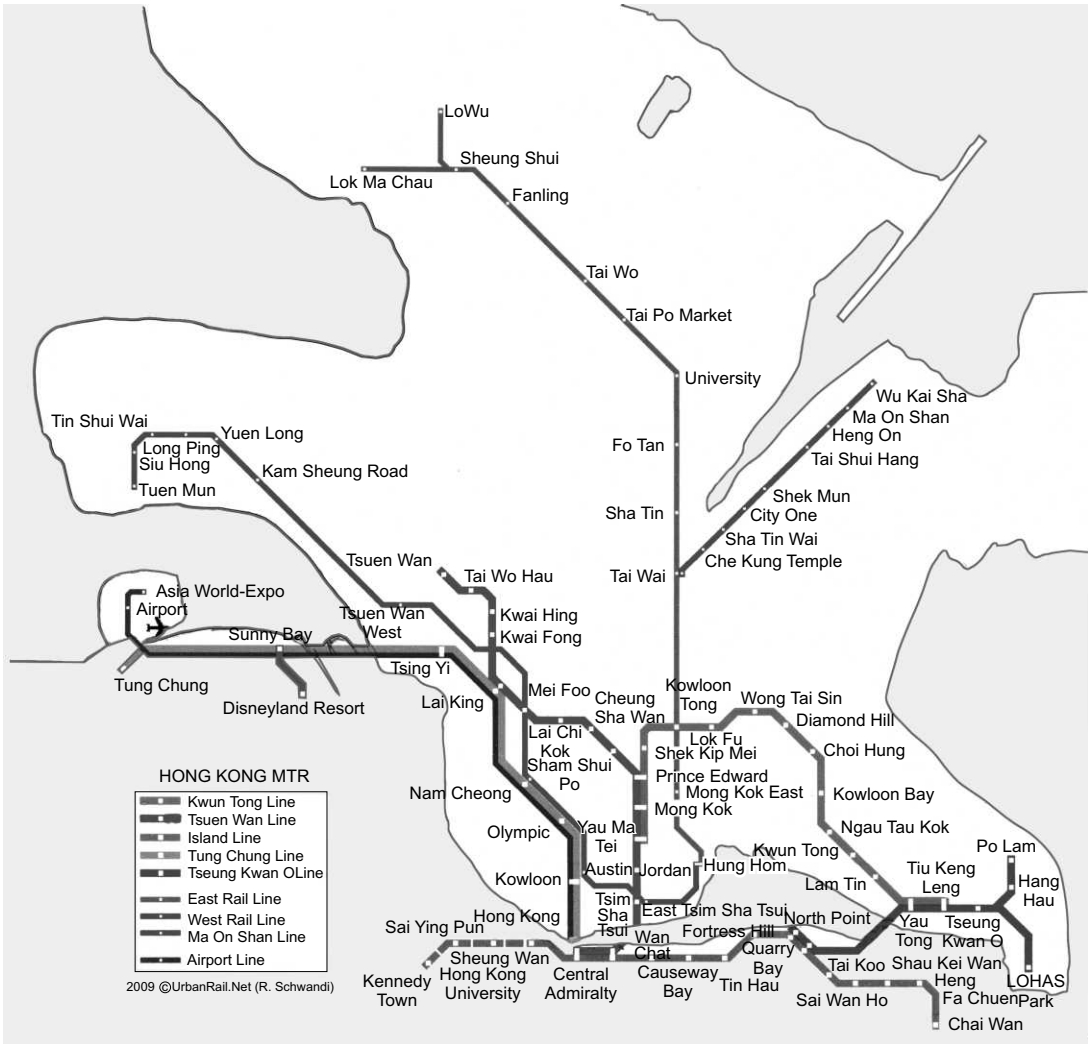
Hong Kong can be considered the pace setter in this respect. The city commenced studies on transport problems in the city through consultants in 1960. They considered three alternatives to

meet the anticipated traffic by 1985. Alternative 1 considered was provision of LRT, alternative 2 a high capacity metro rail, and alternative 3 a combination of both. All these envisaged doubling and electrification of Colon-Kanton Railway to form an integral part of the system. The consultants, in their report submitted in 1969, recommended provision of four lines of a metro rail system totaling 60 km which was estimated to carry 0.8 million passengers per day. This was reviewed again in the light of possibility of serving some new residential areas and lower projection regarding population. The scope of work was reduced to two lines with reduced kilometerage. Sanction was accorded for the first line of 20 km in 1972, which was further modified to 15.7 km. Work was actually commenced in 1975 and part length commissioned in September 1979 and balance by December of same year. The system is designated as MTR. First MTR Cross harbour line from Kowloon to Kanton was commissioned in the following year. Second line of 10.5 km was approved in 1977, construction taken up in 1979 and commissioned in 1982. The system has been steadily expanding, as part underground and part elevated metro. Initial system was done with 21.8% of Government grants, 68% by issue of bonds (to be repaid from out of surplus earning) and balance by commercial exploitation of air space above stations. By 1992, 43.2 km (34.4 km underground and 7.6 km elevated, remaining being transition lengths done) was in operation reported to have been done at a cost of \$ 5050 million. It then carried over 2 million passengers per day. An analysis by TRRL in 1997 indicated that the fare box ratio was 2.2 highest for any metro rail enabling MTRCL to start repaying the debts. Figure 7.7 shows general layout of different lines in Hong Kong.

Construction of Airport Express line 35.3 km long with 5 stations to new International Airport in Landau Island was started in 1994 completed in 1998 and commissioned along with the new airport. The trains operating on this are called Airport Express and they provide check-in facility for the air passengers from Kowloon and Hong Kong stations. They are run at 12 minute intervals and have maximum speed of 130 kmph. It covers the distance in 24 minutes. In 2005, it carried 27,000 passengers per day. The fare is high on same. In order to serve other commuters, there is a parallel MTR — line (Tung Chung line) with a bus link serving a station in different part of airport. While expanding its metro rail network, the MTRCL has also developed an LRT network serving a number of stations as feeder routes. They also operated Feeder bus services from some stations, thus providing a truly integrated network. As of 2009, the network consisted of 10 lines totaling 175 km of Rapid Transit and 12 lines totaling 38.2 km of LRT with 68 stops. It carries 390,000 passengers per day. The RTS carried 3.76 million passengers and other allied systems 500,000 passengers per day in 2009.

## **Singapore<sup>8</sup>**

Another example of a modern Metro rail system which was implemented within a short period, once decision was taken, and which also has proved its utility within five years of opening is the MRT at Singapore. This system was thought of in 1967 and preliminary investigations were done during the year 1972. The construction was started in 1983 at a cost of S \$5 billion (US \$ 2.57 billion then). This was another urban rail transport system, which was completed well within the



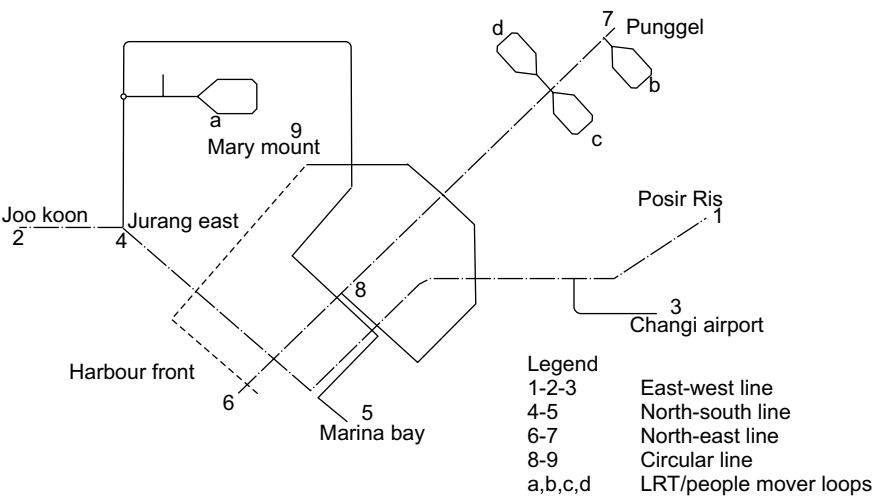
Source: Adapted from UrbanRail.net

Figure 7.7 Metro Rail Systems in Hong Kong—General Alignment

estimated cost and the shortest period of time (7 years). First length of 29 km with 20 stations was commissioned in 1988 and full system of 67 km of Phase I a year later. The system is being extended on continuing basis. This has been essentially due to the quick decision making, a well conceived plan and programme started with adequate preliminary studies and also construction having been done in a period when there was a lull in construction activity in other parts of the world. Reputable contractors from other countries (especially from Japan) could form consortiums with Singapore entrepreneurs and take up this work at a reasonable cost and they could concentrate their energies to complete the job in time. This MRT system, as they call it, has encouraged growth of a number of popular neighborhoods and major activity/commercial centers in outer areas. It is also a system where the large proportion of the first two lines North–South and Eastern lines (44.8 out of initial 67 km) was on elevated alignment. It had 57 stations. Major part of alignment runs along the medians of the road. Tunneling had been resorted to only in the central portion of the city, where the alignment passes through densely built up areas with number of high rise buildings. The system carried 204 million passengers in 1991–92. A link was subsequently provided to Chungi airport from one of the stations on East–West line.

The system has been extended in two more phases. The third line called North–East line of 20 km with 16 stations was completed in 2003. This is fully underground. A circular line linking the three lines mentioned above has been commissioned in 2009. It is 35.7 km long with 32 stations. It is fully automatic with operation of driverless trains. It has its main depot below ground. There are a number of extensions or spurs under construction from these lines due to be opened in stages by 2013, 2018 and 2020. The island city's current programme envisages operation of a total of 278 km of MRT by 2020 and they have a vision to increase it to 550 km MRT by 2050, by far exceeding London's network of 408 km. In 2009, the system carried about 1.952 million passengers per day with a modal share of 42%. The bus system carried 3.085 million passengers. They expect to carry 4.6 million passengers on full system by 2020. One major advantage in Singapore is that they have established a single authority, i.e., Land Transport Authority (LTA) which is in charge of planning, implementation and management of all surface transport related systems. The operation of the metro lines has been entrusted to specialist (private) agencies, e.g., SMRT (Singapore Metro rail Transport) for North–South, East–West and Circular lines and SBS Transit for the North–East line. SMRT operates buses and taxis also. Thus co-ordination between different transport systems becomes easier. The fare of metro rail is regulated by PTC which reviews the same on annual basis. Fare is revised every year based on a formula which is linked to price indices. The formula itself is revised once in three years.

Singapore has also an LRT system (shown in form of loops on the map), which works as a feeder system extending from some MRT stations and covering the regional housing estates near them. First LRT line was established in 1999. Wherever required, the stations are designed to provide interchange facilities with buses and parking lots. Figure 7.8 shows the network and Fig. 7.9 shows the bus transfer facility provided in one of the stations.



**Figure 7.8** System Map of MRT and LRT in Singapore<sup>8</sup>

Presently there are three loops/links of LRT at three stations, which are used as feeder systems to the respective metro line stations. Total kilometrage of LRT is 28.8 km having a total of 43 stops of which ten are not used. This has been functioning since 1999. (source: Wikipedia free encyclopedia)

**Development in Other Cities in South–East Asia**

The other notable cities in South–East Asia which have gone in for implementation of rail based urban transport lines towards the end of last century are: Manila in Philippines, Kuala Lumpur in Malaysia, and Bangkok in Thailand. One thing common in these three cases is that there have been significant private participation in the capital funding of some of their RTS or LRT lines.

**Manila**

Manila was the first city in South–East Asia to have an urban rail system in the form of an LRT on a fully elevated track, which passes through one of their busiest roads. Manila had earlier implemented a major network of electric street cars, which was started in 1905 and grew till 1927 when 170 cars were operated on over 60 km of network to serve a population of 220,000. This



**Figure 7.9** Bus Transfer Arrangements at One Station on Singapore MRT

was built and operated by MERALCO (Manila Electric Railroad and Light Company). Service on this system was suspended during Second World War and the tracks and assets were badly damaged by bombing during the war. Hence it was not resumed and tram lines were consequently removed from roads. Instead people started converting released war time jeeps as Jitneys and provided public transport. Privately run buses and jitneys filled the gap in public transport. With growing congestion city authorities thought of rail based transport. In 1966, they gave permission for building a monorail line, but there was considerable delay in evaluation of the scheme. In the meantime, they engaged Japanese Consultants for detailed studies. The Consultants suggested provision of a north-south rail transit, provision of commuter rail service on the National Railway lines and a number of road projects in outer areas. This resulted in the city taking a decision in favor of LRT network. Light Rail Transport Authority (LRTA) was formed by the Mayor of Manila in 1980 to look after the implementation and operation of the network. Manila presently has three lines Yellow, Purple and Blue.

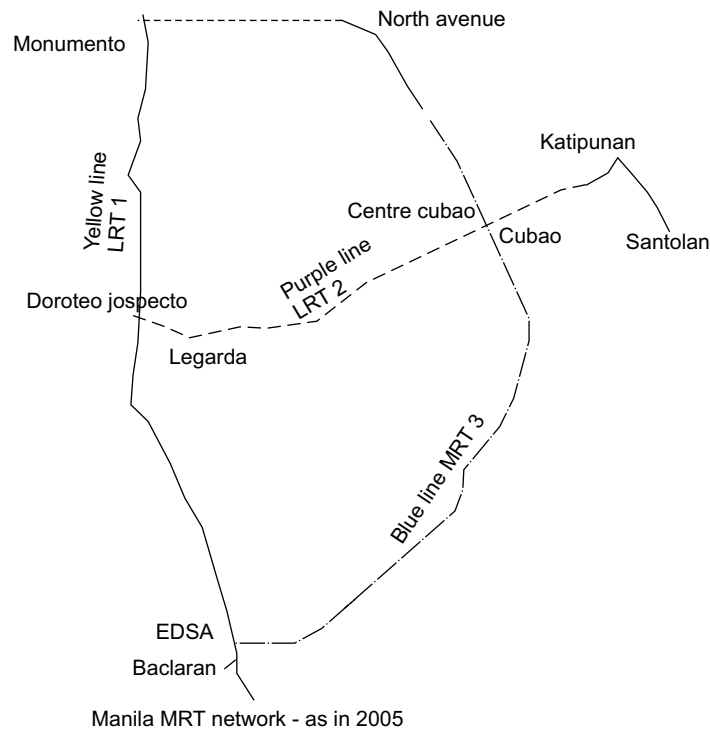
First corridor, called 'yellow line', was identified as 17.2 km North-South line<sup>9</sup>. For this line Belgian Government came forward to provide a gift of 300 million Euros. A Consortium led by Belgian ACEC came forward to invest 700 million Euros to implement the project, which they felt would pay for itself within 20 years. This first line LRT 1 is 17.2 km long with 25 stations and fully elevated system mostly on street alignments. Construction on this line was started in September 1981 and first half portion commissioned on 1<sup>st</sup> December 1984 and balance in May 1985, thus making Manila, the first South-East Asian City to have rail transit. This line is known as 'no frills' line. It operated double articulated LRVs two or three per train and with only roof top ventilation. Stair cases lead from station at ground to platform level. They adopted 750 V DC overhead collection mode. Due to heavy overloading and vibrations, they started failing. The System needed strengthening, refurbishing including provision of air conditioned coaches and also provision of lifts in stations. When modified line was put back on service, the clientele increased considerably. They have since added a fleet of higher capacity trains consisting of 4 (Single articulated) air conditioned units. The line presently carries about 400,000 passengers per day.

LRT 2, the second line is 13.2 km long with 11 stations all on elevated alignment except for one station and its approaches. It runs east-west and is linked to Dorteo Jose, about mid-way on Line 1. It operates 4 car Heavy metro car units with wider cars. (3.2 m instead of 2.5 m of the cars on Line 1) Each train has a capacity of 1628 passengers including 232 standing. The line construction was started in 1990s completed partly in 2003 and fully by 2004. Stations are at two levels and some stations have direct access from concourse level to some adjoining commercial buildings also. It is designed to provide PHPDT capacity of 60,000. It carries about 170,000 passengers daily now (2010). The line was fully funded by the Government.

The third line known as MRT 3 was partly opened in 1999 and fully in 2000. Construction was done by Metro Rail Transit Corporation, a consortium of Mitsubishi heavy industries and others on BOT basis. It is 16.95 km long with 13 stations. It has 3 interchanges with the other two lines. Though built to heavy metro standards, it operates articulated vehicles. Stations originally had only stair cases but subsequently lift and escalators have been added. The fare structure is similar

on the three systems as it is regulated by LRTA. In 2004, it carried 200,000 passengers per day. The government has not had to invest any money in the system but has been paying lease charges for the same. The lease amount comes to about 30 to 60 million U.S. dollars per annum over and above the fare collection. It is learnt that this gives a 5% return to investors.

Figure 7.10 (a) shows the layout of three LRT/MRT lines in Manila.



**Figure 7.10 (a)** LRT and MRT Lines in Manila<sup>9</sup>

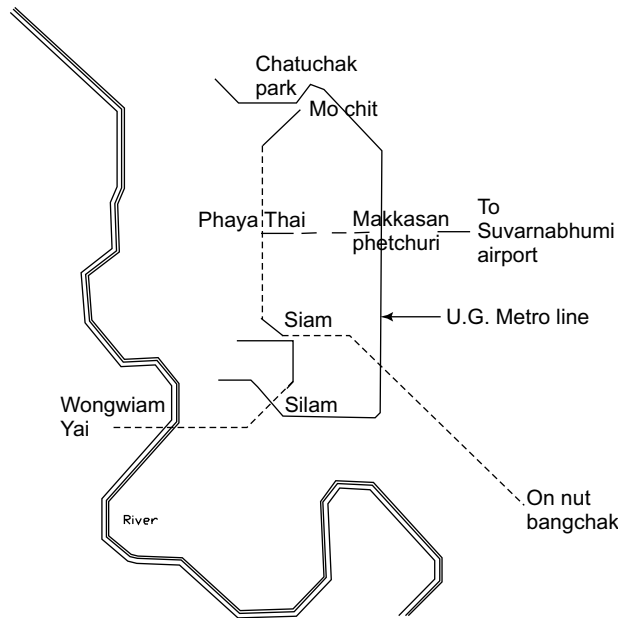
## Bangkok

Bangkok's traffic congestion on roads had become proverbial and the city had been planning for mass transit and elevated road for many years. Fund constraints had been a major problem and they were looking for investors who would provide such facilities based on some concessions. A group led by Siemens came forward to provide BTS (Bangkok Transit System) an elevated metro rail called Skytrain on two corridors with CBD as hub on BOT basis towards the end of last century. The network is 24 km long with 24 stations. It was completed in 2000 at a cost of US\$ 1.23 billion (on an average US \$59 million per km). It can be considered a comparatively successful endeavor by giving fare box ratio of 2.1 carrying on an average 350,000 passengers per day.

At the turn of the century, Bangkok took up also an underground metro rail project to ease congestion within the city. It is fully funded by the Government. It is 20 km long with 18 stations;



its cost works out to an average of US \$150 million per km. It carries 200,000 passengers per day. It is too early to assess if it has been a viable project, but it serves well with interchanges with BTS at 3 stations. Encouraged by the results, the city has an ambitious programme of extending both the systems to about 290 km at a cost of US \$ 13.8 billion.



**Figure 7.10(b)** Metro Rail Lines in Bangkok

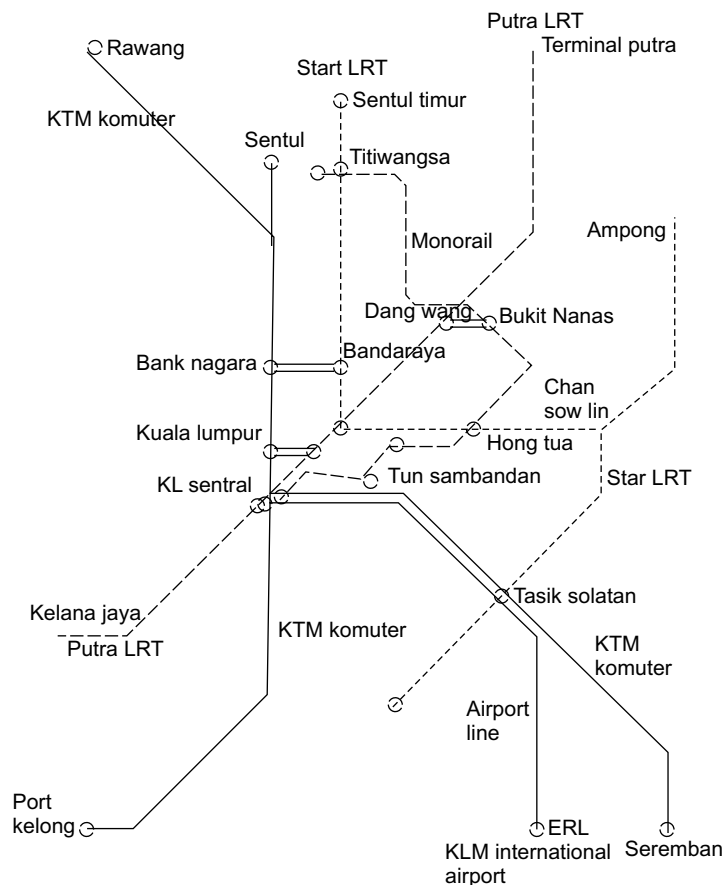
This city has also built a line to connect to the Airport. It is an elevated line running alongside a main railway line and owned by the State Railway of Thailand<sup>12</sup>. This 28.6 km line with 8 stations between Phaya Thaya in the city and Suvarnabhumi Airport operates both commuter trains and Airport Express trains. Figure 7.10 (b) shows the layout of all three systems. While city Express starts from Phaya Thaya, the Express starts from the second station Makkasa which will have check in facilities for air travelers also. Separate platform lines are provided for the two sets of trains at Makkasa and Suvarnabhumi and one intermediate station has passing lines for the Express trains. The train sets are designed for maximum speed of 160 kmph. City (commuter) trains average lower speeds due to closer spacing of stops. It takes 27 minutes between terminii while Express trains take 15 minutes each way.

### Kuala Lumpur (KL)<sup>13</sup>

KL, a city with a population of 1.4 million, had chosen to provide a rail transit in the city to ease the traffic problems at quite an early stage. To start with, it went in for an LRT. It received offers for private participation in implementing the projects. It resulted in building of two LRT lines and one

Monorail line. The first one STAR covers 25 km built at a cost of US \$0.8 billion on BOOT basis with 10% grant, 20% loan, 10% private equity and balance loans in 1999. The assets have since been taken over by the Government. It carries 110,000 passengers a day. The second line PUTRA covering a length of 24 km was commissioned in 2000. It cost US\$ 1.54 billion with a break-up of 25.6% Government loan, 20.4% private equity and balance loans. Assets of this line also have been taken over by Government. It carries about 150,000 passengers per day. The fare box ratio of the two LRTs put together is 1.3.

Kuala Lumpur is perhaps the first city to go in for a Monorail in South-East Asia for commuter service. The 11 km long facility was completed in 2004 at a cost of US\$ 0.32 billion. The government has given a loan of 23.4% and private equity is 22%, with the balance being other debts. It carries 45,000 passengers per day. Fare box ratio is reported to be over 1. The city has built an elevated Airport Express line also from city centre, where passengers have check-in facilities also. It already had a commuter rail service on their Meter gauge lines. The layout of different lines serving the commuters is indicated in Fig. 7.10 (c).



**Figure 7.10 (c)** LRT and Monorail Lines in Kuala Lumpur

A 2005 UN study<sup>13</sup> on working of the rail transit projects in the three cities has brought out some notable conclusions regarding private financing in such projects, as given below:

- (i) The implementation of projects has been more effective. Notwithstanding different technologies and markets and history, it is seen MRT3 in Manila and BTS in Bangkok were completed before the Government funded LRT2 in Manila and Blue line (Metro in Bangkok) in the two countries.
- (ii) Private financing has not achieved its expected results in general. This is evident from the Government having to subsidise Manila MRT 3 by paying part lease amount to concessionaire from its own funds. The Government plans to buy BTS in Bangkok. STAR and PUTRA are already taken over by Government.

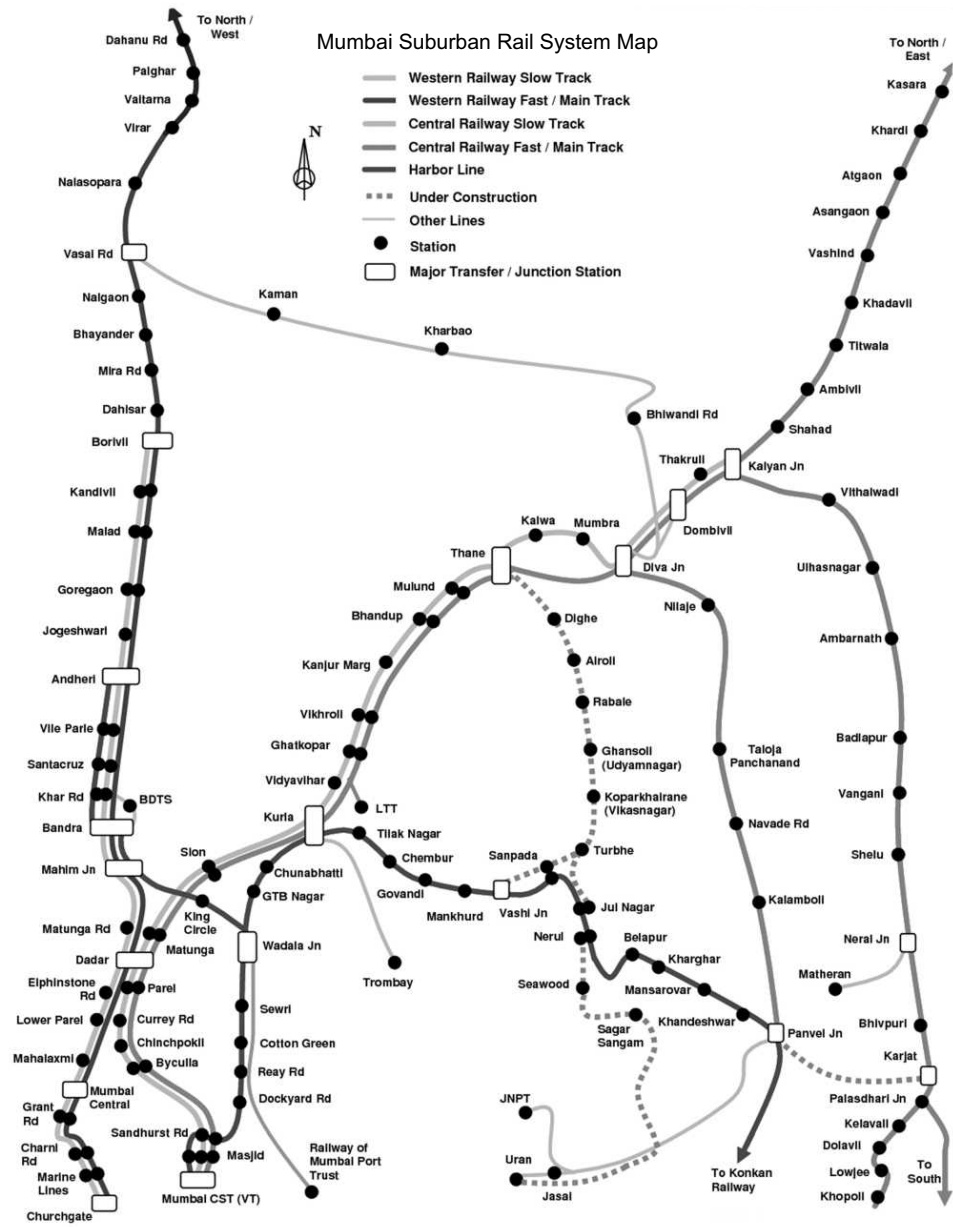
The study attributes 'poor revenue performance largely due to failed complementary actions or unrealistic assumptions'.

## 7.9 RAIL TRANSIT SYSTEM DEVELOPMENT IN INDIAN CITIES

### Mumbai<sup>14</sup>

Mumbai is one city which has had a good public transport base in India, both rail and bus since long. Both have been expanding over time though not commensurate enough for the growth of population and other developments. Both modes have been complementing each other to the benefit of the commuters. The public transport share of vehicular transport in metropolitan area is 78%, highest for any Indian city. But both rail and bus transport systems are hemmed in due to land constraints for further major expansion. The city has started on a programme of supplementing the existing rail infrastructure with a network of metro rail lines and also a Monorail feeder network. The history of their development and current programmes are briefly covered here.

Railways were started in India with the first line from Colaba (now CST-Chatrapati Shivaji Terminus) to Thane in 1853. Mumbai has headquarters and termini for two major railway systems, Western and Central. Both systems operate suburban train services on their systems extending over the length of the full region. Within the metropolitan area, these services are equivalent to Metro rail system in respect of frequency and station spacing. The first suburban train was operated from Virar in north to Back Bay (present Churchgate) on what is now known as Western Railway. The other railways followed suit. The lines were doubled and quadrupled (except from Church gate to Mumbai Central) up to Virar on Western Railway and Kalyan on Central Railway in stages. One pair of lines is used exclusively for suburban trains and the other pair also used for fast suburban services whenever path is available after catering to the long distance trains on the inter-city lines on both Railway systems. Central Railway has another exclusive suburban rail corridor from CST to Navi Mumbai via the harbor area. The route network of suburban Railway in Mumbai Region is about 120 km on Western Railway and 280 km on Central Railway. The fleet strength comprise of 86 nos 9 car sets and 24 nos 12 car sets on CR and 41 nos 9 car sets and 31 nos 12 car sets on Western Railway. D.C. electric traction (1500 V DC) was introduced on both the systems as early as



Courtesy: MMRDA

Note: Sea and water bodies not shown

**Figure 7.11** Mumbai Suburban Rail System Map

1926 and sections are being converted to 25 KV AC progressively. The network extension to Navi Mumbai was started in 1986, applying the new cost sharing formula for suburban railway systems viz., sharing on in the ratio of 1:2 between Railways and State Government. Operation however continues to be that of the Indian Railways. Figure 7.11 shows different suburban rail lines and proposals for additions/extensions.

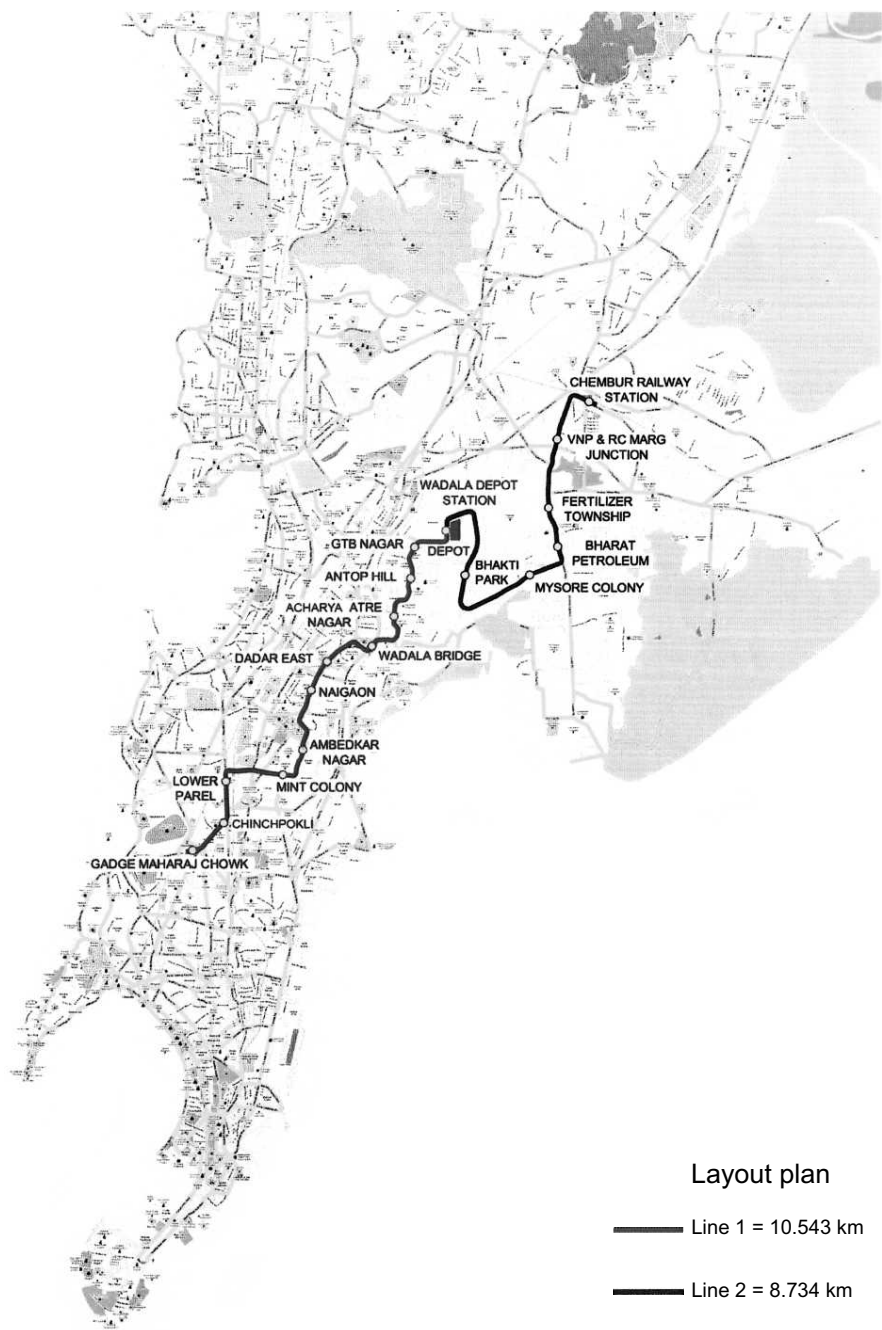
Work of adding some more parallel lines wherever land space is available and optimizing the existing system is in progress. There are bus stops or stands provided at a number of stations for transfer of bus passengers from services run on transverse roads linking to the neighborhoods in the interior. The suburban railway carries bulk of commuters. In 2005, it carried 7 million passengers while buses carried 3.55 million (5.5 million including the access/ingress passengers from trains is included). In 2005, Western Railway operated 813 services and Central railway 1186 trains.

Mumbai has been conducting studies since late 1960s for improving quality of service for urban commuters. It has long since been realized that there are limitations in expanding present suburban rail and bus services. Railways established a Metropolitan Transport Project (Railways), which has been recommending provision of metro rail system.

To supplement suburban railways, many corridors had been identified but none could be taken up for want of funds. With the subject of Urban Rail Transport being transferred to Ministry of Urban Development, Railways are now confining themselves to optimization of the existing system and providing some parallel corridors and extensions in Navi Mumbai, for which a separate unit Mumbai Rail Vikas Ltd (a joint undertaking of Indian Railways and Maharashtra State Government) has been formed. Mumbai Regional Development Authority has conducted a number of surveys and has drawn up a plan for new Metro rail corridors, some Monorail Corridors and a number road based projects. Figures 7.12 (a) and (b) show the major metro rail lines and Monorail proposed respectively. They have proposed to carry out metro rail lines and Monorail lines on BOOT basis, through public-private participation. The first metro rail line of 11.07 km is under construction between Versova and Ghatkopar via Andheri by a Special Purpose Vehicle led by Reliance Infrastructure Ltd and is expected to be operational in 2013–14. This will be to 1435 mm gauge, with 25 KV AC overhead current collection system.

The Versova–Ghatkopar line will be 11.07 km long with 12 stations. The steepest gradient proposed is 4% and sharpest curvature of 100 m radius, the sharpest to be adopted in any metro in India. Such sharp curves are, however, common on Chicago rail transit. The platforms will be on sides and 135 m long about 12 to 13 m above ground level. Stations will be at two levels, the intermediate one serving as concourse with AFCs (Automatic fare Collection machines) and other offices. Lifts and escalators will be provided for access to both levels. Clearance for the road below is 5.5 m. They propose running 4/6 car trains. Traction will be with 25 KV AC overhead current collection. Coaches are designed for 80 kmph maximum speed and service speed average is expected to be 33 kmph (acceleration 1.0 m/sec/sec and deceleration 1.2 m/sec/sec). The design capacity is 60000 phpd and projected trips are 4.75 lakhs to start with and 8.03 lakhs by 2031. The project is expected to cost Rs 2356 crores (Rs 650 crores equity and debt: equity ratio being 30%:70%). It is being executed on BOOT basis.





Courtesy: MMRDA

**Figure 7.12 (b)** Layout Plan of Proposed Monorail Line at Mumbai

The Monorail vehicles will be 4 car units with carrying capacity of 568 passengers. Design speed is 80 kmph. Average speed will be 31kmph and trains will be run with design headway of 3 minutes. Section 1 will have 11 stations and section 2 will have 7. Work commenced on Section 2 in November 2008 and is expected to be completed by May 2011.

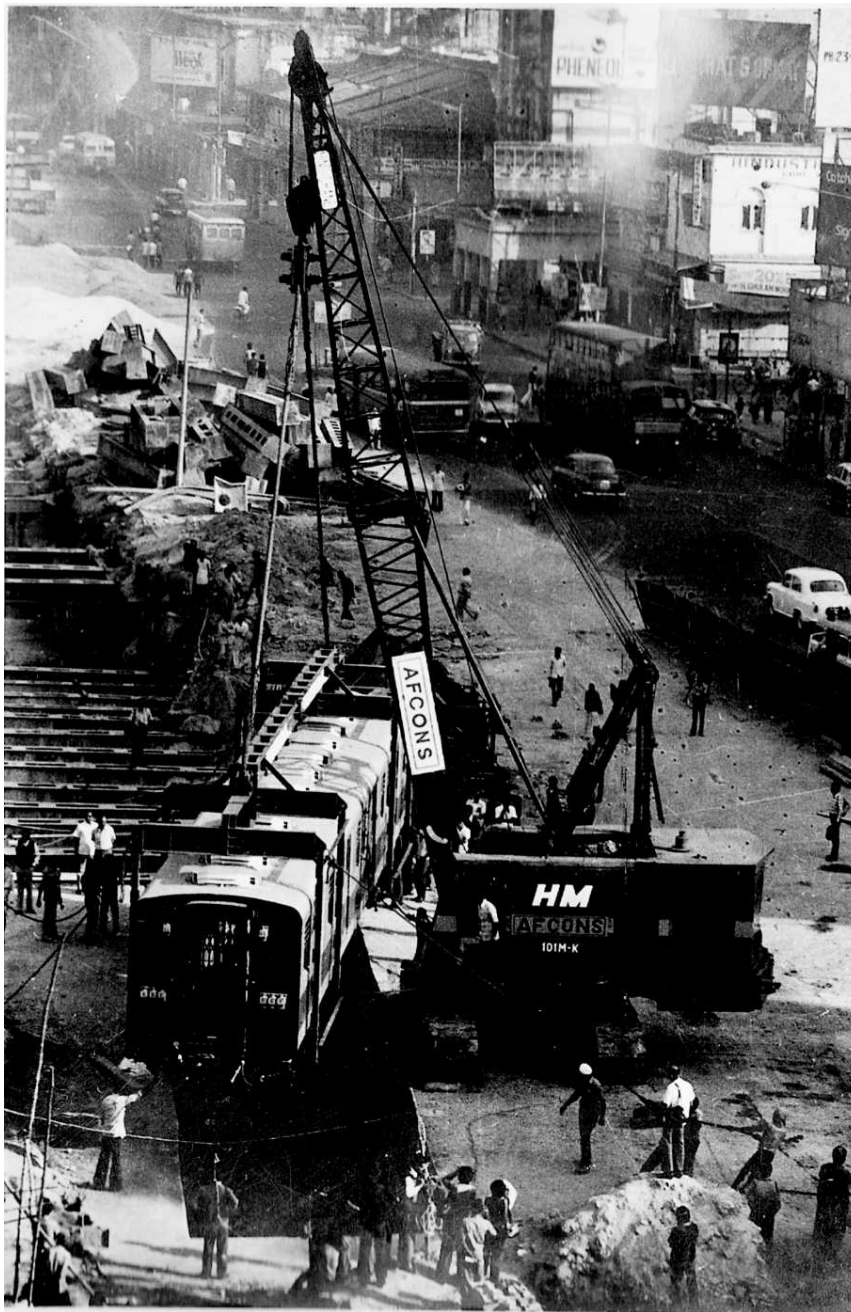
### **Kolkata<sup>15</sup>**

Kolkata is a major metropolis, which in 1960s approached the Railway Ministry for a Metro rail system in the city to ease traffic congestion on roads. It is the only city in India which realized the utility of tram system and retained it, while all the other Indian cities which had tram removed them. The then Chief Minister of West Bengal felt the need for a metro rail in the city as early as in 1949. The city had a study carried out by some French Experts who carried out a traffic study, but that study could not come to any conclusion. Indian Railways established a Metropolitan Transport Project (Railways) organization in Kolkata to take up the study for rail transit system for the city. It drew up a Master Plan in 1971 for five Metro lines totaling 97.5 km in the city. This was reviewed and 3 corridors were shortlisted (Dum Dum to Garia, otherwise called Kavi Nazrul; Bidan Nagar to Ramrajatala; and Dakshineshwar to Thakurpukur) and out of this, the first was chosen on priority. Even out of this, the stretch from Dum Dum to Tollygunge was decided to be taken up. This is 16.75 km long line with 15 underground stations and two on-surface stations, i.e., at either end. A short length at Dum Dum end is elevated and remaining length underground.

Work for this underground metro line on Dum Dum – Tollygunge was commenced on 1<sup>st</sup> June 1973, but there was very little progress on the project till 1978 due to inadequacy of funds, problems connected with relocation of utilities, court injunctions; and problems in regular supply of essential materials. That was a time when the country had foreign exchange shortage and work had to be done mostly by adoption of indigenous expertise, materials and technology. The tunneling work was done by cut and cover methodology using diaphragm walls or sheet piling and using decking plates/units for passage of road traffic, except for about one km length. This length crossing a major railway line, tunneling had to be done using shafts, shields, tunnel boring machine and compressed air. Equipment for this was imported from Russia and Russian experts provided required advice in their usage. Where roads were wider, e.g., NSC Bose Road in Esplanade area, work was quicker. A 3.04 km length between Esplanade and Bhowanipore (isolated length) was ready by 1984. Simultaneously the coaches for the metro had been designed and manufactured by the Integral Coach Factory (ICF) at Chennai. Electrical equipments were supplied by NGEF, a public sector unit of Government of Karnataka and BHEL Bhopal, a public sector undertaking of GOI (Government of India). First set of a four car train was brought to site and lowered on the underground line by making an opening through the road and ground below. Operation on a single line working was started in this isolated section in 1984. Figure 7.13 shows one coach being lowered.

Two years later, a short length Dum Dum to Belgachia at northern was also ready and opened for traffic. The full length was completed and commissioned in 1995. The 16.75 km line cost Rs 1825 crores fully funded by GOI by special allocation to Indian Railways under Urban Transport





Source: Metro Rail Kolkata

**Figure 7.13** Lowering of a Coach for Kolkata Metro

head of account. The gauge adopted is BG, 1676 mm. In order to keep tunnel profile low, the body profile of Meter Gauge coach dimensions was adopted. The tunnel ventilation is by forced air, cleaned and cooled. Train formation is 8 coaches making a length of 162.4m, and total capacity 2590 passengers per train. They are run on 750 KV DC system with current collection from third rail. They are capable of 55 kmph maximum speed and average speed works out to 30 kmph. The system is provided now with ATS (Automatic Train Stop) and ATO (Automatic Train Operation) facilities. Eighteen numbers of the old train sets, which are non-AC are being replaced with new modern AC coaches. Two sets of new coaches are already on trial. Nine more sets will be new coaches while seven are proposed to be made up of existing coaches refurbished with modern equipment and air conditioning.

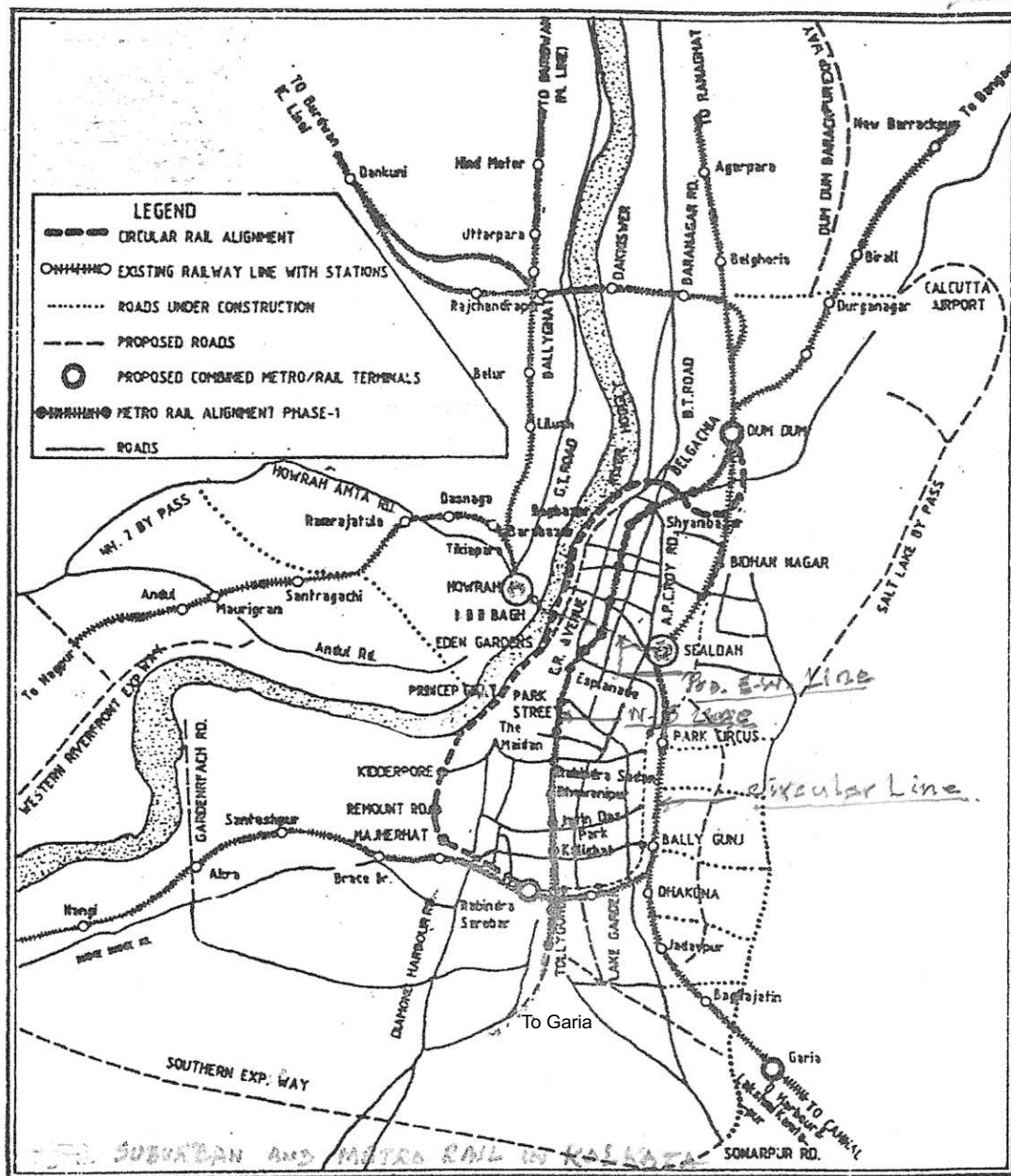
The line has since been extended at southern end from Tollygunge to Kavi Nazrul by elevated track. With the extension, total route kilometerage is 25 km and a total of 23 stations. The six additional stations are elevated. The line is proposed to be further extended from Dum Dum end also and beyond Garia. Trains are presently run at 6 to 8 minute intervals in peak hour and 10 to 15 minute intervals in off peak hours. It carries at present about 5 lakhs passengers per day. The fare is kept very low at Rs 4 for lowest slab of 5 km and maximum of Rs 12 for distance above 20 km. Multi ride ticket of 12 and 48 rides are offered at reduced rates.

The city has started work now also on the building of the originally proposed east–west underground line. Figure 7.14 shows the alignment of the Metro line, Circular rail and other rail lines in around city area.

## Delhi

Though the capital of the nation, Delhi had no rail based commuter system. The old city is densely populated with very few wide roads. It has a few railway lines radiating out, The New Delhi area has been developed with wide roads. Except for the central Connaught Place (Rajiv Chowk) and Central Secretariat areas, it comprised of widely spread residential areas. City received the displaced persons from across the border after partition and with their settlements, it spread out radially. Number of busy radial roads started developing. Planners developed ring roads connecting various nodes on the radial roads. The city became dependant on bus as the sole public transport option, when the city started developing rapidly by widely spreading out on either banks of Yamuna River. Major inter connecting roads, both radial and ring roads started being congested. Realising the need for developing a rail based public transport system for the city to complement the road transport, the Railways set up a Metropolitan Transport Project (Railways) organization and the DDA (Delhi Development Authority) planners also commissioned CRRI (Central Road Research Institute) to do a comprehensive traffic and transportation study at the same time in 1970s.

Based on the traffic studies and their own studies, MTP<sup>®</sup> (Metropolitan Transport Project (Railways)) developed alternative schemes for developing metro rail corridors, some following existing lines and some radial. No decision could be taken, mainly for want of funds. Though about thirty different proposals including an LRT network were investigated, no major corridor materialized. There was a proposal for EMU services on a ring railway also linking the radial lines.

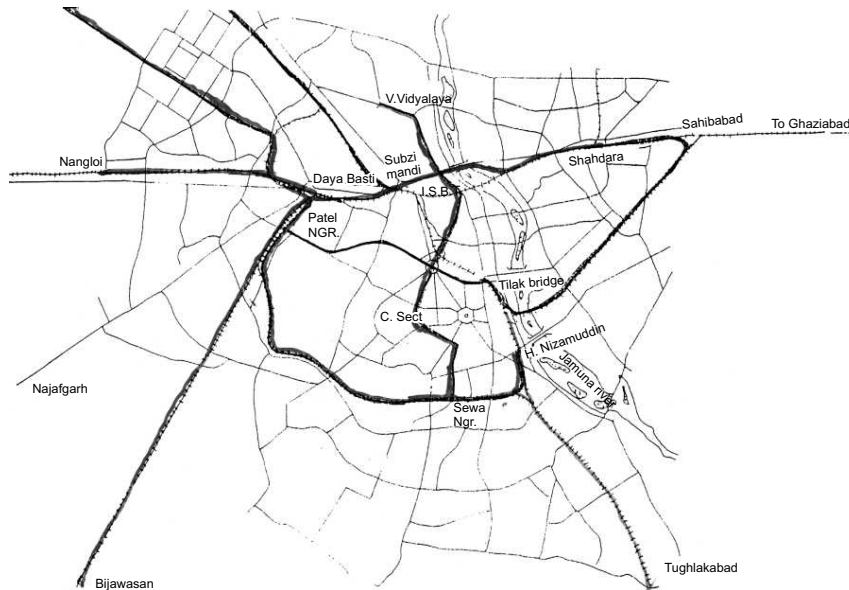


Source: RITES Report on 'New Rail lines in and around Calcutta' 1982

**Figure 7.14** Kolkata System Map

The ring railway project was approved and implemented as a part of road and rail infrastructure projects for Asian Games in 1982. But the ring railway suffered from poor patronage. In 1984, the Delhi Development Authority and the Urban Arts Commission recommended that a metro rail network system should be built in Delhi.

MITES, a Public Sector Transport Consultancy Undertaking under Ministry of Railways was then commissioned by Delhi Government to carry out the studies for a metro rail system. Based on updated traffic surveys, MITES were asked to identify the corridors and design a suitable system. Consultants considered a number of alternatives and finally recommended an Integrated Multi-modal Mass Rapid Transit system and identified a number of corridors, partly surface along existing rail lines and elevated following road or road. A north south underground line was also recommended. The recommended network is shown in Fig. 7.15. They recommended the north-south underground and two east-west at-grade/elevated corridors to be taken up in Phase I. This proposal was approved by both Central and State Governments in the middle of 90s.



Source: MITES Report on IMMRST for Delhi 1997

**Figure 7.15** Basic Metro Rail Network Considered in 1998 for Delhi

Delhi Metro Rail Corporation (DMRC) was set up jointly by Central Government and the Delhi State government with an experienced railway engineer as its Managing Director in 1998. DMRC was given full powers to hire people, decide on tenders and control funds. Japanese Bank for International Co-operation came forward to provide soft loan to cover a little over 50% of funds required. These two factors helped in making fast decisions and uninterrupted implementation of the project. DMRC made a start immediately on detailed survey and planning for the North-South and

a modified East–West line and two Depots. Actual construction was started in 1998. Part length of the first line (Red line) of 25.1 km with 21 stations, mostly elevated with a small surface length, was completed in 2002, as targeted. The first underground line (Yellow line) was partly commissioned in December 2004. The phase I work of 65.11 km including 13.1 km underground was completed in October 2006. This has been done adopting 1676 mm gauge<sup>15</sup>. Traction is with 25 KV 50 HZ AC system with overhead current collection. Standard gauge (1435 mm) has been adopted for the later phases. This is in conformity with the metro rail lines in most of other countries and has wider choice in procurement of coaches and technology. Signaling and operating systems are most modern CATC with cab signaling, ATP (Automatic Train Protection) and ATC (Automatic Train Control). Automatic ticket vending machines are used in stations and smart card facility is available.

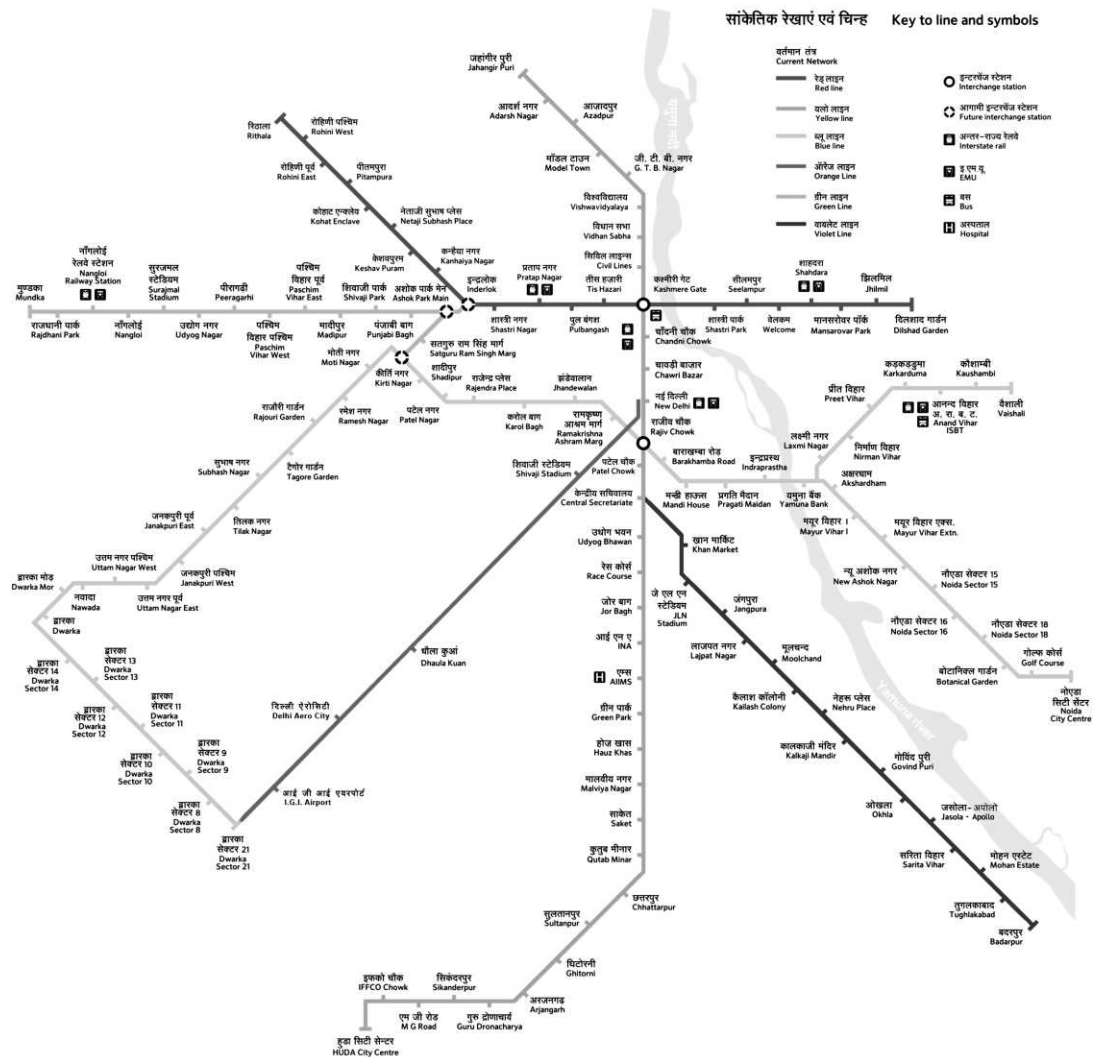
Simultaneously identification of corridors and surveys for Phase II was being carried out by DMRC. Phase II work of 128 km and 79 stations was started in 2003 and was completed by October 2010. By October 2010, just 12 years after construction started, Delhi Metro has commissioned five lines totaling 156 km with 132 stations covering the entire city and extending up to newly developed satellite cities of Gurgaon and Noida. An Airport Express line 22.7 km long with 5 stations being done on PPP basis is awaiting commissioning. Such fast progress has been possible due to the uninterrupted flow of funds and fully empowering the organization to take decisions with no external interference. It can also be attributed to one and same person heading the organization during this period and full commitment of the staff to adhere to targets.

The cost of Phase I and II is reported to be Rs 14,350 crores. The funding pattern comprises of 30% as equity by the two governments, 60% loans (major part from JICF) and subordinate debt and balance 10% through internal resources of property development and revenue surplus. Delhi metro rail is one of the five metro rail systems in the World, which are earning a revenue surplus and self sustaining. The system carried about 1.47 million passengers per day in August 2010. In Financial Year ending March 2009, the system earned revenue of Rs 723.77 crores which resulted in a surplus of Rs 90.43 crores before taxes. The fare charged is Rs 8 at lowest slab up to 5 km and Rs 30 for distances above 44 km. The fare structure is fixed by a Fare Fixation Committee (FFC), presided over by a retired high Court Judge and two other senior government officers. The latest revision was done in 2009 by the third FFC.

Phase III work of 112 km is being taken up with target date of 2015 and DMRC is planning for a 108.5 km Phase IV to be done by 2020, taking total network to over 400 km. Figure 7.16 shows the system.

### **Chennai<sup>16, 17</sup>**

Chennai is the third Indian city which has an electrified suburban rail system functioning since 1931. It comprised of three main corridors covering a distance of about 120 km, of which the main corridor used to be in Metre Gauge. The city has also a well patronized State run bus transport system. Due to lower fare levels on buses and availability of many bus routes parallel



Courtesy: DMRC

Figure 7.16 Delhi Metro Rail System Map—as in December 2010

to the suburban rail lines and to some extent lower frequency of services on some corridors, the patronage of trains had been only about an eighth of bus trips till recently. After the main suburban rail corridor was converted to BG, the traffic has picked up. Presently, the ratio is about 1:4.5. A Metropolitan Transport (Rail) unit was set up Chennai also in early 1970s. The city urban planners carried out a detailed Traffic and Transportation Study in 1971–74, which recommended a metro rail network comprising of one North–South–East line on the coastal belt and a ring railway at the periphery of city limits connecting four major urban nodes. It was to be done in three major phases. The North–South–East line starting from Manali up to Kasturba Nagar (Mylapore) was initially planned to follow mostly road alignments from Manali to Mylapore with partly elevated and partly underground construction to be continued along the Buckingham Canal as elevated up to a little beyond Kasturba Nagar. Beyond up to the Car Depot at Taramani, it was to be ‘at grade’. An alternative to this was also considered following Buckingham Canal from Thiruvottiyur to Basin Bridge and a road alignment from Basin Bridge to Chennai Central beyond which it was to follow the Cooum River and Buckingham Canal alignment up to Kasturba Nagar. A Ring railway (ICC Rail) alignment was proposed parallel to the then proposed Inner Ring Road. The system was proposed as an RTS with 750 V DC traction using third rail current collection, similar to what had been proposed for Kolkata. These corridors included in the First Master Plan for CMA and land reserved.

The project did not take off due to fund constraints. Finally a modified scheme adopting the canal alignment mentioned above with the RTS starting at Chennai Beach and following the Cooum River and Buckingham Canal alignment from opposite to Chennai Central. Revised scheme proposed using EMU trains run on suburban rail, so as to reduce costs and minimize land acquisition problems. It would also facilitate extending some of the trains from the system towards Gummudipoondi and Thiruvellore suburban lines. The elevated structure concept was adopted from Chintadripet onwards to Kasturba Nagar. The work on first 8.3 km from Chennai Beach to Mylapore was sanctioned in 1985, preliminary works land acquisition and of rebuilding infringing structures including rebuilding the Stanley Viaduct in front of Central Station having been started in 1986. Actual field work on the line was started in 1991. It was completed in 1997, delayed due mainly to fund constraints.

In the meantime, there was change in policy of providing funds for such metros and the principle of cost sharing between Railways and State governments was evolved. Next stage of the extension of the line was decided to be up to Velachery (just beyond Taramani) which had been, by then, growing as a major suburban node. This work was partly completed and commissioned with single line working in 2003 and fully in 2007. Velachery station and the car shed nearby are at grade. The line is being presently extended by about 5 km more up to St Thomas Mount as elevated structure following the alignment of Inner Ring Road. St Thomas Mount is a major suburban station on the Tambaram–Beach suburban line. This BG line from Chennai Beach, for most part elevated has been done to full metro rail standards, except that normal EMUs are operated on the same and conventional color light system of signaling is used. This stretch is called MRTS and is being terminated at St Thomas Mount from where the Line 2 of the metro rail starts. Though this 20 km line was fully operational with 10’ minute services in peak hours, the patronage has been far lower

than estimated by different modeling approaches. It is hardly 100,000 passengers per day while the other older suburban lines of about 120 km carry over 10 lakhs passengers and there is steady growth of 2% per annum. This low patronage on MRTS can be attributed to the catchment area of the corridor being residential on one side and Institutional on the other side for most length; operation of good less expensive bus transport on parallel routes, to some extent inappropriate location of some stations and lack of feeder bus service to serve the residential areas around.

Seeing the success of Delhi Metro rail and at the suggestion of the DMRC, Chennai also decided to go in for a proper metro rail network, after considering an alternative form, i.e., Monorail which could not have met the volume of traffic expected on the principal traffic corridors of the city. Metro rail project was approved in 2007. Initially two corridors have been approved and work taken up<sup>16</sup>. They are shown in Fig. 7.17 Line 1, as now approved would be from Washermanpet in north up to International Airport in south<sup>16</sup>. It will pass through highly congested Thiruvottiyur, Mint, Broadway area, CBD, Chennai Central and Chennai Egmore main line terminals, busy Anna Salai and terminate at airport. It will be 32.1 km of which 14.3 km will be underground with 7 stations and remaining length elevated with 10 elevated stations. Line 2 will be 18.1 km, 9.7 km from Chennai Central to Anna Nagar Second Avenue being underground. It will have 17 stations, 9 being underground. The work on project started in end of 2008 and is targeted to be completed by 2014. CMRL have adopted 25 KV AC with overhead current collection. Signaling and control will be the latest providing for Automatic Train Control and Protection as on Delhi Metro. The two lines are estimated to cost about Rs 14000 crores. The GOI and GOTN will together provide 41% of this, partly as equity and partly as loan and balance is coming by way of soft loan from JICA as in the case of Delhi Metro rail. An SPV in form of CMRL (Chennai Metro Rail Ltd) with representatives from GOI and GOTN has been formed to implement and manage the project. Proposals for additional corridors for Phase II have been suggested. Figure 7.17 shows the alignments of Lines 1 and 2 and the MRTS and suburban rail lines.

Recently a network of about 57 km of Monorail on some peripheral and feeder routes has been approved in Chennai on PPP financing basis.

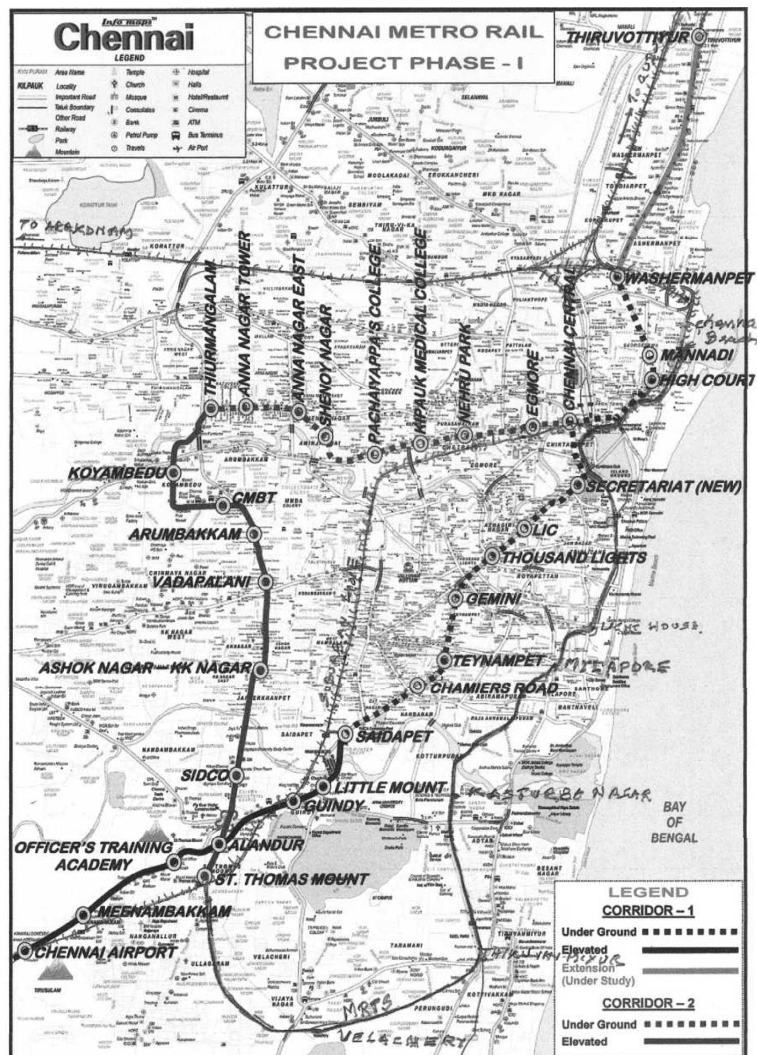
### **Bangalore<sup>17, 18</sup>**

Bangalore is a fast growing city with many industries and is the IT hub of India. Its growth from both spatial and demographic points of view has been phenomenal in the past three decades. The Metropolitan area is spread over 437 sq km and has a population of about 7 million. Next to Delhi, this is the city with maximum vehicular population with over 70% of them being two wheelers.

It has a good railway network on a radial and semi circular pattern and heavily used for inter city travel. The main corridors are intensively utilized and have no spare capacity to run commuter trains. Due to space constraints and fairly steep gradients, expansion of the system has been found difficult. A number of studies, one sponsored by World Bank, were conducted for introduction of commuter rail service but none could be implemented so far. The GOK commissioned MTP<sup>®</sup> Chennai in 1983 to conduct a study for introduction of metro rail service in the city. They carried out a detailed study including a traffic study by the Indian Institute of Management Bangalore



(IIMB) and came up with proposals for an east–west (Hudson Circle to Krishnarajapuram) and a north–south (Rajaji Nagar to Jayanagar) RTS corridors following main road alignments and a circular railway partly following Railway alignment and partly the ring road. This, again, could not be taken up for want of funds mainly. As an alternative, GOK did a detailed study for an Elevated Light Rail Transit System network in early years of this century and had set up an organization to implement it also. With the advent of DMRC and seeing its success, GOK engaged DMRC to carry out a study for introduction of a full metro rail system in the city. DMRC carried out this study

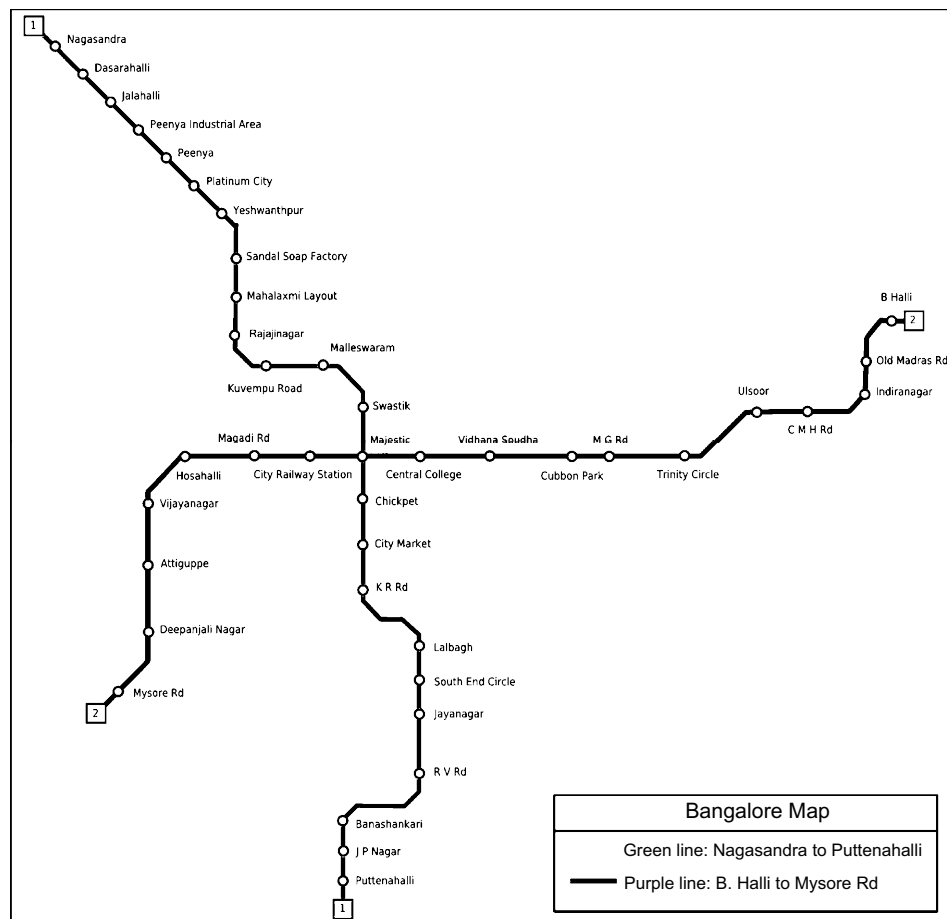


Source: CMRL

Figure 7.17 Metro Rail Phase I lines and Other Commuter Lines in Chennai

in 2005 and came out with specific proposals for two corridors (33 km) one from Yeshwantpur in north to R V Road in South and the other from Mysore Road in west to Baiyyappanahalli in East with a Depot at Baiyyappanahalli. GOI also was interested in implementation of this scheme and some financial institutions came forward to provide loans for same.

The Phase I project of 33 km was sanctioned in mid 2006 and taken up in 2007. Two extensions, one in north and another in south have also been sanctioned since, to be done in continuation, making east–west line 24.2 km with 24 stations and north–south line 18.1 km with 17 stations. It is all elevated except for central 3.4 km of east–west line and central 3.3 km of north–south line which are underground. Majestic station at intersection point is two level underground station. Perhaps this is the first two level underground station to be built in India. The other special feature of this metro is that a transfer line between the two corridors is being provided at Majestic for transfer of train sets between the two lines under ground. The two corridors are shown conceptually in Fig. 7.18.



Source: BLR Metro Rail Mesource Wikipedia Free Encyclopedia

**Figure 7.18** Bangalore Metro Rail—First Two Lines—General Layout

An SPV designated BMRC (Bangalore Metro Rail Corporation Ltd) with representatives from GOI and GOK has been formed for implementing and managing the links. The gauge adopted is standard Gauge 1425 mm, traction 750 DC with third rail current collection. The total cost of the Phase I project is estimated at Rs 8159 crores and the financing pattern is in form of: Equity of 15% each from GOI and GOK, Subordinate debt of 10% from GOI and 15% from GOK and balance 45% taken as Senior Term loans from financial institutions, repayable partly over 15 years period and partly over 25 years. The latter funds come from insurance companies and some PF administrators. This part financing of a metro rail project with indigenously obtained loan to an extent of Rs 3651 crores is another special feature of this project. It is worth noting that GOK is the first State Government in India to impose and collect a fuel surcharge and a cess on stamp duty in the city, which can help the system to cover part costs of such urban transport projects. It is learnt 27% of the collection will accrue to the Metro rail. They also propose keeping the fare at 1.5 times bus fare only. The traffic condition on roads and the choice of alignment are expected to divert large number of trips to the metro rail, as observed in Delhi. Part length from MG Road to Bayyapanahalli has been commissioned since October 2011.

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## 8.1 SYSTEM CAPACITY

### 8.1.1 System Requirements

Any rail system comprises the following components:

- (a) Formation of basic support structure and grade separation
- (b) Track
- (c) Over-head or line side traction equipment
- (d) Safety and controlling equipment namely signals
- (e) Stations-operational facilities, passenger facilities, station equipment, communication facilities, security
- (f) Control centre/room
- (g) Repair and maintenance facilities and stabling lines
- (h) Coaches or cars—both motor, non-motor trailing and those with cabs.

### 8.1.2 Capacity and Right-of-Way

The line capacity is defined as the maximum number of trains which can be run on a section per day or per hour in case of urban transit lines. This depends on the minimum headway between trains, which is dictated by spacing of signals for train following one another in double line (as available mostly in major cities) at a safe braking distance for the train plus adequate distance of extra safety. Headway is defined as the time elapsing between operations of successive trains. On surface lines with at-grade crossings, the headway also depends on acceptable limits of time for holding up road traffic on at-grade crossings, if any. This varies now from 2.5 to 3 minutes in peak hours to 5 to 10 minutes in off-peak periods. With more advanced train control systems, the headway can be as low as 90 seconds to 2 minutes. This is feasible only if there is no grade crossing and entire right of way is properly fenced and the cars are provided with cab signaling and automatic train operation and control.

The Regional and Suburban Rail Systems are mostly surface lines used for both intercity traffic and to some extent in the vicinity of large cities for commuter traffic. In this case, the tracks (generally double line) are carried on a made up formation, either bank or a cutting according

to the terrain it passes through. Its alignment and level are governed by the minimum radius of curvature, the vehicles can take at a safe speed at allowable cant and the ruling gradient is dictated by the trailing load of trains and hauling capacity of locomotives. It needs a clear right-of-way (ROW) of about 30 m. The radius of curvature is generally restricted to 300 m on Broad Gauge and it can go down to 200 m on Standard Gauge (1435 mm). Gradients on surface lines follow the nature of ground and are generally restricted to 1% except where they have to negotiate some flyovers or lines in undulating topography as in Bangalore. For example, there are a few 1 in 37 gradients on the Harbour line at Mumbai.

The formation on top is made up of minimum width required for laying the track and the ballast and also access for movement of maintenance staff, e.g., for Broad Gauge in India (1676 mm gauge) the top is provided with a cross slope of 1:30 to 1:33 falling towards edges from the centre. Where soil is not good, the top 60 cm depth is usually laid with a granular material which will facilitate good drainage and prevent ballast puncturing. Nowadays, a geo-textile sheet is also spread on top of bad banks below ballast or sub ballast to serve the same purpose. Over such formation, a layer of broken stone ballast (maximum size 45 to 50 mm) and of minimum depth of 150 to 300 mm depending on importance of the line (i.e., density and speed of traffic) is used. Since the transit lines will be invariably electrified and track circuited only wooden or concrete sleepers are used. Rails may be welded in short or long panels to reduce joints. Long panel welding is generally restricted to flatter curves of radius 800 to 1000 m or more.

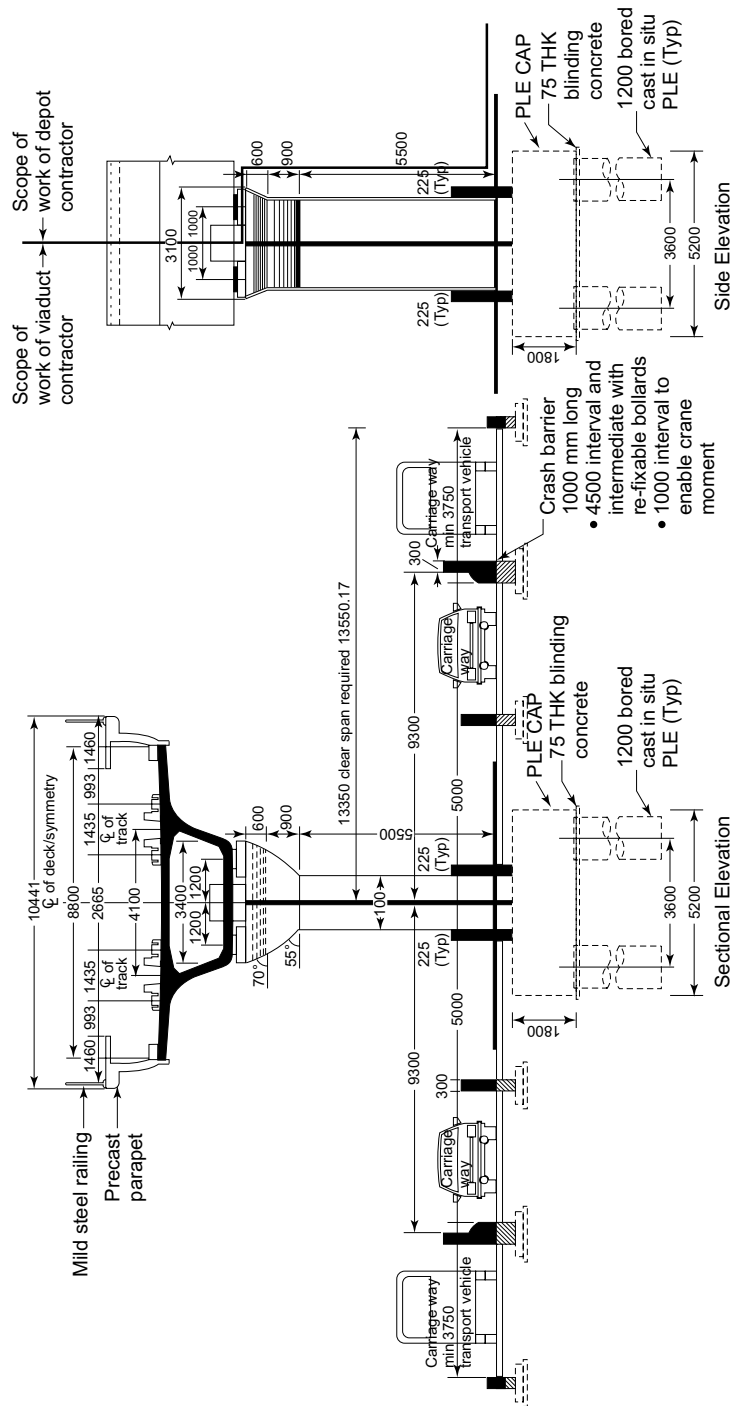
Whenever the line crosses a road, a road over bridge is considered justified and desirable in order to maintain frequency of trains and avoiding delay to crossing road vehicles. Most suburban rail lines in urban areas of Indian cities continue to be surface lines as laid originally, except for a 20 km length of MRTS in Chennai.

### **8.1.3 Constraints**

The major constraints in providing surface lines in cities are in respect of extra land needed for the right-of-way (ROW), which is difficult and expensive to acquire. Secondly, the lines would cause obstruction for cross movement of people/vehicles who have to reach their locations across. Unless closely spaced road over/under bridges and foot over bridges are provided, there is considerable time and extra energy spent by people/vehicles to move across. Trespassers cannot be easily prevented from crossing and causing accidents unless high boundary walls are provided on either side. Even boundary walls are sometimes broken and people gain access to and across the lines.

## **8.2 ELEVATED RAIL**

In order to get over the difficulty of acquiring large areas of land, the railway track can be laid on elevated level also. As mentioned earlier, the earliest form of elevated RRT was used in Chicago and many cities like New York in USA following street alignments. They comprised track carried over steel girders supported by steel trestles. On many roads, they were provided over the pavements on either side of the road. With the advent of tube railways and due to complaints made by residents regarding the smoke, dust and noise nuisance, cities like New York gave them up and went in



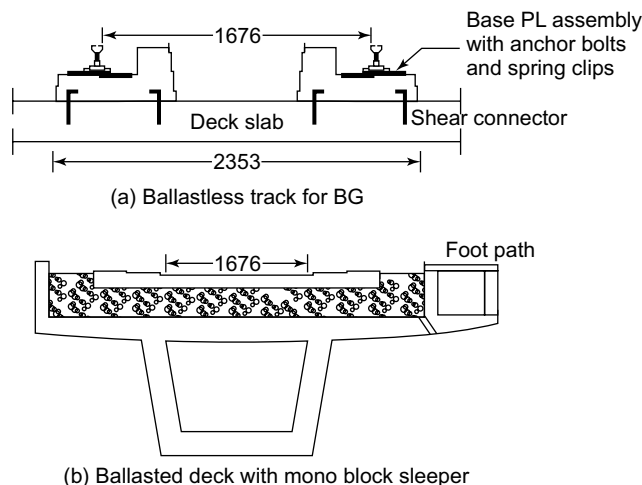
**Courtesy:** CMRL – © CMRL

**Figure 8.1 (a)** Elevated Structure on Chennai Metro Rail Line

for underground railways in busy localities. Some of the old steel elevated structures can be seen functional even now in New York and Chicago.

With the development of concrete and prestressed concrete for structures and ability to provide structures with pleasing views and less noisy tracks, this form of RRT structure has again found favor. The elevated structures under new development was used for Monorail first but, later it has become popular with Duo rail also. Structural forms can be chosen to suit the environment in the area. Noise emanating from track is reduced further by providing baffles and suitable parapet walls on sides in busy localities, so designed as to dissipate and deflect the direction of noise. It is not difficult now to limit noise to tolerable levels. A typical structure used on the Chennai Metro rail line in Chennai is shown in Fig. 8.1(a).

Though elevated or aerial lines are expensive in initial construction, their maintenance cost is very low. It involves considerable saving in right-of-way cost, particularly in busy areas where it can follow the road alignment. By providing slender piers and overhanging decks, space below can also be utilized as shown schematically in Fig. 8.1(a). Since the railway lines cannot be laid at very sharp radius as is possible with roads, some constraints will be felt in busy areas where the alignment will have to be deviated or costly properties will have to be acquired. Track on decks of elevated structures can be laid with ballast or ballastless. (Fig. 8.1(b)). While the ballasted track causes less noise and is less expensive in initial cost, it is expensive to maintain and it can cause dust nuisance. The ballast may need recoupmnt to an extent of 10% to 12% per annum and periodical packing will be called for. It also adds to dead load and requires slightly heavier structure. The ballastless track, on the other hand, is more expensive to provide, easier to maintain and needs special noise dispersal provisions in busy areas. This is discussed in more detail in Para 8.3.2. A ballasted track costs Rs 10 to 12 million per km, whereas ballastless track would cost about Rs 30 million per km (in 2004 costs). Cost advantage of elevated structure has weighed so heavily with Chicago that it has 62.7 km of its total 144.8 km of RTS elevated and in Singapore about 40 km out of 67 km of Phase I is on elevated structures.



**Figure 8.1 (b)** Ballastless and Ballasted Tracks on Elevated Structures



## 8.3 UNDERGROUND SYSTEM

### 8.3.1 General and Technical

Most of the RRTs built earlier are wholly or for most part underground. The construction of underground system consists of providing an artificial tunnel sufficiently below surface and service (sewage/water supply) lines for running a railway system. It invariably comprises a pair of tracks either carried within the same tunnel profile or in separate 'tubes' one for each track. The earliest used sections were mostly circular (or in oval form in some cases) but later box type became common with cut and cover method. The cut and cover method consists of open excavation to the required level, after providing side supports for cuts in the form of piles or diaphragm walls.

Figure 8.2 shows sequence of cut and cover construction. Considerable technological improvements have taken place in the 'cut and cover' method of construction, which earlier depended on sheet piling, driving of which caused heavy vibration. Diaphragm walls can now be constructed in the form of thin RCC sections in trenches made by grabbing soil and retaining the sides with bentonite slurry. Once the diaphragm walls on either side of the box section are constructed, they are strutted across at suitable intervals vertically and horizontally and open excavation for tunnel box can be proceeded without fear of collapse of sides. As excavation proceeds, strutting is done between the diaphragm walls. Once the proper level is reached, the box section can be built up or precast box sections lowered and properly jointed. During this period, cross frames and deck plates can be erected on top for carrying the road traffic at restricted speeds.

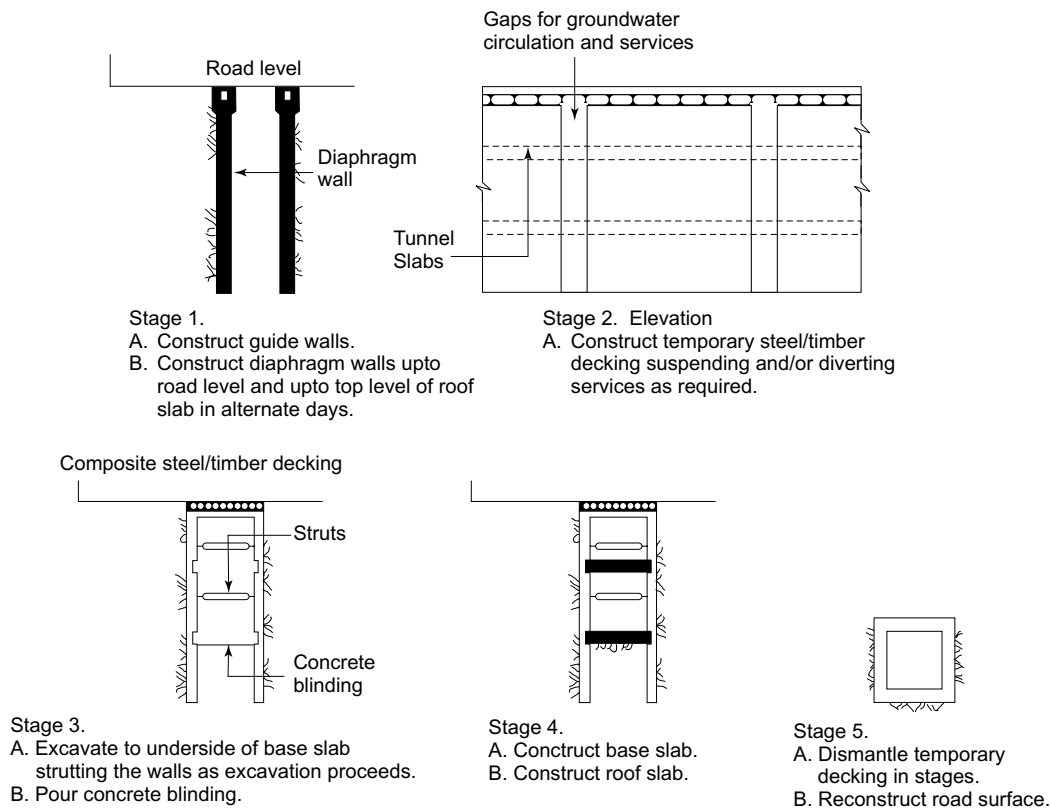
Where depth is considerable or where they have to deflect or turn around (when the alignment would cut across buildings) or where roads are not wide enough, the tunnels are bored through. This boring is most convenient in a circular form, particularly in normal soils. Tunneling by boring is done with mechanical cutters and tunnel boring machines (TBM). Where there is heavy seepage of water, work is carried out using compressed air to keep seepage water out. In some cases, sides can be retained by using bentonite slurry also. These bored holes are all properly lined with cast iron rings or precast concrete elements suitably grouted at joints or by casting the lining in situ. Former is faster and preferred. Figure 8.3 shows a typical tunnel boring machine.

### 8.3.2 Track

In the older form of underground railway lines, the track consisted of rails, sleepers and stone ballast. The sleepers were of timber, as the track had to be track circuited for signaling purposes. Normal side drains were provided and the length was given a gentle grade (a minimum of 1 in 1000) for drainage. Now concrete sleepers or plinths are used ensuring longer life and needing less frequent replacement. Drained water is collected in sumps at intervals and pumped out.

Ballastless track in tunnels has three advantages:

- (a) Ease of drainage and keeping the tunnel clean.
- (b) Easier maintenance as periodical packing and replacement of caked ballast is not necessary.
- (c) The tunnel profile itself can be reduced corresponding to depth of ballast, which is a big economic advantage.



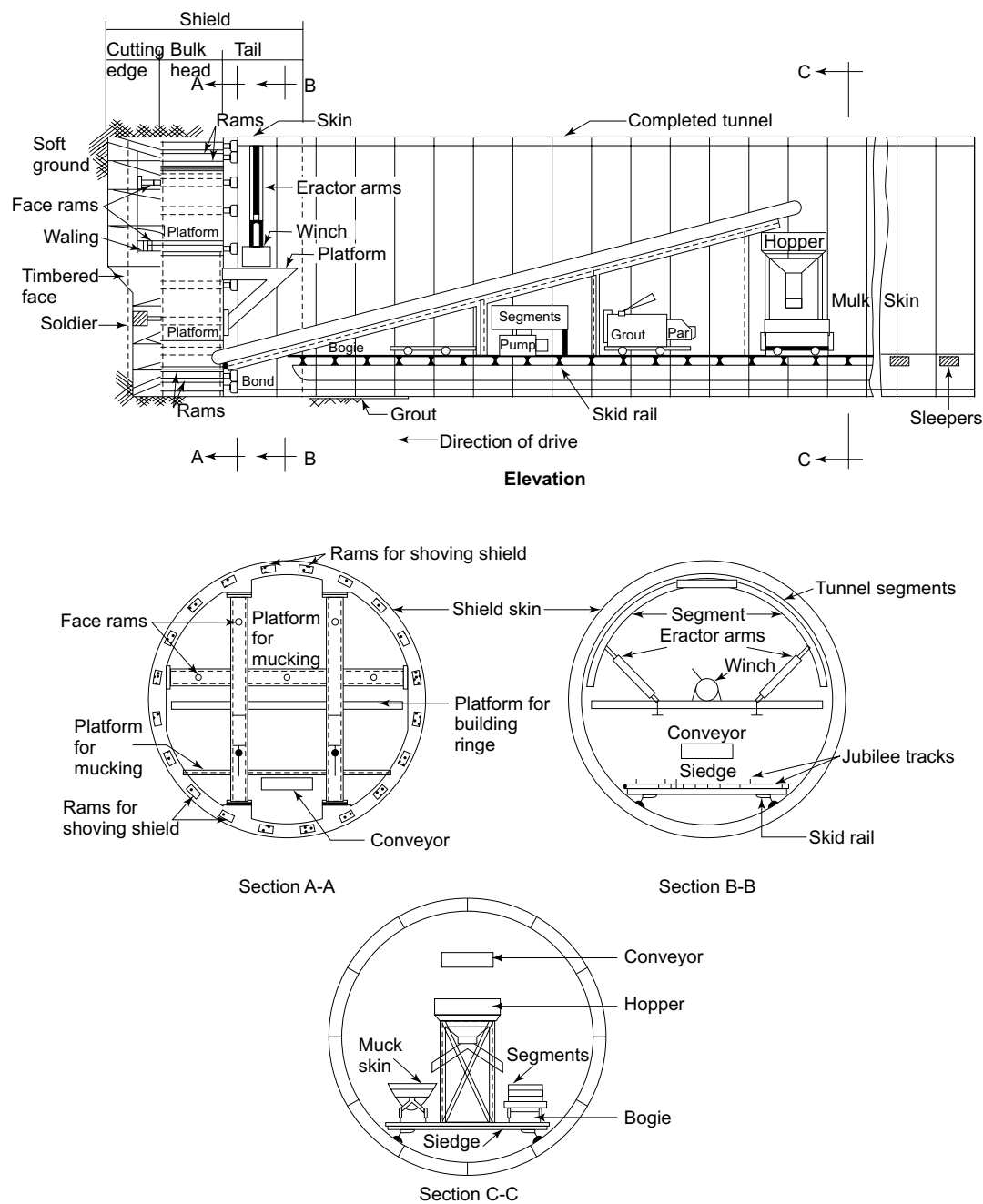
**Figure 8.2** Sequence of Operations by Cut and Cover Method

The main disadvantages of underground construction are the initial higher cost of construction and longer time taken for construction, as well as higher cost of maintenance due to high energy cost in providing adequate ventilation and lighting.

## 8.4 TRACTION ALTERNATIVES AND CHOICE

### 8.4.1 Diesel Rail Cars

Diesel rail cars are still in operation in some places. In some of the RRT lines like New Castle, Diesel rail cars were used till about 1980. These are energy inefficient. They emit obnoxious smoke and hence mostly have been discontinued, as for example in cities like Secunderabad and Bangalore (where they were run in single units). It requires low capital investment (needing no OHE lines) and is suitable in medium size cities and for interconnecting towns. The main advantage is its low turn-around time, due to its having driving cabins at either end. They have higher rates of acceleration and deceleration.



**Figure 8.3** Typical Tunnel Boring Machine

### 8.4.2 Electric Traction

Electric traction has three distinct advantages:

- (a) It is energy efficient. The train does not have to carry the additional weight of fuel also.
- (b) It is the cheapest and cleanest form of energy. Since no idle running of engine is required for quick starting purposes while stationary, there is further saving in energy.
- (c) It provides and much higher acceleration, deceleration and braking capacities, thus reducing the time taken between stations.

In the Indian context, the fourth advantage is that electricity is locally produced from hydro-electric resources or with local coal, leading to reduction in foreign exchange expenditure on import of oil fuel.

There are two forms of current collection for RRT lines, namely, overhead (OH) and third rail (TR). There are also differences in choice of type and voltage of current used in urban transit viz., 25 KV AC, 1500 V DC, 1000 V DC, 800 V DC, 750 V DC and 600 V DC. LRT lines are all on DC system, with their voltage varying as 550, 600 and 750, and they are fed from overhead catenaries.

### 8.4.3 AC vs. DC

The AC collection is a fairly recent choice. 25 KV AC is the standard system for main line electrification on the Indian Railways. This had been chosen in late fifties when mass scale electrification was taken up in India for the following reasons:

- (a) The current conductors can be of smaller sections and thus the catenary system can be economical.
- (b) Sub-stations can be located at farther intervals of 35 to 40 km as against 8 to 10 km for DC and even 5 km for DC busy sections. For lower voltages, still closer spacing may be called for.
- (c) Stepping down from 110 KV supplied by Electricity Board to 25 KV is easier and more economical.
- (d) Locomotives can be made more powerful and efficient with same weight and their tractive effort made more efficient.

The French Railways were the pioneers in adopting this system and probably Indian Railways were the first to adopt it for their suburban sections as well. This system is adopted in the suburban sections of Chennai, Kolkata and Delhi, and was chosen to be compatible with the main lines permitting the use of the same stock on Main lines. But Mumbai suburban section was started with 1500 DC in 1928 when advantage of higher volt AC system was not known. As a historic necessity and considering difficulties involved in form of traffic dislocation during conversion, the same arrangement has been continued. However, this line is also being converted to 25 KV AC, by deciding to use dual voltage vehicle during the interregnum. The higher voltage AC system for RRTs (underground) had not been popular so far due to following disadvantages:

- (a) Though the AC locomotive is comparatively lighter than the DC version for the same operating performance characteristics, this advantage cannot be fully availed of as the power units per

vehicle are proportionately more for the rolling stock for RTS. In fact an AC motor coach is estimated to be 4 tonnes heavier than a DC motor coach of equivalent size and performance. This additional tare weight reduces the carrying capacity for the same axle load. Extra tare weight of 4 tonnes is equivalent to a reduction of capacity of 64 passengers per coach or 192 passengers per three-car unit.

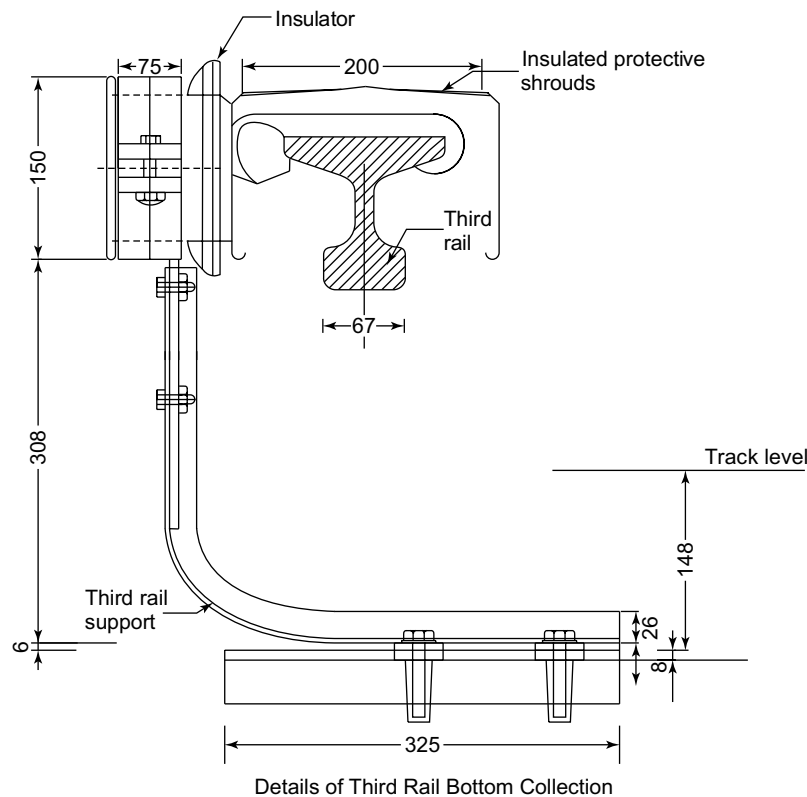
- (b) AC stocks have oil-filled transformers which are potential fire hazards. If these are to be replaced by non-inflammable gas-filled or dry type transformers, which are necessary for underground lines, the weight and cost increase.
- (c) AC system has been adopted only for overhead current collection and not for third rail. For overhead collection, AC requires high clearance, i.e., a height of 5.37 m from rail level to roof. From the point of view of economy, size of the tunnel has to be kept low. This problem has now been overcome by use of trolley bar type of overhead current collection. By special roof held catenary extra space requirement has been reduced.
- (d) The frequent 'Starts' and 'Stops' which are characteristics of RTS presuppose use of dynamic braking, which was not possible with AC traction in the past. In the last decade, however, the thyristor technology has made it possible to adopt dynamic braking with AC.

The DC voltages generally adopted for RRT has been 750 V DC. Higher voltages up to 1500 V have been adopted on a few lines. In new RTS under construction, 750 V DC is still preferred although BART in San Francisco USA has adopted 1000 V DC and the RTS in Hong Kong has used 1500 V DC (with current collection from third rail in tunnel and from over-head catenary in surface and elevated portions). 1000 V DC adopted by BART uses third rail collection. This voltage, however, is not a standard voltage recommended by the International Electro-technical Commission. The choice used to lie between 750 V DC and 1500 V DC. Higher the voltage, higher the section of collector rail and more is the clearance required from running rails. For third rail collection, 750 V DC has been adopted for the RTS in Kolkata and the Metro line under construction in Bangalore. The arrangement adopted is shown in Fig. 8.4. Lower the voltage, closer will be the spacing of substations required for conversion of normal supply of AC power to DC for supply to coaches. This puts up the cost and land requirement in the city, which is difficult to acquire. With technological development in the past decade, the adoption of 25 KV AC traction has also been found competitive and many systems have started adopting this. Entire Delhi Metro system is with this technology. Mumbai and Chennai metro lines under construction have also adopted the same.

## 8.5 SIGNALING AND OPERATING SYSTEMS

### 8.5.1 Signaling

Except for tram stage of LRT, all systems including LRT with tunnel or aerial structure operation need some type of safety and regularity arrangements in the form of signaling. The simplest form of signaling used for urban transit lines is color light signals. These are electrically controlled using low voltage current for their working. In this system, the track rails are used as conductor rails and occupation of the tracks is thus detected directly and a system of relays is used to control and actuate the color light indication on posts. The aspects on the signals are also simultaneously exhibited in



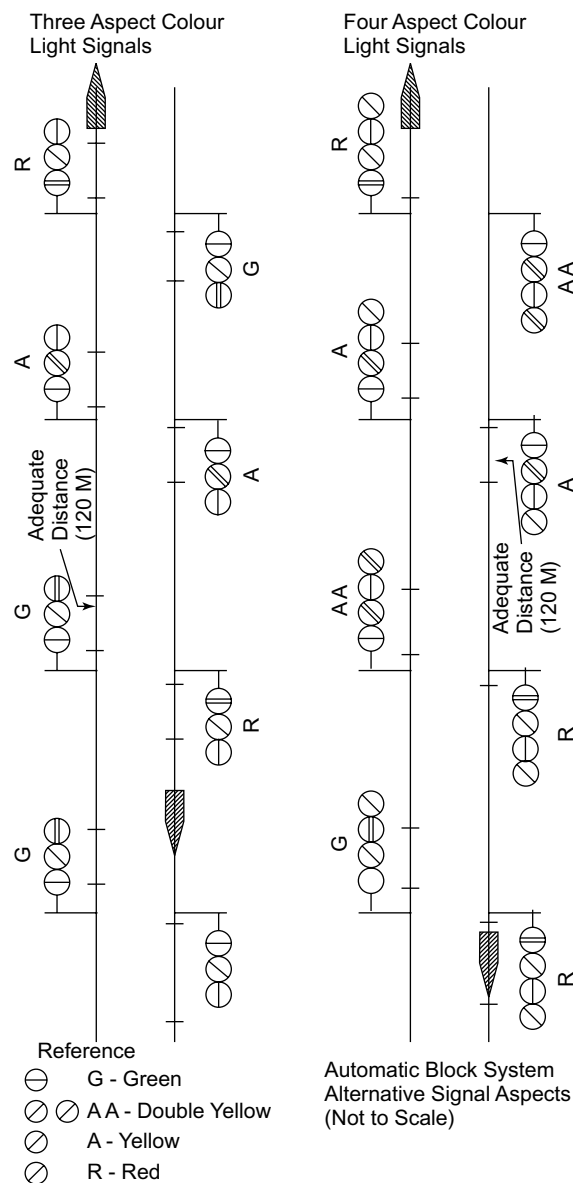
Source: DMRC Report

**Figure 8.4** Third Rail Current Collection – Typical Arrangement

form of lighting on a panel frame in a cabin or a panel fixed on the table of the Station Master. The color light signals can be of 3 or 4 aspects. In the 3 aspects, there are 3 lights on each post. Red indicates danger i.e., that next section (section between next pair of signals plus adequate distance) is occupied. Amber indicates that second section beyond only is occupied, while Green indicates that at least two sections ahead are free of obstruction. The four-aspect signal is for still higher speeds, and has one Red, 2 Amber and one green signal on each post. This combination facilitates indication of train location for 3 sections ahead. Figure 8.5 shows both the arrangements.

### 8.5.2 Advances in Signaling and Control

A further sophistication to ensure safety is to interconnect the signal aspect with the driver's control in the cabin. The first simple device is to provide an indicator on the cabin, which repeats the aspect exhibited by the signal ahead on a miniature signal fitted in the cabin. This gives a visual pre-warning to the driver. A further development is to provide a mechanism, which sounds a horn in the cabin when signal ahead is at 'danger' and the blowing of horn will stop only when the driver presses a handle and driver would then operate the brake. If the driver does not respond,



**Figure 8.5** Three and Four Aspect Signals

the power will be automatically cut off and the brakes also will be applied. The section distance will be such that at the permitted speed in the section, it is generally possible to bring to halt a train sufficiently well behind any train ahead or other form of obstruction on the track. The cabin can also be equipped to obey any speed restrictions on the section and regulate the speed. This stage would thus be one with 'automatic warning system' (AWS).

### 8.5.3 Centralized Train Control (CTC)

In normal CLS (Color Light System), the signals between stations are operated by the Station Master and the section between stations is treated as block sections. Track circuiting acts as an additional precaution to station staff as well as drivers. Where stations are far apart, in order to increase capacity of sections intermediate block signals are provided which divide the section (not necessarily between stations only) and which function automatically. This is known as Automatic Block system and is applicable when movement is unidirectional as in double line sections. In all these, general directions regarding priorities in running trains are given by Controllers giving telephonic instructions/directions to station staff from a Control centre. CTC is a further development of panel interlocking mentioned above. This system involves in linking the control office electronically with line side equipment, in which case the entire operation and train running (including starting and stopping) is managed and controlled by the Controller and Station Master has a role to play only in emergencies. This mode of operation is known as CTC.

### 8.5.4 Continuous Automatic Train Control

Modern urban rail systems go in for CATC, i.e., Continuous Automatic Train Control. This comprises ATP (Automatic Train Protection), ATS (Automatic Train Supervision) and ATO (Automatic Train Operation).

#### (a) Automatic Train Protection (ATP)

This subsystem is provided for achieving the primary purposes of signaling, i.e., train protection more effectively and efficiently. In this system, cab signaling provided integrating line side equipment and instruments in the cab, do ensure that a safe distance is maintained between trains. If the required safe distance is not available, there will be suitable warning for the driver and automatic control of speed of train. If necessary, it will automatically operate the brake. It also monitors the maximum permissible speed on the line and speed restrictions in force. It detects any over speed with audio-visual warning and applies brakes, if necessary. Line side signals shall be provided at diverging routes, i.e., at turnouts to serve as back up signaling in case of failure of ATP equipment.

#### (b) Automatic Train Supervision (ATS)

A further development over this is ATS (Automatic Train Supervision). In this system, a number of video cameras are installed at critical locations in stations and en route and they are connected to closed circuit TV system. Display TV units are available in the control office, where they give display of the situation on platforms and at critical sections on route, besides speeds of trains along the route. Even door opening and closing in coaches and closure of stations during non operational hours are automatically regulated. Any manual interference would be necessary only in case of emergencies or due to some problems arising on route.

This system was first introduced in the Victoria line extension of London tube in 1970s. In some such systems, the driver is there for acting in emergencies. This is a highly sophisticated system



and hence expensive for installation and maintenance. But it affords increase in capacity of the line, as everything is automatic and speed can be maintained at permissible maximum without being subject to driver's responses and capabilities.

### **(c) Automatic Train Operation (ATO)**

The latest development in train control and operation is in the form of automatic train operation, which centralizes the operation of running of the train also to the Central Control Office. In this system, trains can be run according to instructions conveyed electronically from the controller's desk, thus leading to the possibility of driverless train operation. The time table and permissible speeds in different lengths are programmed and input into the computer and the trains are operated by commands emanating from the control desk. This can be automated also. In the normal systems described above, the trains are operated to a fixed time table from central control office or by station staff.

## **8.5.5 Comparison of Operation Systems**

All the above mentioned forms are in modules which can be installed one after the other viz., AWS, ATC, ATS, and ATO. The combined final form is the Centralized Automatic Train Control.

It will be noted that mostly the CTC or ATC is used, and ATC is used in quite a few recently formed systems. ATC gives a capacity of 40 trains an hour. It has been adopted in Washington, BART, Pittsburgh LRT, Hong Kong, and Singapore, to mention a few. It is quite expensive as it calls for sophisticated equipment not only on the line and stations, but also in the vehicles. AWS and ATP can give a line capacity of up to 20 trains per hour and with high capacity vehicles, this can give a PHPDT of 70,000 in dense crush load condition. From considerations of safety, the next step to be aimed at will be ATC, for which the vehicles will need modification. Such modification is overdue from passenger comfort and safety points of view.

A passenger judges reliability of a mode based on its service frequency and punctuality. With electric traction and working of the units with motor coaches interspersed, which have no individual engine to depend on and have less moving parts, the RTS with electric traction is the most reliable mode. Special arrangements are made to ensure reliable power supply to the Railway traction so that minor localized power breakdowns do not adversely affect the services. Occasional breakdowns are possible in surface and elevated lines as well as LRT if miscreants tamper with the catenary. Any breakage of catenary is designed to cause earthing and stoppage of power supply, so that people are safe from danger of electrocution. Such breakdowns are rare with third rail traction. In either case, traction substations are designed and located in such a way that if one fails, the adjacent one can take on the load of failed one also.

## **8.6 ROLLING STOCK**

The metro coach/car size with respect to gauge is designed so that it ensures better stability and provides comfort to the passengers. The acceleration and deceleration are limited to the levels of tolerance of passengers (Rate of change of acceleration is  $1.0 \text{ m sec}^{-2}$  in Kolkata as against  $0.9 \text{ m}$

sec<sup>-2</sup> in BART). In view of high frequency operation (at close headways) high degree of reliability is needed and hence the coaches (motor and trailing) are designed for high quality performance and are made of proved materials of superior standard. The rakes or train formation are designed to be quickly reversible and provided with driving cabins and current collection equipment at both ends. Time needed at terminals will be only for change of drivers, which can be done by the time one set of passengers disembark and the other boards in. In order to reduce noise in underground, the track is provided necessarily with continuous welded rails, elastic clips and elastic pads. The car bodies are provided with acoustic insulation. The major dimensions of the coaches such as those of Kolkata Metro and Surface Metro cars are given in Table 8.1. The general profile of the coach proposed to be used on Chennai metro rail is shown in Fig. 8.6.

**Table 8.1** Characteristics of Coaches

	<b>BG-EMU Kolkata</b>		<b>METRO</b>		<b>LRT</b>	
	<i>Suburban</i>	<i>Metro</i>	<i>(alternatives)</i>		<i>(alternatives)</i>	
Gauge, mm	1676	1676	1435	1435	1435	1000
Length, mm	20726	19500	19500	21400	28000	34500
Width, mm	3660	2740	2740	2880	2650	2400
Height, mm	3810	3500	3680	4300	3365	3260
No. of doors	4	4	4	4	4	4
Floor Height, mm	1197	1035	1154	1240	1000	860
Wheel Dia., mm	952	838	860	860	740	660
Capacity seat	98(112)	58(82)	54(60)	48	72	86
Standing rate/m <sup>2</sup>	8	4	6			
No	226(245)	144	280(304)	291	294	230
Crush at 10/m <sup>2</sup>	284(336)	174(246)	398	278(8/m <sup>2</sup> )		
Ventilation	Normal	Air cooled	AC	AC	AC/normal	
Tare wt., t	48(31.3)	41.9(27.4)	51.3(35.1)	39.0	21.0	
Total wt. t	65	56.0				
Axle load, t	20(13)	14.2(10)	16		10 to12	
Power Voltage	25000/1500	750 DC	1500 DC 25 kv AC	750 (DC)	600/1200 DC	
OH or TR	OH	TR	OH, TR	TR	OH	OH
Max. Gradient	2%	2%	2%	4%	7%	4%
Sharpest curve- Radius, m	300	180(50)	250 (150)	150	75(25)	
Speed Max, kmph	80	80	80	100	100	65

(Contd.)

**Table 8.1** (Contd.)

	BG-EMU Kolkata		METRO		LRT	
	<i>Suburban</i>	<i>Metro</i>	<i>(alternatives)</i>		<i>(alternatives)</i>	
Coml.	35	30	30	30	35	35
Acceleration.m/s <sup>2</sup>	1.1	1.1	1.1		0.90	
Deceleration.m/s <sup>2</sup>	1.1 – 1.3	1.1	1.3	1.1	1.3	1.20

In order to reduce fire hazard, the coach construction is done carefully on all RTS systems. But in underground and elevated construction, specially formed, this assumes a special significance in view of restricted space for people to escape and hence design of cars are made with inflammable materials or self-extinguishing materials. Electrical equipments of all categories need be of special quality to eliminate this hazard. Figure 8.6 (b) shows a general view of the BG Metro Coach used on Delhi Metro rail line.

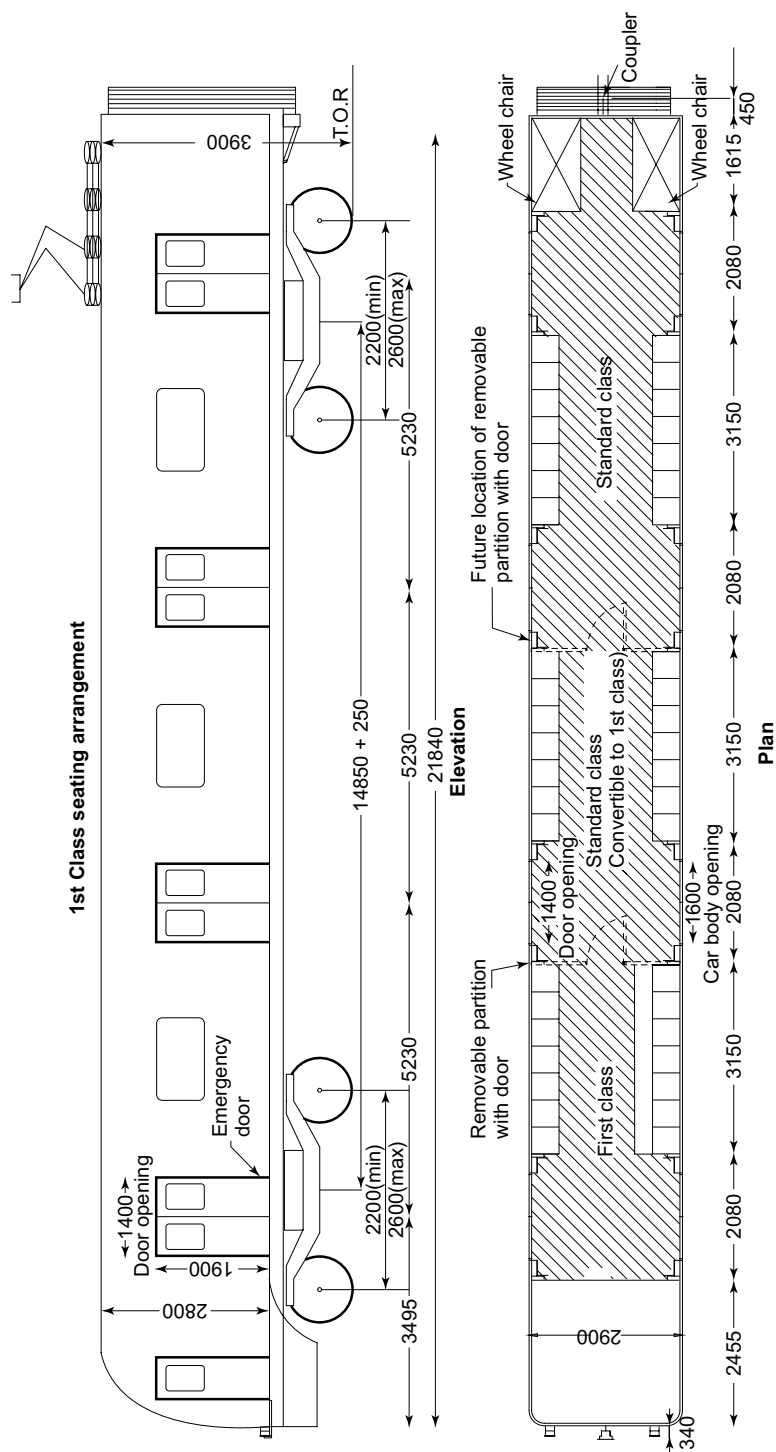
The running speeds are fixed so that the train can be stopped within the specified braking distance under maximum loading conditions and with the rail-wheel adhesion value taken as 15% as against normal 20%. The signal spacing is also fixed taking into account the safe braking distances.

## 8.7 STRUCTURE AND TRACK

### 8.7.1 Right-of-Way

Choice of type of way is a trade-off between availability of land, degree of isolation required and cost. In closely built up areas, the track has to be taken grade separated either by taking them in tunnels underground or by running on elevated structures over the road alignment if fairly wide road with easy curves are available. The likely cost difference while adopting different forms can be understood from the data given in Section 6.4. The extra clearance required is approximately reckoned as 37 mm per degree of curvature.

It has been brought out already that a metro rail system has to be a double line system if satisfactory frequency of services has to be provided. The two lines will have to be spaced apart in such a way that when the vehicles are leaning on both the lines there is adequate clear space between the two vehicles, after taking into account the overhangs and chord offset of the vehicles on the sharpest curve. The spacing between the track centers will have to be such that there is sufficient clearance between passing vehicles to ensure safety. In case of non-air conditioned vehicles with open windows and doors, extra space is required so that hands or overhanging bodies of passengers in passing trains on the two tracks do not touch each other. Extra clearance is required where the line is running on a curve to allow for curvature effect on long vehicles and also the lean effect on vehicles due to the super elevation provided. The vehicles will have additional offset on one or other side of the centre line, due to both these effects. The effects are conceptually indicated in Fig. 8.7



**Note:** All Dimensions are estimated Preliminary and subject to change

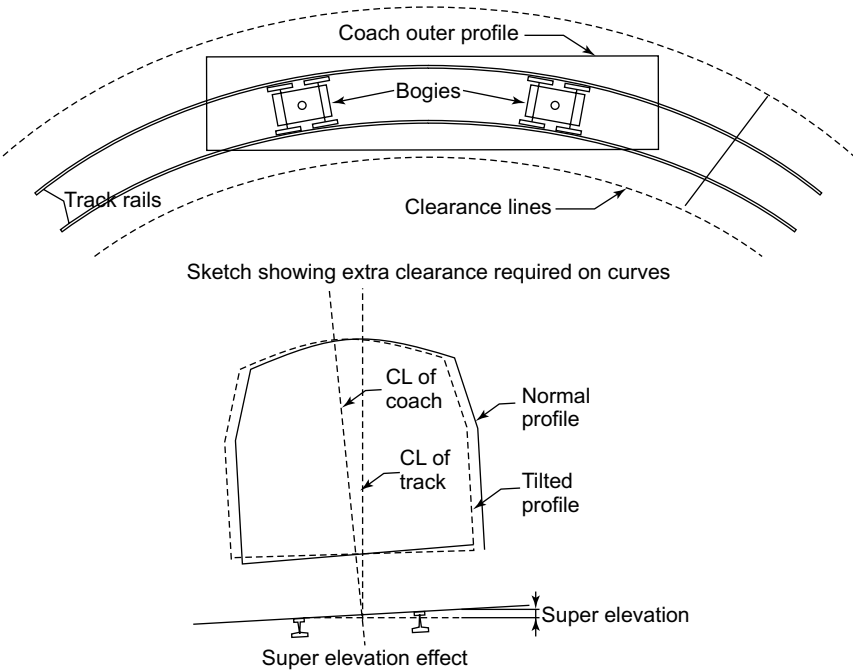
**Courtesy:** CMRL, Chennai © CMRL

**Figure 8.6(a)** Typical Standard Gauge Metro Rail Coach



Courtesy: DMRC, Delhi – © DMRC

**Figure 8.6 (b)** View of a DMRC Train Stabled in Depot



(Bogie not shown in section for clarity)

**Figure 8.7** Curvature Effect on Vehicles and Clearance

In tunnels there should be similarly adequate clearance on the sides between the structure and the vehicle profile. This will call for additional clearance on curves. Taking this into consideration, certain standard profiles are determined for single line and double line tunnels.

The width of the structure on the elevated alignment will have to provide for similar clearances. In addition, in some systems they provide a catwalk or a footpath on either side or in the middle of the double line track structure. The minimum width of such footpath should be 0.60 m clear of the construction gauge profile. These are very much necessary particularly, in the systems where vestibule coaches are not used, as for example on the EMU system used in Indian cities. In addition, provision will have to be made on the formation whether it is on the surface, in tunnel or elevated structures for fixing the traction masts/brackets and for signal posts/brackets where line side signals are used. From the maintenance point of view, it is desirable to avoid having any tall posts on sides of elevated structures in order to facilitate using cantilever arms of mobile inspection vehicles for inspection of sides and underside of structures. Ducts will have to be provided for running of the electric cables and signal cables on ‘at-grade’ and aerial structures. They can be fixed to brackets fixed on side walls of the tunnel and parapet walls on elevated structures. These two system cables should be separated out sufficiently to prevent consequences due to induction.

8.7.2 Gauge

Track by definition consists of a pair of rails kept at equal distance and proper level/cant (super elevation) with the help of transverse ties or sleepers separating the rails. Gauge refers to the shortest distance between the inner faces of the rail head. The gauge of the metro system is a major factor, in determination of which, an in-depth study will be called for while designing on choice of gauge for a particular city or country. The different gauges used for Rail Transit systems and correspondingly for inter-city rail transport system in different countries are given in Table 8.2.

Table 8.2 Railway Gauge in Selected Countries

Country	Main Line Gauge mm	Metro Line Gauge mm
North America	1435	1435, 1000
Russia	1524	1524
Japan	1087, 1435	1087, 1435
China	1435	1435
United Kingdom	1435	1435
Australia	1435, 1600, 1067	1600, 1435
France	1435	1435, 1000 (LRT)
Germany	1435	1435, 1000 (LRT)
Switzerland	1435, 1000 (hills)	1435, 1000
Italy	1435	1435, 1000
Greece	1435	1435

(Contd.)

**Table 8.2** (Contd.)

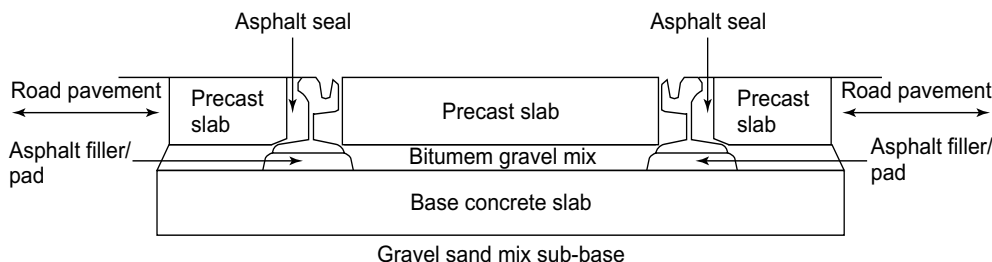
Country	Main Line Gauge mm	Metro Line Gauge mm
Spain	1676, 1000	1435
Portugal	1676	1435, 1676
Argentina	1674, 1435	1435
Brazil	1600, 1000, 760	1600, 1435
Mexico	1435	1435
South Africa	1067	1435
India	1676, 1000, 760, 610	1676, 1435
Thailand	1000	1435
Malaysia	1000	1435
Egypt	1435	1435

It will be seen that most of the countries had adopted the gauge which are predominantly used on the inter city lines for their Metros. Such provision gives the flexibility in respect of mainly conveying the coaches to the city from the production unit or from the port of disembarkation to the system. Secondly where the traction system and platform dimensions and clearances are compatible with each other, it also provides the flexibility of taking the suburban or regional rails on the same track of the metro and providing a few common extended services, particularly where the metro lines pass through some of the terminals and major rail junctions. The other major factor which has to be considered is the cost of production of the vehicles. This depends upon the size of demand. In cases, where only one or two cities in a country plan to go in for a metro system, it is not economical or possible for them to have production units established within the country for supply of coaches to the few systems. Then it will be preferable to use standard gauge, which is used by most of the countries and state of art vehicles can be obtained from a competing market. In such cases, the gauge generally chosen is the standard gauge or one in 1435 mm gauge. Standard gauge has another advantage, since it is possible to use sharper curves than on BG and hence there is better flexibility in choice of alignment.

In India also, the choice of gauge was discussed at length when the Kolkata Metro was designed. Indigenous production of the broad gauge (1676 mm) coaches was more easily feasible in an Indian Railways own production unit (ICF, Chennai) without any major foreign exchange outflow. This gauge was chosen mainly for the facility of hauling the coaches from Madras where the coach production was undertaken, but the body profile was kept same as for the Metre gauge so as to economise on tunnel profile and cost. This enabled construction of smaller profile tunnels and it provides better stability. Though the same gauge is used in Kolkata area for inter-city and suburban services also, no inter running has been attempted due to non-compatibility of traction and current collection system. Though Delhi Metro adopted BG for their Phase I lines, the present policy in India is to adopt Standard Gauge for the new Metros, e.g., Bangalore, Mumbai, and Chennai etc., and later phases of Delhi metro.

Rails of metro rail track are subjected to high wear in view of high frequency of train operation, and hence wear resistant rails are preferred for the track. Except where there are very sharp curves, the current trend is to opt for long welded rail tracks.

Standard Gauge has been adopted for LRT in most of the countries. There are a few meter gauge LRTs also. Even those countries, which adopted their country's gauge for LRT in earlier days are going in for standard gauge now. The rail sections used are lighter 40 kg or 52 kg 60 UIC rails. Where they share the road ROW with other vehicles, special tram line type of rails are used. Some typical section of Tram/LRT track at road level are shown in Fig. 8.8. Since the LRVs are articulated vehicles with ends generally streamlined and widths of 2.54 to 2.70 m, a spacing of 3.8 to 4.0 m is found adequate except in very sharp curves. The axle load of LRVs vary from 8 to 10 tonnes: hence lighter elevated structures will be adequate. However, where the LRT may need to be upgraded in future, all track and structures are built to RRT standards, except that lighter rails can be used for now.



**Figure 8.8** One Type of LRT Track at Grade

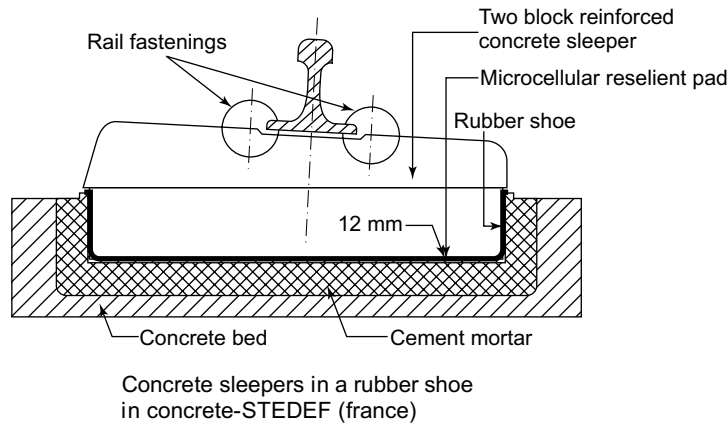
### 8.7.3 Sleepers

Sleepers or ties (as they are known in North America) are provided to keep the rails supported and at uniform gauge along the length. The material used for sleepers should be such that they are non-conducting, so as to facilitate track circuiting of the tracks. The older Metro systems have used timber sleepers which are existing in systems like New York and Chicago elevated lines and some of the other underground systems also like London. The present practice is to adopt concrete sleepers which provide a stiffer and better support to track (vide Fig. 8.1). They also provide the necessary insulation for track circuiting. The spacing of the sleepers is generally kept at 600 mm centre to centre.

However, in tunnels and on elevated structures, many of the systems are providing ballastless track. The ballastless track, alternatively called Direct Fixation track, comprises embedding supporting RCC block or sleepers. On some sections in New York, even wooden sleeper blocks embedded in concrete bed has been used. Alternatively, rails can be directly fixed on to a plinth laid on the slab/invert or over a layer of high grade concrete laid over the invert of the tunnel or the deck of the elevated structure. Rails are fixed by clips over grooved rubber pad, which is supported



by a MS bearing plate. Another harder but resilient rubber pad about 20 mm thick is placed below the bearing plate and they are fixed to the sleeper with bolt and sleeve insert, as shown in Fig. 8.1(b). A French patented design uses concrete sleeper blocks fitted with an elastic 'shoe' embedded in concrete base, Fig. 8.9 shows the arrangement under one rail.



**Figure 8.9** STEDEF Form of Ballastless Track Developed in France

#### 8.7.4 Drainage

Side drains and where necessary intermediate cross drains should be provided in the track so that any water which falls on the surface can be quickly drained off. Generally the track bed or the structure is provided a cross fall of 1 in 33 to 1 in 40 towards the side drains. Saucer type side drains can be provided in tunnels in the middle or sides. In addition, in order to have quick drainage a slight longitudinal grade is also provided on the track in cuttings, tunnels and aerial structures and also stations, minimum being 1 in 1000. It is necessary to provide outlets at intervals to lead away the water, where the elevated or tunnel structure or cutting runs continuously for considerable length between stations. Where such interior outlets are not possible sumps should be provided at intervals, where water can collect and can be pumped out to the outside.

### 8.8 STATIONS

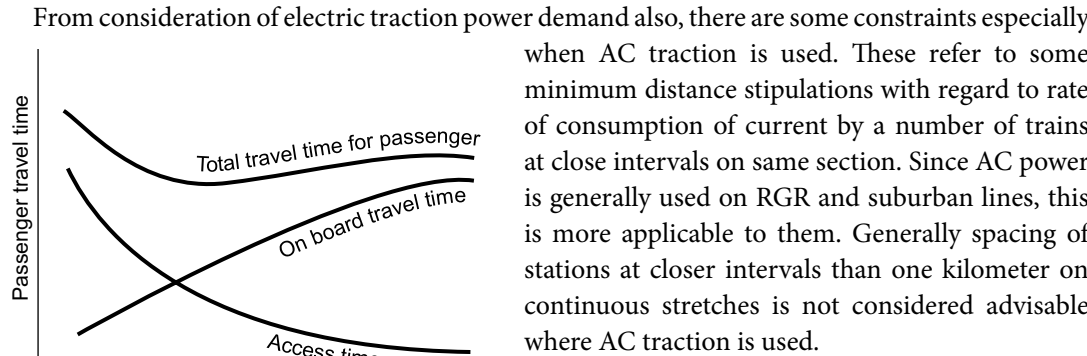
#### 8.8.1 Spacing of Stations

Closer spacing of stations makes the RRT more easily accessible to users and has some impact on the loading. On the other hand, closer spacing increases journey time and reduces speed potential. A few examples of average inter station distances and standard speeds (including stops) on some selected systems are given in Table 8.3.

**Table 8.3.** Station Spacing and Average Speeds on Some Metros

City	Type of Structure of Major Length	Average Inter-station Distance km	Average Speed kmph
Philadelphia	Elevated and Underground	0.93	27.7
New York	Underground	0.88	32.8
Tokyo	Underground	1.00	29.4
London	Underground	1.20	32.3
Chicago	Elevated	1.00	38.2
Kolkata	Underground	1.02	33.0

In urban areas, signal spacing would be determined by headway required and not necessarily at stations only. But in urban areas physical constraints like gradients and curvature are common. The stations should as far as possible be located on tangent tracks (straight lengths) and kept level or with gradients not steeper than 0.10% preferably but not steeper than 0.25% generally. For better passenger service, they have to be located close to major attraction centers also. In outer areas, they will have to be located close to centre of gravity of the area with respect to population and close to major nodes in the road network. Within the city, the line will pass through densely populated areas mostly and hence spacing has to be determined based on a compromise between accessibility, demand and distance required for trains to attain a reasonable operational speed. More the distance between two stations, higher will be the average speed after allowing for acceleration and deceleration. At the same time, the access time for the passenger to the station will go up. The relationship between station spacing and travel time and access time for passenger is conceptually indicated in Fig. 8.10. An example of travel time between some stations as observed on Cologne LRT is shown Fig. 8.11 (Reference 1).

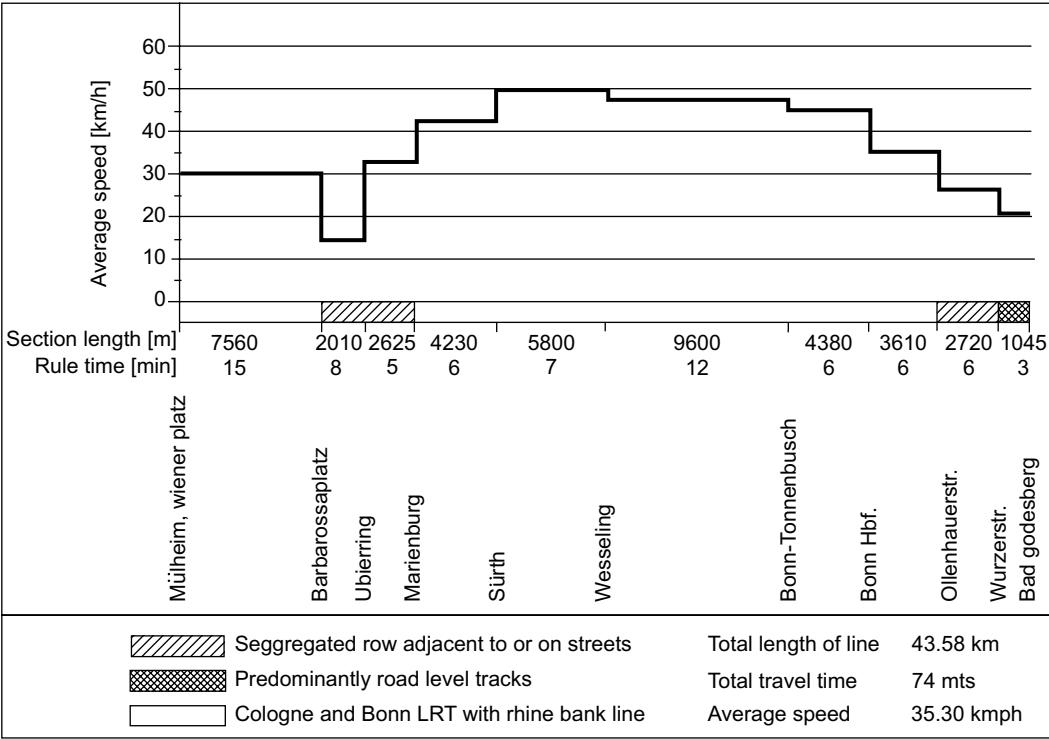


**Figure 8.10** Impact of Station Spacing on Passenger Travel Time

From consideration of electric traction power demand also, there are some constraints especially when AC traction is used. These refer to some minimum distance stipulations with regard to rate of consumption of current by a number of trains at close intervals on same section. Since AC power is generally used on RGR and suburban lines, this is more applicable to them. Generally spacing of stations at closer intervals than one kilometer on continuous stretches is not considered advisable where AC traction is used.

LRT stations are more closely spaced at 600 to 900 intervals in the core area, generally closer to major road intersections. In outer areas, they need be located only at nodal points of suburbs. A typical

spacing in Cologne-Bonn area is indicated in Fig. 8.11, which also indicates the speed attainable with different station spacing. LRT designs can be much simpler as their longest train lengths will be about 80 to 90 m and ticketing can be done at entry into the vehicle. In at-grade and roadside stations/stops, the platform widths can be no more than 3 m wide. Elevated stations can comprise only platforms with automatic ticket vending machines at foot of staircases, unless the line is to be upgraded as RRT in future. Many of the LRVs will be provided with ticket checking machines at the entry doors and passengers can board the trains directly.



Source: Reference 1

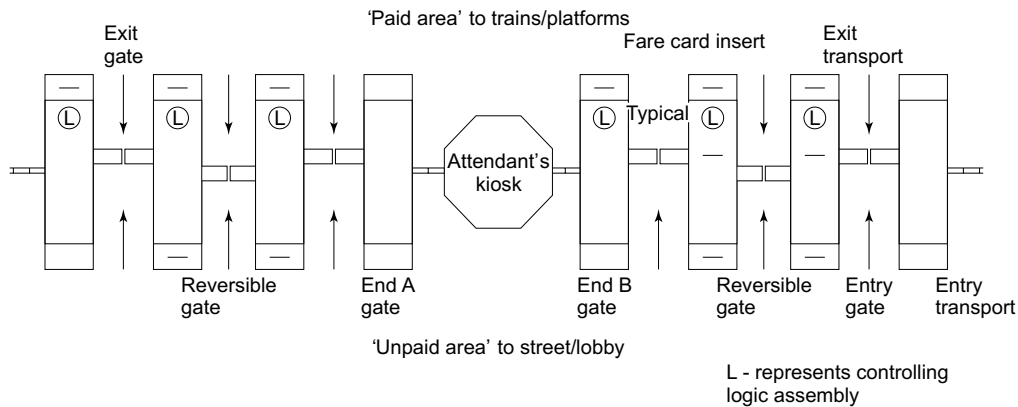
Figure 8.11 Distance Between Stations and Time Taken on Cologne LRT

On busy LRT stations and all RRT stations, entry to platform will be controlled with a battery of stiles operated by ticket scanning machines as indicated in Fig. 8.12(a). Figure 8.12 (b) shows a view of the stile and gate arrangement in one Delhi metro rail station.

8.8.2 Capacity Requirements

Traffic Prediction

Depending upon the intensity of activities within the area of influence of a station including interchange from bus and any other inter-facing railway system, the patronage at each station will



Source: Reference 2

**Figure 8.12 (a)** Typical Passenger Gate at a Rail Transit station



Courtesy: DMRC Delhi. © DMRC

**Figure 8.12 (b)** Ticket Stile and Gate Arrangement at a Delhi Metro UG Station

vary in terms of daily passengers and directional split during peak periods. Knowledge of this patronage, its peak and directional split is essential background to the layout and design of stations and pedestrian facilities. It is also important for selection of type and size of stations, which will have a bearing on costs.

### Design Passenger Flows

From a detailed study of traffic generation, daily patronage estimates are prepared for station design. For the purpose of determining the sizes of passenger circulation facilities, the daily patronage estimates are converted into design flows as under:

- (a) It is assumed that 10% to 13% of the daily flow occurs during morning peak hour depending upon the location of the stations.
- (b) To allow for peaking within that hour, it is assumed that 5% of the hourly flow would occur during the peak 2 minutes.
- (c) The resulting two-way flow is split into one way flows following study of the types of trip generating activities within the station catchment.
- (d) The evening peak is generally assumed to be reversal of the morning peak. Care must however be taken at stations with platforms at different levels to ensure that the flows are properly reversed having regard to the direction of travel of passengers.

Having obtained designed passenger flow, it is possible to assess the numbers and sizes of pedestrian facilities such as platform widths, passages, entrances, stairs, ticket gates and escalators needed at each station concourse. Of these, the number of escalators and staircases is the most ,significant as it has a profound influence on the type and size of the station. Length of platform is determined based on the longest train likely to be operated within next 30 to 40 years and during the expected life period, in case, of tunnels.

8.8.3 Maximum Practical Capacities of Facilities

The following yardstick (collected from different sources) represents the maximum practical capacities that are adopted for design of different facilities in stations. All capacities are expressed in terms of *Passengers Per Two Minutes (PRTM)* to conform to passenger flow charts and peak hour train frequencies.

Station Planning Standards

(a) Design passenger flow/2 min.	5% of peak hour flow
(b) Escalator carrying capacity/2 min (1.00 m width, 30% slope up and down)	300 passengers
(c) Uni-directional staircase/m/2min. Up	126 passengers
Down	140 passengers
(d) Uni-directional passengers/m/2 min	177 passengers
(f) Ticket gates/2 min	70 passengers
(g) Side platform	2.5 persons/m <sup>2</sup>
(h) Island platform	1.5 persons/ m <sup>2</sup>
(i) Concourse	20% of the total areas of platform provided.
(j) Platform (during emergency)	5 persons/m <sup>2</sup> (including safety zone).
(k) Safety Zone on platforms	0.6 m train side 0.25 m wall side

(l) Minimum platform widths	Island platform 10 m Side platform 6 m
(m) Emergency Evacuation time	4.5 min.
(n) Maximum travel distance in emergency	60 m
(o) Walking speed of passengers	1 ms <sup>-1</sup>
(p) Escalator carrying capacity in emergency,/2min.	1 ms <sup>-1</sup>
(q) Staircase carrying capacity in emergency/2min.	
Up	114 passengers
Down	126 passengers.

To allow for irregular flows, inaccuracies in traffic assignments, reduced train frequencies etc., the maximum capacities are down rated by the factors detailed in the following sections of the stations.

(a)	Station Entrance	Normally 60%	
	Platform to concourse and concourse to platform:		
(b)	Escalators	80%	
(c)	Automatic ticket gates	(i) In 70%	(ii) Out 65%

The number of ticket gates allowed for in design should be determined in relation to the escalator provision. The initial installation may however be reduced to reflect passenger flows in the early years of operation.

No. of Escalators	IN Gates	OUT Gates
1	4 + 1 spare	6 + 1 spare
2	9 + 2 spare	11 + 2 spare
3	14 + 2 spare	16 + 2 spare
4	19 + 3 spare	22 + 3 spare
5	24 + 3 spare	27 + 3 spare

In stations where large numbers of commuters disembark at a time, it will not be possible to regulate using stiles only. In peak hours, additional manually operated gates may have to be used, and ticket punching at exit dispensed with at peak hours. Random checking by inspectors can be resorted to.

8.8.4 Emergency Evacuation of Stations

The requirement in this respect is to evacuate people from station platform to another location, usually the next level below platform level. The following basic principles will be followed for calculations:

- (a) Total evacuation time for the movement of all passengers from platform level to the landing at the bottom of staircase or escalator is not to exceed 4.5 minutes.
- (b) Total evacuation time also includes a one minute allowance to cover the time taken to reverse the all up going escalators plus the travel time on the escalators and stairs. Evacuation by down

going escalators and staircase will be taking place during the time taken to reverse the up going escalators.

- (c) Total number of passengers to be evacuated is maximum peak hour arrival train load plus maximum number of waiting passengers on the platform.
- (d) Capacity of the escalators and stairs in emergency evacuation condition is to be taken as 90% of maximum practical capacities.
- (e) The time required for a person to walk from the farthest point on a platform to the head of escalators or stairs must also be considered. Walking speed is assumed as  $1 \text{ ms}^{-1}$  in US standards.

### Station Lift

A hydraulic lift shall be installed operating between concourse and platform in each station. Where stations have platforms and/or plant rooms at more than one level, the lift will serve all the levels. The primary function of the lift is to convey trolley vault transporters, cleaning machines and heavy maintenance equipment between various levels of the station. It will also be required for handicapped persons using a wheel chair. The lift should preferably be located within the secured area at concourse level.

These yard sticks are applicable to LRT stations on its own ROW in respect of platform widths, staircases, gates and emergency evacuation measures. Where the stations are grade separated, it is advisable to provide lifts and facilities required for senior citizens and differently abled commuters including wheel chair users. The level of platform and the gap between platform edge and platform edge have to be suitably designed.

## 8.9 TRAIN OPERATION PLAN AND FLEET REQUIREMENT

### 8.9.1 Train Operation Principles

The philosophy underlying in the design of an urban rail system has the following objectives:

- (a) The train frequency of operation should be such that it meets the sectional demand in most of the sections during the peak hours.
- (b) It should at the same time provide a minimum frequency, consistent with the economy and aspirations of users.
- (c) Length of the train should be minimum required to start with and can be added on as demand increases.
- (d) Multi-tasking of train operation and maintenance staff should be possible.

Services provided should cover 19 to 20 hours leaving at least four hours and preferably five hours for maintenance operation of line, line-side equipment, and coaches.

Normally the modern RRT/Metro trains come with four coaches/cars with driving cabs at either end (2 motor coaches and two trailer coaches). Additions to same are made in twos (a pair comprising a Motor coach and a trailer coach).

Trains are scheduled in the time table providing for 5 to 10 % for delays and making up time. Station dwell times are taken as 30 seconds and at terminals 5 minutes as turn round time. The requirement of number of train consist are worked out keeping in mind the peak hour demand in the predominantly dense links. The capacity of coaches is worked out for normal crowd loading of seated plus standees at 6 per m<sup>2</sup> which can go up to 8 per m<sup>2</sup> in the worst link.

### 8.9.2 Rake Requirement

#### An example

Let us take a typical case of a corridor where the maximum PHPDT will be 27000 in 2011 and 36000 in 2026, for which rake requirement has to be worked out.

It is proposed to operate four car trains with 1040 capacity at 6 standees per m<sup>2</sup> and 1325 at 8 standees. 6 car trains can take 1.52 times this as the extra trailer will not have any cab and can take more passengers.

With 3 minute frequency, the number of trains = 20 per hour.

Capacity provided =  $20 \times 1325 = 26500$

It should meet the demand, though only marginally less than 27000 required.

By 2026, with 6 coach train, each train can take 2015 passengers.

Number of trains required per hour =  $36000 / 2015 = 17.86$  or 18 trains.

Headway required =  $60 / 18 = 3.33$  min or 3.5 min

Since the modern RRT signaling provided has potential for operation at minimum 2 minute intervals, 6 car operation can still continue with headway reduced as the traffic grows further up to PHPDT of 60000, when trains will have to be run at 2 minute intervals.

In the off-peak hours, absolute minimum headway should be 15 minutes, desirable being 10 minutes.

Let the corridor length be 25 km and service speed possible is 33 kmph.

Then running time =  $25 / 33 \times 60 = 45.5$  minutes

Allowing 10% make up time,

Turn round time =  $2 \times (1.1 \times 45.5) + 5 + 5 = 110$  minutes

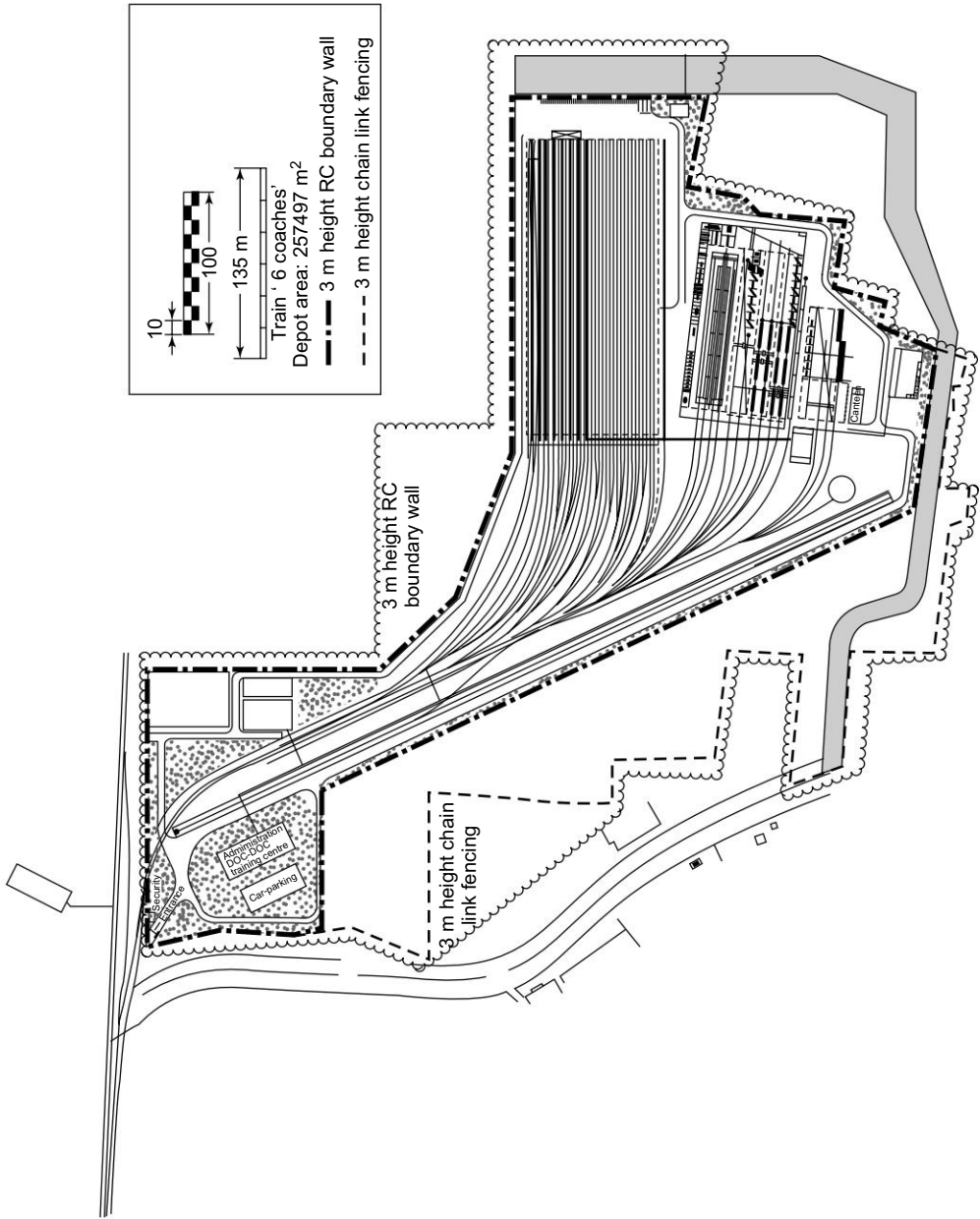
With operation of 20 trains per hour, number of 4 car consist required =  $110 \times 20 / 60 = 36.6$  or 37 numbers

Allowing for 15% for maintenance and repair spares,

Number of rakes required =  $1.15 \times 37 = 42.5$  or 43 equivalent to 172 coaches to start with.

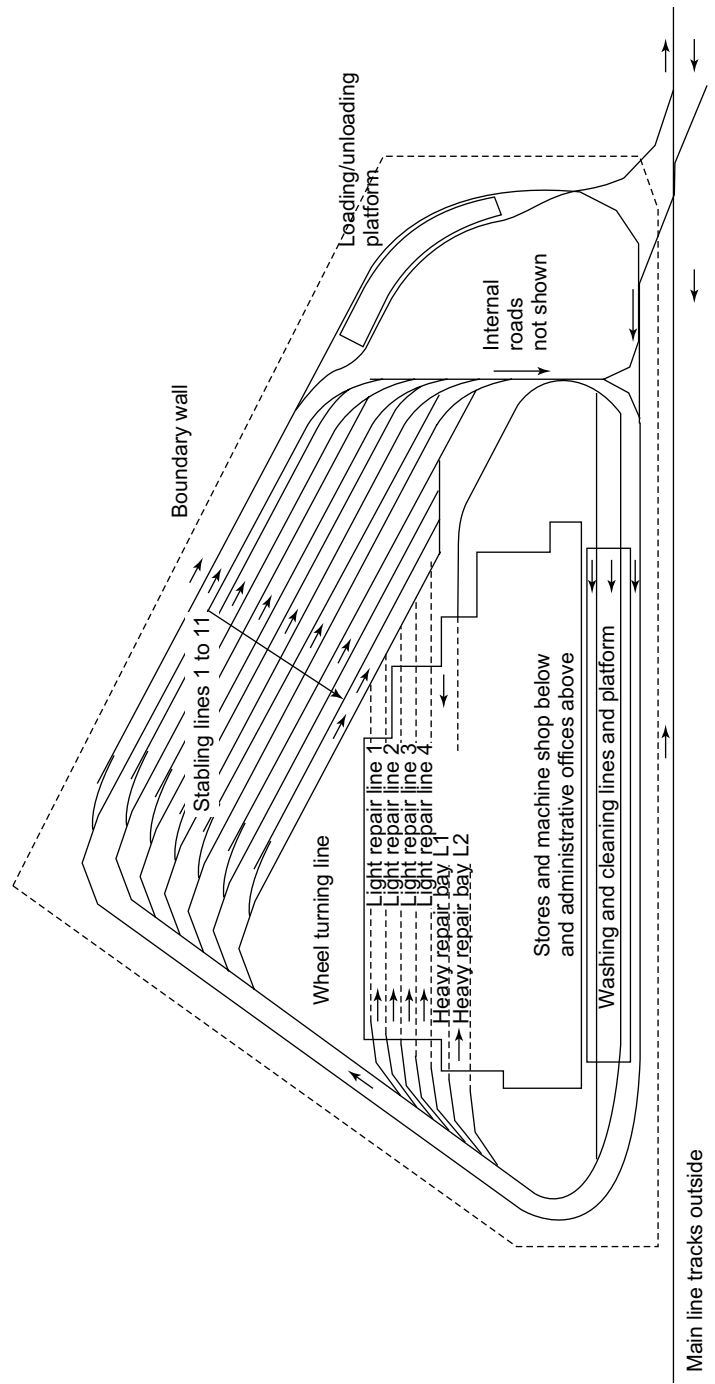
One maintenance and repair depot will be required. In the non-operation hours, normally two rakes each can be stabled at terminals and the remaining will have to be stabled in the depot. While number of lines can be initially provided for stabling (37-4) 33 rakes, space in the depot or additional stabling yards should be planned for expansion for housing six car trains and the increased numbers. Figures 8.13 and 8.14 show typical layouts of a RRT and LRT depot each.





Courtesy: CMRL, Chennai – © CMRL

Figure 8.13 Layout of a Typical Metro Rail Depot



Adapted from Cologne LRT Depot layout

Figure 8.14 Sketch Plan of Typical LRT Depot



Courtesy: DMRC © DMRC

**Figure 8.15** Inside a Depot of Delhi Metro Rail

Figure 8.15 shows inside of a Depot of Delhi Metro rail with trains receiving attention.

## **8.10 MANAGEMENT STRUCTURE FOR A RAIL TRANSIT SYSTEM**

### **8.10.1 Suburban Rail Systems**

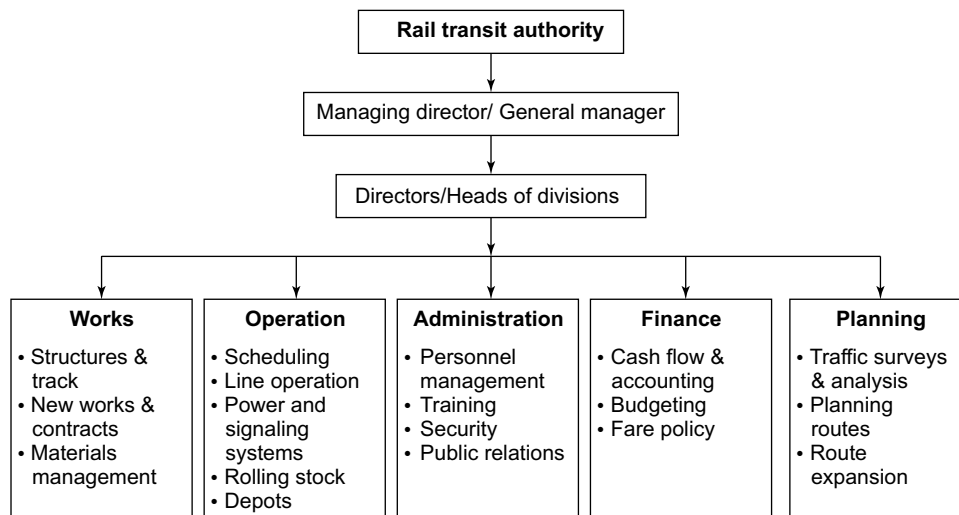
Suburban rail systems form part of the main railway system and hence no separate organization is formed for managing the same, apart from formation of a separate division or section for controlling and looking after the day to day operation of the commuter trains. There will be a separate depot or maintenance shed for maintaining the electric multiple units.

### **8.10.2 Metro Rail Systems**

On the other hand, in the past the metro rail systems and tram lines have been developed as units independent of main line railways either by private entrepreneurs or city governments. The owners have adopted a management pattern for such units on similar lines to that of a bus transport system. In addition they have additional sections to look after the tracks, power system and signaling installations and security.

On larger systems, the management has additional responsibilities of finding resources and also planning for expansion. There will be a number of policy issues and problems of co-ordination with other stake holders and governmental agencies. Maintenance of good Public relations assumes great importance for such public utility service. The basic structure is generally as shown in Fig. 8.16.

The composition of the top management depends on who owns the system. Most of the metro rail systems are now owned fully or partially by the government. Each city has followed a different pattern. Most of them have a board or authority managing the system within the broad policy guide lines laid down by the government. Some like the ones in London and New York have the



**Figure 8.16** Organization Structure for a Large Rail Transit System

apex board comprising both official (executive heads) and non-official members. In London, the non-officials are eminent citizens who are expert economists or administrators. In New York, the choice is political, being nominees of different counties. In New Delhi, the board comprises the functional directors who are regular employees of the system and a number of ex-officio directors representing different ministries of Government of India and of Delhi State Government.

### 8.10.3 Performance Indicators

The administration issues rule books and manuals containing instructions for day to day operation and maintenance of assets. These ensure that safety and security to passengers are provided and the punctuality and reliability of services are maintained. The safety aspect is also monitored by a Commissioner or Inspector of Railway Safety appointed by the Government, who is independent of the railway administration.

The operation of trains is continuously monitored by a control office and senior officials review the punctuality and equipment reliability on daily basis. The overall performance of the system is measured against the under mentioned performance indicators.

Number of passengers carried in year or per day

Number of trains run per day average

Fleet utilization—per cent

Number of coach kilometers run per day

Punctuality—per cent of trains run to time

Energy consumed—average per coach km

Energy consumed per thousand passenger km

Number of breakdowns per lakh coach kilometer

Number of accidents per lakh coach kilometer  
Passengers carried per route kilometer  
Passengers carried per car kilometer per day  
Average length run per car per day  
Cost of operation per car kilometer  
Cost of operation per passenger km  
Earnings per car kilometer  
Earnings per passenger km  
Operating ratio or Fare box ratio  
Review should be done on a monthly/quarterly/annual basis.

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# Coordination of Public Transport

# 9

## 9.1 NEED FOR COORDINATION

The quality of life in metropolitan cities is governed by the efficiency of the public transport systems in facilitating mobility to the people and their accessibility to the various activity centers. Though the demand for public transport in terms of person trips is increasing, the supply falls short of the demand due to resource constraints. Currently rail-based mass transit is either not existing or is inadequate in coverage and frequency in many cities. Bus transport is the predominant mode in most cities because of the flexibility of operation and the relatively lower capital and operating costs. For example, over 80% of public transport trips in Chennai are carried by the bus transit because of inadequate rail facilities and ineffective coordination.

Inadequate provision of public transport facilities results in the proliferation of private vehicles, leading to acute congestion on the roads, inordinate delays, serious accidents, excessive fuel consumption and intense environmental pollution. The National Transport policy should therefore be aimed at encouraging public transport systems in most urban areas. The desirable share of public transport out of vehicular trips could be of the order of 30% for cities of 100,000 population rising to about 85% of vehicular trips or 60% of total trips for cities above 9.0 million population<sup>1</sup>.

The acceptability of a public transport system is governed by its capability to cater to the demand in time and space, with reliability and comfort at a fare perceived to be affordable and reasonable. The other factors influencing the patronage are attractive design of terminals, better connections and transfers, safety, punctuality with reference to a published schedule and affordability of the demanded fares.

The institutional frameworks relating to the components of public transportation vary in different countries. In India, the rail based transport (except the tram service in Kolkata and the Delhi Metro Rail Corporation) is controlled by the Ministry of Railways, Government of India, whereas the road based transport, including bus transit and paratransit, are within the domain of the state governments. Coordination between the rail and bus modes, in matters of planning of facilities, fare structures, scheduling and operation, is conspicuously absent. The consequences are manifested in adverse shifts in modal split, congestion on the roads, over-crowding in the available public transport and increase in road accidents, foreshadowing a decline in the quality of life. There is a clear need for a better coordination of public transport in cities.

The main reasons for the rail transport having less patronage than the bus transport in some Indian cities are two-fold: (a) single journey tickets cost more on rail than on bus; and (b) the accessibility of rail stations is perceived to be unattractive. In Chennai, the bus system carries more passengers than the rail for the above reasons and also since the rail network coverage is limited. The share of rail and bus are nearly equal in Mumbai, partly because of absence of long bus routes parallel to rail lines and also because several bus routes serve as feeder services to the rail facility. There is a clear need for a better coordination of public transport in Indian cities.

9.2 SELECTION OF TRANSIT MODE

Selection of the most appropriate combination of transit modes for a city is the main decision in planning new or expanding existing transit systems. This decision is critical because it has a major influence on the city’s physical, economic, social and environmental conditions and development. Cities with a population of one to two million can manage with bus transport. When the population crosses two million mark, then light rail transit may be added. Rapid rail transit may become necessary for cities with three million population.

It is necessary to consider the site-specific conditions, requirements and constraints. The parties affected are the passengers, the transit operator and the community. The requirements of the parties are summarized in Table 9.1.

Table 9.1 Transit System Requirements

Party	Requirements
Passenger	Availability; Punctuality; Travel time; User cost; Comfort; Convenience; Safety
Operator	Area coverage; Frequency; Reliability; Cost; Capacity; Safety; Passenger patronage
Community	Level of service; Environmental impact; Economic efficiency; Social objective

From the point of view of the passengers, the transit service should be available with respect to locational proximity and frequency of service. The service should be punctual and should involve short travel time. The travel cost, which includes the transit fare and expense to access the transit, should be low. The ride should be comfortable, preferably with ergonomically designed seats, and the overall use of the system should be convenient with regard to access, frequency, clear information and less need for transfer. Passenger safety in terms of accident prevention and security from incidence of crime are also of importance.

The operator of the transit, STU in case of bus service or the railway or metro rail administration in case of rail transit, is concerned with the extent of urban area covered by the service, frequency of departures, high commercial speeds on the lines, costs in relation to potential revenue, system capacity, operational safety and the number of passengers carried.

The community would like to get a high level of service, least adverse impact on the environment, enhancement of the economy and realization of the social objective of facilitating mobility for the average citizen.

The transit modes are characterized by the right-of-way, technology and type of service. Trams, trolley buses and buses which share the carriageway along with private vehicles cannot be competitive with respect to private cars. Semi-rapid transit, such as LRT and buses on exclusive busways (BRT), has relatively higher speeds and reliability. The rail rapid transit provides the highest level of service, but with the highest investment costs.

The alternatives considered are a smaller network of higher performance served by a system of feeders, or a larger network of lower performance system. In the final analysis, it would be desirable to attempt an integrated urban transport system with different modes applied optimally so as to serve the urban area satisfactorily with the minimum overall cost to the community.

The patronage of a rail transit system depends on the advantages perceived by the passengers. The size of the system should compare with the size of the city. For example, in Chennai, the longer Beach-Tambaram line has been crowded, while low occupancy rates have been recorded in the Beach-Mylai line, which was then a short 8-km line. In the latter case, the passenger might not consider it worthwhile to change from a feeder bus. The Beach-Mylai line on being extended to Velachery (another 11.2 km) is since showing better patronage, though not to the extent expected due to poor connectivity.

When the establishment of a new rail transit mode is preferred, its choice should be exercised with great caution. The ridership estimates should be done realistically, as a metro can succeed only with a large number of riders. Necessary funding at the right time should be assured in advance, and construction work should be taken up expeditiously and with due care to cause the least disturbance and dislocation to normal life. Delays result in cost overruns due to increased expenditure on interest, cancellation charges, under-employed labor and plant, besides inflation.

### 9.3 PUBLIC TRANSPORT FINANCING

Financial viability of the system is a key element in the provision of public transport services. A commonly cited reason for poor performance of a bus service is the lack of financial resources for the purchase of new vehicles and spare parts for maintenance. For a transport system to be effective, special mechanisms should be developed to ensure a reliable source of income to meet the commercial and social obligations of the service provider and the community. But with similar loading, private operators and franchisees manage to not only break-even but also earn a profit, mostly due to lower costs and more intensive use of fleet.

Fares constitute the single largest source of finance for a transit company. The most cost-effective systems are normally those that are required to cover all operating costs through fare box revenues and associated earnings from advertising and from renting of premises in terminals for shops. This provides an incentive to the operator to match service with demand, to maximize ridership, and operate in the most cost-effective manner. Fares and service levels should be determined in a



system-wide multi-modal context and be related to the overall economic and social strategies for development and transport. Road user pricing will increase public transport patronage and can improve cost recovery.

9.4 TRANSIT FARE STRUCTURES

9.4.1 Types of Fares

Fare systems are the set of rules to determine the fare to be paid according to the facilities extended and the type of the trip. The fare structure, i.e., the level at which fares are set, is determined by: (a) the costs borne by transport undertakings; (b) the quality of transportation desired, as evidenced by factors such as service frequency, speed of transport and access distance; and (c) competition from other modes of transport.

Transit fare structures have a direct influence on the patronage and productivity of the transit system. The urban planning goal in Indian cities, where a significant proportion of the urban population lives below the poverty line, should emphasize easy accessibility to transit with fares affordable by the common man. Subsidy in some form may be necessary. There is a need to evolve an appropriate fare structure which is a compromise between the cost of operation of transport services and the price affordable by the majority of the residents of the city.

The various types of fares can be broadly classified as: (a) Flat fare; (b) Variable fare; and (c) Special fare. Flat fare is a fixed fare for a trip on a route irrespective of the trip length, and is justifiable in an urban network of short trip length. The variable fare is dependent on trip length, and it can be further subdivided into: (i) Distance fare, where the fare varies in proportion to

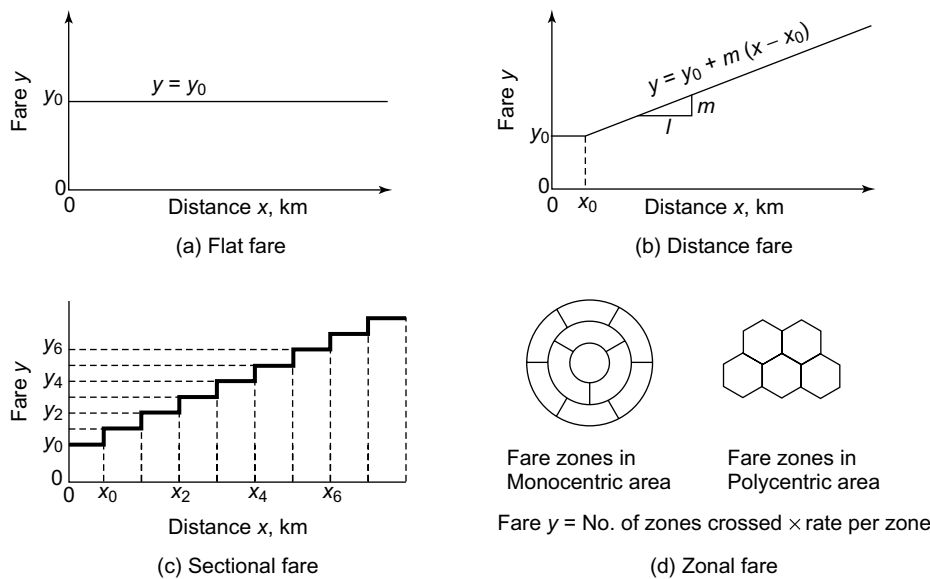


Figure 9.1 Revenue Characteristics of Fare Systems

the distance traveled; (ii) Sectional fare, which is similar to the distance fare, but with the same fare being charged for each section with specified distance interval (e.g., 2 km as in Chennai bus system); and (iii) Zonal fare, where the fare is incremented every time a passenger crosses a zone boundary. The zones may be segmented ring zones for mono-centric high density areas (e.g., Paris and Hamburg), whereas honeycomb-shaped zones are more suitable for polycentric fare regions<sup>2</sup>. Sectional fare is sometimes referred as distance fare in practical discussion. The different types of fares and their revenue characteristics are indicated in Fig. 9.1. Special fares are concessional fares for specific categories of clients, such as students, senior citizens, physically handicapped persons and season ticket holders. A telescopic fare, which reduces as a function of distance beyond a specified distance, is a type of concessional fare.

While flat fare is convenient for fare collection and may produce a particularly strong integrating effect enhancing traffic attraction to the city centre, it is inconvenient for big cities. Distance fare and sectional fare favour the development of the city center and subcenters in case of large cities. Zonal fares may have an integrating effect to include suburbs in the catchment areas of large industries for industrial labor. In metropolitan cities, in India, with multiple local languages and low level of literacy, there may be initial difficulties in introducing zonal fares, but the passengers may soon learn to manage with the system.

#### 9.4.2 Factors Affecting Fare Structure

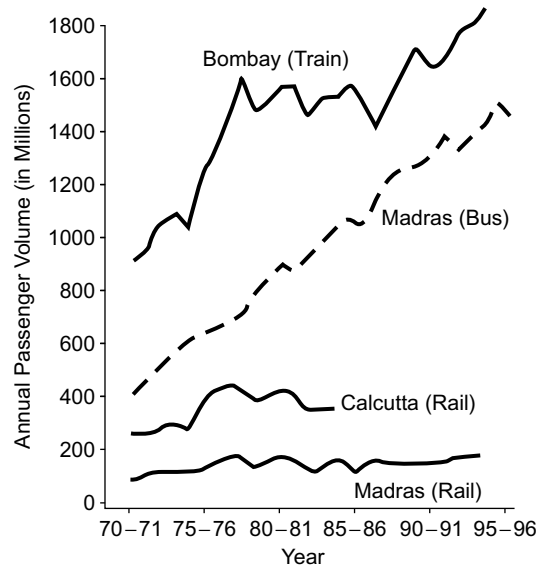
There is no universally agreed approach to fare structures for metropolitan transit trips. The determination of the fare structure is a complex task, involving a compromise between the conflicting demands of the users and the operators. Transit users expect low fares to enable mobility at prices affordable by the urban poor. On the other hand, the transit operators would like the fare structure to facilitate recovery of the full cost of operations with a reasonable margin of profit. The latter proposition tends to ignore a series of planning, social and socio-political goals, which the operator is obliged to fulfill.

Transit fare elasticity is measured by the percentage change in transit travel demand per percentage change in fare level. For conditions obtaining in India, the transit demand is almost fare inelastic for small changes in transit fare. When the rail fare increases substantially at a time when bus fare is left unchanged, a significant shift in modal split from rail to bus is sometimes noticed. The transit fare elasticity varies with trip purpose, income level and level of service.

In a study<sup>3</sup> done in USA covering 77 fare hikes over a period of 20 years, it was found that the fare elasticity was such that for every per cent increase in fare, there was a 0.30% fall in ridership. Based on the study, they evolved a thumb rule that a variation of 1% (increase in fare) caused a ridership change of 0.30% (loss). A similar study<sup>4</sup> done using data from two suburban rail systems one in Mumbai and one in Chennai covering 7-year period revealed that there was fare elasticity of 0.36 in Mumbai and 0.29 in Chennai.

A macro level study done on trend of passenger loading on suburban rail systems in India indicated that significant increase in fare structure on the suburban rail system caused a sharp fall in patronage and it took longer to pick up the growth trend. On the other hand, even the effect of

fare rise on the Chennai bus system was not so sharp, as can be seen in Fig. 9.2. Every sharp drop in loading indicated in the graph is a result of the hike in fare in that year. This has been more prominent in Mumbai since it accounts for high volume of trips.



Source: Reference 4

**Figure 9.2** Impact of Hike in Fare on Passenger Volume

In the case of bus transit, the basic road infrastructure is provided by the State Government, the cost being met from the budgetary resources. The bus operating company meets the cost of vehicles, system operation and maintenance from the fare revenue. In other words, the bus transit fares cover only a part of the total costs to the community. The authorities concerned with the bus operation try to keep the bus fares low so as to provide better affordability and accessibility to the urban poor. Fare elasticity on bus is not so critical to the bulk of the commuters for want of an alternative, but those who have own vehicles tend to attach greater value to comfort and saving in travel time.

For railway operation, the proportionate costs of capital works and maintenance of rail tracks, stations and other infrastructure, besides operating costs, are to be met from the fares realized from the direct beneficiaries. At the prevailing fares, which are already perceived to be high relative to the per capita income of the urban poor, the passenger service in urban areas tends to result in financial loss to the railway administration. Suburban trains have high occupancy during peak hours, but the major part of the passengers (about 65% in Chennai) are season ticket holders who contribute relatively less towards the fare revenue. (Season ticket costs about 15 to 20 times single journey fare.) During off-peak periods, the occupancy is low (at around 20% in Chennai) leading

to deficit. There is a need to provide cross subsidy to sustain the rail transit service. The urban rail system should be treated as an independent unit, and the fare structure for urban rail transit should not be linked with the fare policy applicable to the intercity railway service.

In Indian cities, the demand for public transport in terms of total person trips is increasing because of increasing population. However, the share of public transport in the total trips in percentage terms has been decreasing in recent years, due to inadequacy of public transport facilities and as a result of increasing availability of fuel efficient cars and affordable two-wheelers. For example, the share of public transport in total trips in Chennai declined from 53% in 1970 to 42% in 1991 and 40% in 2001. Out of the public transport trips in 1991, bus transport carried about 90% of the trips, while the suburban rail catered to the rest. Latest trend shows a increased share of trips by trains, with the addition of MRTS and increased frequency of train services. The low share of the rail trips is attributable to the inadequate coverage by the rail transit and the relatively higher fare structure for the rail system as well as operation of long bus routes parallel to rail lines. On the other hand, the share of bus and rail trips in Mumbai used to be equal for many years and in recent years, the rail trips has increased to two thirds of public transport trips. (7 million and 3.5 million train and bus trips, respectively). This has been mainly due to better coverage of rail network and high frequency (over 20 trains each way in peak hours on maior corridors).

It would be desirable, from the point of view of sustainable traffic management, to aim for a modal split of about 75:25 between the public and private transport vehicle trips in the long term. Further, the rail network may be planned to cater for about 60% of the public transport demand, along with expansion of rail network to cover all arterials (both radial and circumferential) and provision of inter modal transfer facilities at major stations. For example the MTR, LRT and Tram (totaling about 200 km) in Hong Kong has a share of about 35% of public transport trips, which they expect will go up to 45% with proposed increase of network to 300 km. The pricing policy (fare structure) could be used as a tool to guide the movement of the modal split towards such a desired objective<sup>5</sup>. This aspect merits serious consideration by the urban planners and the authorities concerned with the operation of transit services.

### 9.4.3 Subsidy

When fare revenues are insufficient to meet full operational and maintenance costs, financial sustainability of the service requires additional guaranteed source of income such as subsidy from government. Subsidies for public transport are of two types: operational subsidy and capital subsidy. Capital subsidies are given by government for buying new fleet and for infrastructural development/improvement. The subsidy is usually in the form of a contract payment from government subject to satisfactory performance of stated social objectives.

Most efficient bus systems such as in Singapore or Hong Kong operate without government subsidy. Some of the bus systems as in Chennai and Bangalore City are able to break even operationally but require capital subsidies. Others, such as several companies in India, France and Germany, which are often successful with respect to level of service and compliance with social objectives, achieve only around 50 to 60 % cost recovery from their operation. These companies rely

on annual subsidies to meet operating deficits and capital expenses. In this case, it is necessary to build-in mechanisms to ensure that sufficient resources are available to pay the subsidies promptly. Most urban rail systems need capital subsidies, while some suburban commuter rail systems need operational subsidies also. Presently urban rail systems in five cities in the world, including Delhi metro, are reported to have operational surplus which can be used for part payment of loans.

There is a widespread belief that urban public transit must be subsidized to enable the poor to afford the fares. However, suitable mechanisms should be devised to ensure that the subsidies are targeted to the poor. One method is to issue special tokens to the poor so that they may use these tokens to buy the transit tickets. Another device is to reimburse a part of the operating expenses based on the performance towards social obligations imposed by the government.

#### **9.4.4 Fare Differentiation**

In order to attract more passengers to the transit service or for better conditions of operation, a transit undertaking may opt to offer differential fares under certain conditions. The fare differentiation may take the following forms: (a) Spatial differentiation, in which case fares are fixed according to the distance, either with a linear variation or with a non-linear variation or in steps; (b) Temporal differentiation, when higher fares are applied during peak periods and lower fares are permitted during non-peak periods (as in London Metro); and (c) Multiple-journey/season ticket involving a discount over basic fares.

#### **9.4.5 Fare Coordination**

Currently, there is no coordination with respect to fare levels between the rail and road based modes in Indian cities. A passenger transferring from rail to bus or bus to rail, or even from one bus to another bus as part of a trip has to buy separate tickets, involving inconvenience, time delay and some financial penalty. This situation forms one reason for the users hesitating to change modes for a trip and for demanding direct bus routes from their origin to destination. The fare structures for the rail transit and the bus mode are different, and these fares are revised at different times through marginal adjustments, without any consultation between the operators of the two modes. The fares have been evolved over a period of time, without the benefit of scientific studies based on sound economics or social objectives.

Modal choice is influenced by the relative fare levels for bus and rail transit (as discussed in Section 9.4.2). Usually, the rail fare, which is already high for single trip, is increased at a steeper rate than the bus fare. Variations in the basic fare levels tend to distort the modal split. An increase in rail fare causes a part of the passengers to shift from the rail mode to the bus mode. In other words, there is a negative fare-elasticity. In the case of Calcutta metro rail, it has been reported that a drop of passengers by 36% was observed in 1992 due to rail fare increase by 100%, because buses were cheaper even though less comfortable<sup>6</sup>. On the other hand, Delhi Metro rail is having high patronage despite comparatively higher fares. This can be attributed to better level of service on the metro and faster tension free travel. Urban transport planning has to recognize the capacity and willingness on the part of the users to pay the levied fares.

The basic premise of the approach to fare coordination is that the fare structures for the two basic modes for metropolitan transit should be uniform, so that a passenger would be free to choose a convenient public transport mode or to mix modes for parts of his trip without inconvenience or penalty.

The zonal fare system followed in cities in UK, France and Germany in effect results in uniform fare for travel by rail or bus transit. This system would promote optimum utilization of the public transport networks, and would ultimately enhance the overall income to the community. The operation of the integrated zonal fare system would require the metropolitan area to be divided into a number of zones of approximately equal areas, each with a clearly identified activity centre. All passenger movements, either by rail or by bus, within one zone are carried out at the same fare. Whenever a passenger crosses a zone boundary, the fare is increased by one stage. If a commuter intends to travel over four zones, he would buy one ticket of value corresponding to four zones. Transfers are made without penalty.

The cost components for bus and rail transit operations are basically different, apparently justifying different fare levels when considered as separate enterprises. However, a uniform fare structure for metropolitan transport can be substantiated on other social and equity considerations. The requirements of traffic space per person for different modes are: car 40 m<sup>2</sup>, bus 4.5 m<sup>2</sup>, and rail 2.5 m<sup>2</sup>. The rail is more economical in land space requirement than bus or car: it is also non-polluting. Thus there is justification in pricing bus travel at a higher level than for rail, which is currently observed in the reverse. Possibly, the bus fare may be kept at the same level as the rail fare in order to reduce competition and mismatch in occupancy ratio as is done in Mumbai.

In view of the overall importance of the transit for the economic sustenance of the metropolis, the capital cost for the transit may be taken as the responsibility of the central, state and local governments, in agreed proportions. The fare structure may be evolved in such a manner that the resulting fare revenue would meet the total costs on operation, maintenance, depreciation and administration for the total transit service (both rail and bus) for the metropolitan area. Such a fare structure would be intermediate between the present rail and bus fares. The fare coordination would need a Unified Metropolitan Transport Authority (UMTA) to coordinate the integrated planning of the infrastructure, financial management (including fare determination and revenue allocation) and operation of the different public transportation modes. With effective functioning of the UMTA, it would be possible to enhance the attractiveness of public transport by offering “one ticket—one timetable—one network” for any trip within the metropolitan area. To start with, combined season tickets between rail and bus can be introduced.

#### **9.4.6 Innovations in Fare Coordination**

With a view to woo riders to transit and to improve the fare box recovery of transport costs, transit companies in European cities have attempted many innovations aimed at enhancing passenger convenience through expansion of region-wide fare integration and sophisticated marketing techniques. The Hamburg Regional Transportation Authority (HVV) is a model of fare integration.

Its “city card” is a monthly ticket which permits ridership on 240 km of rail lines and 2500 km of bus lines in a 40 km diameter metropolitan area that includes more than 2300 bus stops and 160 light rail stops<sup>7</sup>. Similar attempts have been made in other cities in Germany, Switzerland, the Netherlands and Belgium. The tickets which come in the form of credit card size magnetic cards also facilitate the needed management information to the operators. These innovative methods have contributed to the shift of riders from their cars to the transit, thus ameliorating downtown congestion and improving traffic flows for all road users. In India, Delhi Metro has introduced the use of smart cards for fare collection on their system.

## 9.5 TRANSIT MARKETING

Transit marketing embodies a philosophy of management and operation of transit aimed at discovering and exploiting the opportunities to serve the public in the area of public transportation. The view of transit providing consumer-oriented service has evolved from one of providing utilitarian service. A transit organization should adopt a marketing strategy that is appropriate to its position in a competitive transportation market. Since the market for public transportation does not consist of a homogeneous group of consumers, the marketing effort should be directed towards particular segments of the overall market rather than attempt to reach everyone at the same time. Promotional effort should also be devoted to current non-users who may be viewed as potential transit riders.

Transit marketing activities start with the preparation of a marketing plan. The marketing plan is a written document giving a review of the transit marketplace, a statement of objectives, and a plan of action to achieve these objectives. The plan would involve the following basic activities: (a) Market research, covering the mobility needs of the market in terms of service, price and other attributes; (b) Service planning and development, dealing with the basic elements of transit service such as type of service, routing and scheduling; (c) Facility and equipment design and maintenance, to review and evaluate facilities such as transit stops, terminals and transit vehicles to ensure efficient user amenities; (d) Fare determination and review of collection methods to promote attractiveness of transit; (e) Rider information through advertisements and brochures to publicize the services available and advantages of using the service; and (f) Evaluation and monitoring to measure consumers’ awareness and responsiveness through actual ridership behavior, so as to enable initiation of corrective measures. Advertising is thus one of the several basic activities of transit marketing. If a transit organization is to be successful in accomplishing urban goals and in fulfilling citizens’ needs, transit marketing should become a key element in the management function for developing a variety of services to meet varying public needs.

The market for public transportation does not consist of a homogeneous mass of consumers, but is divided into segments of consumers with different needs and desires that require different package of service. The concept of market segments and marketing mix can be applied in transit marketing. For the purpose of illustration, let us assume four segments: high income group; medium and low income group; school children; and the elderly. The marketing mix consists of

all activities relating to product, price and promotion of the transit service, which may be varied to meet the needs of the different transit market segments. The product element includes the types of service, the quality of service and the customer's accessibility to the service. The service types may be divided as: regular route; special services as for a cricket match, temple festival or religious meeting; or chartered services as subscription service for senior employees of major firms. The quality of service would include comfortable seating, air-conditioning, and shelter for passengers, and crew courtesy. Pricing is the second major element in the marketing mix, and is aimed at providing value for money. Promotion is the third part of the mix, emphasizing the benefit of the service, low price and flexibility.

The high income segment may be offered air-conditioned coach express service at a higher price. The medium/low income segment may be provided the regular buses at the basic fare. School buses may be operated at school timings with the children paying concessional fare. The elderly may be encouraged to use the transit services during non-peak hours at concessional fares. Special services and chartered services may be operated at premium fares. The above plan gives a conceptual framework of a possible marketing plan which may be modified to enhance performance.

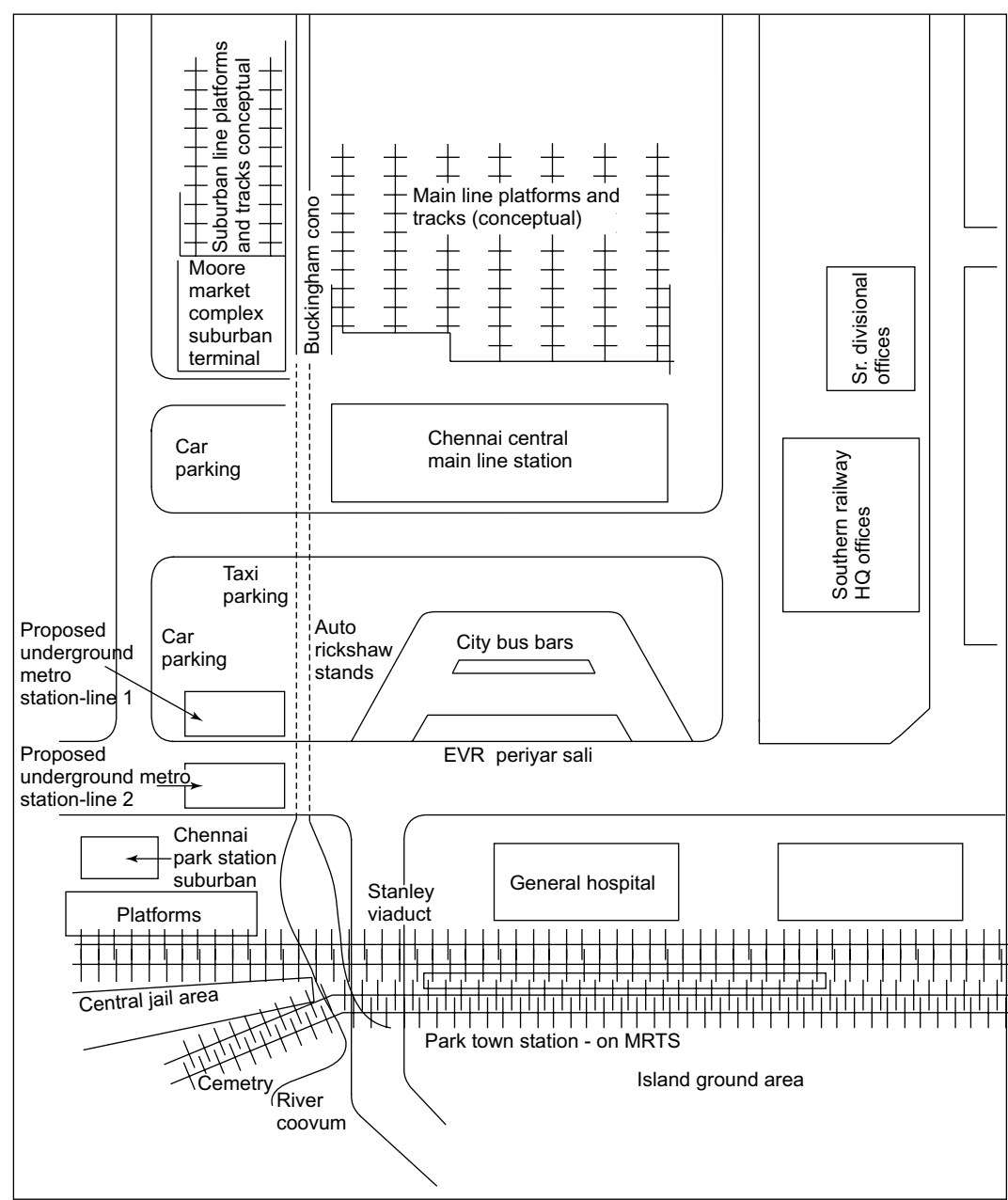
## 9.6 INTERMODAL TRANSFER

The effectiveness of public transportation can be maintained and enhanced only if there is effective coordination among the various modes and conscious steps are taken to ensure intermodal transfer in a safe, convenient and comfortable manner. Hence much attention needs to be devoted to planning, constructing and operating transfer stations between bus and rail modes, besides facilities for transfer to other modes as well, especially for rail stations with rail-bus transfer trips in excess of 500 during the peak hour. Bus bays are to be provided at or close to rail stations, where feeder buses could drop passengers to rail and pick up passengers from the rail mode. Since availability of land will be a major constraint to expansion of transport terminals in urban areas, the provision of intermodal transfer should be accorded high priority at the planning stage itself.

Park-and-ride (P+R) facilities should be provided at most rail stations and major bus terminals in the city suburbs. The additional cost for the facility can be recouped within a short period through collection of parking fees. This measure would result in reduction in the number of private vehicles, especially two-wheelers, on the arterials within the CBD, leading to many intangible benefits with regard to air pollution, traffic congestion and accidents.

Developing countries may study the successful application of intermodal transfer in Germany<sup>8</sup>. An interesting example is the Jungfernstieg terminal in Hamburg, which provides for transfer among five modes of traffic, namely, a four-track U-bahn station, a two-track S-bahn station, another two-track U-bahn station and a shipping berth for inland navigation, besides vehicular traffic on road surface. In some of the new light rail stations in Hanover, the bus stop is located on the other side of the platform to facilitate easy transfer, e.g., transfer station Empelde. P+R facilities are made available at many important stations along the rail network, and these are well utilized. The main stations of the German Railways (DB) invariably have facilities for transfer to LRT lines





**Figure 9.3** Proposed Intermodal Transfer Facilities at Chennai Central Station (Conceptual)

and city buses besides feeder bus to the airport. Metro rail stations in Singapore are provided with transfer facilities for car and buses, as indicated in Fig. 7.8. The city also operates feeder buses from many of their stations. Since all land transport in Singapore come under one department, their inter-se co-ordination has become easy.

Park and ride facilities in form of parking areas for cycles and two wheelers have been provided in Suburban rail stations in Indian cities where land is available. Bus stops on adjacent roads or nearby roads have been provided in many stations, typical examples being Chatrapati Sivaji Terminal, Churchgate and Vikroli in Mumbai and at Chennai Central. Comprehensive Park and Ride provision has been made to cover bus, cars, two wheelers and IPT on most stations recently developed in Navi Mumbai. Delhi Metro rail stations are being provided with such facilities wherever required and the Delhi Metro Rail Corporation operates feeder bus services from some important stations.

Chennai Central has good inter-modal transfer facilities including bus bays within the station circulating area. The proposed Metro rail will have a major station at this location and a major transfer complex is proposed. Figure 9.3 shows the conceptual layout. At the recently commissioned MRTS station at Velachery, provision of good parking facilities has shown heavy patronage of the rail services.

Figure 9.4 shows the parking area provided at Velachery, a busy station on the MRTS at Chennai. The station concourse on one side has a bus terminus also. On a busy working day, over 600 motorized two wheelers, 200 cycles, about a dozen cars and number of auto rickshaws are parked at this station at busy hours.



**Figure 9.4** Parking Areas at Velachery MRTS Station—Chennai

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## 10.1 PARKING PROBLEMS

For any person or cargo moving in a vehicle, a terminal facility is essential both at the origin and the destination. When the person has to stop *en route* for some purpose other than traffic related, the vehicle needs some halting facility, without disturbing traffic flow otherwise on the street. Such a facility is called parking. Parking hardly captures the imagination of the traveler, except when an immediate lack of the some parking space, at the time of need, frustrates. The motorist's concern in cities is not only about 'getting there' but also 'parking there'.

With the increased ownership and usage of private vehicles in the form of automobiles and motorized two-wheelers, parking has become an essential fact of this age, particularly in urban areas. Parking spaces on streets occupy a substantial part of the road space meant for movement. A study conducted in USA some years back indicated that space needed for vehicle storage equaled, if not exceeded the space used for vehicular movement<sup>1</sup>. It is also noteworthy that a personal vehicle is on the move hardly for 2 to 3 hours in a day, while for the remaining period it is 'parked' at the residence or destination and sometimes *en route*. Even commercial vehicles will be found be parked for about 60% of time on an average.

Every vehicle owner would like to park his vehicle as close as possible to his destination, so as to minimize his walking. Depending on the size of the town and locality, the acceptable walking distance varies from 50 m to 150 m, and that too depends on the pedestrian sidewalk facility available. This puts up the demand for parking facilities in the areas of concentrated activities like CBD, shopping areas and industrial clusters.

Parking is a major problem in metropolitan cities. On-street parking which occupies the costly road space meant for movement of vehicles constitutes inefficient use of scarce resources. Restrictions on on-street parking, coupled with provision of parking meters and privately operated off-street parking lots, may have to be adopted in metropolitan areas.

There is an increasing acceptance that planning of parking facilities is a public responsibility and that the construction of off-street parking facilities is a proper field of municipal action. This approach is supported by the following arguments:

- (a) Parking is a part of the highway traffic problem.
- (b) Off-street parking lots have not been developed in adequate measure by private development.
- (c) Assembling of adequate land for off-street parking layout in areas where such facilities are required may need the exercise of the power of eminent domain by the municipal authority.
- (d) Funds for off-street parking facilities can be mobilized more easily by municipalities than by private agencies.
- (e) Metering and regulation of on-street parking can only be performed by a municipality.

## 10.2 IMPACT OF PARKING

The parking facility or the lack of same has the under-mentioned major effects<sup>1</sup>:

- (a) Parking impacts land use, specially institutional and commercial activities in the zone.
- (b) It influences prevailing landscape, environment and architectural experiences over time in the area.
- (c) It influences urban development and redevelopment in business districts.
- (d) Parking, especially on-street parking, adds to traffic congestion and consequential accidents and pollution in the area.

Institutions like offices, commercial establishments and banks employ a large work force which commutes for work. A large proportion of them will require space for parking their vehicles during business hours. In addition, they will have visitors and customers who will require short term parking spaces close by for their vehicles. Inadequacy of such space can be a deterrent to employees and customers, which will in turn affect their growth. Growth of retail business is dependent on attracting shoppers in large numbers. A number of studies have indicated that shops on streets with well regulated on-street parking lots and shopping malls with good off-street parking facilities within or nearby have attracted more business than others.

Off-street parking lots on surface provide open spaces which can be attractively landscaped to add value to the environment. In-built parking facilities underground or on terrace can be architecturally blended in buildings housing commercial establishments. Multistoreyed parking garages can also add to the aesthetic blending with the neighboring buildings.

Any urban development is dependent on the degree of mobility on the streets serving the area. Sustenance in the growth of business districts depends on how free or regulated is the traffic flow on the streets serving them.

On-street parking takes away considerable part of the carriageway for the parked vehicles. When the vehicle is negotiated into the parking slot and when it pulls out, it obstructs the adjacent traffic lane also for the maneuvering, thus holding up the traffic. In the process, some accidents are caused also since all the drivers may not be adequately skilled or experienced in reversing vehicles in a narrow space. If the vehicle is parked close to an intersection, it can cause an obstruction to the vehicle turning on to the main street. More gases are emitted by the vehicles during such processes adding to pollution.

10.3 PARKING SPACE REQUIREMENTS

Parking slot or stall is defined as the space allocated for a vehicle. The requirement can vary depending on size of the vehicle. Presently cars come in different sizes, the large ones being about 1.5 m × 5.4 m and small ones measuring about 1.4 m × 4.5 m. A public parking slot has to cater for the largest car, unless separate lots can be provided for big and small cars<sup>2</sup>. It is not practicable to provide such separate lots. Generally provision is made for predominant size of cars. Size of slot depends also on whether it is for self parking or attendant/chauffeur parking. While an attendant can park a large car in a stall 2.4 m wide easily, a self parker will require a width of 2.5 m to 2.70 m depending on low or high turnover parking activity. The stalls for self parking will have to be larger for ease of maneuvering. In some countries, they vary the slot size depending on turn-over. In USA, they follow four different standards A, B, C and D as indicated in Table 10.1.

Table 10.1 Stall Width Classification in US cities

Class	Width - m	Turnover Rate			Type of User and Location
		Low	Medium	High	
A	2.74			X	Banks, retail outlets, fast food restaurants & other high turnover establishments
B	2.66		X	X	Retail customers, visitors
C	2.58	X	X		Offices, airports, hospitals, residences, visitors
D	2.51	X			Industries, universities, commuter services

Source: Adapted from Reference 2

Stall depth used is generally 5.1 to 5.3 m. For small cars, a stall of size 2.3 m × 4.86 m would do. IRC standard has considered a stall size of 2.5 m × 5.0 m, in formulating their concepts for on-street parking angular layouts. Sizes for parking vans, trucks, buses will be entirely different. So also will be the requirement for parking of motor cycles/scooters and cycles. They are separately dealt with at end of this chapter.

10.4 TYPES OF PARKING FACILITIES

Parking facilities can be broadly classified as: on-street parking and off-street parking. Off-street parking can be sub classified as follows: (i) residential parking; (ii) surface car parks or parking lots; (iii) parking structure (garages).

Parking structures can be (i) Roof parks; (ii) Multi-storey car parks (iii) Under ground car parks and (iv) Mechanical car parks.

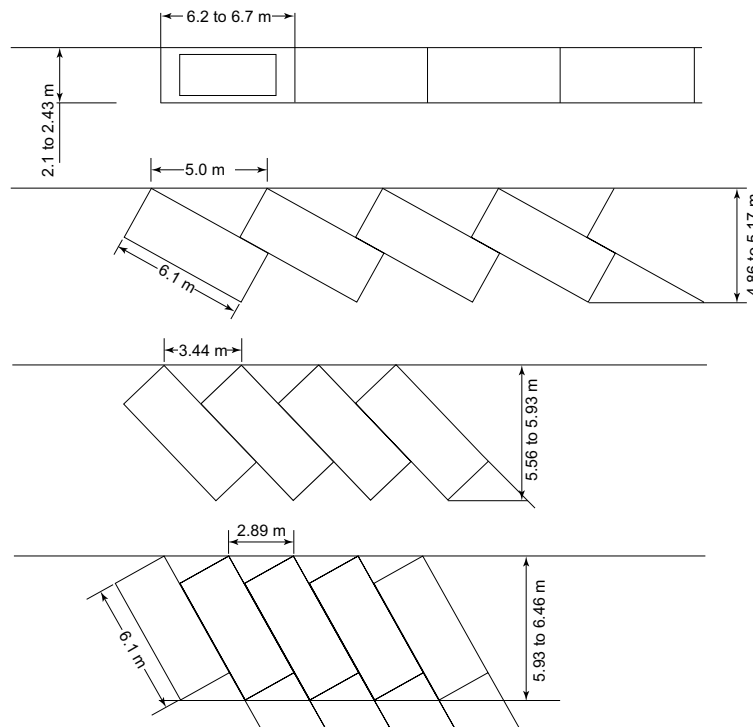
10.4.1 On-street Parking

On-street car parks or kerb parking, as they are otherwise called, use part of the carriageway for parking of cars and motor cycles. It is the most rudimentary form of parking. These are the least expensive since no additional land or paving is required. Only expense is in providing necessary

demarcation lines on road surface, apart from cost of controlling its use. It is the most sought after by the motorists due to ease of access. The motorist can choose the slot available closest to his destination. On the other hand, the curb parking takes away a substantial width of carriageway which would otherwise have been available for movement of traffic. It slows down traffic on adjacent lanes whenever a user pulls in or out of the parking slot. Some studies have found that the capacity of the street with Kerb side parking is reduced by as much as 45% and a 12 m street without parking is equivalent to a 20.5 m street with one side parking<sup>1</sup>. It is suitable where wide roads are available and where there is limited through traffic, like commercial streets and wide by lanes.

Parking slots can be parallel to kerb, perpendicular to or at an angle when it is called angular parking. Different forms are conceptually indicated in Fig. 10.1(a). Parallel parking requires some extra length for the driver to maneuver into or out of the parking slot. Hence it occupies more linear space along the kerb and reduces the capacity of the street length available for parking. Delay caused to traffic on adjacent lane also is more, since drivers can not park in or pull out of such slots in a single operation. But, it occupies minimum width of road and hence leaves more carriageway for passing traffic. A typical slot will measure 6.0 m (along the kerb or road edge)  $\times$  2.4 m. (across the carriageway).

Figure 10.1(b) shows an example of parallel parking on a busy road. It also shows a mid-block Zebra crossing and tut tuts in a Sri Lankan city.



**Figure 10.1(a)** On-Street Parking – Alternative Layouts



Figure 10.1 (b) Parallel Parking on a Highway through a City



On the other extreme, the 90° or perpendicular parking slot will be 2.4 m (along the kerb)  $\times$  5 to 5.5 m across the carriageway. The space requirement for angular parking will lie in between as shown in the figure. In case of angular parking, the drivers will find it easier to park or pull out and that too in a single operation. But it is reported that more accidents take place in angular parking. Delay caused to traffic on adjacent lanes is reduced with angular parking. It has been observed that 60° parking is the easiest for maneuvering and also most economical in space utilization.

Number of cars that can be parked in a given length of the road for different layouts in Indian conditions is obtained from the equations given below<sup>3</sup>.

Parallel	$n = L/6$
30 degree	$n = (L-1.25)/5.0$
45 degree	$n = (L-1.77)/3.54$
60 degree	$n = (L-2.16)/2.89$
90 degree	$n = L/2.4$

where  $L$  is length of stretch in meters.

On-street parking should not be permitted on any one way road of width 4.8 m and on two way roads of width 7.8 m or less. Even in wider roads, it is desirable to restrict parking to one side of the road only. Where it is permitted otherwise, it should be ensured that there are two clear lanes for traffic in addition to space used for parking. A few locations where parking is prohibited are: within 6 m of any intersection; on pavements and cross walks; within 4.5 m of any fire hydrant; within 6 m of any driveway; within 15 m of any rail road crossing; and on any bridge, elevated structure on highway or a highway tunnel.

#### 10.4.2 Off-street Parking

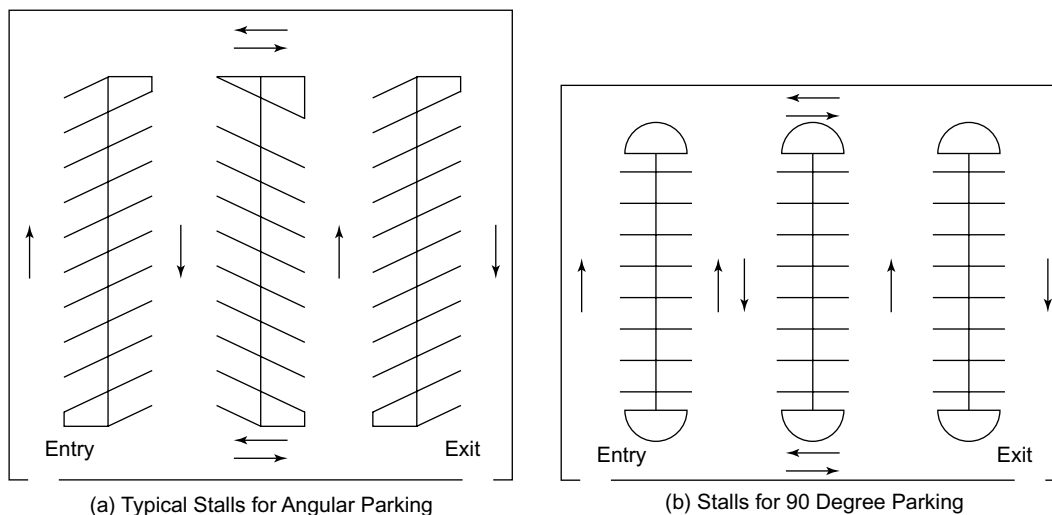
On-street parking facilities can be provided only on wide roads and roads not subjected to heavy traffic. Thus it can solve the problem only partially, viz., in small towns and fringe areas in cities and to some extent on streets with mixed use in larger cities. With the high rate of growth of ownership of motorized vehicles, provision of off-street parking facilities is unavoidable. The simplest and most economical form is surface parking lots, wherever sufficient open space is available for same. In many cities abroad, they have such lots even in busy areas. The growth of their cities and vehicle ownership in them has been almost concurrent. They could foresee the demand for such parking lots and have provided for the same. In many of their cities about 15% or even more of the land in central areas is used for providing parking lots, many operated by private entrepreneurs<sup>4</sup>. Since users are prepared to pay for parking, the owners of such parking lots have found them remunerative.

The layout of the parking lot depends on size and shape of land available and access roads available to reach them. Large parking lots can cater to a large volume of vehicles and can provide for different rates of turnover and be economical to operate. Some planners feel it is preferable to have more number of parking lots of smaller capacities as they can be run more efficiently and time taken to get in and out of them will be much less. A typical layout is to have two rows of stalls served by an aisle. The aisle can be unidirectional or bi-directional and this depends on the

layout and directional character of access roads. The slots can be at 90 degrees or angular and slot space requirements are similar to those discussed in Section 10.4.1. The minimum driveway width should be 2.7 m for uni-directional flow (single lane) and 5.4 m for bi-directional flow (double lane). With angular parking, an aisle width of 3.9 m is provided. For two way traffic, 90 degree layout is the most efficient. On an average, the overall space requirement per vehicle varies from  $29 \text{ m}^2$  to  $30.5 \text{ m}^2$ , the larger requirement being for flatter angle layout<sup>2</sup>. Wide aisles used in them are more inviting than the narrower aisles provided in angular parking.

Surface parking lots have some distinct advantages as (a) there is no ventilation or lighting problems, and good night lighting can be provided using tall poles or towers. (b) they have clear sight lines and give a sense of security to the user (c) they are not restricted by height considerations and hence can be used for taller (emergency vehicles) and commercial vehicles when necessary (d) they are easily accessed by users who do not have to negotiate ramps and sharp bends. It is the most economical both for construction and maintenance as no structure is involved and no artificial lighting will be required in day time. Only disadvantage is requirement of large open space, which will be in short supply on busy roads.

Some typical layouts of off-street parking lots are shown in Fig. 10.2. Large lots are provided with end islands of suitable design. The end islands can be in form of Kerb cut-outs on surface lots and may be painted ones in the parking garages or structures. These are necessary to (i) prevent encroachment into access/cross roads; (ii) to provide clear view at intersections between aisle and cross roads/aisles; (iii) provide necessary turning circle for entering or exiting vehicles. Space within them can be utilized for fixing signage, fire hydrants, etc., and for landscaping. In parking structures, landscaping can be done with potted plants. In shopping malls, it can also be used for parking the push carts/trolleys.



**Figure 10.2** Typical Parking Lots on Surface

### 10.4.3 Roof Parking

Minimum area required for providing a viable parking lot is an acre. Where such open space is not available within walking distance of the activity centre, one has to go in for a parking structure. Simplest form of providing parking space in a building is 'roof park'. The open terrace of roofs of commercial or institution building can be utilized for parking their employees' and customers' cars at a little extra cost. The roof and supporting structures will have to be designed for the extra loads that will be imposed by the storage and movement of the vehicles. Storeyed buildings with large plan area can be used for developing such parking lots. Access to roof can be provided in form of ramps or by mechanical lifts. Ramps will require extra space on sides and length sufficient to provide entry and exit ramps. The grade of ramps should be limited to 10% to 12%. Driving ramps should normally be 4.2 to 5.4 m wide, while 3.6 m width would be sufficient for a long straight length of single lane ramp. Depending on space availability, a two lane single ramp can be provided. If not, single lane rising and falling ramps one on either of the building. Angular parking slots with uni-directional aisles will help best space utilization in such case.

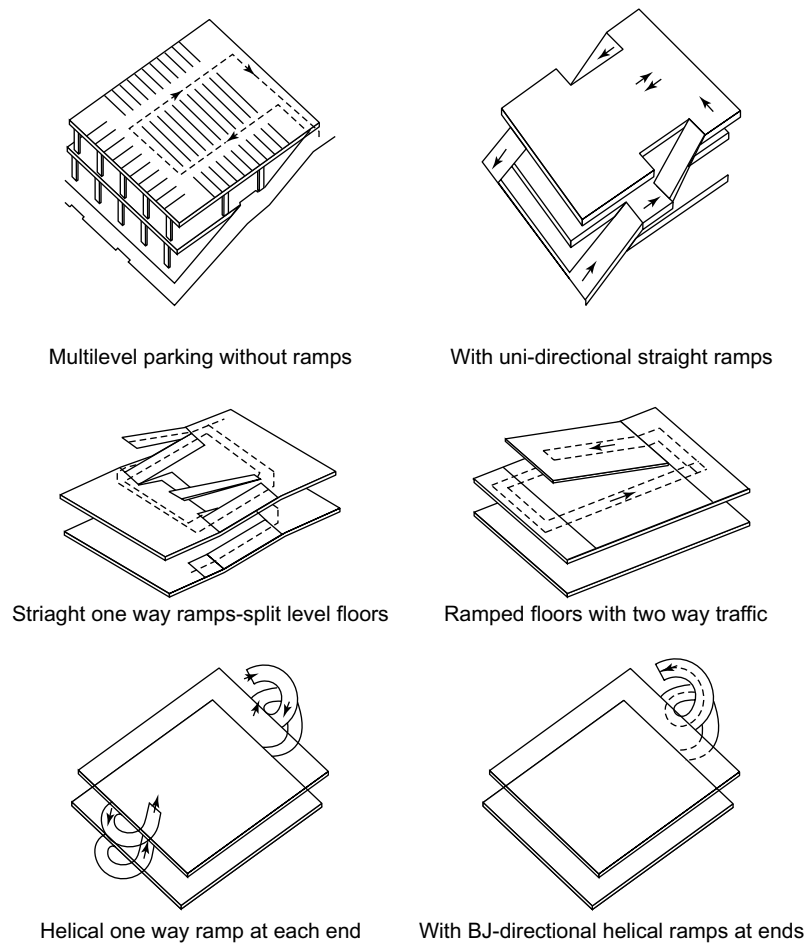
Capacity of a self parking ramp is 400 per lane and where fee collection booth is provided on exit ramps, capacity will go down to 150 to 200 per lane. Number of cars that can be parked in such roof top parks will be limited. Roofs of adjacent buildings can be utilized, if their roof levels are not at large variance by a single access ramp to provide a linked system of car parks on a street.

### 10.4.4 Multi-storeyed Car Parks

In most cities, it will be difficult to find large open spaces for providing parking lots, especially in commercial districts where the demand for space is high and at a premium. In such cases, the best alternative is to go in for multi-storeyed parking structures. The most cost effective and functional parking structure would have limiting capacity of 400 to 500 cars. Time taken for parking and (more so) for exiting will be too high to be attractive at higher capacities, particularly, when the parking charges are to be collected at the exit. It is desirable to restrict the number of floors to 5. Parking stall sizes used in such car parks is 2.5 m × 5.0 m. Aisle widths can be restricted to 4.5 m for angular parking and 6.1 m for 90 degree parking. Ramp gradient and sizes will be same as indicated in previous section. Inside radius of curves on ramps or otherwise is 7 m. Minimum vertical clearance is 2.1 m. Allowing for beams and slabs depth floor to floor height would be about 3 m. Parking area should be well lighted and ventilated. Minimum light intensity should be 5 foot candles in the parking area and 10 foot candles on ramps and corners<sup>2</sup>. If the building is not walled in but sides are open, no artificial ventilation will be called for. Floors should be well drained. Some parking garages go in for sloping floors. Sloping floor grade should be restricted to 4% to 5%.

Ramps may be straight ones on sides of structures or helical at ends. There are a number of variations in helical ramps. From the point of view of fatigue to user, number of bends and turns to be negotiated by a self parker should be restricted to five, which means number of floors restricted to six. Floors should be designed for a live load of 400 kg/m<sup>2</sup>.

Figure 10.3 shows a few types of multi-storeyed parking structures<sup>2</sup>.



**Figure 10.3** Types of Multi-storeyed Car Parks<sup>2</sup>

#### 10.4.5 Mechanical Car Parks

Where space is very restricted and has to be optimally utilized, modern trend is to go in for structures without ramps but with mechanical lift arrangements. There are two types in these also. In one alternative, the lift is used only for transfer of vehicle from floor to floor and movement within the floor from lift to parking slot and vice versa is done by drivers/attendants. In the other alternative, mechanically operated transfer trolleys or cradles are used for transfer of vehicle between the lifts and parking slots. The main advantage is that such garages can be provided even where plot size is limited as in case of CBDs and dense built-up areas. Disadvantage is that their maintenance cost is high, their turnover will be low. It is desirable to provide for duplicate lift arrangements so as to avoid total disruption in case of failure of one lift. Another problem connected with mechanical parks is that they cannot deal with surges of parking demand.

Hold-ups at entry points require large holding area between the main road and the lift for the waiting vehicles and prevent queue extending to the street at entry. Surge during exit time will cause delay to the user who can get frustrated. They are good where the demand is uniform throughout the day. Many patented types are available in the market and many apartment complexes are going for them in cities like Mumbai.

#### **10.4.6 Underground Car Parks**

Car parks can be provided in the basement of the multi-storeyed buildings for use of the residents, employees and customers, (last named in case of shopping malls). They are least intrusive and help in optimal utilization of land area available. Those under buildings are rarely used as public parking lots and generally not made available for one who has no business in the premises. Underground car parks for use of public can be provided under open spaces which have other land use like parks and play grounds. Typical examples of underground public car parks include the ones at Rajiv Chowk, New Delhi, and at Hyde Park, London.

The design principles are the same as for multi-storeyed car parks. They can be in more than one level. They involve excavation below ground and construction of heavy retaining walls. Deeper one goes, more the problem of seepage related problems and they require heavy retaining walls. Generally they are restricted to two levels and at the most to three levels. Two level garages have become quite common in shopping complexes and offices, e.g., the ones at Spencer Complex, and Two Wheeler parking lot in CMBT, both in Chennai.

### **10.5 PARKING CHARGES AND COLLECTION MECHANISM**

#### **10.5.1 On-street Parking**

Generally no parking charges are levied for parking on street in residential areas and collector streets, since most users will be residents or their visitors. On other streets, like sub-arterials and commercial streets, a charge is levied. Main purpose of such charges should be to restrict the duration of their use and prevent long term use by the property owners, who should have otherwise provided for parking spaces within their premises. The revenue collection should cover at least the cost of maintenance and staff costs and any capital cost involved in providing the facility. Such charges may be collected by engaging attendants or by installation of parking meters. In most cities in developed countries, parking meters are used. Working of parking meters is described in Section 10.5.3.

#### **10.5.2 Parking Lots**

Parking lots and garages levy a charge in order to pay for the land, construction and maintenance costs and staff. When they are privately managed, an element of profit is also included. In order to increase the turnover and thus serve more users, the charges have to be levied based on duration of occupation. The charges are made telescopic so that the longer user pays more per hour.

Collection of parking charges can be done at entry, centrally or at exit. The first alternative is not advisable, since it will hold up cars at entry and back up will go into the streets adversely affecting

the traffic flow on the street. The first alternative is used where a flat rate is charged. In this, the driver pays the charge and picks up a receipt/ticket while entering the complex and parks the car in a vacant slot. On return, he picks up the car and hands over the receipt to the operator at the exit gate, for him to open the gate and let the car exit.

In the second case, the driver receives a card with time of entry punched on the same. The parker on conclusion of his business returns to the central cash counter produces the card and pays the parking charges due to the cashier, who would issue a receipt to him. The parker will hand over the receipt at exit gate for the attendant to open the gate/barrier for him to exit. In this method, the detention at exit gate is minimal and the parking lot can deal with 360 or more cars per hour and hence is suitable for lots with large turnover. It is more suitable for large surface lots and parking lots with short duration and large turnover parking as in railway stations.

In the third method also, the parker picks up a time-punched card at the entry gate. In this case, when he is to leave, he picks up the car and hands over the card and charges due to the attendant at exit barrier, who would then lift the barrier to let the car out. In this case, cash collection takes more time and a cashier-cum-attendant can deal with about 180 cars per hour only. This method is more commonly used in underground and multi-storey parking lots.

### 10.5.3 Parking Meters

Parking meters are used mainly for controlling kerb side parking. Since it is time based, it also indirectly helps in reducing parking duration by individual vehicles and thus increases the turnover/capacity. Parking meters were first introduced in USA in 1935 and in UK in 1958. The basic form of the meter was developed by a student in the Oklahoma State University<sup>5</sup>. This manual meter has a timing device and works on the principle of being actuated by inserting a coin and operating a lever/handle. An advancement of this is an automatic meter, a facility in which an attendant can wind the clock mechanism periodically to pre set time. When a coin is inserted in the slot provided for same, it activates the clockwork mechanism and a needle moves to show the time duration for which parking can be done for the value of coin inserted. As time passes, the needle moves back towards zero. When the bought time expires, needle returns to zero and a flag or other indication denoting expiry of time appears on the dial of the meter and clock mechanism starts operating the mechanism to indicate excess time. If the motorist returns within the excess time permissible, he can insert the coin of value equal to excess time charges. The meter will return to neutral position and he can leave. If he does not return even within permissible excess time, a red flag will appear on the meter. In such a case, the parker is liable for prosecution and higher penalty. The vehicle can be towed away also. Coin collection system is important in parking meter revenue. The system is so designed that the collection from individual meters is directly transferred into a collection device without being handled by the collector. Alternatively, two containers can be used for a meter. When one container is full, it is removed and the second empty one inserted in its place. The collected containers are transferred to the central counting centre, where they are emptied and counted in secure surroundings.

This system was followed for over 40 years till digital meters were introduced in 1980 with electronic components and mechanism and digital display of time available. In modern meters, the payment can be made by swiping a credit card or inserting a smart card in the slot to activate the meter. A further advancement is that some meters have a visual sensor. When the parked car pulls out, the sensor resets the timing mechanism so that the unused time by previous user is no more available for the next arriving parker. There are about 60,000 such meters in New York alone.

Parking meters may be fixed as single meter or double meters. They are fixed on the side walk set about 20 to 30 cm inside of the Kerb edge. In parking lots central pay and display machines are used for accepting payment for multiple slots and displaying the status of any slot, when checked by attendant. Payment can be made using credit cards or smart cards. They work on similar principle as digital meters. In more sophisticated parks, there are sensors, which can indicate if a slot is occupied or free.

10.6 SPACE REQUIREMENT FOR OTHER VEHICLES

Cities in countries like India have to provide for parking of other personalized vehicles like motorcycles, cycles, auto-rickshaws also apart from cars. Buses and commercial vehicles are provided separate parking lots or slots. They are provided separate space in surface level parking lots. In some cases, they may be provided covered spaces also. The space requirements for them are given below. There is some small variation in standards followed by different cities.

Motor cycles and scooters	1.2 m × 2.8 m (1.0 m × 1.8 m)
Bicycle	0.9 m × 2.0 m
Auto-rickshaws	2.0 m × 2.5 m
Maxi cabs, Light commercial vehicles	3.0 m × 8.5 m (3.5 m × 7.0 m)
Bus and truck	3.00 m × 10.0 m (3.5 × 10.0)
(Hong Kong specifies 3.5 m × 11 m for HGV and 3.5 m × 12 m for buses)	
Containers	3.5 m × 16.0 m (3.5 m × 16.0 m)

Figures in brackets are those specified in Chennai.

10.7 PARKING STANDARDS

10.7.1 Normal Requirements

In order to conserve the road space for the purpose for which they have been built, i.e., for free movement of vehicles, on-street parking has to be restricted. In order to achieve this, the owners have to provide for parking space in their residences and the employers and shop owners have to provide space for the vehicles of their employees, visitors and customers. Their obligation has to be set out in form of some regulations and standards. It is found that there are no uniform national standards or yard stick followed in advanced countries. Each city or state follows its own standard, though the difference between standards in one another is not very large. They are based on some yardsticks suggested by some national professional bodies, but with some variations to suit local

conditions. One such example is the ‘Parking Principles,’ Special Report No. 125 drawn by the Highway Research Board in USA. London, for example, follows three standards, one for central London, one for inner London and a third for outer London (suburbs). The yardstick for central London calls for less number of spaces per unit area of construction, so that there will be fewer parking spaces available for motorists and more of them will use the public transport. For example, they require provision of 1 space per 1000–1500 m<sup>2</sup> of floor area in Central London, while in Inner London it is 1 per 600–1000 m<sup>2</sup> and in Outer London 1 space per 100–600 m<sup>2</sup>. With a stringent parking policy and entrance fee policy coupled with provision of good public transport, they have been able to restrict the trips by auto in central area to 13%, and in Inner London to 41% against 68% in outer London<sup>6</sup>.

In India, the IRC<sup>7</sup> have laid down guidelines for provision of parking spaces in urban areas. Examples of such provisions include:

Offices	one space for every 70 m <sup>2</sup>
Industrial premises	one per 200 m <sup>2</sup> or part thereof
Shops and markets	one space for every 80 m <sup>2</sup>
Restaurants	one for every 10 seats
Theatres and cinemas	one for every 20 seats
Hospitals	one for every 10 beds
Restaurants	one for every 10 seats
Hotels and motels	
Four and Five star	one/ 4 guest rooms
Three star	one / 8 guest rooms
Two star	one/ 10 guest rooms
Motels	one/ each guest room.

Residences—for plots up to 300 m<sup>2</sup>, community parking area is specified. For larger plots, percentage of open area to be ear marked for parking in individual plot for different ranges are specified. For apartment buildings and multi-storeyed group housing, number of parking spaces required has been specified in terms of one per number of dwellings.

Different city development authorities have specified the requirements in terms of number of spaces/slots per specified built up area for different types of dwellings and service buildings.

10.7.2 Special Parking Requirements

This section deals with special requirements while designing parking lots for different public utility facilities.

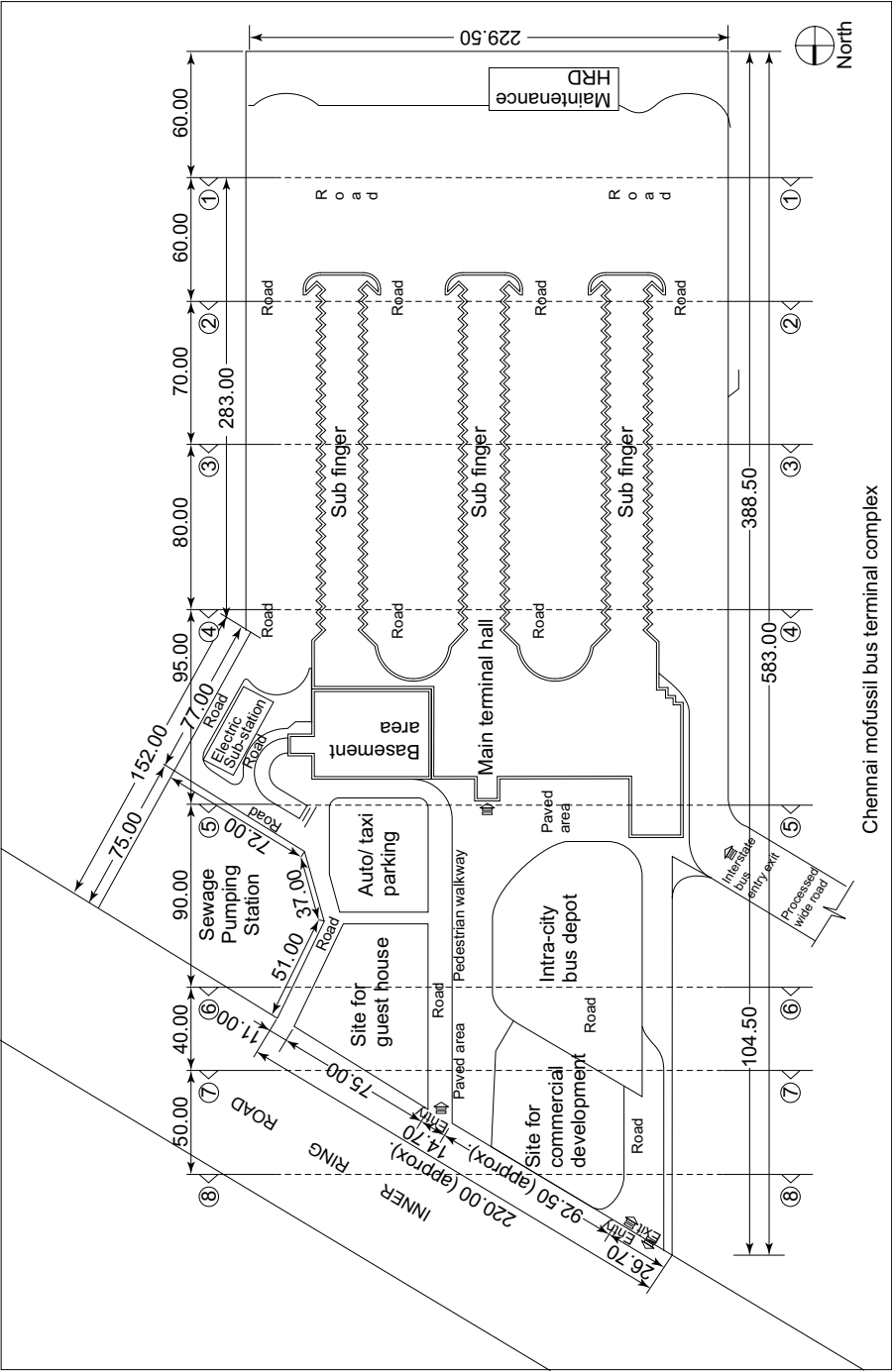
*Office developments:* During peak hours, the vehicle flow will be subjected to moderate high levels. (about one third of the total in each peak hour). Most will be long duration parkers. Visitors will be in small numbers. Additional provision will have to be made for pick up and drop off of passengers, delivery and pick up of goods as well as mail.



*Industrial establishments:* Apart from providing for individual shift staff requirement, some additional spaces will be required for overlap. The number of visitors will be much smaller. Parking space for visitors in this case and in offices should be located as close as possible to the office buildings. There will be considerable truck movement and loading and unloading bays and waiting bays will have to be provided for goods. In large establishments, the parking areas for office staff and for labor will have to be sited at different locations. Bicycle and two wheeler parking requirement will be significant and careful assessment is called for. Layout and routing of pedestrian walkways should be carefully designed so as to minimize conflict/crossing points.

*Railway stations and Inter-city Bus terminals:* Parking facility provision is an essential part of railway stations dealing with inter-city trains. They will vary from station to station and depend on pattern of arrival and departure of trains, volume of traffic in different times of day/night and socio-economic characteristics of passengers. While majority of inter-city passengers may use paratransit and public transport for access/egress, significant numbers will be using private vehicles. Parking space provision will be required for them in addition to space required for paratransit vehicles. While large proportion of departing passengers may only be dropped at the foyer of station, visitors who come to pick up the arrivals may have to park the vehicle for short periods, while waiting for the train arrival. Parking requirement for them and for paratransit will be of short duration. The requirement of parking spaces and foyer capacity will have to be worked out based on sample surveys or based on the experience gained from similar stations. In inter-city bus stations, large number of buses will need to be parked for short to medium duration with adequate facilities for ticket booking for a number of destinations, waiting halls for passengers, loading platforms for a large number of buses. Fuel stations and washing facilities and some idle parking bays also will have to be provided. Intra city bus stops and parking lots for IPT and private vehicles will have to be provided within the same complex. Figure 10.4 shows the layout of the Chennai Mofussil (inter-city) Bus Terminus commissioned in 2002. It is considered largest such station in India and is spread over about 10 hectare area in Chennai.

Provision of parking facilities at commuter rail and metro rail stations has gained much importance in the context of need to divert more commuters to public transport. About one third to one half of commuters walk to the stations. They require well laid out pedestrian walkways with safe crossing points leading from adjoining approach roads. The facilities for others will have to include provision for (i) bus bays for loading/unloading (ii) IPT (paratransit) loading and unloading points and some spaces for their queuing or waiting (iv) private vehicle drop-off and pick-up points close to entrance/exit of stations. In addition, spaces will have to be available for both short term and long term parking. Unlike in western countries, the private vehicles used for access in Indian cities comprise of a few cars and more of motor cycles/scooters and cycles. The modal mix of access trips will differ from station to station. The detailed passenger transport study for the line would give an idea of the modal mix of accessing passengers at each station. In absence of same, some assumptions can be made based on sample surveys at existing rail transit stations in the city. A typical range of such modal mix based on some surveys in Mumbai and Chennai are given Table 10.2.



Source: CMDA / RITES Study for CMBT

Figure 10.4 Chennai Mofussil Bus Terminus—Layout Plan

**Table 10.2** Modal Split of Access Trips to Urban Rail Station (in percentage)

Access Mode	As observed in Navi Mumbai in 1999		As observed in Chennai in 1993	Suggested norms
	Minimum	Maximum		
Walk	35	60	63.6	55 to 60
Bus, vans	16	30	14.6	20
Auto-rickshaw	17	27	0.2	1
Taxi	1	3	2.4	2
Two wheeler	3	3	2.2	5
Cars	1	2	0.2	0.5
Bicycles	1	2	16.9	10 to 15

**Source:** Adapted from Reference 8

The parking space requirement is generally worked out to cater for 25% of peak hour loading/unloading of passengers. Norms followed in arriving at space required for accommodating the parking or waiting vehicles are given in Table 10.3.

**Table 10.3** Mode-wise Parking Space Factors at Rail Transit Stations

Mode	Occupancy Ratio per Vehicle-numbers	Parking Duration- hours	Space Factor
Bus and vans	70	0.25	1
Auto-rickshaw	2	0.25	0.67
Taxi	3	0.25	1
Two wheelers	1.5	3	1
Bicycle	1	3	1
Car	2	3	0.67

**Source:** Adapted from Reference 8

## 10.8 PLANNING FOR PARKING

Making provision for parking on-street or off-street is an important part of city planning. Planners include this as one of the components of their periodical traffic and transportation studies or carry out periodic studies at macro level for entire city or at micro level in problem areas. The planning involves: (i) carrying out parking surveys and study the nature of demand for parking in terms of numbers and duration; (ii) study of growth of vehicle population and trend in growth; (iii) assess likely changes in land use and their impact on traffic on major roads; (iv) based on these assess future demand at different locations in consonance with the parking policy and standards set, city-specific, if any.

Survey locations on-street and off-street are selected based on a reconnaissance of the streets in busy areas and major activity centers for different types of vehicles (cars, auto-rickshaws, two wheelers, vans, buses, trucks, etc.). Parking survey at a location makes an inventory of space available and also occupancy. Occupancy survey is done on a working day for 12 hours on all lots selected for survey, preferably on same day. If it is not possible, the city can be divided into three or four areas and survey done in each area on a single day. Survey in major shopping centers open on Sundays should be done on a Sunday, preferably first week of the month. The main aim of parking survey is to identify parking accumulation and duration in various locations. For this purpose, the enumerator makes out an inventory of vehicles with their Registration numbers during every half hour. Analysis done for a typical location in a major mixed residential location including a higher educational institution in a metropolis is given below in Table 10.4.

**Table 10.4** Results of Parking Survey on a Street in Bangalore

Duration	Car	Two-wheeler	Auto-rickshaw	Bus	Truck	Total number	Per cent of Total
Up to half hour	262	400	204	5	60	931	58.7
30 min to 3 hrs	103	149	68	1	19	340	21.4
3 hrs to 6 hrs	43	88	40	0	11	182	11.5
6 hrs to 9 hrs	30	48	24	0	6	108	6.8
More than 9 hrs	0	16	8	0	2	26	1.6
Total turnover	438	701	344	6	98	1587	100.0
Average parking duration, hr-min	1 – 32	1 – 51	1 – 48	0 – 30	1 – 41	1 – 44	

**Source:** RITES Study

The actual count in each hour is used to draw the graph showing parking accumulation during different parts of the day and to arrive at peaking pattern and average accumulation. The half hour census in case of sites with heavy accumulation will have to be further analyzed at shorter intervals to arrive at the minimum number of spaces required to meet the peak demand, since the same space might have been occupied by more than one vehicle in that period. Future demand for parking space will have to be estimated based on growth rate of vehicles and development potential of different areas. Proposals for off-street parking requirement will be worked out based on policy. Trend in many cities abroad is to limit provision of parking space and price them in central areas so as to restrict entry of private vehicle into them and increase provision of public transport facilities serving the area.

**10.9 PARKING MANAGEMENT STRATEGIES**

Facilities for parking of private vehicles are costly. Users tend to prefer on-street parking, and often resort to unauthorized parking on kerbside than to avail parking lots and garages. The strategies for

parking management should aim at both reducing the demand and supplying the provision at an affordable price. The demand can be reduced by providing adequate public transportation facilities and by making the parking financially attractive.

A list of possible strategies for parking management in CBD areas is shown in Table 10.5, along with supporting actions that would aid successful implementation of the strategies<sup>9</sup>.

**Table 10.5** Parking Management Strategies and Supporting Actions

<b>A.</b>	<b>Parking Management Strategies</b>	
	1.	High rates of parking fees for single occupancy vehicles
	2.	Low rates of parking fees for short term parking, and high rates for long term parking
	3.	On-street parking allowed only for short term parking
	4.	Eliminate on-street parking
	5.	Eliminate peak period on-street parking
	6.	Strict enforcement of parking regulations
	7.	Reserved parking for priority vehicles (for taxis, handicapped persons)
	8.	Residential parking permits (to discourage commuter parking)
	9.	Limitations on number of parking spaces in CBD areas
	10.	Limitations on parking garage construction
	11.	Parking tax on users
	12.	Parking stall tax on parking garage/lot on owners
	13.	Bicycle parking
	14.	Transit station parking
<b>B.</b>	<b>Supporting Actions</b>	
	1.	Improve transit service
	2.	Provide Park-and-ride lots
	3.	Increase Bicycle facilities
	4.	Adopt Staggered work hours
	5.	Provide Peripheral parking
	6.	Priority treatment for high-occupancy vehicles

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# Non-Motorized Urban Transportation

# 11

## 11.1 ROLE OF NON-MOTORIZED MODES OF TRAVEL

Currently, most urban transportation planning studies in developing countries tend to concentrate on facilities for motorized transport (public and private). The proliferation of motorization leads to increased traffic congestion, environmental deterioration and traffic accidents. Non-motorized transport (NMT) is one of the effective alternatives to alleviate the negative aspects of motorization. The share of non-motorized modes of travel in the total trips lies in the range of 33 to 50% depending on the size and the socio-economic characteristics of the concerned city. The non-motorized modes of travel consist of pedestrian movement, bicycles, cycle rickshaws and animal drawn vehicles. Non-motorized modes use indigenously available human and animal energy, are non-polluting, safe and user-friendly: they involve low costs for operation. These modes are an ideal option for trip length up to 5 km, and are convenient in congested areas and for shopping and school trips. A judicious mix of motorized and non-motorized modes is to be arrived at for each city in order to result in an optimum urban transport system.

Walking is perhaps the most fundamental mode of transport for short distances, and the next reliable mode seems to be the bicycle. Pedestrian movement and bicycles are extensively used. Cycle rickshaw is an adaptation of the bicycle with three wheels, and is intended to carry two passengers on a taxi-like service and is widely used in most Indian cities. A further adaptation of the cycle rickshaw operates as a means of transporting children to school, and is used in limited numbers in urban centers. Animal powered vehicles are generally used for freight transport, though Tongas (horse drawn) are still in limited use in smaller cities for passenger traffic, seating four to six passengers. While pedestrian- and bicycle-friendly facilities are necessary, a quality urban environment ensuring safety, proximity and access are also essential to maximize non-motorized travel. Walk constitutes 27% to 38% of total trips in mega cities in India. For example, walk trips in Chennai, which was 27% in 1984 had in fact increased to 28% in 2006, while cycle trips had come down from 11% to 6%. This can be partly attributed to removal of cycle tracks where it existed in the intervening period and increase in two wheeler ownership.

Extensive intermixing of non-motorized and motorized traffic on urban roads leads to traffic congestion, increase in journey time and accidents. The safety of pedestrians and bicyclists

deteriorates as motorization increases. Appropriate measures of urban transport planning and traffic management, with sympathetic treatment of non-motorized traffic, may result in a more satisfactory situation than at present. Proper urban planning requires provision of adequate, predictable and dedicated funding to construct non-motorized transportation capital projects, and to ensure adequate maintenance and preservation of existing facilities. Figure 11.1 would give an idea of mix of traffic in a major metropolis when cycle tracks were available.



**Figure 11.1** Mix of Traffic on a City Road With Cycle Track

## 11.2 IMPORTANCE OF PEDESTRIAN FACILITIES

Circulation of pedestrians is of vital importance to the modern metropolis. The city derives its vitality from the interaction among people at places of business, assembly and recreation. Every trip—be it by car, bus or train—begins and ends as pedestrian movement. In urban areas of developing countries, the pedestrian trips constitute a significant portion of the total trips. For example, nearly 28% of the total trips in Chennai are made by walk. This proportion is not likely to diminish in the near future in view of the increasing trend in the ratio of the poor with respect to the overall population. In Indian cities, pedestrian trips are significant not only for micro-accessibility but also for intra-urban mobility.

Pedestrian involvement in traffic accidents is high, accounting for 35 to 45% of the total victims as in Chennai. About 70% of pedestrian accidents occur while crossing the road. Hence pedestrian traffic management in Indian cities is a major concern deserving serious attention regarding provision of pedestrian facilities. Formulation of an effective process of managing pedestrian traffic as an important element of the total urban transportation system is essential.<sup>1</sup>



### 11.3 PLANNING FOR PEDESTRIAN MOVEMENT

The planning attention and the resource allocation devoted to the pedestrian facilities are generally inadequate. The current emphasis in transport planning and management tends to be biased towards facilities to increase carriageway capacity for vehicles resulting in inadequate attention to the impact of such actions on pedestrian movement. The level of service offered to pedestrians depends on: (i) freedom to select the walking speed; (ii) ability to pass and overtake slow walkers; and (iii) ease of cross and reversal of flow. Development should be arranged to enhance pedestrian experience: easy access to buildings; shelter from the elements; security; and easy access to transit and neighboring services. Priority should be accorded in the design of routes used by school children, senior citizens, physically challenged persons and commuters. Pedestrian facilities should be continuous along all major streets and highways; these should be direct and interconnect with all other modes of transportation.

It is important to segregate the pedestrians from vehicular traffic to reduce conflicts and accidents. The major facilities for pedestrians on urban roads include sidewalks and pedestrian crossings. The latter comprise zebra crossings, underpasses and over bridges. Until recently, very little study has been directed towards observing pedestrian behavior and in using such data in the integrated design of the road space with due attention to walking as a traffic mode. In consequence, the traffic management of pedestrians leaves much to be desired.

The characteristics of pedestrian travel should be recognized while designing pedestrian facilities. Pedestrian travel is localized and is highly concentrated in retail and commercial areas. For example, the volume of pedestrians per hour found on Anna Salai in Chennai<sup>2</sup> varied at different locations on the same stretch of road as: 1110 at km 1/4, 10250 at km 2/1, 2970 at km 2/5 and 1480 at km 4/5. Pedestrian trip purposes vary by location and time of day. Pedestrians tend to keep walking distances as short as possible. If the walking environment is clean and attractive, the walking distance may be increased. The trip length of walk trips tends to be around two to three kilometers. The mean speed of pedestrian on level ground was found to be 0.9 m/sec at zebra crossing, 1.2 m/sec in the tunnel of pedestrian underpass and 0.6 m/sec on road surface without designated crossing<sup>2</sup>. Pedestrians generally prefer at-grade crossing to grade separated crossings. A single pedestrian occupies a basic space of 0.66 m × 0.30 m requiring 0.20 sq. m area. When he carries baggage on both hands, he may require a space of 0.56 sq. m (0.99 m × 0.60 m). The space requirement will be about 0.64 sq. m (1.40 m × 0.43 m) for a couple strolling arm in arm<sup>3</sup>.

### 11.4 SIDEWALKS

Sidewalks are provided on most urban arterials, collector streets and in commercial and residential areas. However, the quality and the width of sidewalks are often inadequate. It is not uncommon to witness widening of carriageway on the arterials at the expense of sidewalks. Such a practice is inadvisable, as the pedestrians tend to spill over to the carriageway causing conflicts with the vehicular traffic. The top surface of the sidewalk should be maintained clean, even and free of dangerous potholes, so as to encourage people to use the sidewalk.

The minimum clear width of sidewalk should be 1.5 m for peak pedestrian traffic up to 3,000 persons per hour. The width should be increased by 0.5 m for every additional 1,500 persons per hour. Suitable additional width should be provided at locations of heavy concentration such as movie theatres and stadiums. Pedestrians usually stay away from a wall or a shop window by about 0.45 m unless extremely crowded. In areas where window shopping is encouraged or appreciation of monuments and heritage structures is intended, additional width of about 0.6 m of sidewalk should be provided. This concept does not seem to have been realized in practice at many locations.

The capacity and serviceability of sidewalks in cities are often impaired considerably due to cluttering of service facilities and encroachment by hawkers and extension of shops. Though some of the service facilities are necessary, their location should be regulated to reduce interference with pedestrian flow. The social considerations of removal of hawkers from the sidewalks defy an equitable solution which would be favorable to the affected poor and at the same time are harmless to the traffic situation. Since a significant part of the urban population seems to like the service rendered by the hawkers, it may be desirable for the city authorities to consider the possibility of developing low cost off-street market spaces near crowded areas with relatively low daily/weekly rents so that the number of hawkers on the sidewalks may be reduced. Some cities follow the policy of not permitting hawking on footpaths with less than 2.7 m width. The hawking stall width is then restricted so that a minimum clear width of 1.5 m is available for pedestrians. The sidewalk should be segregated by a raised kerb of 225 mm height or be raised from road level. It is observed that low footpaths of 100 to 150 mm height above road level encourage better usage. Provision of guard railing at the kerb has been found effective in preventing pedestrians from straying on to the carriageway. This provision has also been used to channelize pedestrians towards the designated crossings. When railing is provided, the tendency of the hawkers to occupy the sidewalks is discouraged by the dominance of the pedestrians. The improvement of sidewalks is perhaps the single most important measure to be attended to by authorities concerned with traffic management in many developing country cities<sup>4</sup>.

## **11.5 PEDESTRIAN CROSSINGS**

Designated pedestrian crossings are necessary to ensure safety of pedestrians wishing to cross busy urban roads. The types of pedestrian crossings include: Zebra crossing, Pedestrian underpass, and Pedestrian over bridge. While zebra crossing and crossing at signalized intersection or midblock crossing permit time segregation, grade separated crossings such as underpass and over bridge facilitate space segregation.

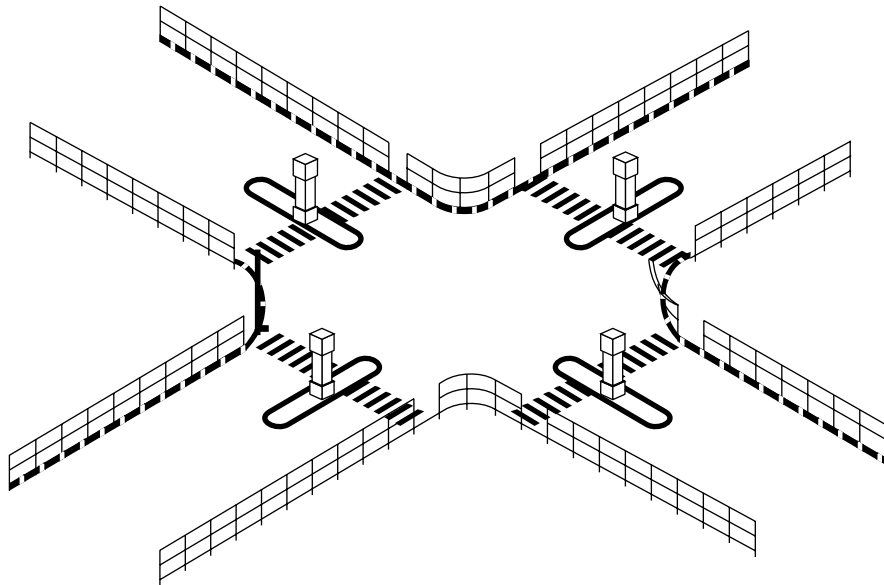
### **11.5.1 Zebra Crossings**

A zebra crossing is the cheapest device to provide a protected crossing. Zebra crossings are to be provided at the intersections and at a midblock location, if necessary. The white stripes and the stop lines forming the complete zebra crossing should be provided in the interest of saving lives, though the painting involves additional expenditure. The British Highway Code requires that the vehicle driver should give priority to a pedestrian once he steps on to the carriageway on the designated

crossing<sup>5</sup>. The compliance of such a stipulation is difficult to rely on in developing countries with a large population and low levels of literacy. A study on the behavior of pedestrians and drivers at three unsignalised midblock zebra crossings without police control in Chennai showed that typically about 41% of the pedestrians were risking their lives in making wrong crossings<sup>6</sup>. Only 2% of the drivers stopped for the pedestrians and 10% of the drivers managed to keep moving while the pedestrians were using the crossings. The presence of police personnel at these crossings leads to better compliance. Provision of kerb railings for about 50 m on either side of the crossing helps to guide the pedestrian traffic on to the pedestrian crossing. Zebra crossings with pedestrian activated signal control are not very effective in cities in developing countries due to misuse. Pedestrian refuges (or traffic islands) aid pedestrians to cross wide multi-lane roads safely. The width of the refuge should be at least 1.8 m.

### 11.5.2 Crossings at Signalized Intersections

Pedestrian crossings at signalized intersections are found to be very effective. However, it is necessary to ensure provision of sufficient green time for the crossing pedestrians, particularly while crossing wide roads. The introduction of “flashing green” signal to indicate the approach of the end of the green time for pedestrians will be useful. The adoption of 4-way simultaneous pedestrian phase in busy commercial areas merits consideration. Kerb railing should be erected on either side of the zebra crossing for adequate length along the road to make the crossing effective. Central refuge and bollard may also be added as shown in Fig. 11.2 to enhance safety. Figure 11.3 shows a typical such pedestrian crossing on a major city road.



**Figure 11.2** Railings and Pedestrian Crossings at Intersection



**Figure 11.3** Typical Zebra Crossing and Railing Nr. Intersection

### 11.5.3 Pedestrian Underpasses

Provision of a pedestrian underpass (sometimes referred as subway in India) is an engineering measure towards reduction of accidents. It involves high cost on construction and maintenance. In this system, the vehicular movement is at grade and the pedestrian movement is below in tunnels or underground concourses. Pedestrian underpasses can be constructed by the cut-and-cover method as done in Chennai or by bored tunneling which is prohibitively expensive. The advantages of the underpass include: complete elimination of conflicts between pedestrians and vehicles at points of crossings; built-in protection from sun and inclement weather; least disturbance to normal cityscape; and provision of direct linkage to existing underground systems and major activity centers. The disadvantages are: high cost of construction; need for changes in grade and numerous entry points; loss of visual contact with the city surroundings; and potential security problems. If a few well-designed shops are established along the tunnel part of the underpass, the cost of the underpass can be partially or fully recovered. The entry/exit points of the underpass should be made conspicuous and elegant so as to attract the user. This can be done by attending to lighting, signage and landscaping at the entry/exit. Multi-arm underpasses may be considered at intersections with high volume of pedestrian movements. This will be particularly effective if the pedestrian volume at a signalized intersection requires a cycle time of more than 150 s.

When properly designed and maintained, a pedestrian underpass can effectively attract users and afford them a protected crossing. On the other hand, an underpass not used by pedestrians due to inappropriate location, inadequate design, unimaginative access treatment, or unsatisfactory perception by the intended user may turn out to be a liability to the community. The planning

of pedestrian underpasses in the past has relied more on the engineering design to cope with the estimated volume of pedestrians than on a consideration of the perceptions, feelings, attitudes and behavior of the potential users. In consequence, many an underpass has suffered erosion in the extent of effective utilization, casting doubts on the cost effectiveness of the facility.

A study of the effectiveness of pedestrian underpasses in Chennai<sup>7</sup> has revealed that: (a) Good underpass compliance can be expected only when the traffic on the road is heavy and there is continued police presence; (b) When the width of the carriageway is less than 20 m, it is difficult to expect the pedestrians to use the underpass; (c) Pedestrians tend to avoid an underpass with long ramps if the traffic on the road is in the form of platoons; and (d) The alignment of the underpass tunnel and the access points should be close to the desire lines of the users. Pedestrian violations at the underpass locations can be reduced by the provision of median railings for about 50 m on either side of the centerline of the underpass.

#### 11.5.4 Pedestrian Over Bridges

Pedestrian over bridges across roads have generally been unsuccessful, relative to pedestrian underpasses or at-grade crossings. People do not seem to mind walking down first, and by the time they arrive at the other end, are not conscious of the trouble of walking up. In contrast, when they reach an over bridge, people hesitate to climb stairs and look for alternatives. Pedestrian over bridges are likely to be successful only across railway tracks and across wide roads with heavy traffic. Provision of escalators would encourage the aged and the children to use the over bridges. Elevated walkways may be found successful across roads opposite railway stations.

Skywalks are an extension of idea of pedestrian over bridges. It is an elevated walkway dedicated to the pedestrians for accessing facilities. They have been used in many cities in commercial areas to connect different commercial centers. Minneapolis is reported to have the longest network of skywalk connecting 69 blocks. They may be used to interconnect tall buildings at different levels, e.g., Petrona's Tower in Kuala Lumpur. Mumbai is the first city in India to go in for skywalks on a big way. They mainly aim at provide easy and safe access to busy suburban railway stations by providing skywalks in continuation of foot over bridges in the station. They have planned to provide 50 skywalks in the metropolitan area at a cost of about Rs 600 crores. They will connect railway stations of high concentration and commercial points to destinations having heavy pedestrian flow. Some of them have already been completed.

First one to be completed about 2 years back is a skywalk on the east side Bandra Railway station connecting it to Kalanagar, a length of 1.3 km. One more on west side is proposed. Bandra is a major railway station in Mumbai dealing with more than a thousand suburban trains and about 5 lakhs passengers a day. About 39% of them access the station by walk, 32% by bus, and 16% by auto and remaining by other modes. The ones from east side after development of Bandra-Kurla Complex have increased. The width of sidewalk is with 4 m clear walkway and it is made of steel frame structure with Polycarbonate Sheet roofing and deck is 6 m above ground level. It has four sets of staircase landings and it is to be integrated with existing foot over bridge of Bandra station. Another skywalk, but a shorter one in concrete has been completed at Chembur. Other cities in India are also planning for skywalks at important locations.

## 11.6 BICYCLE FACILITY PLANNING

Though cycling as a means of transport has been in practice since 1890's, bicycle facility planning is a relatively new activity in urban transportation management. Until recently, the professionals entrusted with road design, maintenance and operation did not consider bicycle as a design vehicle in the road design practice. Before the advent of the private car, the bicycle was a major form of intra-city transport. The bicycle has once again emerged as an important form of transport, mainly in view of the high cost of fuel and motorized vehicles, and to a lesser extent due to a renewed interest in physical fitness and environmental concerns. Its potential as a means of transportation in urban areas is being increasingly recognized. No longer is it solely identified with recreation or exercise, or as a convenient way for children to get around. The bicycle is being used increasingly for commuting to work, to school, to shops, and other activity centers. It is estimated that there are about 80 million bicycles in India<sup>8</sup>. In Indian cities, the bicycle is one of the predominant modes of transport. For example, the share of bicycles in the total number of trips is about 14% in Chennai and about 33% in Bangalore. In Beijing, China bicycles account for about two-thirds of the urban trips during peak hour<sup>9</sup>.

It may be interesting to compare the energy used in different modes of travel. A bicyclist moving at 19 kmph uses 64 kJ per passenger-km. A pedestrian walking at 4.0 kmph uses about 328 kJ per passenger-km. The relative uses of energy by different modes in kJ per passenger-km<sup>9</sup> would read as: bicyclist 64, pedestrian 328, bus 656, railway 1115, car 2786 and aircraft 6360. Further, cycling is pollution-free, quiet and requires relatively less operating space. The half-hour travel range of a cycle is about 9 km, which is greater than the radius of many a typical city. It also provides door-to-door service and needs less parking space. Thus it is important to encourage cycling as an alternative mode of transportation for short distances.

There are, however, some serious deterrents to the use of cycles. These include adverse weather conditions, the danger arising from cycling in dense city traffic, the pollution caused by motor vehicles and spray of dirt from vehicles in wet weather. Provision of separate cycle routes would reduce the severity of some of the deterrents.

There are different types of bicycle trips in an urban area, such as: (i) Neighborhood riding by children and for shopping; (ii) Recreation riding, along routes with scenic views and those leading to parks and lakes; and (iii) Commute riding for home-to-work and school trips.

## 11.7 PLANNING CONSIDERATIONS FOR BICYCLE TRANSPORT

The approach for the planning of facilities for bicycle mode differs from the procedures applicable for other modes of transport. The following factors need consideration:

- (a) The cyclist is unprotected and is vulnerable to serious injury in case of fall or collision with other vehicles or objects. Hence it is desirable to segregate the cyclist to the extent possible in the interest of safety.
- (b) The normal speed of a bicycle is low relative to the other vehicles on the carriageway, and hence the cyclist should keep to the left edge of the roadway in order to avoid obstructing the flow of traffic.

- (c) The average trip length for bicycles is short, and the travel is more oriented to local and collector streets rather than arterials and freeways. The trip length is usually between 5 and 10 km.
- (d) Because the cyclist is exposed, the use of cycles is influenced by the climatic conditions.
- (e) Safe storage of bicycles at intermodal terminals (e.g., railway stations and major bus terminals) and security of cyclists on bikeways through parks should be ensured.

The needs of cyclists must be considered while planning major highway construction projects. On rural roads and urban collector streets, provision of adequate road width permits shared use by motorists and cyclists. When resurfacing roads, the shoulders should be fully resurfaced along with the carriageway. The cycle tracks, when provided, should be clearly marked. Provision of clear space for cyclists enhances safety for both motorists and cyclists.

## 11.8 TYPES OF BICYCLE FACILITIES

Various types of facilities may be combined to form the bicycle network. They may be classified as below:

- (a) *Bike Path* A fully segregated and protected right-of-way designated for the exclusive use of bicycles.
- (b) *Bike Lane* A restricted right-of-way designated for exclusive or semi-exclusive use of bicycles. Vehicle parking and access to property are allowed, though traffic of vehicles is not allowed. A variant of the bike lane is the protected lane, where the parking of vehicles is prevented from encroaching on the bike lane by use of bumper blocks normally employed in parking lots.
- (c) *Bike Route* A shared right-of-way along the street, designated as bike route by signs placed on posts or stenciled on the pavement. Use of a different colored pavement for the bikeway will be found attractive.

The signed bike routes have not been very successful in reducing bicycle-car conflicts. Beyond indicating to drivers to anticipate cyclists, these facilities do not aid bicycle safety. On the contrary, such routes tend to create the illusion of provision of safe facilities by designers, who are unconvinced of bicycle facility needs or uncertain about implementation of better treatment.

The bike lanes, especially those with protective barriers, have proven quite effective in separating motor vehicle and cyclist flows. Bike lanes add legitimacy and credence to the cyclist's presence on the road and delimit a physical area for cycle riding, eliminating the tendency of the cyclist from straying on to the lanes intended for motor vehicles and also inducing a sense of security in the cyclist. Similarly, the motorist also feels more confident in his lanes, resulting in better travel speeds and flow capacities. However, delineation lines are not effective in view of the cyclist's tendency to ignore them. Especially in developing countries, positive physical separation is necessary to ensure safety.

Sidewalk bikeways have not been very successful. The reasons for this experience include: (i) Sight distances are poor at driveways; (ii) Poor visual relations between cyclist and motorists occur at intersections; (iii) Sidewalk bikeways are used bi-directionally despite signs to the contrary; (iv) Sharing space with pedestrians is hazardous particularly to children, the blind and the old; (v) Sidewalk surfaces are of poorer quality than street surface; and (vi) Sidewalk widths are often inadequate to accommodate both pedestrians and cyclists safely.

Bikeway corridors in their own right-of-way are in many ways desirable and attractive, if properly planned and well maintained. Problems arise if the surroundings are unattractive or if the surfaces are of inferior quality or if these are away from population centers.

## 11.9 BICYCLE NETWORK PLANNING

A comprehensive bicycle network plan will require the following steps:

- (a) Prepare an inventory of existing facilities. Determine traffic volumes, speeds, parking conditions, on-street facilities, and physical dimensions of the streets. Explore availability of public right-of-way.
- (b) Forecast demand for the bicycle facility. Conduct origin-destination studies or home interviews regarding bicycle usage according to the number of cycles and number of riders in the family, number and type of trips.
- (c) Establish planning and design criteria. The alternative facilities considered should satisfy the planning criteria relating to safety, environmental attractiveness, system continuity and cost effectiveness. The dimensional requirements shown in Fig. 11.4 may be incorporated in the design criteria<sup>11</sup>. Delineation of the bicycle lane is essential for on-street bicycle facilities. The width of cycle tracks should preferably be 3.0 m. One-way cycle lanes should have a minimum width of 2.5 m. The design speed may be taken as 20 kmph for level route.
- (d) Design bikeway network and facilities. The bikeway routes are to be established to satisfy the requirements of access, protection and continuity. Intersections have to be designed carefully.
- (e) Consider alternate plans where appropriate.
- (f) Evaluate the plans and select the optimum final plan.
- (g) Implement the selected plan.
- (h) Evaluate the results.

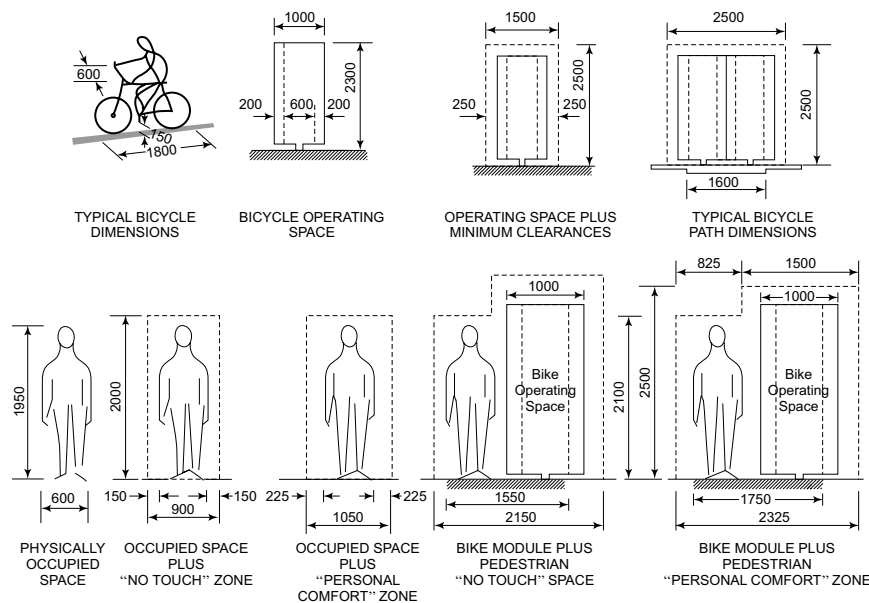
According to IRC: 86-1983<sup>12</sup> separate cycle tracks are justified, when the number of vehicles using the route is more than 200 per hour. Minimum width should be 2 m. The capacity for a two lane cycle track with 3 m width may be taken is 50 to 250 cycles, for two way traffic and as 250 to 600 cycles for one way traffic. With width of 4 m, the capacity goes up to 250 to 600 for two way traffic and over 600 for one way traffic.

The comprehensive bicycle network plan should serve all cyclists in the planning area. It should provide continuous routes connecting the smaller community bicycle systems. An example of such a plan is the 'honeycomb' system suggested by the City of Dallas. Here the bicycle paths having exclusive right-of-way form the honeycomb, providing a network of travel between the individual zones and around the zone. Within each zone, the bicycle lanes on city streets provide the movement within the zone and outward to the bike paths. Bike routes provide access to higher type facilities.

## 11.10 BICYCLE PARKING

Bicycle parking facilities should be provided at bus terminals, transit stations, park-and-ride lots and major activity centers. Appropriate parking racks and lockers may be provided, depending





**Source:** Adapted from Reference 11.

**Figure 11.4** Bicycle Facility—Dimensional Requirements

on the duration of parking. Short term bicycle parking can be as simple as a stationary object to which the cyclist can lock the frame and the wheels. Long term parking facility should provide for protection against theft of the bicycle and accessories.

### 11.11 CYCLE RICKSHAWS

Cycle rickshaws first appeared in 1920 and spread all over India during the 1930s. They are used in many South East countries, e.g., Indonesia and Myanmar. The cycle rickshaw is pedal-driven and permits a speed of about 10 kmph. It can carry a payload of 200 kg or two passengers. It is also used for carrying small children to school. There are about 5 million cycle rickshaws in India<sup>8</sup>. The design and technology of cycle rickshaws need improvement. Their main drawbacks include single brake of poor quality, single gear, poor suspension and exposure of driver to sun and rain. Limited efforts are in progress to improve the design of cycle rickshaws. In view of the energy efficiency and employment potential for the poor, these vehicles should be suitably accommodated in urban transport planning. The role of cycle rickshaws in urban transport is further discussed in Chapter 12.

### 11.12 PEDESTRIAN MALLS AND PEOPLE MOVER SYSTEMS

As traffic grows to meet the capacity of the road space, the quality of life in the CBD tends to suffer from the adverse effects of motor traffic: smoke, noise, visual intrusion and lack of safety. This is particularly evident in shopping activities. Current trend is to declare certain areas in the

CBD as pedestrian malls (also known as pedestrian precincts) as part of redevelopment, e.g., Coventry city centre and Stevenage town centre in the UK, and certain areas in the historic part of Munich, Germany. A policy of traffic restraint is followed to permit servicing of the shops during the night hours. Exclusion of motorized vehicular traffic in a large part of the city centre enhances the environmental quality and the facilitation of comfortable shopping leads to commercial benefits. For success of pedestrianisation, good public transport facilities, especially rail transit and convenient parking for private vehicles at the periphery of pedestrian malls are essential.

People mover systems are those specially meant for movement of car users from the fringe parking lots to the activity centers. There are many variants to these systems, including moving belts, minibuses, electric trains like those in world fairs, and monorail systems. An integration of people movers, shopping areas, parking garages can be innovatively managed so as to revitalize the CBD area, at the same time providing for various modes of traffic.

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## 12.1 DEFINITION

Intermediate Public Transport (IPT), sometimes known as Paratransit, refers to road vehicles used on hire for flexible passenger transportation, which do not follow a fixed time schedule. They may or may not follow a fixed route. Paratransit services include: cycle rickshaws, auto rickshaws, taxis, minibuses, carpools, vanpools, subscription buses and demand-responsive (dial-a-ride) vehicles. Minibuses, also known as Jeepneys in Manila and Jitneys in USA, can operate efficiently as feeder services to transit routes. In other words, IPT includes all modes which provide a transport service for a price, filling the gap between private transport and conventional bus transport in terms of fare level and quality of service.

Paratransit system deserves to be recognized as an important element in the urban transportation scene<sup>1</sup>. The system is desirable in situations where: (a) the number of travelers with similar demand pattern is small and inadequate for conventional bus transit; (b) use of smaller vehicles will reduce congestion; (c) passengers have to carry luggage; (d) there is a significant saving in cost over use of a private car; and (e) private transport is not available and public transport is inconvenient. Besides enhancing mobility, paratransit also permits additional opportunities for gainful employment for a significant segment of the urban population.

## 12.2 CLASSIFICATION OF SERVICE

The service provided by IPT can be brought under two broad classifications, i.e., and taxi-like service and bus-like service<sup>2</sup>.

Bus-like services refers to services provided by the vehicles in a predefined manner in terms of origin and destination. They are continuous point-to-point services with intermediate stops for boarding and alighting. Such intermediate stops would be only informal and subject to minor variations at the discretion of the operator or driver.

Taxi-like services, on the other hand, refer to services of intermittent nature provided with complete flexibility in respect of origin, destination and even route, which are dictated by the passenger.

The essential differences in form and characteristics of the bus-like and taxi-like services are indicated in Table 12.1.

**Table 12.1** Classification of Intermediate Public Transport

Characteristics	Bus-like Service	Taxi-like Service
Route and form of service	Fixed—Point to Point but pick up and dropping points flexible; Shared with other passengers	Origin-destination and route flexible and dictated by passenger at user's discretion—Personal/ individual service
Scale of operation	Large or small	Small
Vehicles used	Minibus or small bus, SUV, Saloon car, Shared taxi/auto-rickshaw, Jitney/ Jeepney, Dial-a-ride vehicles	Sedan cars, vans, auto rickshaws, cycle rickshaws, hand pull rickshaws, tongas, jutkas, and bullock carts
Fares	Fixed uniform and generally regulated by government	Self regulated informally under specified norms; Some governments may regulate also.
Motive power	Mechanical	Manual or mechanical or animal drawn
Organisation	Operated as a fleet by Private groups/ entrepreneurs or local authorities	Mostly individually owned and operated by self or on individual contract between owner and driver
Suitability	Larger cities like Delhi, Kolkata, Bangalore, Manila, Ankara, and Chennai and medium size cities such as Meerut, Amritsar, Bhopal	All urban areas- more in cities but available in medium size towns with good roads. Rickshaws – for residential streets, collector and sub arterials
Load factor	High	Low
Average trip length	Generally 5 km and above	1 to 5 km
Fare or cost per trip	Low	Medium to high

## 12.3 OPERATIONAL CHARACTERISTICS OF PARATRANSIT VEHICLES

### 12.3.1 Non-Motorised Vehicles

#### (a) Cycle Rickshaws

The earliest form of paratransit comprised of horse-drawn or bullock-drawn carts, coaches or tongas. In many cities, man-drawn pull rickshaws were used both in India and abroad. They were with single occupant or for two passengers. Their numbers declined or disappeared in many cities and replaced by cycle rickshaws in 1950s, but they are still used in some localities in Kolkata. The cycle rickshaw is very much prevalent in large numbers in medium size cities and towns in India. It is the preferred mode in some congested areas in larger cities like Sadar Bazaar and walled city in Delhi, peripheral areas in Kolkata, northern part of Chennai, and many areas in Hyderabad and

Ahmedabad. They are still popular in medium size cities like Amritsar, Kanpur, Vadodara and Varanasi. They are, however, being edged out in many cities and areas by the auto-rickshaw.

A recent study<sup>3</sup> in Amritsar has indicated that cycle rickshaw is more popular with senior citizens and women. It is hardly 1.5 m wide and is easily maneuverable. It can easily pass through lanes and bylanes and is the most suitable form of IPT in parts of cities with narrow roads, suburbs, market areas and dense residential areas. In many areas, it provides an affordable transport for school children, when operated as a shared service. A modified form is also used for goods transport in small lots. A study by TRL in some third world cities<sup>2</sup> has brought out the operating characteristics of cycle rickshaws in cities in different parts of the world. Some comparative figures are given in Table 12.2. Though the survey has been done in 1979, the findings are equally applicable now as a form of comparison.

**Table 12.2** Comparative Performance Indicators of Cycle Rickshaws

City/Town	Population- million	Number of Vehicles per 1000 population	Vehicle- km per day	Passengers carried per Day per Unit	Average Trip Length- km
Chiang Mai	0.1	20	NA	10-15	NA
Faridabad	0.2	19	22	18	1.8
Meerut	0.5	18	24	25	1.5
Penang	0.5	6	12-20	NA	NA
Gulbarga	2.3	15	25	8	1.8
Kolkata-cycle type	4.0	0.6	69	23	3.0
Kolkata-pull type	4.0	5	43	17	2.0
Delhi	5.0	1	13	18	1.0

The productivity in terms of throughput and speed of operation is low as it is dependant on a human being with limited physical energy and stamina. It is comparatively more expensive per trip than by public transport but it provides more comfort, convenience in terms of door to door service and flexibility in routing than a bus or even a minibus. Sociologically, the service is frowned upon as it imposes a burden on the person operating the vehicle and affects his health. On the other hand, it also provides an employment opportunity to people, who have not learnt any skill and own no land to till.

*(b) Animal Drawn Vehicles*

Tongas or coaches are horse drawn and are the earliest form of passenger transport in both urban areas and intra urban travel. Tongas are still in operation in many cities and towns in northern India. They are drawn by horses and can seat four to six. They are used similar to a normal taxi in several medium size cities and small towns in the north. They have been in use as a shared taxi in Delhi for long. As per 1979 count<sup>2</sup>, larger cities like Delhi had 0.4 vehicles per 1000 population as against 1.1 per 1000 in a medium size city like Meerut. They transport on an average about 60 to 70 passengers per day with average passenger trip length of 3 to 4.5 km and ply 30 to 45 km per day.

A different form of cart drawn by horse known as jatka has been in use in the south. They started dwindling in most cities since 1980s with the advent of auto rickshaw. However, some of them can be seen plying in smaller towns, especially in pilgrim towns like Tirupathi and Palani and some residential localities like Malleswaram in Bengaluru. They are generally banned from plying on major roads in such cities. Their contribution to urban transport in small towns is still significant, wherever they ply.

### 12.3.2 Motorised Vehicles

#### *(a) Saloon Cars*

Automobiles in form of saloon/sedan cars with seating capacity of 4 to 5 persons and omni vans are being used as metered taxis all over the world. They can be equated to private vehicles in terms of flexible, door-to-door service provided to the user, except that the service is provided at an agreed price. In order to achieve some uniformity, their service conditions, area of operation and fare structure are regulated by the governments. They are mostly metered. With technological developments and better economy, air conditioned cars also have been inducted into such taxi service. They may be individually owned or owned by companies. Nominated parking areas (taxi parks) are provided in important locations like airports, rail stations, CBD and major market centres for being available to be hailed by user when needed. In places like Delhi, telephones are provided at such stands so that the resident can call for one through telephone. Their loading capacity is specified by the licensing authority.

The number of such taxis available varies from 0.5 to 3 per 1000 in developing countries. In India, it varies from 0.8 to 1 per 1000 in large cities. On an average, a saloon car taxi plies 90 to 150 km per day in 7 to 10 trips and carries 18 to 20 passengers per day. The average number of passenger carried is 1.8 to 2.5. Average trip length depends on type of city and in Delhi, a city of distances, it is 10.4 km.

A modified version of this system prevalent in most Indian cities is the 'call taxi' system. A company would own a number of cars, which are equipped with meters and also phones. When a passenger needs a car, he has to just phone the telephone of the company and specify the place where required, and duration/purpose for which he needs the car. The owner's assistant locates the nearest available vacant vehicle and directs it to report to the client at the place specified. On completion of journey, the driver reads the meter and presents a bill to the user and collects the fare. In smaller towns, the demand not being so high and trips not being long enough, such taxis ply both inside town and also ply passengers to nearby areas. There are both metered and not metered ones and the fares are negotiated in the latter case. They work within some guidelines laid down by local authorities or their own associations.

Saloon cars are used as share taxis in India only in Mumbai and Kolkata at present. They have been functioning in Mumbai since 1970s and they provide a very efficient and economic form of service. Normal taxis (four-plus-one seaters) are used as share taxis in peak hours and as metered service in other times. The pick up points for share taxis are fixed and marked as "Shared Taxis", where the taxis line up in peak hours. The vehicle moves out as soon as each is filled up. The

destinations are marked on the windscreen. They are so popular that they get filled in within a minute or two of its pulling at the stop. They may drop passengers *en route* at request. Fare is generally fixed on point-to-point basis. The rate is decided upon between the taxi unions and traffic authorities. It is higher than for bus but much lower than for metered taxi. Thus this service helps considerably in bridging the gap between the high demand and supply of transport in peak hours. The service provided is fast, comfortable and comparatively cheap and is very popular for access trips by commuters to other public transport modes, e.g., for commuters in Mumbai traveling from northern parts of the city by train.

*(b) Auto-Rickshaw*

Auto-rickshaw as a public transport vehicle appears to be an innovation from South Asia. It is a three-wheel vehicle operated by a scooter engine (original one started with conversion of a Lambretta scooter). It has a low floor (to suit the small size scooter wheels), metal body and a canvas roof. It has drop down sides. The driver sits in front on a single seat and the rear main seat can carry three passengers with some light luggage hold space behind the seat. The steering is done using the handle bar in front. With its overall dimensions of 2.6 m × 1.4 m in a triangular plan, the vehicle has a very small turning circle. It can ply on very narrow roads (4 to 5 m wide) and weave through traffic quickly. Its maneuverability due to wedging action possible with its triangular shape is beneficial in terms of flexibility, but at the same time it leads to more accidents. Drivers tend not to follow lane discipline, causing obstruction and slowing of the traffic apart from being accident prone. Though the vehicle is operated by a two-stroke petrol engine, versions with four-stroke engines and using CNG are coming into the market. In fact, only CNG fueled auto-rickshaws and buses are allowed to ply on Delhi roads. It is a popular mode in all South Asian countries and cities in many South-East Asian countries like Sri Lanka, Thailand, Cambodia, Indonesia and Vietnam, though with minor variations in their body. In fact, it is the main mode of travel for tourists in Angkor Vat and a major IPT mode in Bangkok and Jakarta. They are differently called in those countries viz., *tuk tuk* in Sri Lanka and Thailand, *Bajaj* in Jakarta, *baby taxi* in Bangladesh, *Chand gari* or *Qingqui* in Pakistan. Their numbers have been growing very fast. It has made appearance in some cities in South America, e.g., *Mototaxi* in El Salvador. It is learnt that they are being introduced in UK (as share taxi in form of *Tuc tucs* in Brighton & Hove) and in some cities in Netherlands (tuk tuks imported from Thailand). Vietnam uses a version adopting motor cycle engines with larger bodies and higher load capacity.

The rate of growth of auto-rickshaws as taxis has been phenomenal in Indian cities and towns. For example, in Chennai it was 1.1 per 1000 population in 1981 and more than 5 per 1000 in 2007. The share of IPT in Chennai grew from fraction of a per cent in 1984 to 4% in 2006. In a medium size city like Bhopal, it has grown by 2.54 times in 17 years reaching 12586 in 2002 (about 8 per 1000 population). Performance of an auto-rickshaw varies with size of a city.

It makes about 18 to 25 trips per day covering 75 to 210 km and serving 27 to 75 passengers per day on average, depending on size of city and availability of public transport. Average trip length varies from 4.2 to 6.6 km in larger cities to 2.5 km in medium size city like Vadodara. Longer the average trip length, lower the number of passengers carried in a day. The average occupancy is 1.5 in larger cities and 2.1 in medium size cities.

Another form of shared auto-rickshaws known as *phut-phuts* is used in certain areas of Delhi. These have been in existence since 1950s. They also have six seats, three facing front and three facing rear, similar to a tonga, apart from that of the driver. They were at one time, a popular mode of travel in more areas in Delhi, e.g., from the Central Secretariat to Connaught Place (Rajiv Chowk) and New Delhi station, but its popularity has declined now. They cause lot of noise, apart from the smoke.

The other motor-cycle converted *Tempos* have six to eight seats, but during peak hours may carry more persons. They are similar to auto rickshaws with metal bodies having open sides and canvas tops but longer and higher floors. The drivers/owners of such vehicles have their own unions and they decide on point-to-point and intermediate fares. In many cases, the owners do not involve in their day-to-day operation. They either employ a driver who maintains and operates the vehicles and share the earnings or rent out the vehicle to a driver for a daily fee. The driver is responsible to maintain the vehicle and provides the fuel and lubricants and keep the surplus. The vehicles are registered and licensed and are subject to operation under the normal city traffic regulations. In many cities, designated places or parking areas are provided for such vehicles in CBD and busy centres, railway stations and central bus stands. The origin-destination and route for vehicles operating from each such parking point may be specified by the traffic police or mutually agreed upon by the operators unions. Same applies to the fare structure, which generally follows a slab system.

#### (c) Bus Services

Shared services are provided by smaller buses as IPT. Such services though are point-to-point ones are flexible in terms of *en route* stoppages and timings. Larger buses are also used to provide point to point unscheduled services, as contract carriages, school buses or chartered services for office goers, mainly related to work trips and following major roads.

#### (d) Minibus

Minibus is a smaller bus or van converted for shared service. Regular minibus has 20 to 25 seats and does not provide for standing. Nevertheless, the operators tend to overload them with some standees in the passageway during peak hours. They can be operated on narrower roads like collector streets in residential areas and some crowded market places. Due to lower capacities, they can be more quickly filled in and they provide a better load factor.

There are two forms of ownership and operation of minibuses. They can be operated by a company or groups or sub contracted by the state transport units and operated in a more organized manner. Alternatively, they may be individually owned or rented as in case of auto rickshaws mentioned above, which would form the informal sector operation. In either case, the routes are fixed but intermediate stops and pickup points are flexible. In most cases, they are operated by a driver who is helped by a helper who scouts for passengers, remembers where passengers are to alight, and collects the fare. Mini buses may provide intracity service or from city to suburbs or neighbouring market centres/villages. The fare in regular mini buses is distance based and in company buses, even ticket may be issued. The fare on mini buses in the informal sector may be fixed point-to-point or in slabs by the state government or by the operators unions.



In India, minibuses are operated on a regular basis in large scale in Delhi and Kolkata to supplement the service provided by regular buses. The routes are fixed point-to-point so as to provide service from CBD, Secretariat and important business nodes and railway stations to different residential areas. Part of the routes may overlap also with regular bus route. They are not run to any scheduled timings but have route numbers displayed on buses along with destination. They generally depart as soon as they fill up.

Mini buses are operated by the informal sector in many other cities like Bengaluru. They originate from central locations or business centres, where some waiting spaces are provided for them to load and unload passengers. Some states, which operate public transport bus in cities, do not permit minibuses to operate within the urban area, but license them to operate from some urban nodes and towns to neighbouring settlements, market centres and clusters of villages, not served by public transport buses. Even there, some are operated from certain residential areas to CBD or major work centres by mutual arrangement between residents and operators as contract services. Minibuses are, however, permitted to be operated regularly for carrying children to schools and back, providing door-to-door services in most cities and towns, subject to some regulations regarding carrying capacity and speeds. It is an ideal form of IPT for providing feeder services for metro railway stations from respective areas of influence.

The concept of minibuses is common to many third world countries, where comparable services are operated. A comparison of their performance as reported by a TRL<sup>2</sup> study is shown in Table 12.3.

**Table 12.3** Comparative Performance of Minibuses

City/ Town	Vehicle Capacity	Passenger per Vehicle per Day	Average Trip Length, km	Vehicle-km per Day	Load Factor
Kolkata	23	295	5.0	103	0.6
Surabaya, Indonesia	11	180	4.5	135	0.7
Kuala Lumpur	14-16	500	8.2	192	1.4
Kingston, Jamaica	10-20	80	NA	220	NA

**12.4 IPT IN OTHER COUNTRIES**

In many countries in Africa, IPT are the only type of public transport services available. Two forms of IPT in use in such countries are the regular taxi service and the shared taxi service. They are designated differently in different countries<sup>4</sup>. The shared taxis are known popularly as bush taxis or *taxi bousse* in African countries and Jeepneys or Jitneys in many other countries. For example, in Algeria and Canada, they are called Taxi Collectif; Tro tro in Ghana; Marshrutka in Russia; Pestero or Combi in Mexico; Molue or Denfo in Nigeria and Dolmo in Turkey. The shared taxi service uses either converted SUVs and station wagon type or ‘estate’ type automobiles or minibuses or light buses. The mini buses come in different capacities, depending on the make and country of

manufacture. The estate type vehicles are used with 8 seats (2 in front with driver plus 3 each in rear two rows) or 10 seats (2 in front and 4 each in rear two rows). The routing and fares are flexible. Minibuses used have a capacity varying from 14 to 23.

There are some common features in their operation in most countries. A share taxi route generally starts in a central location in the CBD or near a major market and proceeds in different directions. The routes follow major roads. Major cities and larger towns may have a number of such starting centres in the form of taxi parks, motor parks, lorry parks or garages. The city route may end at smaller such parks or collection centres in suburbs. The taxis have no scheduled time of departures and each would leave as soon as it is full. They may be company owned or individually owned, but operators in all countries have some form of informal unions. Ticket prices vary and in many cases, it is set by the government. In most cases, fare is collected at start of journey and in some services, it may be collected at the time of alighting. The bus would follow a designated route, but passengers are dropped or picked up at stops *en route* with some flexibility. The drivers have enough practical knowledge of the mechanism of the vehicle so as to attend to minor breakdowns *en route*.

12.5 ROLE OF IPT IN INDIAN CITIES

Simultaneously with the growth of private vehicles, the numbers of taxis and auto-rickshaws are growing at a fast pace in most cities in India. Table 12.4 indicates the share of IPT in number of vehicles in some major cities<sup>5</sup>.

Table 12.4 Share of IPT Vehicles in Some Cities

[Percentage]			
City	Personal vehicles	IPT	Public Transport
Pune	92	7	1
Patna	87	10	3
Lucknow	97	2	1
Kolkata	94	3	3
Hyderabad	94.39	5.23	0.38
Chennai	96.27	3.40	0.32
Bangalore	95	4	1
Ahmedabad	92	6	2

Source: Reference 5

The share of IPT in transport supply is increasing in most cities, while the concept of shared auto-rickshaw is gaining acceptance in cities like Chennai. The minibus is likely to assume a greater role as a feeder service to rail transit in major cities. Share of IPT trips in Indian cities has been growing fast. According to a recent study<sup>6</sup>, share of auto and paratransit trips in medium and large cities ranges from 5 to 10%.

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## 13.1 IMPORTANCE OF URBAN GOODS MOVEMENT

Any urban area needs an efficient system for the movement of goods for its sustenance. Urban goods movement (UGM) is therefore an essential component of urban transportation. UGM involves the transportation of, and terminal activities associated with, the movement of goods as opposed to movement of people in the urban area. Until recently, very little attention had been devoted to problems relating to UGM, and long range planning strategies for freight movement have been inadequate. The lack of attention towards UGM has been due to<sup>1</sup>: (a) the freight industry, being in the private sector, is not vocal with the politicians though it bears many of the direct consequences of UGM problems; (b) lack of awareness of the citizens that the increased prices caused by UGM problems are eventually borne by them; (c) tendency of the transportation planners and traffic engineers to be preoccupied with concerns of passenger movement rather than sympathetically examine the requirements of UGM; and (d) inadequate coverage of UGM planning in academic training in universities.

Awareness of the importance of UGM planning is not yet widespread. A very significant cause of street congestion is the situation arising from the distribution of goods and services. Transport planners have been complacent with the feeling that a planned traffic management for passenger transport would automatically be adequate for freight traffic as both passenger transport and freight traffic use the same carriageway. Efficiency of freight traffic affects the public in many ways. Delays and additional travel caused by each of loading/unloading space add to the cost of transportation. Poor geometric features lead to accidents of trucks and other vehicles. Inadequate land use planning evidenced by improper location of commercial and industrial establishments and of truck terminals lead to avoidable inconvenience due to congestion and air pollution and noise pollution. Significant improvement in the productivity of urban transportation systems can be achieved, if proper planning and management of UGM are explicitly attended to.

## 13.2 CHARACTERISTICS OF URBAN GOODS MOVEMENT

Characteristics of UGM are vastly different from those of passenger movement. The unit of carriage in passenger transport is the individual person. In freight transport, it is the consignment, the

commodity or collection of commodities travelling together as a unit from a single despatch point to a single receiving point. The sizes of consignments vary for the different consignments, and also vary within a commodity type depending on the distance to be moved. Freight movement is unidirectional; unlike passenger transportation, goods are unlikely to return to the point of their original departure. Where breakdowns occur in the passenger transport system, passengers provide quick and vocal notice of the difficulties. Goods consignments are voiceless. Finally, while the passengers are able to transfer directly from other activities, freight consignments must be prepared for transport, packaged and perhaps stored, loaded and unloaded, documented and checked.

Each mode of freight transport has some unique features. Intra urban freight distribution relies almost solely on truck transportation. In India, intercity freight traffic is dominated by road freight trucks, primarily because this permits door to door transport and quick movement with very few interruptions. UGM demands are created by the economic activities of production and consumption. A convenient way of considering UGM is to identify the principal economic units in an urban area and to develop an understanding of their internal structures and their associated commodity movement demands.

UGM can be viewed from a variety of perspectives. For example, for mode choice decisions, the characteristics of freight shipments must be considered, whereas the design of physical facilities should take into account the characteristics of freight carrying vehicles.

### **13.2.1 Freight Characteristics**

Commodities constitute the basic units of UGM. The major commodities moved each day would include industrial inputs and outputs, food items, petroleum products and miscellaneous cargo. For a city like Hyderabad, industrial commodities and food items may be highly significant<sup>2</sup>. Planning for freight transport was earlier focused on commodities. Though commendable, this approach was found to be too complex and beyond the limits of technical resources available for urban freight movement planning at local levels. The current trend is to base planning decisions on the movement of freight vehicles and the types of land use that generate such trips.

### **13.2.2 Vehicle Characteristics**

The internal distribution of freight in an urban area is mostly by trucks. The transport planner should be familiar with the characteristics of these vehicles. In India, commercial vehicles are classified into two major groups, namely, Light Commercial Vehicle (LCV) and Heavy Commercial Vehicle (HCV). A commercial vehicle whose gross vehicle weight (GVW) is less than 30 kN is called a light commercial vehicle, and one with GVW more than 30 kN is classified as a heavy commercial vehicle. HCV may be further classified as medium trucks (2 axles) and extra-heavy tractor-trailer (3 axles). The road freight transport is dominated by two-axle rigid trucks, typically in excess of 80% of all commercial vehicles<sup>2</sup>. Articulated and multi-axle vehicles account for less than one per cent of the freight fleet.

Light commercial vehicles are very efficient for collecting and distributing freight within an urban area. These form a substantial portion of the total commercial vehicle fleet in developed countries. In India, LCVs account for about 24% of the total commercial vehicles. It should be pointed out that there is no universally accepted classification scheme for commercial vehicles, and the definition of light, medium and heavy trucks may vary in different countries.

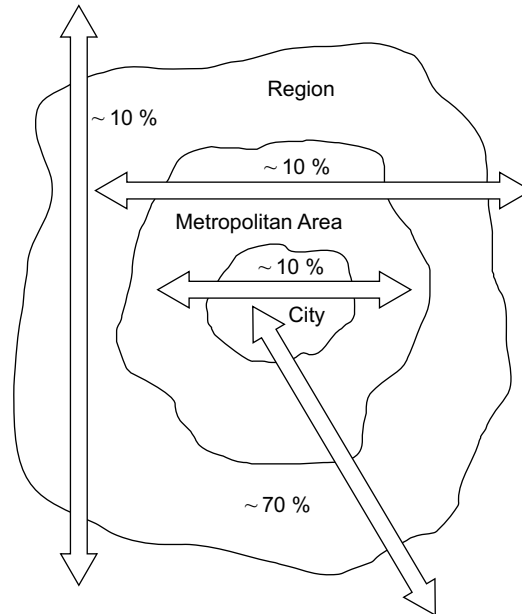
### 13.2.3 Pattern of Truck Movements

Based on the origin and destination of truck trips, urban goods movement may be broadly classified as: (a) movement between urban area and external locations; (b) movement between internal locations; and (c) movement of goods passing through the urban area<sup>3</sup>. The proportion of these categories of trips depends on the size of the urban area. The pattern of truck movements relating to a metropolitan region is shown conceptually in Fig. 13.1. Typical values of approximate extent of these movements are also indicated.

Goods movements with one trip end at an external location and the other in the urban area involving “external-internal” and “internal-external” movements may include: (i) movements directly to and from urban activity centres such as industries or major commercial establishments; or (ii) movements via urban freight terminals. Freight that moves via a freight terminal will involve a pickup or delivery truck trip within the urban area. A large proportion of external trips is made by heavy trucks including semi-trailer and truck-trailers.

Internal (intra-urban) movements may relate to inter-industry goods movement and household-based goods movements within an urban area. Inter-industry trips are accomplished by trucks of various sizes. The use of large combination vehicles, i.e., semi-trailers, tractor-trailers and truck-trailers for internal movements are usually limited to trips between large manufacturing and wholesale establishments. Residential goods movements usually involve the delivery of consumer goods, maintenance and service vehicles (predominantly LCVs), and public vehicles like garbage trucks.

Through movement of goods does not have any significant relation to the economic activities of the urban area under consideration, it can have significant environmental and safety related consequences, since all bypassable movements are made by heavy trucks that can cause serious noise and air pollution problems. The percentage of bypassable commodity traffic appears to decrease with increase in the population of the city<sup>4</sup>.



**Figure 13.1** Typical Truck Movements in a Metropolitan Region

### 13.3 PROBLEMS OF URBAN GOODS MOVEMENT

Economic activities within the urban area give rise to urban commodity flows. The import of materials for consumption and processing and the export of manufactured goods are required to maintain the economic activities. The UGM problem has many components: e.g., rising physical distribution costs, congestion, conflicts with passenger movements, accidents, air and noise pollution, pavement wear, and excessive energy consumption. However, the impact of these problems depends on the parties involved in goods movement. Each party influences the UGM problem in a different way and suffers differing impacts due to UGM policies and solution strategies.

A summary of the main concerns of the parties involved in UGM is given in Table 13.1. Transportation planners and traffic engineers have to approach the various parties involved (stake holders) and ascertain their views with respect to the problem to enable the formulation of an appropriate solution.

#### 13.3.1 Congestion

Traffic congestion is a major problem associated with UGM, resulting in additional direct costs to shippers and carriers and indirect costs to users of private vehicles, public transit and highway facilities. Modern business practices, such as 'Just-in-time' production, rely heavily on an efficient road network, and delays due to congestion may adversely affect the industrial productivity and competitive status of the products. The congestion may be due to parked trucks or due to truck movement in the traffic stream or due to both. This problem will become more serious as cities grow in size and in diversity of commercial and industrial activities.

**Table 13.1** Parties Involved in UGM and Their Concerns

Party	Main Concerns
Consignor/Consignees	Movement, cost and quality of freight service
Freight companies	Cost and delay due to traffic congestion; Routing and operation restrictions; damage to cargo
Truck drivers	Poor design of consignor/consignee terminal facilities; inadequate geometric design of roads and intersections for large vehicles
Car/two-wheeler drivers	Delay and reduced sight distance due to trucks in traffic stream and blocking of lanes by trucks while loading and unloading; size of trucks
Pedestrians and bicyclists	Reduced sight distance due to trucks; size of trucks; air pollution and noise pollution caused by trucks
Residents	Noise, air pollution and vibration caused by trucks; overnight truck parking in residential areas
Highway agencies	Damage and deterioration of road pavements due to heavy trucks; highway safety and accidents
Transportation/urban planners	Safe and efficient movement of people and goods; negative impacts of trucks and terminals

**Source:** Adapted from Reference 1

### 13.3.2 Vehicle Size and Stability

Loading a truck to the rated weight may at times involve piling the load to a height that makes it potentially unstable. Larger floor area to accommodate the load without exceeding the safe extent of piling can be achieved by extending the overall length of the truck because the maximum width of the truck is limited. This is being achieved now by use of multi-axle trucks. This raises the question of maneuverability. The multi-axle trucks and container flats are designed as tractor-trailers with articulation. The geometrics of most urban roads are not adequate for accommodating the turning radius of large trucks and trailers. To make turns at intersections, especially left turns, large trucks have to cross the centre line and encroach on a portion of the road meant for oncoming traffic. Otherwise the rear wheels may go over the kerb and cause the freight to shift and be damaged unless the speed is reduced significantly. This aspect should be checked at major intersections with heavy concentration of large trucks and the turning circles of kerbs at intersections designed with adequate radius.

### 13.3.3 Safety and Environmental Concerns

The noise and vibration generated by the movement of large trucks annoy the residents and create major controversies. While night deliveries have relieved CBD congestion somewhat, the noise pollution from truck movement has become serious because of the lower ambient noise levels at night. Traffic engineers face a dilemma as their routing plan cannot satisfy all the residents of the city. Restriction of trucks on one route may lead to the environmental problems on other routes.

Safety related problems also surface due to truck movements in urban areas. When an accident involves a truck, the severity of the accident is likely to be high. Articulated vehicles are particularly prone to cause serious accidents in case of loss of control due to jack-knifing or trailer swing.

### 13.3.4 Damage to Road Pavements

Pavements are designed to withstand the passage of a specified number of equivalent standard 82 kN single axle loads over a period of 15 years. The current limits for axle loads in India are given below:

Single axle fitted with 1 tyre	30 kN
Single axle fitted with 2 tyres	60 kN
Single axle fitted with 4 tyres	102 kN
Tandem axle fitted with 8 tyres	180 kN

The overloading of trucks is a serious occurrence in recent years. The magnitude of overloading of commercial vehicles beyond the 82 kN axle load on Indian roads has been observed to be in the range of 20 to 76% on the NH network<sup>2</sup>. This would cause faster deterioration of pavements. Pavement damage due to heavy trucks and the possible allocation of highway cost among various road users in the form of user charges are now receiving increased attention of highway engineers. Strict regulation of axle loads of freight trucks is essential to preserve the service life of road pavements.



### **13.3.5 Problems Related to Truck Terminals**

Truck terminals are currently found scattered all over the urban area and some are located within densely populated residential areas with unsatisfactory access for large trucks. Truck terminals tend to attract commercial activities and truck oriented operations such as truck repairs and stores supply on roads leading to the terminal resulting in congestion and other adverse impacts to the locality. Hence the location of truck terminals should be so determined that it reduces the truck movement through residential areas. Terminals located close to major trunk routes would justify special design features and treatments such as exclusive access roads and buffer strips around the terminal sites, so as to avoid adverse impacts due to trucks on local roads and adjacent developments.

### **13.3.6 Loading and Unloading of Trucks**

One of the common problems of UGM involves the pickup and the delivery of goods. Inadequate off-street facilities for loading/unloading in CBD area leads to congestion on main streets. The present practice of the layout and design of shopping complexes shows a lack of concern for the needs of UGM. City authorities should ensure that their zoning ordinances and building codes relating to commercial and industrial complexes incorporate adequate provisions for efficient operation of trucks. With the increased movement of goods by containers, port cities will have to provide for a number of Container Freight Stations (CFS) at peripheries for imported containers and those for exports.

## **13.4 GOODS TRAFFIC MANAGEMENT IN URBAN AREA**

Problems associated with UGM as discussed in the previous section are likely to remain and intensify, unless timely steps are taken by government and all concerned to limit truck axle loads and to regulate freight traffic. The different management techniques for truck traffic can be grouped under: (a) Truck oriented techniques; (b) Freight oriented techniques; and (c) Land use oriented techniques.

### **13.4.1 Truck Oriented Techniques**

The truck oriented approach involves segregation of truck traffic by special routes, by size and type of vehicles and by time. Route restriction is already in practice in the case of very heavy trucks carrying large indivisible consignments and in the case of trucks carrying hazardous materials. It is applied to roads with weak bridges or other physical limitations. Continuous monitoring and efficient route signing and marking are essential for this measure. Segregation by type and size of trucks is conditioned by arguments related to truck productivity. While smaller vehicles offer greater maneuverability in urban mixed traffic, larger vehicles tend to result in better economic productivity. By restricting the time periods for loading/unloading, the adverse impacts of trucks on pedestrian space and vehicular movement can be reduced to a certain extent.

### 13.4.2 Freight Oriented Techniques

Goods can be sorted according to sizes, and smaller vehicles may be used for collection and delivery. The effectiveness of these measures depends on the optimum utilisation of different sizes of vehicles in the fleet.

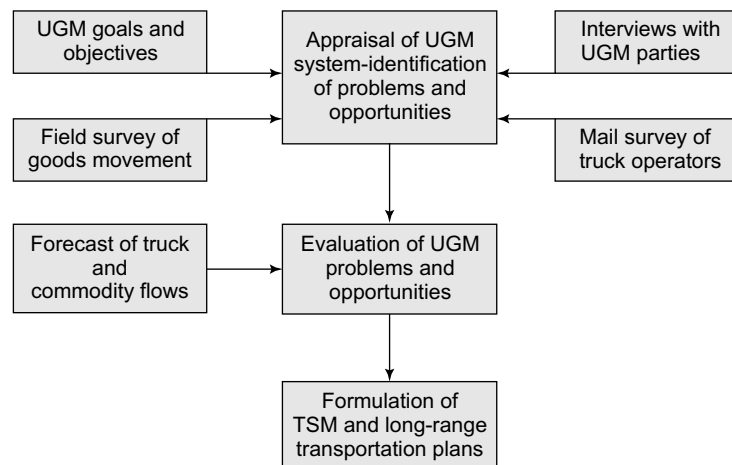
### 13.4.3 Land Use Measures

UGM problems could be reduced by proper relocation of truck movement generators like godowns, offices of transport operators and wholesale markets away from primary generators of passenger traffic. Urban planning may encourage the location of goods generators to be near rail terminals. Truck terminals with all required facilities may be developed on the fringes of the city. This is the policy being followed in most Indian cities. Truck terminals, apart from providing adequate parking slots for trucks, multi-axle tractor-trailer type trucks and container flats with good circulating area, should provide for some office space, motels or some boarding places, rest room (toilet and bath) facilities, fueling stations, canteens and some recreation places for the drivers.

## 13.5 URBAN GOODS MOVEMENT PLANNING PROCESS

### 13.5.1 Three-Phase Planning Process

Since efficient distribution of goods is essential for urban development, UGM should be devoted special attention in comprehensive urban planning and urban transportation planning. A three-phase UGM planning process<sup>5,6</sup> is shown in Fig. 13.2.



**Figure 13.2** UGM Planning Process

The appraisal of the community's existing freight movement system constitutes the first phase. The more obvious deficiencies are identified and a preliminary list of opportunities is drawn. For

this purpose, a quick review of the goods distribution system is performed in the light of the UGM goals and objectives, by conducting interviews with the parties involved in UGM, by mail surveys of truck fleet operators or by field survey of the region. The selection of any one or more of the above alternatives to appraise the situation will depend on the community's resources and initial commitments to the UGM. Field survey of goods movement will familiarise the planner with the problems and opportunities identified through interviews and mail surveys and it allows the planner to discover additional problems and opportunities not recognised or indicated by the interviews.

The second phase involves the evaluation of the UGM operations, and conceptual testing of alternatives, taking into account the forecasts of commodity flows and matching opportunities with problems such as limitations imposed on the transportation agencies.

The third planning phase is the formulation of a sound plan for Transportation System Management (TSM) and long range plans for goods movement in the urban area with regard to identified problems and opportunities.

### **13.5.2 Urban Goods Movement Study**

Any comprehensive transportation study should begin with the definition of the community's goals and objectives relevant to UGM. Goals for the area and specific sub-areas can be developed with the cooperation of local authorities by discussing with them area-wide problems and issues. Specific objectives should also be defined for both long term and short term plans. The study should facilitate the preparation of both short term and long term plans. Development of long term plans should be based on forecast of goods movement in a horizon year, while short term plan is based on the present situation. The programme should include: (a) a regional goods transportation study; (b) an area goods transportation study; and (c) a goods transportation facility study. In each of these studies, the main influence of goods movements, population, industry and employment should be considered. Commodity movements and movements of freight vehicles are to be determined. Information on land use and zoning laws should be considered. Sources of information include common carriers, transport operators, industries, truck owners and retail shippers.

Goods movement data may be collected by cordon survey. The following components of intercity traffic may be collected from truck operators and transport agents: (a) traffic outward from godowns of the transport enterprises in the study area; (b) traffic outward direct from consignor's place in the study area; (c) traffic inward to godowns of the transport enterprises in the study area; and (d) traffic inward direct to the consignee's place in the study area.

## **13.6 GOODS MOVEMENT FORECASTING**

Forecasting the demand for freight transport and its distribution are important to ensure adequate investment in infrastructure. The current composition of freight vehicle fleet in India consists predominantly of two-axle rigid trucks. Longer articulated truck usage is rather slow except for container movement. Conscious efforts should be directed to promote the use of articulated trucks as a long term measure towards efficient management of freight traffic<sup>7</sup>.

For the purpose of analysis, it will be useful to differentiate between resident oriented goods movement trips which serve the resident population of the community and location oriented goods movement trips which serve the basic industrial and employment activities of the population. Resident oriented trips are influenced by socio-economic characteristics of the population and can be forecast in a manner similar to person trips. Location oriented trips are independent of the socio-economic characteristics. Obviously, the nature and amount of goods that serve the basic economic activities in a manufacturing centre will be different from those in an industrial area. This difference between the two kinds of goods movement trips will call for different techniques to forecast each of the two types.

Truck trip generation for different types of land uses and categories of establishments is useful to stratify the truck trips by truck type, and to consider the combined effect of truck and other vehicular trips. Trip generation rates for truck trips are not stable over days. Hence data collected over short periods of time are not representative of the traffic demand and are not adequate to develop prediction equations.

The modeling of goods movement can be considered in two approaches, one by projecting the number of freight vehicles and the other by considering the actual goods. Trip patterns may be classified as: (a) Single shipment loads that can be large enough to cover the capacity of the truck; (b) Single origin with different deliveries; and (c) Simultaneous pickup and delivery at each stop.

Attempts have been made to derive truck trip generation equations of the intrinsic form

$$T_i = a + bN$$

where,  $T_i$  is the daily trips produced in zone  $i$ ,  $N$  denotes the total number of private trucks in the area, and  $a$  and  $b$  are constants. However, these equations have not been useful for predictive purposes because of the unstable nature of the truck trips. Another approach is to consider the goods themselves as the basis for forecasting. The distinction between resident oriented and location oriented goods referred earlier may be taken into account. It may be necessary in a practical study to consider both the approaches relating to the number of trucks and the commodities, and to judiciously apply engineering judgment to arrive at a realistic forecast.

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## 14.1 NEED FOR INNOVATIVE APPROACHES

Urban transportation is a multi-disciplinary initiative to meet the mobility requirements of an urban area. The continuous growth of cities results in increased demand for transport infrastructure, with capability to accommodate fast movement of traffic with safety. As the urbanization of the world moves from nearly one-half to about two-thirds of the population, the need for integrated urban transportation becomes increasingly important. While the provision of roads has been a major element in infrastructure investment in recent years, pressure on the road network and consequent level of road congestion has become more acute with the rapid growth in road traffic. Road travel is a major source of air pollution in urban areas. At the current and anticipated levels of growth of traffic, the levels of pollutant emissions are expected to rise to alarming proportions in the near future, unless conscious efforts are mounted now to effectively reduce the number of vehicles on the road. Effective methods to control the traffic demand and to induce commuters to adopt the public transport mode are to be evolved. The transit modes are to be made attractive in terms of savings in travel time and travel cost.

Transportation systems currently tend to emphasize mobility, i.e., getting from origin to destination. As a result, planning efforts tend to concentrate on land use and transportation policies, including transport demand management and infrastructure improvements intended to speed up traffic. Since transportation is a means to an end, the aim in planning should include accessibility to needs and destinations. This would call for additional consideration of factors favorable to social and environmental sustainability, such as shortening trip lengths by arranging closer proximity between needs and destinations, and reducing or eliminating trips through extensive use of technology, e.g., tele-work, tele-shopping and tele-banking. Thus, innovative transport planning improves mobility as well as accessibility in the city.

## 14.2 CLASSIFICATION OF URBAN TRANSPORTATION INNOVATIONS

Innovations relating to urban transportation may be broadly classified as:

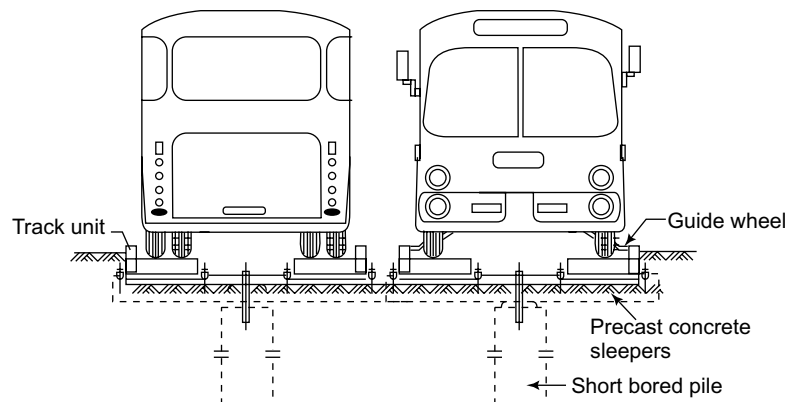
- (a) Bus-related innovations

- Track Guided Bus
  - Duo Bus
  - Busways
  - Bus Rapid Transit (BRT)
  - Bus Route Rationalization
- (b) Rail-related innovations
- Induction Motor Technology
  - Magnetic Levitation Vehicles (Maglev)
- (c) Innovative Planning Concepts
- Integrated Urban Transportation
  - Geographic Information System (GIS)
  - Intelligent Transport System (ITS)

These innovations are briefly discussed in the following sections.

### 14.3 TRACK GUIDED BUS

A recent development in bus transit is the track guided bus, which runs on an exclusive busway track for a major part of the route length and is guided by lateral guide wheels attached to the front axle<sup>1</sup>. The system originated in Germany and is known as 'Spurbus' or 'O-bahn'. As shown schematically in Fig. 14.1, the track consists of precast concrete track slabs fastened to precast sleepers, which in turn are supported on concrete bored piles of short length. The bus is equipped with two guide wheels which are mounted forward of the front axles. The guide wheels 'feel' their way along special guiding kerbs, and operate directly on the steering shaft of the bus. Whenever the bus approaches one of the two kerbs, the guiding wheels transmit a steering adjustment to the front wheels and the vehicle maintains a path in the middle of the guideway. The normal operating speed is about 60 kmph on guideways. The passenger capacity is about 60 to 90 persons per vehicle.



**Figure. 14.1** Track Guided Bus

A slightly modified system, known as Guideway Bus, has been developed in Japan. Here, guide wheels are used at both front and rear axles. The guide wheels located at front project out to the side to steer the bus mechanically along the guideway. The rear guide wheels are fixed in place and do not project outward beyond the body of the bus. These serve as stoppers in case the bus starts to slip sideways. The front running wheels are provided with support rings inside the air filled rubber tyres which protect the front wheels and allow the bus to continue operating on the guideway even when the bus gets a flat tyre. The floor of the guideway is adopted as a solid concrete slab instead of track units on sleepers.

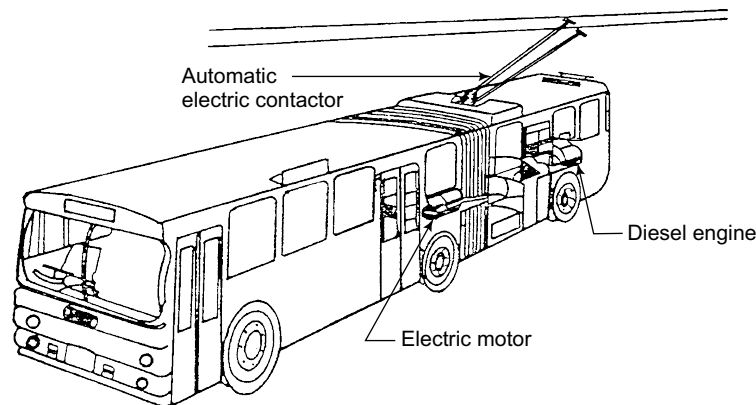
In view of the exclusive right-of-way, the speeds can be increased. The longest O-bahn track (12 km) in operation is at Adelaide, Australia, where speeds up to 100 kmph have been achieved. Where exclusive bus track is not convenient due to site conditions, or at crossings, the bus can be steered by the driver as a normal bus. Driving into the special kerbed guideway is facilitated by a funnel shaped entrance. When the bus is on the guided track, the driver has no steering work, but attends to other functions. It is possible to use the light rail right-of-way for track guided buses in CBD areas, as is done in Essen, Germany.

The guideways can be on open ground or in tunnels or may be on elevated structures. In case of elevated track, a U-shaped trackway may be adopted to reduce noise levels. Raised bus stop platforms facilitate convenient boarding and alighting. Automatic steering and driving on concrete track slabs reduce tyre wear. Track guided bus system can be an alternative to light rail or suburban rail system for moderate volumes of traffic (less than 7,000 passengers per hour per direction). The system can be integrated into an existing bus route network and can be expanded in stages.

## 14.4 DUO BUS

Another recent development in urban bus transit is the articulated Duo Bus<sup>1</sup>, which can be operated either by an electric motor as a trolley bus or by a diesel engine as a normal bus. This articulated bus (Fig. 14.2) permits operation in the suburbs with the full output of a diesel engine. On urban stretches, where installation of a contact wire is more economical, the vehicle is driven by an electric motor having the same output, in order to use the advantages of the electric drive, namely, low noise emission and no air pollution. In case lateral guide wheels are added, a track guided service is also possible, e.g. routes through tunnels may be used jointly by tramways, LRT and Duo buses. Both electric and diesel drive equipment are operated via the same pedals and levers to avoid extra work for the driver. System change-over is fast, taking only 15 to 30 s. Maximum speed is about 60 kmph. The acceleration and deceleration rates are  $1.0 \text{ m/s}^2$  and  $1.3 \text{ m/s}^2$ , respectively. The rating of the electric traction is about 180 kW and that of the diesel engine is about 177 kW. The electric motor is of a compact size and low weight. The total capacity is for about 170 passengers. Though the technical advantages are attractive, the adoption of this system in cities of developing countries may be economically unviable at the present time in view of the high initial cost and high maintenance cost of the bus.





**Figure 14.2** Duo Bus

## 14.5 BUSWAY

For corridors with moderate volumes of traffic, segregated right-of-way for buses may be adopted, with or without track guide wheels. The busway may move on concrete tracks as in Adelaide or on paved median space as adopted for 'key-route' buses in Nagoya. The operational features of the busway are less sophisticated than those of the bus rapid transit.

## 14.6 BUS RAPID TRANSIT (BRT)

Conventional diesel buses have a capacity of 80 to 90 passengers in crowded condition and in mixed traffic conditions can transport about 7,000 to 9,000 passengers per hour in a direction at an average speed of about 15 kmph. LRT and RRT for mass transit of commuters are highly capital intensive. Hence many cities which had earlier planned for rail transit explored alternative ways of using the bus itself for mass transit, especially in Latin America. The Bus Rapid Transit (BRT) was developed as a result of such a process of evolution, seeking to secure a viable transit system approaching the transportation services obtained from LRT, by combining advanced bus technologies and innovative techniques of operation and management.

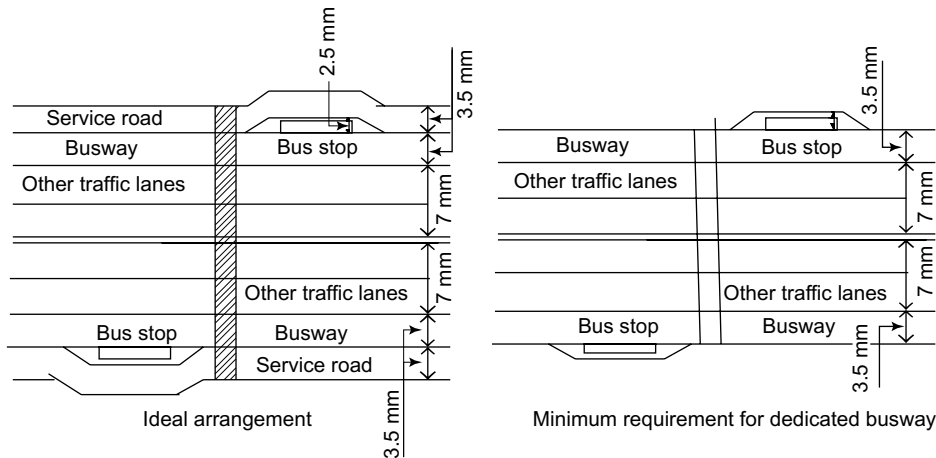
BRT, in its present form, is a high-quality bus-based transit system, which operates on segregated right-of-way providing bus priority at intersections, special bus stations or stops with shelters and raised loading platforms and providing automatic ticket vending machines at entry to such shelters. In the process, the flexibility of buses is combined with the efficiency of rail transit, resulting in greater service reliability, enhanced customer convenience and movement of larger number of commuters<sup>2</sup>. The cost of a typical BRT system is likely to be about 10% of a comparable LRT system and roughly 2% of an underground metro rail system. BRT has evolved as one of the most cost-effective mechanisms of public transport for most cities. The system facilitates a rapid and high quality service over a full network for the city.

The major BRT elements are: (a) Running ways; (b) Stations; (c) Vehicles; (d) Fare collection; and (e) Service and operation plan. Some advanced systems have passing lanes at stations for fast limited stop buses to overtake the normal service buses, as on Trans Milenio in Bogotá. The commercial speed of regular services is around 21 to 23 kmph while that of the express services is about 32 kmph. A normal BRT lane requires about 3.5 to 4.0 m width, while the stations are normally about 2.5 to 5.0 m wide. The exclusive road width needed for BRT use alone would be about 10 to 13 m, while provision of passing lanes would require about 20 m. In cities which do not have continuous roads wide enough to set apart the required bus lanes, BRT services are run on dedicated lanes where available and are operated as express buses on the intervening mixed traffic streets. The vehicles are provided with more doors, which are wider than those for a normal bus. The adoption of station-based fare collection rather than bus-based collection enables rapid fare collection. Reducing delay is the key to better performance of bus rapid transit.

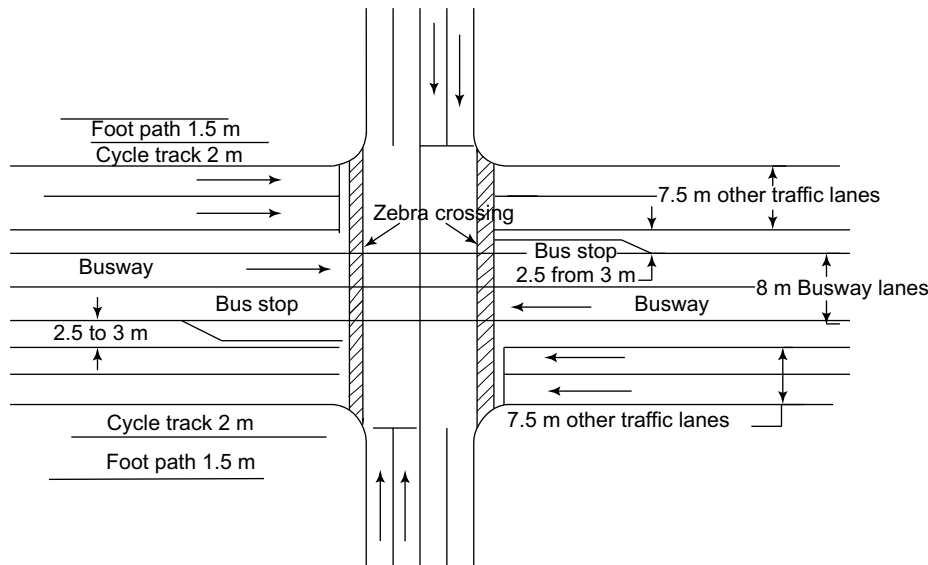
The earliest city to adopt BRT as a comprehensive transportation option is Curitiba<sup>3</sup> in Brazil, which operates 6 lines totaling 65 km. It was started as a simple bus line on kerb side busways, aiming to contain urban sprawl by aligning population and economic growth along the BRT corridors. The success of the Curitiba system is due to the fact that the BRT system was developed in close coordination with land use policies and community development plans, besides achieving increased speed due to strong supporting features such as traffic signal priority at intersections, bus stations with level-floor boarding and advanced fare collection techniques. Many other cities in Latin America followed suit with the concept. The preferred alternative now is to adopt the two or four-lane dedicated busway concept in the middle of the road with stations provided in islands between the lines as in Bogotá, Colombia, where the services commenced in 2000. In fact, Bogotá had planned for a metro rail project on their main corridor, but later gave it up in favor of BRT. Their main corridor is a four-lane BRT with normal and fast express services using articulated buses (with 160-passenger capacity). They are fare-integrated with smaller buses in the outskirts of the city. It is reported to have a peak hour directional volume of about 45,000 passengers per hour per direction (phpdt) on the four-lane corridor. Cities like Sao Paulo and Santiago consider the BRT as a complement to their metro rail systems. Following their success in South American and Mexican cities, many US cities like Los Angeles, Pittsburgh and Miami have adopted BRT on some corridors. Europe and UK have started BRT in a few cities for linking city centers with newly developing suburbs, e.g., Paris, Eindhoven and Edinburgh. The first city to have BRT in India is Pune where a BRT corridor is implemented on one of the State Highways passing through the city, followed by a pilot corridor in Delhi. Ahmedabad is another city which has commissioned a corridor of BRTS very successfully. Please see case studies in Section 14.12.

There are two types of BRT, one using the lanes in the middle of the road and the other using kerb side lanes defined as busways. Figures 14.3 (a) and 14.3 (b) show typical layouts of the two alternatives. They indicate minimum requirements. The former is preferred for providing better throughput, but it requires a road with minimum six lanes plus a pair of service lanes, when located on busy roads. Minimum of 28 m ROW will be required. It is desirable to provide a cycle track 2 m wide and a foot path 1.5 m wide in lieu of service road, in case of shortage of space. If wider ROW

is available, cycle track and foot path should be provided between the last through lane and the service lanes. Provision of a safe, convenient and secure access for pedestrians is a key component of BRT station planning, requiring considerable engineering judgment and knowledge of local customs. Any real or perceived deficiency in the quality of access will impair the efficiency of BRT service.



**Figure 14.3 (a)** Bus Rapid Transit System with Busway on Kerb Side

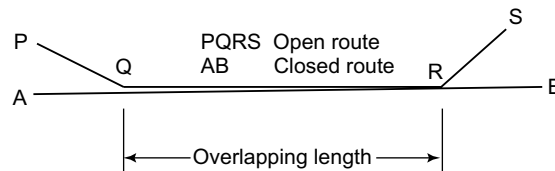


**Figure 14.3 (b)** Bus Rapid Transit System on Median

Station spacing is critical in ensuring success of a BRT system. In general, larger spacing would facilitate higher operating speed of vehicles, while a shorter spacing would improve accessibility to passengers. Normally, the spacing adopted would be in the range of 500 m to 800 m.

Location of the station relative to an intersection is a debatable issue in BRT planning. The station can be located in any one of the following configurations: (a) At the intersection before or after the traffic signal; (b) At the intersection, after the signal in one direction, and before the signal in the other direction; (c) Single median station near the intersection; and (d) Midblock. Each option has advantages and disadvantages. Depending on the local situations, and the need to optimize any particular aspect (e.g., road width, passenger walking time, vehicular operating speed), any desired option may be selected using engineering judgment.

As a system, BRT is classified as 'closed' or 'open' system, as shown in sketch below. In the closed system, the BRT buses run from terminal to terminal of the defined length of busways, and access to the BRT lanes is limited to a prescribed set of operators (e.g., Curitiba and Bogota). On the other hand, in the open system, the same buses can exit the corridor and link up to other terminals in outlying activity or residential centers (e.g., Taipei). Normally, the closed system facilitates better quality of service, whereas the open system has led to lower quality of operation due to congestion at stations and intersections. A list of some cities having successful BRT systems indicating their salient features is given in Table 14.1. The BRT system has the potential to enhance the image of the urban commuter bus system from a low level to one of a high-image transit system.



**Figure 14.4** Closed and Open Systems of BRT

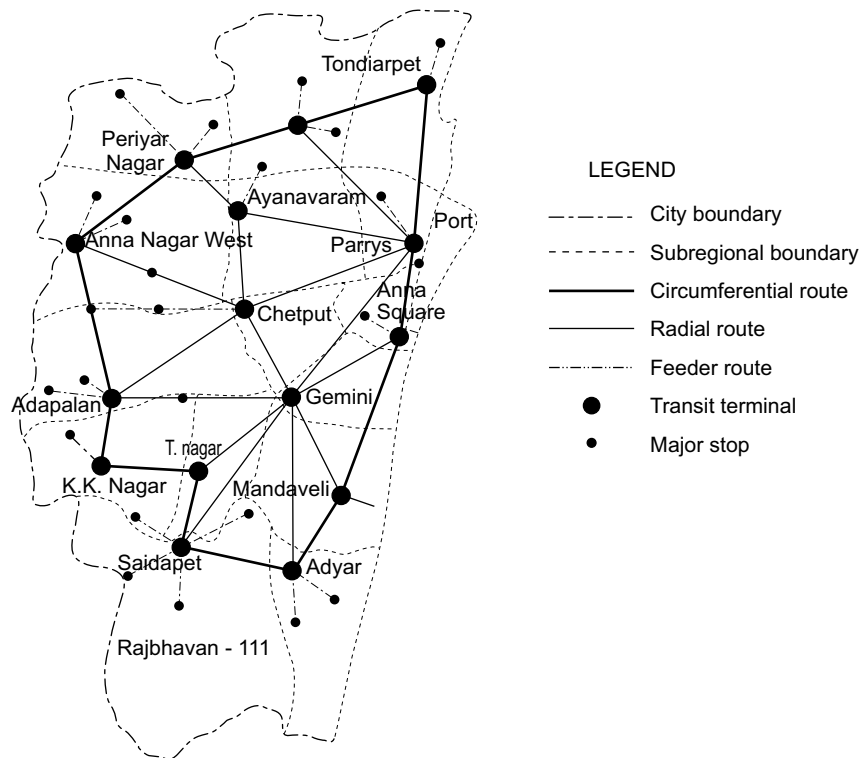
## 14.7 BUS ROUTE RATIONALIZATION

The quality of service and the economy of operation of a bus system can be enhanced by implementing an optimal route network. In most cases, the existing route networks in urban areas have evolved without the benefit of application of any scientific approach, resulting in excessive overlaps of routes and concentration of routes over a few road links. A conceptual framework, known as the multi-nuclei concept, has been proposed with an illustration of possible application to the Chennai city bus system<sup>4</sup>, as shown in Fig. 14.5. The major radial and circumferential routes connect the terminals, while the minor feeder routes radiate from the terminals. The major routes may be arranged to pass through a number of terminals and to have a practical route length (about 20 km). The frequency may be varied in a modular form to cater to the varying traffic demand. The vehicle depots may be suitably situated close to the terminals to reduce non-revenue trips (dead-km). The adoption of the multi-nuclei concept would lead to a reduction in the number of routes, while the overlapping of routes would be minimized. In order to ensure success of this scheme, special attention should be paid to develop the appropriate fare system and to redesign the terminals to facilitate seamless transfer from one bus to the next within the terminal. The proposed concept merits detailed study by metropolitan bus transport organizations.

Table 14.1 Selected Bus Rapid Systems in Service in 2007

Sl. No.	City	Year Started	Length of Trunk Corridors km	No. of Busways	No. of Trunk Buses	No. of Stations	Comm- ercial Speed kmph	System Passe- ngers Per Day '000	Daily Peak Trips '000	Trunk Vehicle Capacity	Trunk Vehicle Length m
1	Curitiba, Brazil	1972	65	6	232	123	19	562	20	232	24.0
2	Bogota, Colombia	2000	84	6	1013	107	27	1450	45	160	18.5
3	Quito, Ecuador	1995	26	2	155	77	18	327	10	160	18.5
4	Sao Paulo, Brazil	2003	130	9	N.A.	235	22	2780	35	100	18.5
5	Beijing, China	2004	16	1	87	18	22	120	8	160	18.0
6	Nagoya, Japan	2001	7	1	25	9	30	9	N.A.	75	12.0
7	Seoul, S.Korea	2002	86	6	N.A.	73	17	N.A.	12	75	10/12
8	Taipei, Taiwan	1998	60	11	N.A.	150	17	1200	10	69	10/12
9	Jakarta, Indonesia	2004	47	3	N.A.	54	17	140	4	75	12.0
10	Los Angeles, USA	2005	23	1	30	14	34	22	N.A.	120	18.0

Source: Adapted from Reference 2



**Figure 14.5** The Multi-Nuclei Concept Applied to Chennai City

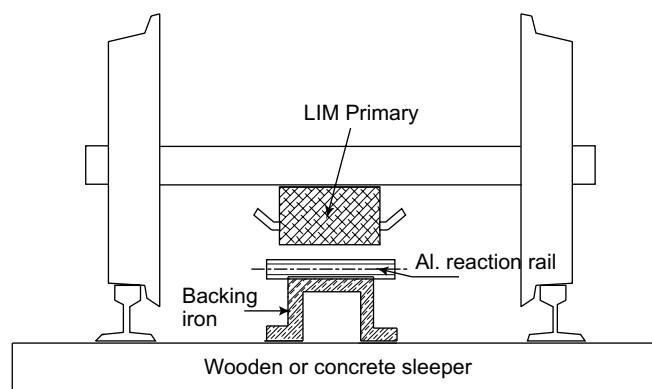
**14.8 LINEAR INDUCTION MOTOR TECHNOLOGY**

With the advent of electricity and its applicability to transport vehicles, the early forms of the tram and rail rapid transit vehicles (metro rail) made use of DC (Direct Current) motors for traction. In this mode, the motors are fitted to the bogies and the rotary motion of the armature of the motors is conveyed through a system of gears (toothed wheels) to the axles of the multiple unit coaches. In turn, the wheels rotate and the rotary motion is converted to linear motion through the friction between wheel flanges and the rail surface. The tractive force thus generated is a product of the vertical load transmitted by the wheel and the coefficient of friction between wheel and rail. It thus becomes proportional to the laden weight of the coach. When the rail top is wet, this traction is adversely affected as the coefficient of friction on wet rail is very much reduced. Sand is applied to rail top ahead of the wheels to induce more friction and consequent increase in tractive effort. This dependence of vehicle movement on the rail wheel friction also limits the gradient. Limiting gradient for conventional EMUs is 3.5%. About three decades back, the Paris metro tried to overcome this constraint by use of cars fitted with rubber tyred wheels running over the floor of the track for traction and providing rails and flanged wheels in addition for purpose of guidance

on some of their lines. Though by this modification, they found steeper tracks are possible, the technology proved costlier in initial and maintenance costs and needed more energy input thus increasing power consumption. Hence this technology did not spread further.

Linear Induction Motor (LIM) system is a recent development made in this direction and a few systems have been built and are in operation in Japan, Canada, USA and Malaysia. As the name suggests, 'LIM refers to cut open and unrolled version of rotating induction motor'<sup>5</sup>. The stator and rotor members of normally rotating induction motor are unrolled into flat form and fixed so that their surfaces are brought in proximity of each other. The stator is the primary and rotor is the secondary unit. The primary member is installed underneath of coach body and the secondary is laid flat on the floor in the middle of the track, between the rails. The primary member comprises of three phase winding and is fed with AC current supply. The secondary is a continuous conducting plate made of copper or aluminum and is fixed over a steel channel fixed in the centre of the track over the sleepers or on solid floor of the tunnel/deck of girder of elevated structure. Propulsion is derived from the magnetic force between the primary coil mounted on the bogie (axle) of the vehicle and reaction from the plate laid on the floor (called reaction plate). The primary member is also of flat configuration and occupies very little space below the floor of the coach. No other drive unit is fixed below the floor. Rails on track and flanged wheels on vehicles are still provided for guidance.

The gap between the reaction rail and the primary unit has to be maintained at 12 mm. This is the only aspect of maintenance which calls for care and vigilance. The mechanism is such that, the wheel diameter can be reduced from normal 860 mm of metro cars to 580/650 mm, thus facilitating lowering of coach floor. This consequently reduces tunnel size requirement in underground construction. Figure 14.6 shows the concept of LIM technology applied to the transit system.



**Figure 14.6** Schematic Diagram of Metro Rail Service with LIM Technology

LIM system has following advantages:

- (i) Since traction does not depend on rail-wheel friction, steeper gradients up to 8% is possible.

- (ii) Since the axles on a bogies need not be fixed parallel to each other and rigid, sharper curves are possible and the curvature would depend more on the length of the vehicle body and their overthrow. LIM tracks can therefore follow street alignments more easily.
- (iii) Due to simplicity of traction mechanism, there will be less noise produced, and less heat generated from the motor. Reduction in tunnel size and less heat produced will reduce current consumption on air cooling or conditioning in underground lengths.

The main disadvantages are their comparatively higher initial cost and marginally higher power consumption.

This form has been used to a large extent in special locations/corridors, requiring steep grades, sharp curves and predominant under ground construction through busy areas. A few locations where LIM technology has been used for advanced or automated transit system are indicated below:

Vancouver in Canada adopted the LIM technology as early as 1985 and built a line of 22 km with 15 stations known as Skytrain. (It used the Advanced Rapid Transit system of Bombardier, using LIM technology.) It was expanded in 2002 by addition of Millennium line of 27.5 km and 20 stations. The system carried 210,000 passengers per day in 2007. A similar system of 7.1 km with 6 stations was built in Scarborough, Canada in 1985.

Detroit has used the technology and in 1987 commissioned an elevated downtown single line loop in their CBD connecting a number of corporate centers, city stadium and shopping arcades following city roads. It is 4.7 km long with 13 stations.

The Japanese have used this technology since 1990 for building one line each in Osaka, Tokyo, Kobe, Fukoka and Yokohama.

Malaysia has built one line (Automatic Rapid Transit System) of 29 km with 24 stations in Kuala Lumpur (4.4 km tunnel, 2.11 km at-grade and balance elevated). Commissioned in 1999, the line presently carries about 170,000 passengers per day and up to 350,000 on festive days.

Recently, New York introduced two short links from JFK Airport using this technology, one to New York subway terminal and another to connect the Long Island commuter line. Beijing has built an airport link (rapid transit) of 28 km with 4 stations using the same technology.

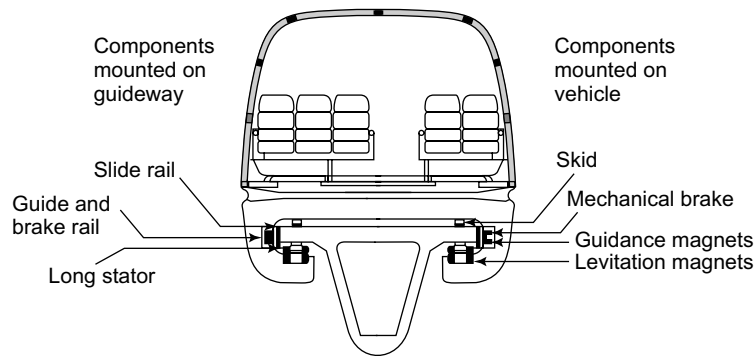
The principle of LIM has been extended further with addition of magnetic levitation to develop the Maglev system.

## 14.9 MAGNETIC LEVITATION (MAGLEV) VEHICLES

Considerable efforts are being expended towards development of high speed surface transport (HSST) system using magnetic levitation (maglev) vehicles<sup>6</sup>. Though the initial aim was to bridge the gap between the speeds of the train and the airplane to enable fast intercity travel in Europe, recent efforts attempt to apply the principles for intra-city travel, especially between airport and the city. Among several attempts, the Transrapid System developed in Germany has been the most successful. The only current commercial application is the Shanghai Transrapid Maglev Train from Pudong International Airport to Longyang Road Station in Shanghai, China inaugurated in 2004. Here the highest speed of 501 kmph has been achieved over a track length of 30 km. While the speeds achievable are appropriate for intercity travel, the system is not likely to compete as



practical solutions for intracity urban transport in view of the short inter station distances and the high cost.



**Figure 14.7** Cross Section of a Typical Maglev Vehicle and Guideway

The major components of a Maglev vehicle are shown schematically in Fig. 14.7. The main feature of the vehicle is the contactless levitation, guidance and propulsion/braking system. The levitation and guidance system consists of suspended frames with a row of individual electromagnets. Lateral guidance to keep the vehicle centered on the guideway is provided by the interaction of the guidance magnets mounted to the side of the vehicle undercarriage and the steel guidance rails attached to the guideway. The guideway is equipped with armature coils with three-phase winding. Levitation magnets pull the train up to the track while guidance magnets keep it centered on the track. A control system ensures that a steady gap of 10 mm is kept between the magnets and the guideway. When the magnets are switched off, the vehicle rests on a suspended skid system on which it can be reliably stopped in the event of a fault.

The propulsion unit is a long stator synchronous linear motor fixed to the underside of the guideway. The concept is similar to a three-phase motor cut open and rolled flat. The rotating magnetic field of the motor which is produced in stator windings and turns the rotor now becomes a traveling magnetic field which engages with the magnetic fields produced on board the vehicle, thereby thrusting it forward. The traveling magnetic field is produced over the entire length of the guideway, and hence the name 'long stator'. The reaction section in the form of levitation magnets is housed in the vehicle. A converter controls the linear motor's driving force and frequency in such a way as to utilize propulsion for driving and braking.

As electricity is the only energy source, the maglev is environment-friendly without any harmful emissions. Its elevated track avoids the disruptive effect of the track crossing agricultural fields and inhabited areas at ground level.

#### 14.10 GEOGRAPHIC INFORMATION SYSTEM (GIS)

One of the latest modeling tools used by urban planners in planning, operation and management of urban systems is the Geographic Information System (GIS). The GIS is a computer based

graphic system, which is designed to help in compilation, storage, retrieving, analysis and display of spatially referenced data. It is a versatile tool used in urban and regional planning and also management of urban systems<sup>7</sup>. GIS can be used for different activities of urban planning and management including:

- Land use - transport planning
- Area level planning
- Corridor/right-of-way preservation
- Transport master plan preparation at city level and zonal level
- Public transport system development and management
- Bus Route planning, and
- System integration like inter-modal co-ordination.

A specific sub-tool known as GIS-T has been developed for use in transport planning. It is considered a cost effective tool and has four components viz. technology hardware and software; data capture and integration; users and their requirements. The data input cover the following:

- *Transport related attribute data*—spatial entity in numerical and descriptive terms, e.g., land use, trip generation rate in tabular form.
- *Raster data*—relating to physical features like rivers, institutions, major commercial complexes.
- *Line data*—roads, transit systems, stations, sewer lines.
- *Area data*—like zones, hills, and water bodies.

GIS retains the data inputs in different layers, which can be superimposed for study and analysis during planning operations.

During the process of analysis of data and decision making, GIS uses the spatial data and other tools in combination: e.g., (a) tools of travel demand modeling (as in the four step modeling) with unique capabilities for digital mapping; (b) geographic data base management; (c) presentation of graphics; and (d) application of sophisticated transportation or statistical models. The collation of the analysis with graphic capabilities enables an interactive approach to planning and management. Partitioning and clustering of area/zones during the analysis is also possible. The interactive approach of GIS with visual display enables the planner to do matrix manipulation and network analysis, e.g., determination of shortest path by distance, time or cost.

GIS is being used in developing countries at macro level studies for planning and preparation of master plans for the region or a city and at micro level studies for bus route planning for part of a city or a transit system design for a corridor or design of utilities like water supply, drainage, etc. For more details, readers are referred to References 7, 8 and 9.

## 14.11 INTELLIGENT TRANSPORTATION SYSTEM (ITS)

### 14.11.1 ITS Concept

Intelligent Transport System (ITS) covers a broad spectrum of co-coordinated activities, each of which is used in transportation with the objective of saving time, energy and operating cost, besides

enhancing safety. ITS is a combination of a number of technologies from IT, communications and electronics and mapping, aiming to facilitate management and control aspects in transportation.

### 14.11.2 Technologies Used in ITS

Various technologies used in ITS are listed below first to understand their role in ITS<sup>10</sup>:

- (i) *Wireless Communication*: Short range communication has been in use in different ways for vehicle tracking and intercommunication. Research is on for applying the long range facilities like 3G and GSM for transport related activities.
- (ii) *Computational communications and vehicle electronics*: Techniques in process control, artificial intelligence and computing are used in combination with other technological developments for improved mobility of road users like navigation.
- (iii) *Floating car data*: Mobile phones on the move transmit their location data continuously. This technological feature and the fact that at present every car driver normally carries a mobile phone are used for locating the car and consequently derive traffic flow conditions at different locations and travel speed.
- (iv) *Sensing technologies*: Intelligence based sensing technology is being applied in different ways for safety and system management activities. Vehicle-cum-infrastructure based sensors can be used to control the speed of the vehicle. Vehicle to infrastructure and infrastructure to vehicle electronic beacons can be used for identification and inter-communication. In a simple form, the sensor technology is used for detecting over-speeding and erring vehicles and taking action against them. The sensing technology in combination with e-commerce facility is used for fare collection.
- (v) *Inductive loop detector technology*: Inductive loops or magnetic sensors can be installed in the pavements at specified locations for vehicle detection, counting, as well as monitoring weights of vehicles in motion. There are a number of variants available in the market using this technology.
- (vi) *Video Vehicle Detection*: Video cameras installed at different locations on the road are used for a number of applications in traffic control and management functions, such as electronic toll collection, congestion pricing, emergency notification and enforcement of traffic regulations.
- (vii) *Geographical Positioning System*<sup>11</sup>: Geographical Positioning System (GPS) is a system basically developed as a surveying and location aid and it has found wide use and applicability in transportation applications. GPS provides the road user with different navigational parameters like relative distance, co-ordinates of different locations.

The system works as follows: Satellites orbit the earth and, at any point of time, at least four satellites will be in a visible range of any location on earth. A GPS receiver placed at a point would receive signals from these four satellites. It uses the rays from three satellites to fix the terrestrial co-ordinates and the fourth for time delay measurement. These readings lead to the determination of the exact location of the receiver in terms of universal co-ordinates and time. The accuracy of co-ordinates of location is within 12 m of the correct one when only the receiver is used. If another land based transmitter is fixed close by for reference, the signals take less time to reach the receiver and the accuracy can be improved to be within 2 m.

This principle is used in a WAAS (Wide Area Augmented System) by fixing a receiver in a vehicle and having a reference ground station in an area for monitoring movement of the vehicle as well as estimation of its speed. Traffic police can make use of the WAAS for purpose of co-ordination among their units in a city. Bangalore Metropolitan Transport has been making use of this system for monitoring the movement of their buses on city roads. Many other transport undertakings are trying to introduce this system to monitor their fleet on the road.

### 14.11.3 Applications to ITS

The combined activities where one or more of the above mentioned technologies have been used for improved and/or safer functioning of transportation system can be grouped under:

- Mobility management
- Communication and Information
- Safety enforcement
- Transit management
- Vehicle navigation
- Travel demand management
- Environmental management.

*Mobility management:* Mobility management can be on an arterial or an expressway. This comprises of providing guidance sensors on roads, surveillance cameras combined with CCTVs for monitoring movements and control of speeds. The CCTV will help in detecting traffic build up and arranging for diversions and notifications in time and also taking timely action in case of emergencies and accidents.

*Communication and Information:* Short range communication facilities like VHS and UHS are used by the traffic controllers and enforcers to communicate with each other and take action for traffic management in a network of urban roads. The traffic control office continuously give out information to road user on traffic conditions on different corridors and information on weather conditions/forecast as necessary through local FM radios. Most of the present day cars being fitted with radios, drivers can tune in on them and based on the information can plan their routes. Railways use this facility for enabling communication between the driver and the guard of a long train, and with the nearest station in case of emergencies.

*Safety management:* The easy availability of communication facilities helps the traffic managers to notify in advance to the road users information on any situation likely to lead to accidents like breaches, fires, road blockages, etc., On freeways and also in vulnerable locations, there is a practice of stationing emergency medical units, which can be contacted by road users in case of any accidents, using cell phones or road side phones. Vehicle technology is such that there is an integrated e-call device in the cars, which gets activated in case of an accident and gives out information on its location, time, etc. Such information can be picked up by the emergency medical team for immediate action.

The railways have developed a system incorporating the sensor technology for detection of trains moving in opposing directions to prevent accidents in form of collisions,

*Automatic Train Control/Operation:* Different advanced technologies in communication, use of sensors on infrastructure and vehicles, and CCTV are integrated by the modern urban rail transit managers in their operation and safety of trains and also serving their passengers better. Their track circuiting and signaling arrangements ensure that the trains can follow each other at a safe distance and conflicting movements are avoided. The signal aspects are synchronized with the equipment in the vehicle so that the driver can read its aspect directly and if he fails to obey a stop signal, the mechanism warns him and in case of no response still, automatically stops the train. Use of line side sensors and corresponding vehicle sensors can even control the speed of the train wherever required automatically. This has led to some of the metro rail systems like Victoria line in London to operate a train without a driver, through commands issued from the control center. Visual indication of movement of trains on the line is indicated on the display board in control center and also on the boards kept in the adjacent stations. Passenger information is continuously communicated to the moving train regarding next stop or any emergency and to stations regarding next train and any delays for automatic display. The controller gets continuously visual indication of conditions on platforms and critical locations in stations through the CCTV monitors in the control centre. It facilitates him to take prompt action whenever required and make necessary announcements through the Public Address system kept in the stations.

*Vehicle Navigation:* A very major innovative activity combining advanced vehicle technology, computer, GIS and GPS is the introduction of vehicle navigation system. The system makes use of various navigational tools like a GPS receiver, an antenna, data cables, power supply, serial port connectors and a PC with a vector map of the area (in its ROM or in form of CDs) fixed in the vehicle. Necessary data is fed into the map and stored in the software used by the supplier of the system in GDF format. The driver of a vehicle equipped with this facility can by scanning through the map displayed on his computer locate himself; find the shortest or quickest route to his destination; locate a facility like a hospital or a stadium, including the best route for same. The traffic data received from the traffic controllers is fed into the system to learn about traffic flow condition on the alternative possible routes to help the driver to choose best route.

*Fare collection system:* The magnetic coding of cards and electronic cash transaction possibilities have eased the manner of ticketing and fare collection on public transport. The need for passengers to queue behind the counters for buying tickets every time they travel has been simplified, first with the introduction of magnetic coded tickets which can be taken from a ticket vending machine. It is inserted in a slot at ticket style at entry to station for entry and similarly at the gate at exit at destination for exiting. In buses, the fare collection box would accept the same and open the style for entry. Exiting from bus is not controlled since the fare structure in such buses is on a single slab system.

Now this system has been improved and further simplified by introduction of smart cards which can store a value of payment. The smart card has to be swiped in a slot at the gate of origin station for entry. When it is similarly swiped at the slot in the exit gate at destination station, the mechanism inside the booth automatically deducts the fare due for the journey made. The card can be topped up when the balance goes low at ticket counters in a station, on line, by phone or at

travel information centers established by the Transit Company. This system is in vogue on Delhi Metro Rail system in India. Vehicles being equipped with sensors for automatically paying tolls avoid delay at toll booths and speeds up the traffic.

*Transport Demand Management:* Transport demand comprises of generation of trips leading to demand for space to move and means of movement in minimum time. Some of the components of ITS described are used not only to minimize the number of trips but also to manage their mobility in an optimal manner. One of the means of reduction in trips is by doing the job through electronic communication, i.e., telecommuting. This has been made possible by availability of extensive phone networks and tele or video conferencing facilities, lap tops, internet and broad band facilities.

Car pooling or ride sharing is facilitated by telephonic communicator or commuter alert system, through which one can get information on availability of a seat or demand for a seat in the direction in which one has to travel. High occupancy lanes provide faster movement and in some cities, there are separate Parking lots or spaces for use of HOV users. Ride sharing using HOV lane facilities saves time for the user and reduces congestion on the corridor resulting in effective demand management.

*The Advanced Transport Information System (ATIS):* Information on traffic flow condition on major corridors in the city is made available continuously and can be accessed through internet and the commuter can use the information for planning his route of travel or even opt to work from home.

## 14.12 CASE STUDIES

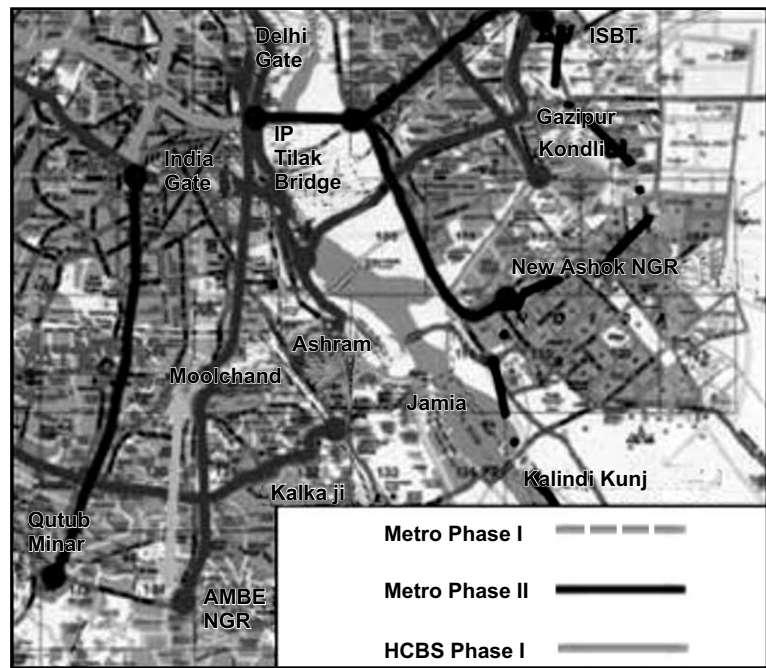
### *BRTS in Indian Cities*

The interest in BRTS (Bus Rapid Transit Systems) started being shown only since the turn of this century. Bus has been the main stay of urban commuters in Indian cities except for Mumbai, Kolkata and Chennai. After many years of planning for metro or light rail systems in major cities, only Delhi could make a real start on a bold scheme in 1998, encouraged by the availability of a large soft loan from Japan. The high cost of rail based modes and their limitations in flexibility of routing made planners look for bus based mass transit. The busway experiments had not borne expected benefits and the rapid growth of private vehicles on the road increased pollution beyond safe levels in cities like Delhi. The success story of BRTS in cities like Bogotá and Curitiba was available before the planners. The Central Pollution Control Board took the initiative and organized a major Workshop in Delhi in 2002. Decisions taken in that meet can be considered the starting point for bold initiatives in this respect by many Indian cities. Pune was the earliest to introduce a median based BRTS on one corridor leading to a suburb in 2007, using conventional buses.

### *Delhi BRTS*

Delhi went in for an elaborate study and prepared a master plan for a network of BRTS in three phases on 26 stretches totaling 310 km to be integrated with the metro rail lines. Phase I envisaged 7 lines over 115.5 km, vide Fig. 14.8. The Delhi Government formed a Special Purpose Vehicle, DIMTS (Delhi Integrated Multi-modal Transport System) for planning and administering this as well as future Monorail, etc., in Delhi area. They chose one of the busiest road corridors from Dr Ambedkar Nagar to Delhi Gate a length of 14.5 km to introduce the system first. This corridor

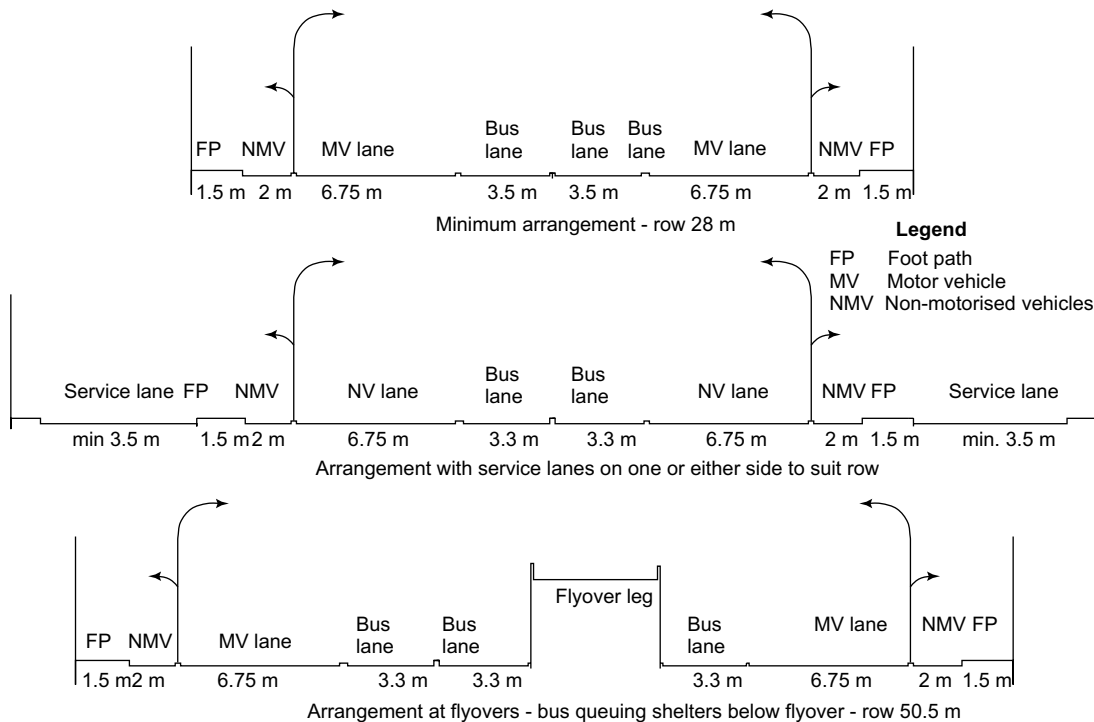
has one of the busiest intersections in Delhi, (Chirag Delhi) with over 135,000 crossing the intersection on a busy day. Ninety per cent of them are cars, auto rickshaws and two wheelers and within them, 35% to 40% are cars and jeeps. First stretch of about 5.8. km from Dr Ambedkar Nagar to Moolchand was commissioned in November 2008.



Source: CSE Study Reference 12

**Figure 14.8** Delhi BRTS Routes Planned

The ROW on the corridor varies from 28 m to 51.5 m. They went in for a BRTS on the median. The minimum configuration is 2 lanes in middle for BRTS of 3.3 m each. It is flanked on each side by two car/two wheeler lanes (6.75 m), an NMV lane (2 m) foot path (1.5 m). Where more ROW is available they have provided Service lane on one side or both sides. At intersections they have an extra passing lane with bus shelter and platform 2.5 m wide on approaches to intersections. Different arrangements are shown in Fig. 14.9. The bus stands vary from 40 to 58 m to accommodate four to six buses. The bus queuing shelters are spaced at 500 to 700 m intervals and if intersection is farther apart, a mid block bus station is provided. The buses have priority signals at inter sections. One major difference on this corridor from normal BRTS is that these lanes were open to all buses on the route including State Transport buses, Blueline private buses, School buses and Contract buses. In fact about 100 to 120 buses pass the busiest intersection in a peak hour on the corridor. Fare is collected on board. The passengers use the pedestrian crossings at the intersections or specially provided at mid-block stands guided and helped by traffic wardens employed by the DIMTS. Still there is fear of risk involved in crossing the busy lanes.



**Figure 14.9** Different Configurations on BRTS Corridor in Delhi<sup>12</sup>

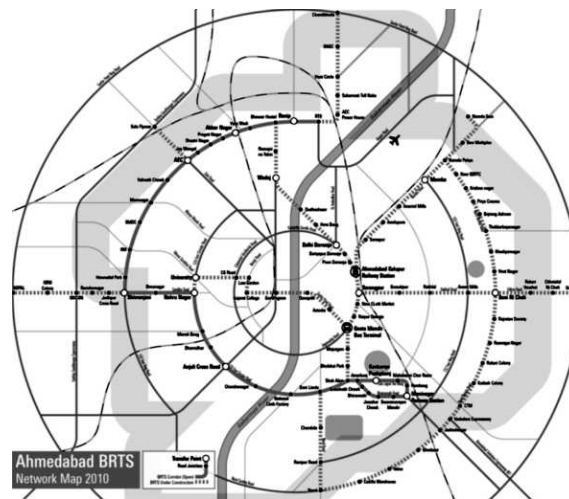
The system has received mixed reaction. While it has been welcomed by the bus users, the other vehicle users have been offering considerable resistance. The government has persisted with the facility and it has brought significant benefit to bus users in form of faster movement. A study done in early 2009 has shown that the average speed of buses on the length had improved from 12 to 18 kmph while those of cars on adjacent lanes and marginally come down from 14 to 12 kmph. Some of the private vehicles users had indicated that they would shift to the bus if the level of service can be improved and better buses run to fixed schedules. The State Transport has introduced low floor AC and non-AC buses to an extent of 13% of buses on the stretch on the route and some of Blueline buses have been diverted. The drivers of private buses are being trained and educated on how to use the facilities. Some of the school buses also have been moved to the car/TW lanes. There have been debates whether further BRTS should be on kerb side lanes. But such change is not considered desirable since enforcement of exclusivity of kerb lines for buses and prevention of encroachment by car parking and hawkers is difficult. Also the bus movement will be interfered with by left turning traffic at every inter section<sup>12</sup>.

#### *Ahmedabad BRTS*<sup>13</sup>

On the other hand the pilot project done in Ahmedabad has been more successful. They have also adopted the BRTS on the middle lanes. The lanes have been segregated by low kerbing and the



system has been provided with attractive bus stations at intervals. They are air conditioned, with ticketing and waiting facilities and provided with low platforms for boarding and alighting. Sliding doors are used at the bus stations. Stations are spaced at average 550 m intervals. Low floor AC 12 m long diesel (Euro III standard) buses are used and run to predetermined schedules. Average speed recorded in central area is 22 kmph. Frequency in peak hour is 12 buses per hour. In short, it has been designed to the standards adopted on Bogotá's Trans Milenio and Curitiba's Rede Integrada de Transporte. The first part length of the corridor was opened in October 2009 and balance of RTO-Kankate Fort (total of 18 km of which 12.5 km is of dedicate lanes) was commissioned in December same year. Flyovers *en route* are split to provide for central BRT lanes. The Government has formed a separate Ahmedabad Janmarg Company Ltd for planning, implementing and managing the system. While Janmarg provides the infrastructure facilities buses are run by private entrepreneurs selected on open tendering process. They are paid on kilometer operated basis. Fares are controlled and collected by Janmarg. It varies on distance of travel and varies from Rs 2 to Rs 11. Electronic paper tickets for vending machines are used. With the introduction of BRTS, the Ahmedabad Municipal Transport Corporation has done route rationalization for integrating other bus services with BRTS services. The services have been received well by public and even about 1% of car users have shifted to the system. 57% of users are for work trips and 28% for education. The first corridor carries on an average 90,000 passengers per day with PHPDT of over 3,000 on a link. The city has drawn up Phase I plan to cover 47 km and Phase II plan for another 58 km. Figure 14.10 is a schematic showing the corridors functioning and proposed.



Source: en.Ahmedabad BRTS from en.wikipedia.org

**Figure 14.10** Layout of Ahmedabad BRTS

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