Integrated Public Transport Systems: A Guidebook for Policymakers

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Preface

Efficient public transport is no longer a choice but an imperative for modern cities striving to address challenges like traffic congestion, greenhouse gas emissions, air pollution, and other negative externalities. Integrated services offer seamless travel and smooth operations. When cities are planned as transit-oriented and inclusive, accessibility is greatly enhanced. Digital technologies can also further enhance the operational efficiency of urban public transport systems.

However, many Asian cities operate a combination of different public transport systems without due consideration to interoperability or connectivity between modes. Due to the multiplicity of agencies with functional overlaps, urban and transport planning processes are pursued in an unintegrated manner, leading to misalignments of travel demand and public transport infrastructure and operations. Furthermore, there is wide variation in the utilisation of intelligent transport technology among Asian countries and cities. A lack of awareness among policymakers and limited institutional capacities limit the wider application of digital technologies in urban transport.

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To address these challenges, ESCAP initiated the project "Building Capacity for the Integration and Application of Digital Technologies in urban public transport systems in Asia-Pacific Cities" (Project ID: 2021-TD-001), which aims to build the capacity of cities to enhance the overall sustainability of urban public transport systems, evaluate the existing state of urban mobility, and provide innovative solutions in planning and developing integrated public transport systems. A key part of this project was to create a guide on how to integrate urban and transport planning and develop integrated public transport systems that incorporate digital technologies.

Establishing an integrated public transport system is a complex task. To develop this Guidebook, the authors conducted extensive research on state-of-the-art integrated public transport systems from around the world and consulted experts from the Asia-Pacific region. They also drew on the sustainable mobility assessments implemented under ESCAP's Sustainable Urban Transport Index (SUTI) project (see United Nations ESCAP, 2022). The resulting Guidebook is therefore grounded in tried-and-tested integrated public transport systems.

For ease of reference, this Guidebook is structured according to the key elements of an integrated public transport system.

- It begins with the foundations of public transport systems, the **institutional frameworks for integrated public transport systems** (Chapter 2) and integrating **land use and transport planning processes** (Chapter 3).
- Chapters 4 to 6 then describe the different options available to policymakers when designing their systems, including transit-based **public transport modes** (Chapter 4), **operational strategies** (Chapter 5), and **interchanges** (Chapter 6).
- The next two chapters explain the important role played by **data and digital technologies** in operational planning, management, and monitoring integrated public transport systems (Chapter 7), as well as different approaches to **fare integration** (Chapter 8).
- Finally, ways to incorporate **gender and social inclusion dimensions** in the planning and design of integrated public transport are described (Chapter 9).

To further illustrate these themes, a sister volume to this Guidebook, ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific***, presents good practices from the region. Readers are encouraged to read the Compendium in conjunction with this Guidebook.

It is hoped that all stakeholders who are involved in urban and transport development and operations in Asia and the Pacific, including government officials and policymakers, service providers, public transport agencies, and operators, will find this Guidebook and the Compendium of Good Practices helpful for planning integrated public transport systems in their cities.

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Acronyms and Abbreviations

AFCS	Automated Fare Collection System
AI	Artificial Intelligence
ATIS	Advanced Traveller Information Systems
ATM	Automatic Teller Machine
ATMS	Advanced Traffic Management Systems
AV	Autonomous Vehicles
AVLS	Automated Vehicle Location System
BCM	Bus Contracting Model
BEV	Battery Electric Vehicles
BI	Business Intelligence
BMTLA	Bengaluru Metropolitan Land Transport Authority
BRTS	Bus Rapid Transit System
CAD	Computer-Aided Dispatch
CBD	Central Business District
CMP	Comprehensive Mobility Plan
CNG	Compressed Natural Gas
DDU	Driver Display Unit
DMS	Depot Management System
ERF	Electronically Registering Fare Box
ERP	Electronic Road Pricing
ETA	Estimated Time of Arrival
ETD	Estimated Time of Departure
ETMs	Electronic Ticketing Machines
GCC	Gross Cost Contract
GHG	Greenhouse Gas
GIS	Geographical Information System
HMC	High Mobility Corridor
ICE	Internal Combustion Engine
IoT	Internet of Things
IPT	Intermediary Public Transport
ITMS	Intelligent Transit Management System
ITS	Intelligent Transport System
LF	Load Factor
LRT	Light Rail Transit
LTA	Land Transport Authority (Singapore)
MaaS	Mobility as a Service
MRT	Mass Rapid Transit
MTR	Mass Transit Railway
NCC	Net Cost Contract
NCMC	National Common Mobility Card
O/M	Operations / Maintenance
OBU	On-Board Unit
OHE	Overhead Equipment
ONDC	Open Network for Digital Commerce
PA	Public Announcement
PHPDT	Peak Hour Peak Direction Traffic
PIS	Passenger Information Systems
PPHPD	Passengers Per Hour in Peak Direction
PPP	Public Private Partnership
PT	Public Transport
ROW	Right-of-Way
SDGs	Sustainable Development Goals
SMC	Surat Municipal Corporation
SOP	Standard Operating Procedure
SPV	Special-Purpose Vehicle
STU	State Transport Undertaking
SUMP	Sustainable Urban Mobility Plan
SUTI	Sustainable Urban Transport Index
TCCC	Transit Command & Control Centre
TfL	Transport for London
TOD	Transit Oriented Development
TOM	Ticket Office Machine
TPU	Ticket Processing Unit

1

Introduction

Hongdae (Hongik University) Subway Entrance, Seoul. Photo: iStock/Jae Young Ju

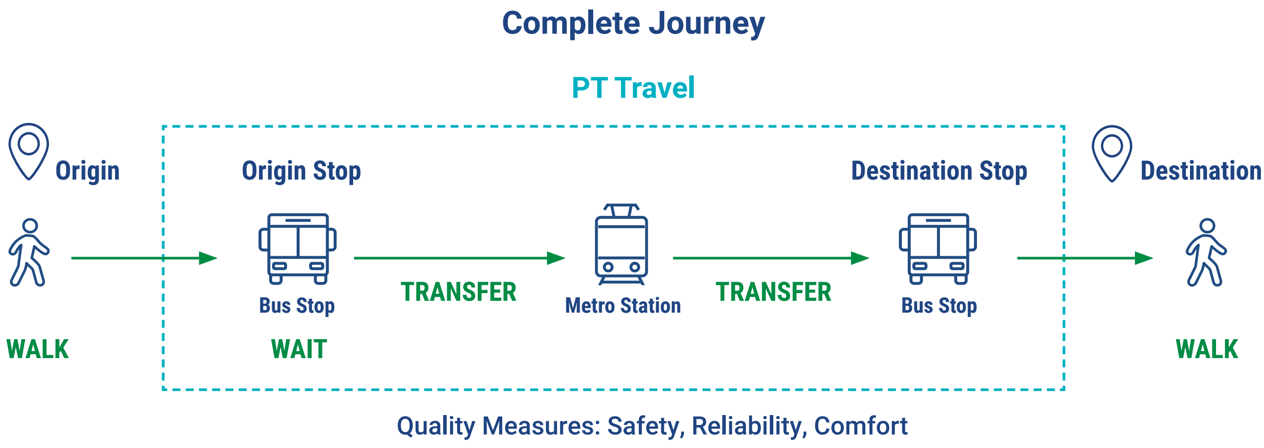
1.1 WHAT IS AN INTEGRATED PUBLIC TRANSPORT SYSTEM?

Most Asian cities are large and economically vibrant, characterised by high-density, mixed land-use development. In many cases, the rapid rates of economic and population growth have led to a surge in private vehicle use and put pressure on public transport systems, which in turn has contributed to severe congestion, travel time and costs, accidents, poor air quality, and growing greenhouse gas emissions. While some cities in Asia and the Pacific are leaders in public transport, studies have also found that public transport systems in the region generally perform poorly in terms of operational efficiency and service quality.[1] ESCAP's Sustainable Urban Transport Index (SUTI) assessments, for example, found that the overall performances of cities in the region were generally below par.[2]

Poor public transport does not necessarily mean a *lack of services*. Indeed, most cities have multiple modes of public transport, such as buses, metro, commuter rail, and bus rapid transit systems. Problems arise when these modes are managed and operated by different operators without adequate connectivity. For example, some cities have recently introduced high-capacity transit systems, but they are often planned as separate systems with little effort to integrate them with existing modes such as bus services, which are the primary providers of public transport services in many Asian cities. This makes operations inefficient for the operators and cumbersome for users.

Integrating public transport systems can make a substantial contribution to resolving these problems. The core principle is to make it easy for individuals to move from one mode of transport to another by providing seamless connectivity between modes (Figure 1.1).

FIGURE 1.1 Various legs of a multimodal journey



Source: Adapted from CEPT/ADB (2023).

While various authors and organisations have proposed their own definitions of an integrated transport system (Box 1.1), we define integrated public transport as:

"a system which combines various transport modes and operators, through organisational and planning processes, facilitated through the adoption of infrastructure and technologies, to maximise ease and efficiency for passengers."

Greater utilisation of public transport can have economic, social, and environmental benefits for individuals, organisations, and society as a whole. It also benefits transport operators. In particular, integrating public transport helps cities move their people efficiently and seamlessly without relying on a single mode. This can lead to more people shifting from private cars and two-wheelers to public transport. Some of the other benefits of integrated public transport systems are described in Table 1.1.

TABLE 1.1 Benefits of integrated public transport systems

For passengers	• Improved travel experiences on public transport, comparable to journeys using private vehicles. • Increased reliability and safety. • Reduced travel times and costs. • Greater coverage, accessibility, and flexibility while planning journeys/trips. • Increased physical and mental well-being. When public transport is accessible to citizens, users walk 8 to 30 minutes more daily compared to non-transit users, increasing their daily physical activity.[3]
For Transport Operators	• Lower unhealthy competition and brings complementarity to the system. • Increased public transport ridership and revenues. • Optimal utilisation of vehicles, increased efficiency, and enhanced capacity of each mode and for the system as a whole.
For Society	• Lower greenhouse gas emissions. It is estimated that public transport has the potential to reduce harmful CO2 emissions by 37 million metric tons each year through measures such as curbing the increase in vehicle miles travelled, alleviating congestion and supporting more efficient land use patterns.[4] • Lower per capita fuel use and greenhouse gas emissions compared to private vehicles. • Greater road safety and quality of living. • Optimal use of scarce urban street space: On average, a bus can accommodate the equivalent passenger load of approximately 5.83 cars.[5] • Greater social inclusion and cohesion: While all residents are affected by poor public transport, it is often the socially and physically disadvantaged who bear the biggest brunt.

Source: Adapted from CEPT/ADB (2023).

1.2 CHALLENGES OF INTEGRATING PUBLIC TRANSPORT SERVICES

The benefits of integrating public transport in cities are evident. But implementing it on the ground is riddled with obstacles, including those described below.

- **A multiplicity of operators:** As public transport systems are introduced with different time horizons, integration sometimes requires previously existing services to be discontinued, which is often resisted. Gains in efficiency and potential ridership and revenue increases are often not appreciated.
- **Institutional inadequacies:** Sometimes no agency has the legal backing to mandate integration, and operators continue with how they have been operating.
- **Financial barriers:** Integrating different systems involves investments in infrastructure, both digital and physical. Mobilising investment resources and cost-sharing between agencies/ operators can be challenging.
- **Technological barriers:** Integration also needs compatible physical, technical and operating infrastructure. Public transport agencies procure services of different operators under contractual agreements whose terms and conditions may not always match. Technologies used by operators for information sharing, fare collection, etc., may not allow interoperability.
- **Political barriers:** Lack of political will is a major issue in reforming public transport. The lack of appreciation of the benefits of integration is also a challenge.
- **Public awareness:** The implementation of new systems usually happens over a protracted period. People need to adopt new ways of travel. During the implementation period, there will be hurdles that cause inconvenience to the public, resulting in resistance.

Overcoming these barriers is a challenge. However, it can be achieved by taking a holistic and collaborative approach to integration, and by involving multiple stakeholders such as government agencies, transport operators, urban planners, and the public. The synergies and complementarities between various measures should be coordinated to create an efficient transport system.

1.3 STRUCTURE OF THIS GUIDEBOOK

For ease of reference, this Guidebook has been structured according to the key elements which need to be put in place to achieve an integrated public transport system:

Chapter 2. Institutional Frameworks for Integrated Public Transport Systems: This chapter describes urban transport functions and presents different institutional models to facilitate the planning and delivery of transport services in an integrated public transport system.

Chapter 3. Planning Integrated Public Transport Systems: This chapter presents different approaches and methodologies for preparing urban and transport plans for integrated public transport systems.

Chapter 4. Urban Public Transport Modes: This chapter describes the main transit modes used in urban public transport modes, their application and selection.

Chapter 5. Operational Strategies: This chapter focuses on principles, concepts, and techniques for preparing the operating strategy of integrated public transport networks and services.

Chapter 6. Interchanges: This chapter describes different types of interchanges and their roles in connecting different modes and services within stations.

Chapter 7. Data and Digital Applications: This chapter introduces how data and digital technologies are applied in integrated public transport systems, such as for traffic management, user information, and public transport operations planning and management.

Chapter 8. Integrating Fare Systems: This chapter presents different approaches to formulating integrated fare policies, level and structure, and collection and distribution.

Chapter 9. Gender and Social Inclusion: This chapter describes gender and social inclusion issues in public transport and how these can be addressed in the planning and operations of integrated public transport.

Chapter 10. Way Forward for Integrated Public Transport Systems: This chapter summarises the Guidebook with key messages for transforming and describes some of key emerging technologies which are expected to support and transform integrated public transport systems in the future.

Case studies to illustrate these chapters are given in the sister volume to this Guidebook, ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

Photo: iStock/AsianDream

1.4 SUMMARY

Many cities are planning to expand their public transport systems through network expansions and introducing a new high-demand public transport mode. The transition to green mobility is also taking place at a rapid pace. Given these opportunities, cities should integrate their public transport systems to provide seamless travel for customers as an alternative to private modes. Policymakers, municipal officials, and transport operators must work together to plan and operate these public transport systems. While integrated public transport systems are a critical part of any strategy to improve urban mobility, there is no single model of an integrated public transport system. This Guidebook will discuss the different approaches which policymakers and transport operators can choose from to achieve integrated public transport systems.

BOX 1.1 Different definitions of integrated public transport

1. Public transport network which **combines different transport modes to maximise ease and efficiency for passengers** in terms of time, cost, comfort, safety, accessibility, and convenience.
2. Integration is an **organisational process** that includes elements of the public transport system (network and infrastructure, tariffs and tickets, information, and marketing, etc.) and allows operators to communicate more effectively with each other. This results in an overall improvement in travel conditions for quality services.
3. Integrated transport system encompasses the totality or greater part of a city's territory, and offers public transport user the possibility to use multiple transport modes means that work in coordination through infrastructure, fare model and common validation systems.
4. Public transport integration includes the **comprehensive planning of services within an urban market** to facilitate seamless, **multi-operator journeys**. It entails the organisation of modes and services into a rational system of operational features in terms of routes, frequencies, timetables, fares, and ticketing, as well as policy aspects, such as planning, marketing, and development.
5. Transport integration is an **organisational process** through which the planning and delivery of elements of the transport system are brought together across modes, sectors, operators, and institutions to increase the net environmental and societal benefits.

Sources: 1. Higbee, B. (n.d.). 2. NEA, OGM, TSU (2003). 3. Mobility Academy. (n.d.). 4. Rivasplata, C. (2006). 5. Preston, J. (2012).

2 Institutional Frameworks for Integrated Public Transport Systems

Meeting on sustainable transport, Ulaanbaatar, Mongolia. Photo: Madan Regmi

2.1 CREATING A ROBUST INSTITUTIONAL FRAMEWORK

Urban and transport governance processes in most cities have evolved incrementally, resulting in a multiplicity of agencies with overlapping functions and jurisdictions. In many cases, agencies take operational decisions independently, which impacts both the customer and the operators adversely. For example, in many cities, the customer is made to change modes/routes multiple times during a single journey and to pay a transfer penalty each time a mode/route change is made. This means additional time and cost of travel.

Inadequacies in existing institutions, such as laws, regulations, rules, and structures governing the operations and interactions of organisations and stakeholders, can also impede progress toward sustainable transport. With overlapping services, there is an imbalance in the overall demand and supply, suggesting that resources are not being used efficiently. A typical case of multiple agencies delivering urban transport functions with overlapping jurisdictions is illustrated by the city of Delhi (Figure 2.1). It should be noted that in addition to the various agencies below, the cities of Faridabad, Ghaziabad, Gurugram, and Noida, which are part of the National Capital Region, also operate their own public transport buses.

FIGURE 2.1 Agencies responsible for transport in Delhi

Source: ESCAP

To deliver balanced supply-side and demand-side measures, actions must be coordinated at the institutional level. According to a World Bank study (2013), the most effective approach is to establish a lead agency responsible for urban transport, particularly in rapidly growing cities that require multimodal transport systems. However, the study also emphasised the importance of involving different stakeholders by establishing a robust institutional framework that clearly defines planning, coordinating, and operating processes. Such a framework would consist of:

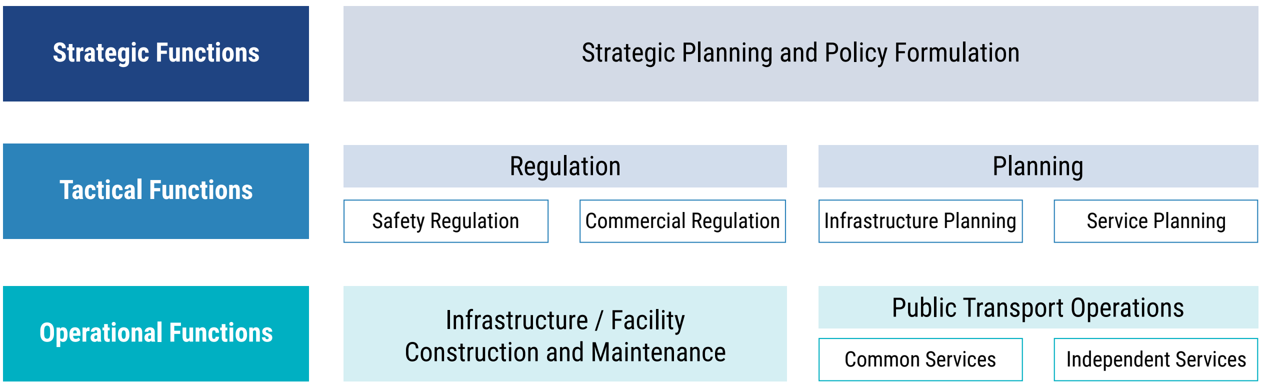
- **A core agency(ies)** set up through an act of the legislature or an order of the government
- **A defined set of functions and responsibilities to deliver,** and
- **A set of powers, resources and procedures (rules, regulations)** allocated to support the assigned roles.

2.2 URBAN TRANSPORT FUNCTIONS

The decision areas for urban transport service delivery are classified hierarchically by their strategic, tactical, and operational functions. According to the World Bank (2002), there needs to be an appropriate allocation of functions to levels and institutions in the regulation, management and delivery of urban transport services. Drawing on World Bank (2013), this section describes the three levels of functions for public transport (Figure 2.2), namely:

- **Strategic level** – what do we want to achieve?
- **Tactical level** – what product can help to achieve the aims?
- **Operational level** – how do we produce that service?

FIGURE 2.2 Functions to be performed for the provision of urban transport



Source: Adapted from World Bank (2013)

2.2.1 STRATEGIC FUNCTIONS

Strategic functions involve defining the vision, identifying objectives, and establishing broad policies and strategies to achieve them. These include:

- Urban and transport planning
- Long-range major infrastructure investment needs assessment and financial planning
- Safety standards, financing investments and operations
- Fixation of fares based on desired cost recovery from fare box and other sources
- Clarifying the role of the private sector
- Network plan/coverage
- Setting performance standards, and
- Governance structures and institutions.

In an ideal situation, the above functions would be performed by a lead institution, such as the Land Transport Authority (LTA) in Singapore, Transport for London (TfL), Mass Transit Railway (MTR) in Hong Kong, China and Bengaluru Metropolitan Land Transport Authority (BMLTA) (see Section 2.3 below and also Chapter 2 in the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific*** for more information).

2.2.2 TACTICAL FUNCTIONS

Tactical functions involve decision-making about how to achieve the defined objectives. These functions can be divided into two sub-levels, Regulation and Planning.

Regulatory functions are usually required under statute, involving some aspects of public health, safety, and equity. They can be further divided into safety regulations and commercial regulations.

- **Safety regulations** typically seek to ensure that the operation of transport services is safe, and include issuing driving licenses, vehicle specification, vehicle fitness test, driving speed regulation, pollution control, traffic management, etc.
- **Commercial regulations** seek to ensure a degree of equity, prevent monopoly pricing, and attempt to match supply and demand (e.g., route permits for public transport operators, operating conditions such as frequency and hours of operation). Fares are prescribed to ensure that public transport is affordable to all sections of society.

Planning functions are not usually required by statute but are necessary for systematic and efficient investment and operations. In the context of urban transport, planning functions can be classified as infrastructure planning and service planning.

- **Infrastructure planning** allocates scarce public money to various public transport infrastructure developments such as roads, public transport facilities, sidewalks and parking spaces.
- **Service planning** includes designing the network or individual routes in terms of terminals and alignment, determining demand along routes and supply arrangements to meet the demand, establishing operating standards, calculating the level of service on each route, developing contracting terms and contracting operations, designing a compensation mechanism, and monitoring and evaluation.

2.2.3 OPERATIONAL FUNCTIONS

Operational functions are responsible for executing infrastructure and service plans efficiently, encompassing infrastructure development and public transport operations.

Infrastructure Plans involve infrastructure construction, management, and maintenance activities for roads, bridges, footpaths, parking facilities, transitways, bus stops, and terminals.

Services involve the operation of public transport services and can be categorised into two parts:

- **Common services** are essential for all operators, often involving natural monopolies that benefit from economies of scale. Examples of common services include the provision and upkeep of bus stations and passenger terminals, passenger information systems, revenue sharing among operators, accident recovery, public relations, security services, and dispute resolution.

- **Independent services** involve the day-to-day operation of specific facilities and services, such as bus systems, metro rail systems, tram systems, BRT, and parking garages. These functions include vehicle scheduling, staff deployment for public transport services on different routes, maintenance schedules for vehicles, fare collection and deposit, procurement of spare parts and stocks, and the maintenance of rolling stock.

2.3 EXAMPLES OF DIFFERENT INSTITUTIONAL MODELS

Different cities have developed their own institutional models for delivering integrated public transport, according to their city context. Based on a review of global good practices, four types of institutional models were selected as potential examples to other cities. For a more detailed description of these examples, please refer to Chapter 2 of the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

- Single authority responsible for integrated land use and transport development - **Land Transport Authority (LTA), Singapore**
- Single authority as regulator and organiser of urban transport with existing institutions - **Bengaluru Metropolitan Land Transport Authority (BMLTA), India**
- Urban local body for planning and managing public transport - **Surat Municipal Corporation (SMC), India**
- Single agency for coordination - **Transit Alliances, Germany.**

2.3.1 SINGLE AUTHORITY RESPONSIBLE FOR INTEGRATED LAND USE AND TRANSPORT DEVELOPMENT

In 2021, an average of about 5.3 million passengers a day used public transport in Singapore, which is comprised of public buses, Mass Rapid Transit (MRT) and Light Rail Transit (LRT). The popularity of public transport lies partly in the effectiveness of its unique institutional model. Singapore pioneered the consolidation of various transport entities into a single authority, the Land Transport Authority (LTA). The LTA plans the long-term transport needs of the city and sets out clear objectives in long-term strategic plans. With the LTA overseeing and managing all the public transport modes at strategic and tactical levels, the public transport system in the city works as a single integrated unit. This model requires merging all agencies delivering public transport functions into a single unified agency, which is a long-term process requiring a high level of political commitment and resources, and involving significant administrative restructuring.

2.3.2 SINGLE AUTHORITY AS REGULATOR AND ORGANISER OF URBAN TRANSPORT WITH EXISTING INSTITUTIONS

The Bengaluru Metropolitan Land Transport Authority (BMLTA) is a good example of a single agency which coordinates all land transport activities in collaboration with existing institutions in the city. To combat congestion arising from population growth and motorization, it was thought that the unification of several city transport agencies under one umbrella was necessary. By forming an agency like BMLTA and restructuring the roles and responsibilities of existing institutions, it was possible to bring the relevant stakeholders involved in urban development onto a single platform. The BMLTA acts as a regulator, organiser and coordinator of urban transport planning and management. This allows existing agencies to continue to operate with modified functions/jurisdictions and operations to deliver integrated services.

2.3.3 URBAN LOCAL BODY FOR PLANNING AND MANAGING PUBLIC TRANSPORT

The case of Surat City demonstrates how local bodies can also effectively plan and manage urban and public transport. However, this is feasible only if local bodies are adequately empowered through legislation to undertake such a responsibility. The Surat Municipal Corporation (SMC) is legally empowered to deliver public transport services under the Gujarat Municipal Corporation Act. The SMC delivers strategic functions such as the preparation of the Surat Development Plans with Surat Urban Development Authority (SUDA) as well as the Comprehensive Mobility Plans. The city operates three bus-based public transport systems, including the Bus Rapid Transit System (BRTS), the city bus service and the High Mobility Corridor (HMC). All three systems operate on an integrated network and information system, with a single fare structure and single ticket for the entire journey (Box 2.1).

2.3.4 SINGLE AGENCY FOR COORDINATION

Transit alliances act as an umbrella organisation, legal entity or administrative unit to oversee and coordinate integrated public transport. The concept of transit alliance appeared first in the 1960s and became popular across Germany and other parts of Europe. For example, the Verkehrsverbund, the German public transport alliance system, is regarded as the first and most successful form of integrated transport in the world.[6] The Rhine-Main Transit Alliance (RMV) has representatives from 19 major cities in the Frankfurt and surrounding regions and works with the public transport regulatory authority and 153 transport operators. The model balances the interests of responsible authorities and operators and involves minimal restructuring of service delivery institutions. By linking different modes and local authorities, it can eliminate competing transport services and coordinate all services efficiently, resulting in additional fare revenue which increases the profitability of the system[7]. The transit alliance also undertakes joint initiatives such as advertising and public relations campaigns to enhance the image of public transport. City authorities offered subsidies to the operators to cover any operational losses due to the integration efforts.

2.4 INTEGRATING PUBLIC TRANSPORT IN PRIVATISED MARKETS

In many countries, national and municipal governments still shoulder a substantial portion of the cost of public transport. For example, the Government of China is heavily subsidising the cost of public transport in cities.[8] However, it is becoming more common to unbundle operational functions and invite the private sector to provide them." A Public Private Partnership (PPP) is the provision of public service by a private partner under an agreement with a public agency, for a specified period and with the provision that the authority can charge an agreed fee. The argument for this model is that it takes advantage of private sector efficiencies in operations, attracts private investment to manage natural monopolies, and can incorporate universal service obligations. Table 2.1 depicts different options for the management of public transport operations, ranging from entirely public to private.

TABLE 2.1 Management of public transport operations

ENTIRELY PUBLIC	**Public Supply**	Services and associated facilities are completely owned and operated by public agencies.
	Service Contracts	Facilities are owned by the public agency and some of the services are contracted to private agencies.
	Management Contracts	Facilities are owned by the public agency, but the operations are fully contracted to private agencies.
	Concessions Contracts	Facilities are owned by the public agency but need costly improvement and capacity addition.
	Build-Operate -Transfer	New facilities need to be built and operated.
	Joint Ownership	Jointly owned by public and private parties.
ENTIRELY PRIVATE	**Private Supply**	Facilities are owned by private agencies and also operated by them.

Source: ESCAP

The success of private sector involvement in public transport depends on finding the right business model for that particular service. As Figure 2.3 shows, there are a range of different business models which can be employed. One of the main differences between the models are in the ownership, management and financing of assets (mainly vehicles). The designs of the institutional framework and business model therefore go hand in hand. Having a clear understanding of the respective parties' roles when involving the private sector can help ensure that the different parties share the same objectives, as has been demonstrated in the case of Surat's Sitilink services (Box 2.1).

2.5 SUMMARY

The institutional integration of public transport systems is imperative for the effective and efficient functioning of urban mobility. By bringing together various transport agencies, stakeholders, and governing bodies, institutional integration can lead to improved coordination, streamlined decision-making, and enhanced overall service quality. However, there is no one-size-fits-all model. The choice of the model depends on each city's unique circumstances and needs. Historical context, existing governance structure, size of the city, number of modes and operators, political values, and administrative cultures can all influence the most appropriate model. It is essential to tailor approaches to specific contexts.

FIGURE 2.2 Generic business models

BUSINESS MODEL	DESCRIPTION	EXAMPLE
Outright Purchase Model (OPM)	State Transport Undertakings (STUs) purchase Bus with battery, chargers and gets charging infra installed at its own cost; and relies on warranty and training for Operation and Maintenance (O&M)	Uttar Pradesh and Calcutta under Faster Adoption & Manufacturing of Electric Vehicles Scheme (FAME) I
Gross Cost Contract 1 (GCC 1)	All assets supplied, financed, owned, and operated by private entity against pay per use and assured km contract	India FAME II
Gross Cost Contract 2 (GCC 2)	All assets financed and purchased by STU & operated and maintained by consortiums against pay per use and assured km contract	Buses financed under Jawaharial Nehru National Urban Renewal Mission (JnNURM), outsources to Private Operators.
Net Cost Contract Model (NCC)	Assets financed by the STU & Private entity. STU retains ownership and O&M is done by Private operator with support of training from Original Equipment Manufacturer (OEM)	Indore, India
Financial Lease (FL)	Vehicles financed and owned by Financial Institution & given on lease to STU for O&M with support of training from OEM	Some cities of China
Unbundling Model (UM)	Vehicles purchased by STU and battery is leased. Charging infra. Could also be leased purchased or oursourced.	United States of America, where Proterra sells the buses and batteries are leased.
Financial Lease + Unbundling (FL+UM)	All assets are supplied by manufacturer through leasing. ESP leases battery from OEM; resposible for O&M of battery, charging infra.	Shenzhen, China
Utility Provider Led Model (UPM)	Utility provider offers complete solution through different contracts (with STU for service, OEMs for supply of assets and bus operators for operations)	Santiago, Chile. Being attempted by National Thermal Power Corporation Ltd. (NTPC) in India

Source: Janani, V., Gautam, P. (2021)

BOX 2.1 Private sector involvement in Surat's bus services

In Surat, Sitilink's key business components were unbundled for private participation across groups that comprise customised buses and depots; ITMS, control centre and fare collection system; bus network and stations/ terminals; and support services such as housekeeping and security (see figure). While these components are interdependent, each component has its own planning, design, procurement, supervision and management requirements. To deliver efficient services, Sitilink developed business models which aim to enhance productivity and quality. Moreover, they aim to achieve cost efficiencies and minimise long-term employee liabilities and legacy costs by outsourcing services to the private sector. City bus services and bus rapid transit services are being operated on a Gross Cost Contract basis (GCC), where private operators are paid based on the performance of operations.

Source: Center of Excellence in Urban Transport, CEPT University

3

Planning Integrated Public Transport Systems

Aerial picture of railway station in Delhi, India. Photo: Brett Cole

3.1 APPROACHES TO INTEGRATING LAND USE AND TRANSPORT PLANNING

Urban form and design can greatly influence travel patterns and infrastructure needs. For example, the distribution and density of land use determine the demand for transport, with higher densities often correlating with increased reliance on public transit and non-motorized modes. The term "integrated land use and transport planning" represents a holistic approach to urban planning that harmonises land use and transport to create sustainable, efficient, and liveable urban environments.

Urban and transport planning practices involve a range of strategies, principles, and methodologies used by city planners, urban designers, transport engineers, and policymakers. Effective integration requires careful consideration of access management, environmental impact, and economic development. Concepts such as Transit-Oriented Development (TOD exemplify the intentional integration of land use and transport planning, fostering mixed-use communities around transit hubs. Before elaborating on this and other key concepts used for integrated land use and transport planning, it is useful to look at the different characteristics of traditional land use and transport planning and integrated planning approaches.

3.1.1 DEVELOPMENT PLANS

Master Plans (or Development Plans are prepared by metropolitan or urban development authorities. Their fundamental purpose is to guide and regulate physical development and land use within the area under their jurisdiction for a medium- to long-term period, typically 10 to 20 years, with periodic revisions (such as every 10 years. These plans are developed based on current and future forecasts of factors such as development patterns, socioeconomic characteristics, economic prospects, environmental considerations, and demographics. Some typical land use indicators include the following:[9]

- **Density** can be used as an indicator to plan city size and structure. Compact city activities result in shorter trip lengths and times and may also attract people to walk/cycle.
- **Concentration of activities** such as polycentric or mono-centric development depends on patterns of growth within the city, redevelopment of areas, and reinforcement of urban sub-centres around public transport nodes.
- **Activity mix** also has an impact on travel patterns. Mixed-use developments generate shorter trips and non-motorised trips.

3.1.2 TRANSPORT PLANS

A Transport (or Transportation) Plan is a strategic document that outlines a comprehensive set of policies, goals, and strategies related to transport within a city. The primary purpose of a Transport Plan is to guide the development, management, and improvement of transport infrastructure and systems to meet the mobility needs of the population, while addressing environmental, economic, and social objectives. Typical transport policy measures include:

- **Building** a road network in a newly developed area
- **Completing** a road network by adding missing links and developing a road hierarchy system

- **Extending public transport networks** to new areas or improving accessibility by public transport through frequency/capacity improvements.

Conventional transport planning primarily focuses on the development and management of transport infrastructure, often without a strong connection to land use planning.

3.1.3 INTEGRATED LAND USE AND TRANSPORT PLANS

Integrated land use and transport planning is a holistic and sustainable approach that recognizes the intrinsic connection between how a city is developed and how people move within it. It seeks to harmonise land use and transport to create more liveable and efficient urban environments. Some of the differences between conventional and integrated planning are described in Table 3.1. As cities vary in size, density, settlement patterns, socio-economic systems, and mobility patterns, it is important to consider these factors when planning city development. Large cities might require interventions at the regional level to integrate land use and transport, whereas small cities may require intervention at the city level.

TABLE 3.1 Comparison of conventional and integrated planning approaches

COMPONENT	CONVENTIONAL TRANSPORT PLANNING	INTEGRATED LAND USE AND TRANSPORT PLANNING
Focus	• Emphasis on vehicle movement and high-cost mass transit. • The objective is to increase capacity and in turn speeds. • Focuses on mobility.	• Emphasis is on moving people and goods to connect them from where they are to where they want or need to go. • The objective is to minimize travel and its negative effects to achieve sustainable development. • Focuses on accessibility.
Approach	• Adopts a rationalist approach to present a long-term plan which generally has a bias towards major capital investment projects (highways, flyovers & rail transit). • Ignores pedestrian, non-motorised vehicles (NMV), and public transport requirements as well as better management of existing and new capacity.	• Adopts integrated approach to match the needs of all types of people. Modes often arranged in a 'hierarchy', with pedestrians, cyclists and public transport at the top and car users at the bottom. Road space is allocated accordingly. • Assumes land use and transport to be interdependent. Decisions are based on the common vision. • Perceives development and transit as a cyclical process. Hence enhance accessibility through mobility and proximity.
Future recommendations	• Predict and provide forecasting. • Assumes the future to be predictable; adopts a most likely future based on a year-by-year sequence of events. Forecasting is the key element of the process. Uses demand modelling to validate often pre-ordained future investment alternatives.	• Planning for desirables- Visioning and back-casting • Recognizes that the future is uncertain and adopts a vision-led scenario planning approach. Expects new trends; emphasizes strategy based on cities' strengths and weaknesses, as well as threats and opportunities. • Uses modelling to evaluate alternative ways of achieving vision. Uses travel/network models to evaluate alternative land use/transport schemes along with other evaluation techniques.

Institutional structure	• Fragmented institutional structure and professional structures dominated by engineering and economics disciplines	• Promoting multi-sector, cross-jurisdictional partnerships; adopts multi-disciplinary integrated approach
Decision -making	• More technocratic/decision-maker-centric with little public input	• People-centric • Adopts participatory process
Planning process	• Planning with a long-term horizon is a discrete, one-off activity	• Planning is a continuous process with monitoring/updating/ periodic reviews. • Planning through a consultative process and established principles.
Perception	• Road as a vehicle carrier	• Road as a public space used for personal travel and to carry goods.
Appraisal criteria	• Appraisal through economic analysis with a focus on initial investment cost, vehicular O/M costs, and travel time savings as main decision criteria.	• Appraisal addresses broader socio-economic and environmental/ sustainability as well as transport system goals.
Outputs	• Projects & investments	• Strategies, institutions and indicative investments are subject to further definition in subsequent (alternative) analyses

Source: Swamy and Sinha (2012).

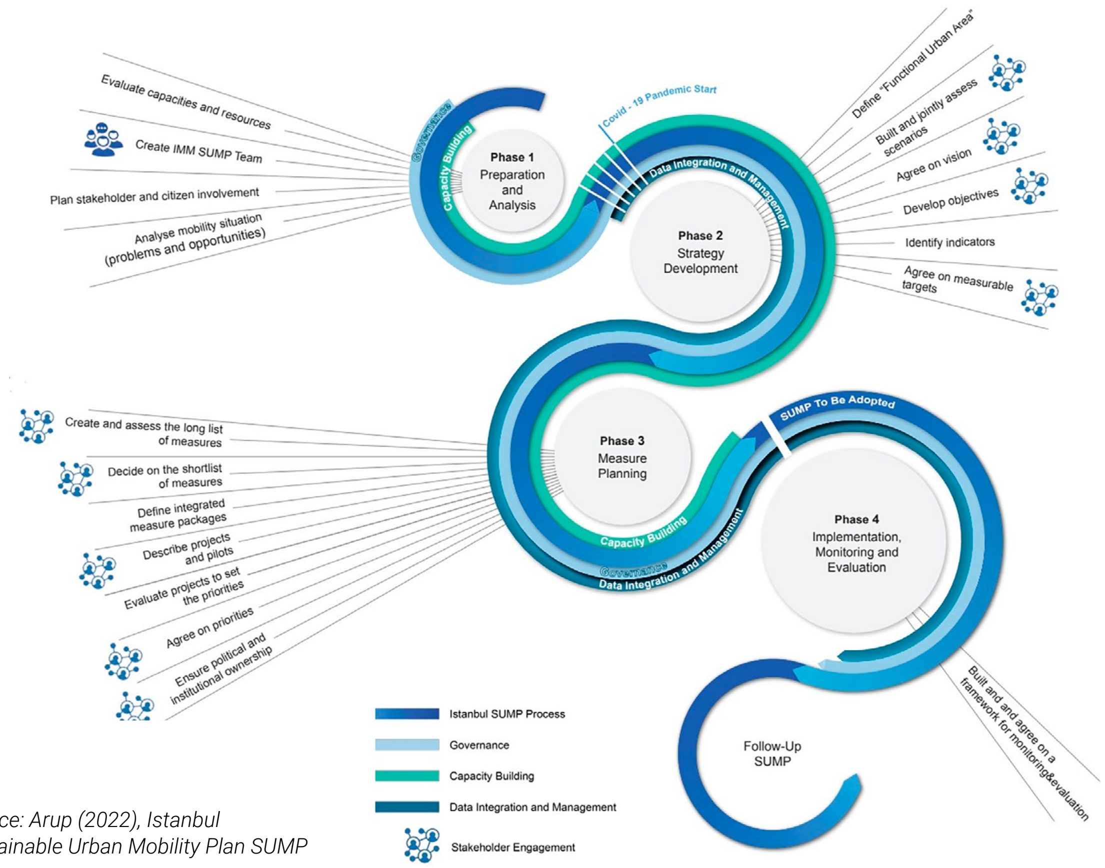
In many cities, the preparation of urban plans is statutory, whereas transport plans are prepared when cities feel they are necessary. Development Plans and Transport Plans may therefore not be prepared concurrently. Moreover, Development Plans are prepared for a specific time horizon, while Transport Plans may be more short-term and limited to a few major projects (such as the construction of a mass transit system).

To implement an integrated approach, it is therefore helpful to create a comprehensive planning framework to strategically connect urban land use planning with the design of the transport network. It is also helpful if the plan is backed by an associated institution. For example, under India's National Urban Transport Policy (NUTP) adopted in 2006, municipalities are required to develop Comprehensive Mobility Plans (CMP). CMPs are strategic frameworks to integrate transport modes, land use planning, and environmental, social, and economic factors. They typically encompass public transit, private vehicles, walking, cycling, and emerging forms of mobility, as well as technological innovations (India, 2014). In 2016, the planning guidelines for CMPs were supplemented with the Toolkit for Preparation of Low Carbon Mobility Plan, thereby cementing the links between mobility and sustainability goals. Though municipalities have had varying degrees of success in implementing their CMPs, the fact that some 500 cities are expected to develop them suggests that they will have a transformative effect on urban transport systems in India.

See also Box 3.1 on Istanbul's experience in developing a Sustainable Urban Mobility Plan and **Chapter 3 of the *Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific*** for other examples of integrated planning.

BOX 3.1 Istanbul's Sustainable Urban Mobility Plan

Sustainable Urban Mobility Plan (SUMP) is a European Union concept emphasizing sustainable urban transport solutions. SUMPs integrate walking, cycling, public transit, and private vehicles into an environmentally friendly network, prioritizing emissions reduction and energy-efficient transport. They encourage multimodality, integrate land use planning, focus on safety and accessibility, and leverage innovation for economic viability and long-term adaptability. The figure shown below is a graphical representation of the process which Istanbul Municipality followed in developing its SUMP. As can be seen, public participation is a key aspect throughout the development of the SUMP. Over a two-year period, a thorough assessment was conducted of the needs of various stakeholders, including a visioning exercise to identify priorities.



Source: Arup (2022), Istanbul Sustainable Urban Mobility Plan SUMP

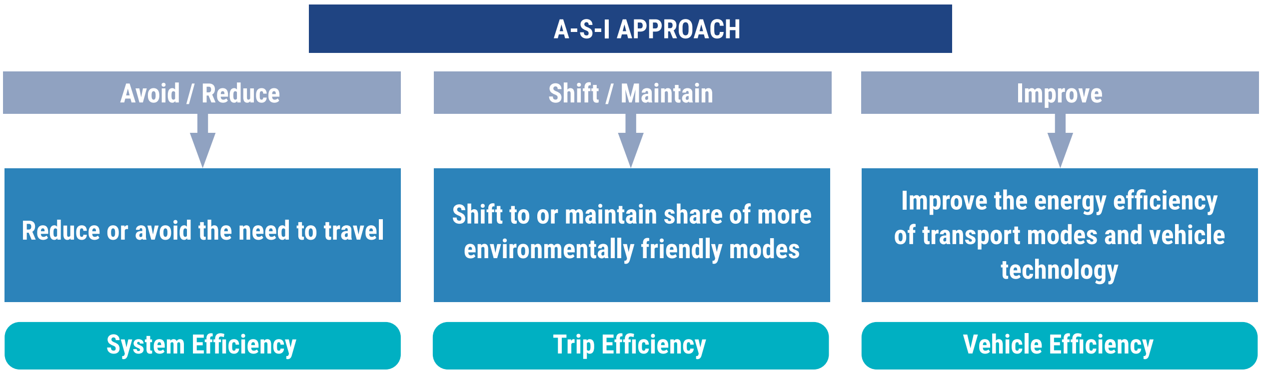
3.2 KEY CONCEPTS FOR INTEGRATED LAND USE AND TRANSPORT PLANNING

Over the past fifty years, a number of useful concepts have emerged which have proven to be useful when integrating land use and transport planning. These concepts are further described below.

3.2.1 AVOID-SHIFT-IMPROVE APPROACH

In the early years of transport planning, vehicle-oriented approaches mainly led to the expansion of road space, which did not help solve the problems of congestion, deterioration of air quality, and increasing GHG emissions. Rethinking mobility and city planning through the Avoid-Shift-Improve (ASI) approach addresses the mobility needs of people instead of vehicles (Figure 3.1). The ASI approach follows an order where 'Avoid' measures are implemented initially, followed by 'Shift' and finally 'Improve' measures.

FIGURE 3.1 Avoid-Shift-Improve Approach



Source: GIZ (2011). Sustainable Urban Transport: Avoid Shift Improve (ASI).

- **'Avoid'** refers to the necessity of reducing demand for transport, thereby enhancing the overall efficiency of the transport system. The requirement for motorised travel and trip length can be reduced through compact urban development. Urban development plans should ensure that residential, workplace and recreational zones are closely connected, and densities managed adequately.
- **'Shift'** seeks a modal shift from the most energy-consuming modes to more environment-friendly modes, such as public transport and active transport (walking and cycling). Public transport modes generate lower energy consumption per passenger km due to higher occupancy levels compared to private vehicles. This would mean curbing specific modes with limited interventions on land use, except policy measures which aim to enhance densities along transport corridors.
- **'Improve'** focuses on the larger transport and environmental economies, particularly improving the efficiency of vehicles and optimising the operational efficiency of public transport. Improving energy sources, such as using renewable energy to charge vehicles, also falls under the 'improve' pillar.

3.2.2 URBAN STRUCTURE

The spatial allocation of people and activities influences the intensity of urban development. Urban growth typically takes place as sprawl, mono-centric compact development or poly-centric decentralised concentrated development. These structures evolve based on a combination of various enabling parameters, such as size, density distribution, land use, activity locations, and road networks (Figure 3.2):

FIGURE 3.2 Urban Growth Patterns

Source: CoE-UT CRDF (2022). City Electric Mobility Strategy (CEMS).

- **Sprawl:** The sprawl scenario is characterized by the city's expansion beyond its administrative boundaries, leading to horizontal growth. This results in the urbanization of extensive areas surrounding the city, characterized by low-density, scattered settlements, and reliance on personal vehicles for transport.
- **Mono-centric (compact development):** This scenario is defined by a single central area of compact and densely populated development with closely located facilities. It features concentrated development hubs or nodes along transport corridors.
- **Poly-centric (decentralized concentrated development):** In this scenario, the city experiences concentrated growth in a limited number of central hubs or nodes, while the remainder of the city witnesses low-density development.

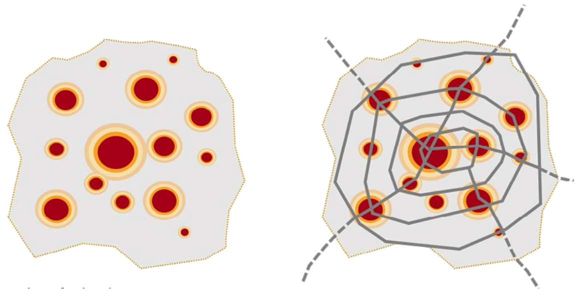
Cities need to consider density as a critical criterion to keep the urban structure small. The current density of a city is a reference for planning future densities. A compact city involves high-density development and trip lengths which are relatively shorter. However, a densely developed city will not have the scope to increase its density further as the city is already built, so it will be limited to regeneration and vacant land development. As the population of a city increases, there is a tendency to increase trip lengths. To make the transport system efficient, the activity centres and mixed-use developments should be planned accordingly.

3.2.3 COMPLETE NETWORKS AND COMPLETE STREETS

A common observation across many Asian cities is that major roads are not effectively linked to one another by smaller streets. Additionally, the road layout primarily caters to motorised transport, neglecting the needs of pedestrians and cyclists. Consequently, there is a pressing need to address the diverse needs of different road users. This can be done by establishing a street hierarchy, improving conditions for cycling and walking, increasing the number of safe pedestrian crossings, and giving priority to public transit, all while ensuring the smooth flow of vehicular traffic.

A Complete Network refers to a road network that accommodates all modes of transport and the needs of all users, including pedestrians, cyclists, private vehicles, and public transport users (Figure 3.3). The road network shapes the city structure: for larger cities, networks which have a ring or radial pattern at the city level are the most efficient, while grid-iron or radial, star or linear patterns work efficiently for smaller cities. The road network is efficient when it is complete, i.e., there are no missing links. To do this, a Complete Street may comprise of separate lanes for different modes or speed limits, dedicated signal systems for vehicles and non-motorised transport, and subway or foot overbridges where required. A complete road network ensures the availability of alternate routes, shorter trip lengths, higher accessibility of public transport, and safety and comfort for non-motorised mode users.

FIGURE 3.3 Complete Networks



Source: India, MoHUA (2013).

Complete Streets also aim to improve safety, promote physical activity, reduce pollution, and foster a sense of community. The streets are designed to provide universal access for all categories of users and interactive spaces, aiming to keep the streets lively throughout the day. For example, spaces for street vendors who are sensitive to the local context are provided, which can help avoid their encroachment over pedestrian or vehicle space.

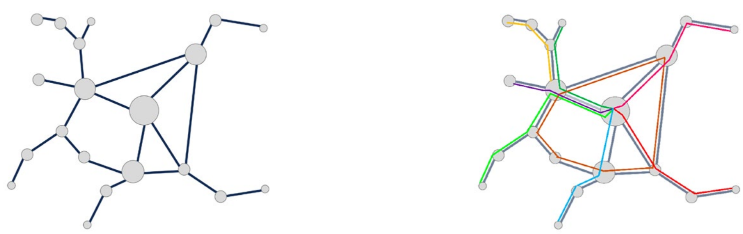
3.2.4 STRATEGIC ALIGNMENT AND PUBLIC TRANSPORT

The alignment of a public transit system is a multifaceted process that goes beyond simply drawing lines on a map. It involves a holistic approach that considers the current needs and travel patterns of the population, connectivity to major destinations, and the potential to spur economic development. As noted by Rodrigue and Ducruet, "Transportation networks are a framework of routes linking locations. The structure of any region corresponds to networks of economic and social interactions."[10]

Once a public transport network is established, routes can be planned to connect areas within that network (Figure 3.4). Typically, a network is planned in long-term strategic transport plans (such as the Comprehensive Mobility Plans in Indian cities), based on land use and growth scenarios, Transit Oriented Development (TOD), estimation of demand on the identified corridors/network, identification of hierarchy, and the pattern of the public transport network for strategies of integrated public transport. A detailed feasibility study is therefore required to plan a network's main corridors.

Expanding public transport is a challenge in newly developed areas. In these areas, delays in public transport service provision sometimes encourage people to buy private vehicles, so it is important to plan strategic transport measures at the same time as spatial development. This ensures transport systems have the capacity to support the various land-use developments. As noted below, the alignment of new developments with public transport generates value from the development and can be used to fund further transport investments.

FIGURE 3.4 Illustration of route structure across an integrated public transport network



Source: ESCAP

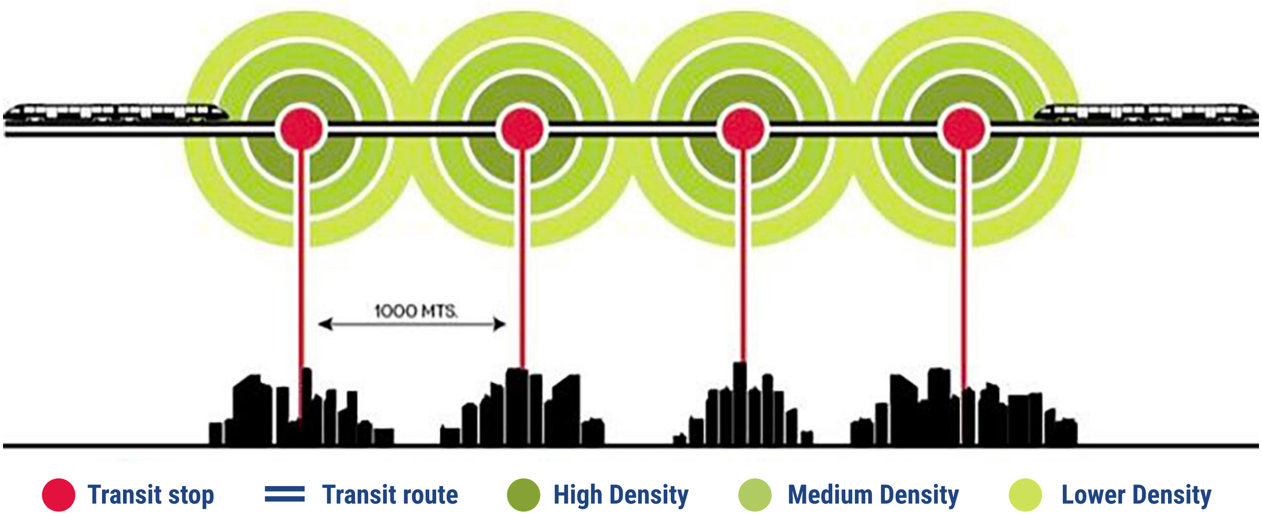
Important points to keep in mind when designing the alignment of the public transit system include:

- **Efficiency and network integration:** The alignment should provide a network rather than isolated corridors. A well-connected network ensures that people can seamlessly move from one part of the city to another without the need for multiple transfers or disjointed travel experiences.
- **Connectivity to major activity centres:** The alignment should prioritise connecting major activity centres within the city. These centres may include commercial areas, educational institutions, and cultural or recreational hubs.
- **Consideration of existing patterns:** Analysing how people currently move within the city helps make data-driven decisions to improve routes, schedules, and transit services. It ensures that the new system meets the actual needs of the population.
- **Catalyst for area development:** Public transit can act as a catalyst for area development, particularly in neighbourhoods with low-income housing and poor accessibility.
- **Right of Way availability:** Considering right-of-way availability is crucial when choosing transit alignments. This involves identifying dedicated lanes or corridors where public transit can operate efficiently without interference from other traffic, thereby improving the reliability and speed of transit services.

3.2.5 MAXIMIZING LAND USE-TRANSIT ORIENTED DEVELOPMENT AND VALUE CAPTURE

TOD is the planned development of transit areas along public transport routes, such as bus-based transit, metro, suburban rail and High-Speed Rail routes. This provides an incentive for people to live, work and shop within a short walking distance from the station (Figure 3.5). Development of mixed land use across TOD reduces the need for long-distance travel, while non-motorised modes of transport, drop-off facilities, park-and-ride facilities and adequate parking facilities should also be prioritised to facilitate easy transfers.

FIGURE 3.5 Density distribution along Transit Orient Development



Source: India, MoHUA (2017a)

TOD enables high-density mixed land-use development and can reverse the trend of sprawling development that relies on private vehicles. In particular, TOD provides a mechanism to maximise the potential of land and capture its value to finance development. Land value capture is where land value goes up due to a change in land use, public investment, or other decisions. Commercial development along the transit network adds value to the land, and part of these earnings can go into future development or infrastructure enhancement. Land value capture can be done in a TOD zone through mechanisms such as Additional Land Value Tax, Betterment Levy, Development Charges or impact fees, or Transfer of Development Rights. Around Asia, TOD has been successfully used to maximise land values.

3.2.6 SMART GROWTH STRATEGIES

Handy (2005) highlighted the pivotal relationship between transport and land use and the application of smart growth strategies to counter urban sprawl in the United States. Proponents of smart growth strategies make four key propositions. Firstly, they assert that building more highways contributes to urban sprawl, a pattern of unplanned city expansion. Secondly, they argue that increasing the number of highways leads to a rise in driving, potentially exacerbating traffic and environmental issues. Thirdly, they believe that investing in light rail transit systems encourages higher population densities, fostering more compact and walkable communities. Lastly, they argue that adopting design strategies aligned with new urbanism would decrease reliance on automobiles, promoting more sustainable urban living.

As of now, there is not enough evidence to conclusively support any of these four propositions, though research has been conducted on each point. Even in cases where there's been substantial investigation, the ability to predict the impact of smart growth policies remains limited. This underscores the complexity of how the interaction between land use and transport development plays out in the context of smart growth strategies.[11]

3.3 SUMMARY

Effective land use-transport integration is a complex, context-dependent endeavour which should take into consideration each city's unique characteristics, such as its settlement patterns, socio-economic conditions, and political context. Some cities may wish to build upon existing integration concepts, while others may need to introduce entirely new strategies. The process of integration is not linear but rather dynamic and cyclical, where land use and transport continually influence each other. Accessibility, comfort, and efficiency are maximised by organising the physical form and land use pattern so that travel demand, trip lengths and travel times are minimized. The goal is to minimize negative socio-economic and environmental impacts while creating positive sustainable urban development. For examples of land use and transport planning, please refer to Chapter 3 of the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

4

Urban Public Transport Modes

Mixed traffic in Ho Chi Minh City, Viet Nam. Photo: Canh Do

4

4.1 CLASSIFICATIONS OF PUBLIC TRANSPORT

Understanding the unique advantages of each transport mode and the synergies between them can help cities unlock the potential of integrated public transport systems. As Table 4.1 shows, public transport modes can be classified by ownership, with a further distinction between public transport and intermediary public transport (IPT) systems. Public transport modes may also be classified by their technical characteristics; Vuchik (2007), for example, classifies urban public transport modes based on their right-of-way (ROW) exclusivity, technology (mechanical features of their vehicles and ways) and type of operations. While recognising the role of taxis and motorcycle taxis, as well as the growing importance of shared services, in linking public transport and providing first/last mile connectivity, the focus of this Guidebook is on integrated urban public transport involving passenger vehicles constructed or used for collective mobility and the associated institutions, infrastructure, and operating systems. The following classification is adopted:

- **Bus-based public transport systems:** buses and bus priority systems
- **Rail-based public transport systems:** metro rail, monorail, Light Rail Transit, trams
- **Specialised public transport systems:** ferry, ropeway, funicular, elevator, etc.

TABLE 4.1 Classification of Urban Passenger Transport Modes

No	CHARACTERISTICS OF THE SYSTEM	URBAN PASSENGER TRANSPORT MODES		
		Public Transport (PT)	Intermediary Public Transport (IPT)	Individual Modes
1	Routes and stops	Fixed/ regulated in case of private-stage carriers	Flexible (licensed/contract/ stage carriers)	Flexible
2	Schedules	Fixed and preannounced	Flexible	Flexible
3	Fare	Fixed, preannounced	Fixed (regulated)	Not applicable
4	Access	Accessible to all	Accessible to all until hired. Once hired, not accessible to others	Accessible to self and her/his group
5	Ownership & Control	Public or private operators may own. The public authority may license routes to the private sector.	The operator may own or rent them. They operate under specific government regulations.	The vehicle may be owned or given by the company only for her/his use.
6	Examples	Public bus/Stage carriers, Bus Rapid Transit (BRT), tram, overground trains, metro, scheduled ferry, minibus	For hire services like Auto-rickshaws, Bike- taxis, and Taxicabs, as well as ride-share services such as Uber.	Personal vehicles include passenger cars, motorcycles, scooters, mopeds, and pedal bicycles.

4.2 BUS-BASED PUBLIC TRANSPORT SYSTEMS

Buses are the primary public transport mode in almost all urban centres. Bus-based systems are flexible and offer several advantages:

- **Easy to match demand and supply:** In urban services, customers desire short headways, for example, 5 minutes or less during the peak period and 8-12 minutes during the off-peak period. Bus types can be decided based on the demand on the routes/corridors.

- **Flexible operations city-wide:** Due to their size, buses can negotiate sharp turns and operate on narrow roads in mixed traffic conditions.
- **Lower costs:** The capital and operating costs of the buses are lower than rail-based public transport systems.
- **Convenient and easy in technology replacement:** As the life of most buses is 8-12 years, technology can easily be upgraded during replacement.
- **Road safety:** Buses provide safer travel, create less congestion on the road and emit fewer pollutants per passenger kilometre travel compared to private vehicles. The potential of causing a fatality on-street per passenger km travelled by bus is 1/25th of a car.[12]
- **Adoption of improvements incrementally:** Service quality improvements are possible with minor modifications in the street network and the application of technology.

The overall performance of a bus-based public transport system is mainly dependent on three broad aspects: vehicle (bus) design, operating strategy and energy choice.

4.2.1 VEHICLE DESIGN

Though bus designs vary from country to country, they can generally be classified as mini, midi, standard, double-decker (Figure 4.1), articulated and bi-articulated, based on their size and passenger carrying capacity. Vehicle design also includes features such as floor height, size of doors, door position, and number of doors. These features influence driving efficiency, passenger comfort, convenience, safety, and universal access.

Buses usually require minimal infrastructure, such as platforms and bus stations. Platform height, number of doors and width are critical for universal access and operating efficiency. For example, in India, for example, urban buses are built with 400-, 650- and 900-mm platform height (Figure 4.2). The platform of 400 mm floor height provides easy access to passengers but hinders internal movement due to at least two additional steps; 650 mm height features a step entry and a near-flat interior floor for improved movement; and 900 mm floor height offers a completely flat interior floor. This is ideal for a BRT system with a 900 mm station height, enabling level boarding for faster and safer access.

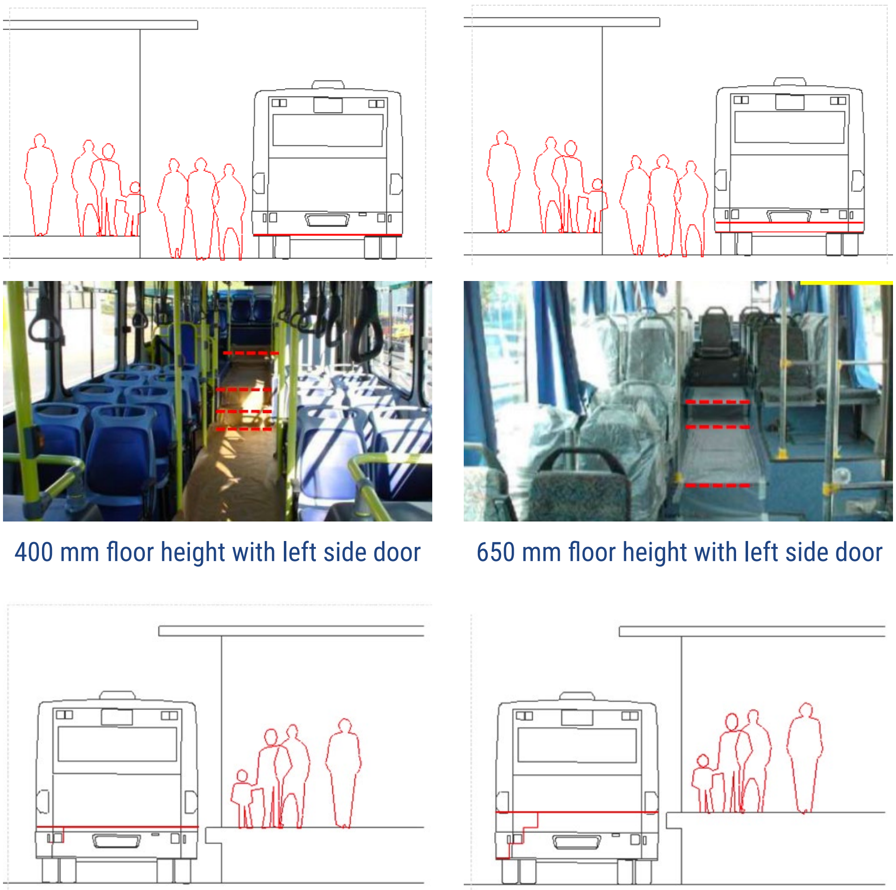
FIGURE 4.1 Double-decker bus in Singapore

Photo: Madan Regmi

4.2.2 OPERATING STRATEGY

There are different ways to operate buses in a city: in mixed traffic, in a partial priority environment, and in a full priority environment (Figure 4.3). For example, as cities grow, buses moving in mixed traffic may experience slower average speeds, longer travel distances and more severe traffic congestion (Figure 4.4). The speeds of buses range from 10 to 16 km in most medium and large cities of Asia. This results in low vehicle utilisation, decreasing schedule adherence, poor ridership, reduced revenue, and finally adverse economics of operations. It is therefore necessary to prioritise buses, either in a partial priority or full priority environment.

FIGURE 4.2 Station and Bus Dimensions



400 mm floor height with left side door

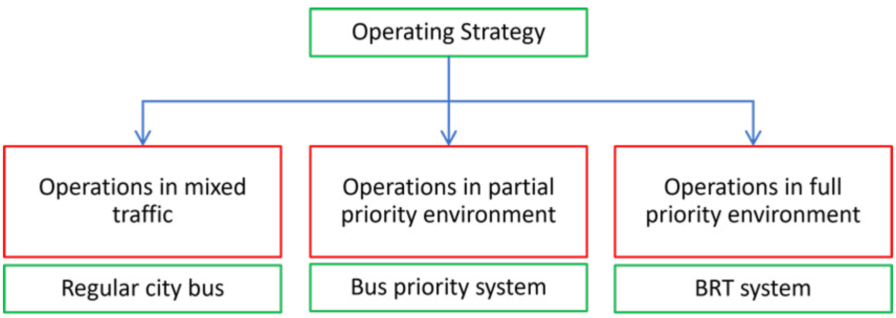
650 mm floor height with left side door

900 mm floor height with right side door

1150 mm floor height with right side door

Source: Gautam, I. P. (2017)

FIGURE 4.3 Types of operating strategy



Source: ESCAP

FIGURE 4.4 Mixed traffic in Mumbai, India

Photo: Brett Cole

Bus operating strategies differ by the level of priority given to them. The lowest level of priority is when buses have junction/signal priority, while the highest level of priority is when buses have completely segregated bus lanes with median bus stations (full priority environment). Most Bus Rapid Transit Systems (BRTS) fall within this category.

4.2.3 OPERATIONS IN PRIORITISED STREETS (BUS PRIORITY)

Bus priority refers to a package of priority measures which cities can implement to suit their local conditions. There are various types of bus priority measures such as bus-only lanes, junction priority, signal priority, median bus stations, and so on, which cities can adopt with very marginal infrastructure cost compared to major public transport infrastructure projects. According to some estimates, buses can gain an estimated 10-15 per cent in travel speeds and also improve schedule adherence with such measures.

4.2.4 OPERATIONS IN FULL PRIORITY ENVIRONMENT

Giving full exclusivity to public transport increases travel speeds from 10-16 km/hour (in mixed traffic) to 20 to 26 km/hour, and it can also increase up to 40 km/hour with express/limited stops services. In this category, the most common public transport systems are Bus Rapid Transit Systems (BRT or BRTS) and Guided Buses. A BRTS involves the integration of buses, supporting infrastructure, and operating strategy (Box 4.1). To some extent, BRT is comparable to LRT, Monorail and Metro in terms of travel speeds and line capacities. In 2024, it is estimated that there are a total of 191 cities operating BRTS with a total network length of 5,842 km.[13]

Meanwhile, a guided bus system is where buses are customized to travel on guided pathways to achieve greater operational speeds. There are different types of guidance technologies, namely, kerb-guidance, optical, electromagnetic and central-rail guided. At present, 15 guided bus systems are operating worldwide, with kerb guidance being the most predominant across the different technologies. The first system was established in Essen (Germany) in 1980, while the latest one commenced in Luton (United Kingdom) in 2013 (Figure 4.5). The existing systems are just suburban links with an average corridor length of 13 km and do not form an urban network. As they are used as suburban corridors, the station spacings are larger (average of 4-5 km) and average operating speeds reach between 60-70 km/hour.

FIGURE 4.5 Guided bus in Luton, United Kingdom

Photo: David Kemp

Arriva bus at Stanton Road bus stop

4.2.5 FUEL TYPE

Fuel type is important from the point of view of air quality and climate change. Most buses are manufactured with internal combustion engines (ICE) and use diesel or compressed natural gas (CNG) as the fuel. In line with the Paris Agreement adopted at the UN Climate Change Conference (COP21) in 2015, several national governments have mandated the use of CNG as a public transport fuel, mainly to tackle the problem of particulate matter and other health-hazardous pollutants (Figure 4.6).

FIGURE 4.6 CNG bus in Hanoi, Vietnam

Photo: Jenny Yamamoto

BOX 4.1 Bus Rapid Transit (BRT) systems continue to spread

The popularity of BRT systems continues to grow across the globe. A BRT system involves assembling a wide range of elements, including buses, bus stations and terminals, BRT network, running ways, fare, ITMS system, operations planning & management, branding, and communications.[20] The full BRT system can achieve speeds in the range of 24-28 km/hour, depending on the level of segregation. For example, Istanbul BRT (with complete exclusivity) achieves travel speeds as high as 40 km/hour. BRTS capacities vary considerably, depending on the treatment of different elements. Its capacities can be comparable to that of a metro system; for example, Bogota's BRTS carries about 50,000 PPHPD on one of its corridors.

Launched in 2004, TransJakarta is a complete BRT system which operates on dedicated bus lanes with high-capacity buses. It is the longest BRT system in the world, with a network length of 251 km. The smart card-based fare system offers seamless integration with other modes of transport in Jakarta. The extensive corridor-based system covers multiple neighbourhoods and important destinations, with high-frequency service and extended operating hours. Jakarta continues to expand its BRT infrastructure, promoting sustainable mobility and reducing congestion and pollution. The daily ridership of TransJakarta has substantially increased to over 800,000 daily passengers by 2019 with the expansion of the network.

Meanwhile, the Hubli-Dharwad BRT in Karnataka is the highest capacity BRT system in India, featuring dedicated bus lanes, high-quality bus stations, and an intelligent transport system. The BRT system integrates with other modes of transport and employs a fare collection system. The Hubli-Dharwad BRT system commenced in 2018 to link Hubli and Dharwad city, with a total corridor length of 22.5 km and 32 stations on the corridor with overtaking lane. The total travel time of the whole corridor is about 35 minutes for an express service and 55 minutes for a regular service.

Photo: Taufik Hidayah

Sources: Power, M. (2019); EURACTIV Press Release Site. (n.d.); ITDP (2019); Directorate of Urban Land Transport, U. D. (2020); Hubballi-Dharwad BRTS Company Limited (2021).

In China, the government has created a variety of business models to propagate electric buses throughout the country (Box 4.2), especially to help with the purchase of new vehicles and battery systems.[14] The electrification of buses not only reduces emissions but also makes bus operations economical, compared to ICE. In India, the unified tender for electric buses from six Indian states & Union Territories (UTs) recently received price quotes for electric buses which were 29 per cent lower than that of diesel buses.[15] India envisages 50,000 electric buses on the road in the next five years.[16]

BOX 4.2 The electric bus revolution in China

By the end of 2021, there were an estimated 419,500 electric buses out of a total of 709,400 urban buses and trolleybuses in China. By vehicle fuel type, this comes to nearly 60 per cent of the total, with the rest made up of diesel vehicles (11.1 per cent), natural gas vehicles (15.7 per cent), hybrid vehicles (12.2 per cent), and hydrogen energy vehicles (0.4 per cent). This transition has been driven by significant government support, as well as the active cooperation of various stakeholders. In addition to providing financial support for acquiring New Energy Vehicles (NEVs), batteries and infrastructures such as charging stations, local governments and businesses have used a variety of different policies and business models to promote the electric vehicle transition.

For example, under the Shenzhen NEV Promotion and Application Work Plan, key actions include improving the management of NEVs manufacturers and products; improving the safety monitoring system of operating NEVs; establishing NEV and battery recycling systems; and formulating accident response strategies. But perhaps the most critical element is the creation of a big data platform for "Three Networks Integration" (telecommunications, media, and information technology). This platform will collect, store, and analyse data from various sources, including NEVs, charging stations, public transport operators, grid networks, and user behaviour, to provide information for decision-making and policy formulation. It is another example of how data, digital technologies and NEVs are reshaping urban transport, with implications for future integrated public transport systems.

Photo: Xiao Li

Sources: China, Ministry of Transport (2022); United Nations ESCAP (2023).

Trolley buses are electric vehicles that draw power from dual overhead wires using spring-loaded trolley poles (Figure 4.7). They were one of the first mass transit systems and have been in operation for a considerable period. They use overhead equipment (OHE) to derive electricity. As they have no vehicular emissions, they are environmentally friendly. In the past, they were constructed as single-unit, double, and triple-unit buses, but recently battery electric vehicles (BEV) are becoming popular.

FIGURE 4.7 Trolleybus in Ulaanbaator, Mongolia

Photo: Madan Regmi

4.2.6 LINE CAPACITIES BY BUS TYPE

The capacities that the bus systems can achieve under mixed traffic and in BRT systems by frequency are given in Table 4.2. It illustrates the directional line capacity of buses based on their type as well as headway. The capacities for buses suitable for BRTS operations can vary significantly:

- **In mixed lane operations:** PHPDT of 80 to 1,320 is feasible without confronting bunching and other issues. With bus priority, this can be stretched to 1,400/2,200 by increasing frequency or deploying double-deck buses.
- **Exclusive ROW:** Where there is an exclusive ROW, a PHPDT of 15,000 is achievable. Though this can be stretched to 24,000 with the deployment of a 3-articulated-bus convoy and/or with overtaking lanes on a fully dedicated corridor, the operational benefits may be higher with the adoption of rail-based systems for PHPDT higher than 150,000.

TABLE 4.2 Directional line capacity of buses by type and headway

No	BUS TYPE	DIRECTIONAL CAPACITY BY HEADWAY IN MINUTES (NO. OF BUSES/HOURS)										
		No. of buses per hour		4	5	6	7.5	12	20	45	45 (90)	45 (135)
		Headway in min.		15	12	10	8	5	3	1.3	1.3	1.3
		Length (m)	Capacity (no. of passengers)	Single Vehicle							Convoy of 2 vehicles	Convoy of 3 vehicles
1	Mini	7-7.5	20	80	100	120	150	240	400	900	1800	2700
2	Midi	9-9.5	40	160	200	240	300	480	800	1800	3600	5400
3	Double Deck-Midi	9.5	70	280	350	420	525	840	1400	3150	--	--
4	Standard	12	70	280	350	420	525	840	1400	3150	6300	9450
5	Double Deck-Standard	12	110	440	550	660	825	1320	2200	4950	--	--
6	Articulated	18	110	440	550	660	825	1320	2200	4950	9900	14850
7	Bi-articulated	24	180	720	900	1080	1350	2160	3600	8100	16200	24300

Note: i. Shaded boxes indicate services suitable for exclusive lane (BRT) operations. All other services suitable for mixed traffic operations. ii. Line capacity is carrying capacity (seated and standees), at 100 per cent load factor, assuming that passenger trip length is the same as that of the line. However, if passenger trip length was only half of the line trip length, carrying capacity of the line would be double that indicated in the above table. iii. In the literature, articulated and bi-articulated bus capacities range from 110-120 and 180-230, respectively. iv. Double-decker buses are built on 9.5 and 12 metre long buses.

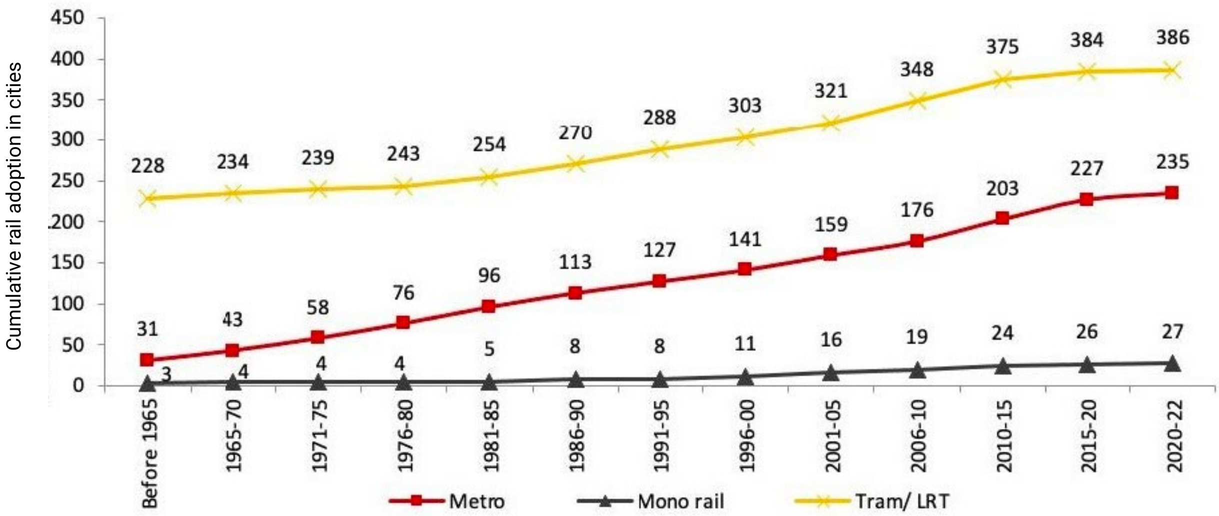
4.3 RAIL-BASED PUBLIC TRANSPORT SYSTEMS

Three main types of rail-based systems operate in urban areas as trunk systems and often cater to high-demand corridors: metro rail, trams/Light Rail Transit (LRT), and monorail. Before the 1960s, Light Rail/Tram had been the most popular rail transit mode across the globe compared to metro and monorail systems. However, in the 1960s and after, around 200 cities established metro rail, while only 110 LRT/Tram systems were started. Metro rail has been the most preferred rail mode of the last five decades (Figure 4.8).

4.3.1 METRO RAIL SYSTEMS

Metro rail is a high-capacity, high-cost system with fully segregated right of way, which is mostly elevated or underground (sometimes at grade). The first metro line was built in the year 1863 in London and extended to cover 402 km (2023) of tracks and 272 stations, serving 1.35 billion passengers a year.[17] Today, 235 cities across the globe have operational metro rail systems with a combined network length of 20,488 km.[18] For example, Delhi inaugurated its first Metro line in 2002 with a length of 65 km, but has now expanded to 391 km with a daily ridership of 6 – 6.5 million passengers.[19] Meanwhile, the Dhaka Metro commenced operations in 2022 (Figure 4.9).

FIGURE 4.8 Cumulative rail transit adoption in cities (worldwide) over time



Source: Swamy, H.M.S., Lokre, A., Sinha, S. and Daftardar, C. (2016). Various sources after 2016.

FIGURE 4.9 Dhaka Metro

Photo: Takatoshi Moriwaki

As shown in Table 4.3, the main notable feature of metro rail systems is their capacity to carry a substantial number of people in a short period. Its highest known carrying capacity is 90,000 passengers per hour per direction (PPHPD), as observed in Tokyo and Beijing. Travel speeds range between 30 to 40 km/hour. The station spacing is generally 1 to 1.2 km apart, which also aids in achieving higher speeds while limiting local access. Metro rail systems are energy efficient and a safe rapid transit option. However, their high capital and operating costs, requirement of longer trip lengths, minimum threshold level of ridership, and other characteristics limit their application to large cities with established transit markets.

TABLE 4.3 Technical characteristics of metro rail

TYPE OF METRO	LIGHT CAPACITY METRO	MEDIUM CAPACITY METRO	HIGH CAPACITY METRO
Cars per Train	2-3	4-6	6-8
Pax per train	500-750	1000-1500	1500-2000
Min Curve Radius	60 m	100 m	120 m
Coach width	2.6 m	2.9 m	3.2 m
Capacity (PHPDT)	10-20,000	20-45,000	45-80,000

Source: India, MoHUA (2017b)

4.3.2 MONORAIL SYSTEMS

Monorail vehicles ride on a single rail or are suspended on a beam.[21] The first monorail was opened in Wuppertal, Germany, in 1901. Since then, there have been a total of 54 applications, of which 27 may be termed as urban applications while the other 27 are specialised applications over short stretches, such as theme parks, plazas, and indoor parking connectors. Box 4.3 describes the KL Monorail in Malaysia's capital city.

Monorails normally run with 3-6 cars with a carrying capacity (PHPDT) ranging from 5,000 to about 20,000 per hour. Their capital costs are stated to be about $28 million per kilometre. Experts suggest that their operating costs are comparable to or even higher than that of metro systems, which provide much higher capacity. Such high costs and vendor-specific technology constrain potential applications of the monorail. As there are no emergency exit options between stations along the network, safety has also become a major issue. However, the monorail's small volume and compact structure make it appropriate in complex terrain conditions and narrow streets.

BOX 4.3 Kuala Lumpur (KL) Monorail, Malaysia

KL Monorail is a straddle-beam supported system that extends to a length of 8.6 km, connecting the Kaula Lumpur Sentral in Brickfields to Titiwangsa terminal in Jalan Tun Razak and passing through the Golden Triangle CBD. The line consists of 11 stations separated from each other by about 0.5 km to 1 km. With a capacity of one train at 244 (48 seating, 196 standing), the system currently has an average hourly capacity of 3,416 PHPDT (per hour per directional demand). In 2019, the daily ridership was about 46,000 passengers, with an average PHPDT of around 2,628 (77 per cent of hourly capacity).

Sources: Cmsadmin. 2021. Kuala Lumpur Monorail. Railway Technology; KL Sentral Monorail Route Schedule (Jadual), Fare (Tambang), (n.d.), Train36.com, UrbanRail.Net. (n.d.).

Photo: iStock/Boarding1Now

4.3.3 TRAMS/ STREETCARS/ LIGHT RAIL TRANSIT (LRT)

In the late 19th and early 20th century period, trams or streetcars were the most visible and popular transit modes in European cities.[22] In Asia, trams were operating in 35 cities, but most cities abandoned them as private vehicle ownership grew after World War II. However, interest in bringing them back as an LRT system has increased over the last few decades, and currently operates across 386 cities, but only about 19 in Asia. With a segregated ROW similar to BRT, LRT is a relatively fast and safe mode. High-density development, the density of traffic, the mix of vehicles and road user behaviour are factors which tend to limit the scope of LRT in Asian cities.

4.4 TECHNO-ECONOMIC CHARACTERISTICS

Technical and economic suitability are always the key criteria for the adoption of any mode. The summary comparison for mass rapid transit systems in terms of technical and cost parameters is presented in Table 4.4 below.

TABLE 4.4 Techno-economic considerations

INDICATORS	METRO RAIL	LRT	BRT	MONORAIL
Type of Segregation	Elevated or underground	At-grade with horizontal segregation	At-grade with horizontal segregation (soft or hard)	Elevated
Capacity (PHPDT)	15,000-90,000	5,000-12,000	3,000-40,000	5,000-20,000
Travel Speeds km/hour	30-40	18-24	20-28	30
Cost per km	36-73 million $	12-16 million $	2.5-3.6 million $	18.2-24.4 million $
Average Station Spacing	1,000-1,200 metres	600-800 metres	500-600 metres	1,000-1,200 metres
Period of implementation	3-6 years	5-10 years	2-4 years	6-10 years
Land acquisition	Not required except for depots	Re-allocating road space does not require major land acquisition	Re-allocating road space does not require major land acquisition	Not required except for depots

Source: India, MoHUA (2017b).

4.5 SUMMARY

As the world urbanises, more and more cities will require mass rapid transit systems to meet their growing urban mobility demand. A wide range of bus and rail-based MRT options are available. The costs of developing and operating these vary significantly, as do their performance. While choosing a system, one tends to look at the maximum capacity a system offers. But in most cities, such a high level of demand does not exist. Therefore, both the maximum capacity and minimum thresholds must be considered. Furthermore, the development of any new public transport system should follow integrated planning approaches, taking into consideration the urban landscape, physical space, existing public transport services, and institutional systems. For a selection of examples of public transport modes, please refer to Chapter 4 of the *Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific*.

5

Operational Strategies

Dhaka Metro. Photo: Takatoshi Moriwaki

5.1 WHAT IS AN OPERATIONAL STRATEGY?

The mobility needs of people vary over space and time. As discussed in Chapter 3, these variable patterns are affected by population growth, spatial expansion, transformations in land use structure, changing socio-demographic and economic characteristics, as well as evolving transport technologies. One recent trend in large and medium-sized cities is to introduce mass rapid transit modes without adapting existing bus services. This often results in a supply-demand imbalance on city buses as well as on the MRT. Such changes in the supply or demand of public transport should be addressed through the municipal government's public transport operational strategy (also known as an operating strategy).

According to Zimmerman and Kang (2015), the twin objectives of an operational strategy are:

- To optimize the allocation of resources and coordinate services to achieve efficient/cost-effective operations, i.e. matching supply to the observed or anticipated demand

- To guarantee a seamless ride for users, including easy transfers between different lines/routes and modes within the system.

The operational strategy involves a series of interrelated decisions regarding the allocation of various public transport resources. These resources include the network, routes and services, range of service, frequency, stops, fares, and so on. As discussed in Chapter 3, planners may first consider the most appropriate type of public transport services, i.e., what type of transit lines and networks are desirable, given land-use characteristics and other factors. To decide on the type of services, they will also need to consider some key operational characteristics, as described below. Further examples of operational strategies can be found in Chapter 5 of the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

5.2 ROUTE STRUCTURE OF PUBLIC TRANSPORT SERVICES

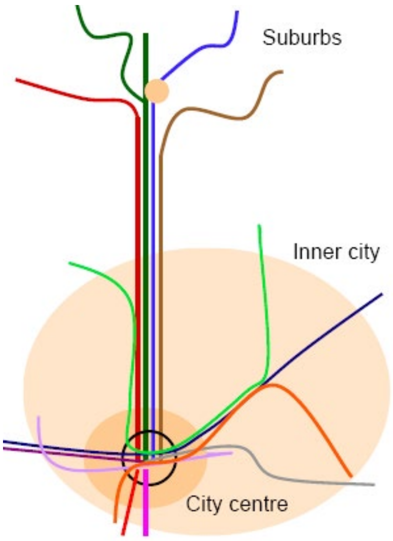
Route structure is the organization and layout of a public transport system's routes within a service area. These routes may be comprised of transit lines (rapid transit corridors and routes designed to connect a terminal to another terminal) and subsidiary routes. A transit network is formed when these services and modes are connected through interchanges. The two main types of services are direct-route services and trunk and feeder services.

5.2.1 DIRECT-ROUTE SERVICES

Conventionally the routes in urban areas are organized to provide 'direct services' (Figure 5.1). This type is also known as the 'many to many' or 'many to one' route structure. In this type of route structure, customers are provided with options to travel directly from origin to destination without resorting to transfer.

While this appears to be convenient from the customer's point of view, in reality, the services delivered are unreliable, involving long waiting times and forced transfers. Most routes either pass through or have the city centre as the terminus, which then makes it necessary to have a large terminal and depot facilities. Problems get compounded as cities incrementally extend existing routes and add new routes over time. Some additional features of direct services are:

FIGURE 5.1 Features of direct-service routes



Source: Adapted from Nielsen, Lange, Mulley, and Nelson (2006)

- Numerous overlapping lines/routes
- Fleet thinly spread over too many routes leading to low frequency, meaning excessive waiting times
- Availability of large pieces of land for infrastructure is difficult to mobilise
- Travelling through congested city centres means excessive delays and uneven headways
- Buses also congest city centres
- Uneven occupancy on buses at different times and places
- Competition within and between subsystems resulting in poor economics for the operator

5.2.2 TRUNK, COMPLEMENTARY AND FEEDER SERVICES

Integration is the process of aligning lines or routes to provide services as a connected network. Integrated routes are classified as 'trunk', 'complementary' and 'feeder' routes. Combining various services facilitates efficient division of roles, including BRT, LRT, monorail, metro and ordinary buses.

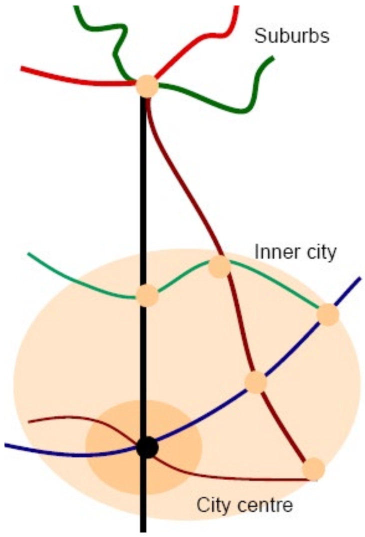
Trunk Routes: Trunk routes are high-demand routes, mainly running on urban arterials and connecting various parts of the city (Figure 5.2). They generally run from one end of the city to city centres or run on ring roads. The route lengths tend to be long, but frequencies are medium to high. Examples include large buses running on arterials in mixed mode or high-capacity systems such as BRT, LRT, and MRT. Travel speeds tend to be higher due to relatively wider stop-spacing (say 500 to 600 m in the case of BRT and 1000 to 1200 m in the case of LRT/MRT) and because they run on a prioritised network.

Complementary Routes: Complementary routes are also the main component of the public transport network but play a supplementary role to the trunk routes. They are designed to be straight and usually run on second-order arterial/sub-arterial routes, catering to medium to long trips. They may run in mixed traffic lanes with medium to large-capacity buses.

Feeder Routes: As the name suggests, these routes feed passengers from local areas (which are not covered by the trunk routes) to the trunk services. They tend to use smaller vehicles to serve low-density demand at higher frequency. They mainly run on collector distributors and local streets. Unlike trunk routes, feeder routes are not necessarily aligned straight. Often, they tend to take small detours to collect passengers from the inner areas. They may also be structured as circulators. Stop spacing varies but can be as close as 250 to 300 metres. Additional features are:

- Local travel opportunities in the low-density areas/suburbs
- High-quality service in radial corridors
- Less congestion in the city centre
- Several smaller and more efficient interchange points
- Few large city terminals
- Better coverage of the inner city

FIGURE 5.2 Features of trunk feeder service routes



Source: Adapted from Nielsen, Lange, Mulley, and Nelson (2006)

5.2.3 OTHER TYPES OF SERVICES

Other types of services are the 'Rapid' and 'Express' services. These tend to be a form of trunk routes and provide faster service.

Rapid Service: Rapid services are faster than regular services as they have different infrastructure and operating elements. Rapid transit services may be operated as all-stop, limited-stop, or non-stop services (Express/limited-stop or non-stop service). BRT, LRT and Metro services are often considered to be rapid services as they tend to be faster than regular services. In-street public transport in mixed lane operations achieves a speed ranging between 14-18 km/h. With bus priority on-street, the speeds may increase to about 20 km/h. With modifications in the infrastructure such as running ways, lanes, level boarding, off-board ticketing, wider station spacing, etc., speeds may further increase to 24 to 40 km/h.

Express Service: Express services are also fast, but the speed is achieved by skipping stops. The service may halt at a few stops on the route or may be operated as a non-stop service which stops only at the final stop.

5.3 KEY CONSIDERATIONS WHEN DESIGNING PUBLIC TRANSPORT SERVICES

5.3.1 SERVICE COVERAGE

Service coverage can be defined from two perspectives: geographical area and population coverage.

Geographical area: Cities do not function in isolation and therefore must extend public transport services to peripheral settlements. Generally, the operational jurisdiction extends beyond the city limits. In India, the services are extended up to 15 km from the city administrative boundaries in large cities (e.g., Municipal Corporations), and up to 10 km in smaller cities.

Population coverage: The goal for cities is to provide access to public transport to all city residents. In practical terms, this implies aligning routes and stops such that 100 per cent of households are within 500 metres (as the crow flies) of a public transport stop.

5.3.2 RIGHT-OF-WAY (ROW)

ROW is the land strip used for the operation of public transport. ROW is classified according to the type of segregation. As Figure 5.3 shows, as we move up the level of segregation (1 to 4), both line capacity and travel speeds increase, while reliability and safety also improve.

FIGURE 5.3 ROW classification based on segregation

Level 1 – Transit operations in mixed traffic (Travel speeds – 12-18 km/h)

Level 2 – Transit operations in mixed traffic with priority at stations (Travel speeds 18-20 km/h)

Level 3 – Transit operations with complete horizontal segregation at grade crossings (Travel speeds - 22-26 km/h)

Level 4 – Transit operations with complete horizontal/vertical segregation without grade crossings (Travel speeds -30-40 km/h)

Source: Center of Excellence in Urban Transport, CRDF, CEPT University

5.3.3 SPAN OF SERVICE

The span of service is the time between the start of the first morning trip and the latest evening trip. The span of service varies by the day of the week.

- On weekdays, urban transport services generally operate for 16 hours (two shifts), e.g. 6:00 am to 10:00 pm. However, in larger cities, services may operate for 18 hours, e.g. 5:30 am to 11.30 pm.
- During weekends, the services start late and may end late. For instance, on weekends, Delhi Metro starts its first schedule at 8:00 am and the last service at 11:00 pm.

Cities may also operate 'night services' to cater to the needs of customers arriving at or departing from regional train/bus terminals or airports. These services may operate throughout the night and sometimes have timetables aligned with the arrival or departure of regional trains/flights.

5.3.4 CHOOSING THE LOCATION OF STOPS, STATIONS, INTERCHANGES AND TERMINALS

Both stops and stations are facilities where passengers wait, transfer or board/alight from vehicles. Stops may be a simple post or a small structure to provide shade and some seating facility. Stations are larger, with additional amenities for passengers such as external ticketing. Interchanges are places where more than one route/line connects, enabling passengers to transfer. Terminals are start/end stations of a route, which are also designed as interchanges.

The spacing of stops and stations determines both travel speeds and the level of access to public transport, as shown in Table 5.1. Closer stop spacing provides greater accessibility but lower speeds, and wider stop spacing limits access but provides higher speeds.

TABLE 5.1 Stop/Station Spacing

SL. NO	SERVICE TYPE	TYPICAL SPACING	REMARKS
1	City bus	250-350 m	Narrow spacing in city centres and wider spacing in the periphery
2	BRT	500-600 m	May vary with the density of the population
3	Metro/LRT/ Monorail	1000-1200 m	While 1000-1200 m is seen as technically optimum spacing, some cities have chosen to adopt narrow spacing to provide greater accessibility (some parts of the metro in Paris, for example, have 600-700 m)

5.3.5 TRAVEL SPEED AND TRAVEL TIMES

Travel speed or the operating speed is the average speed offered to the public along a transit route or line, i.e., the time taken to travel divided by the distance travelled by a customer. These vary by mode of journey, leg of journey and operating conditions. A typical station-to-station trip depends on:

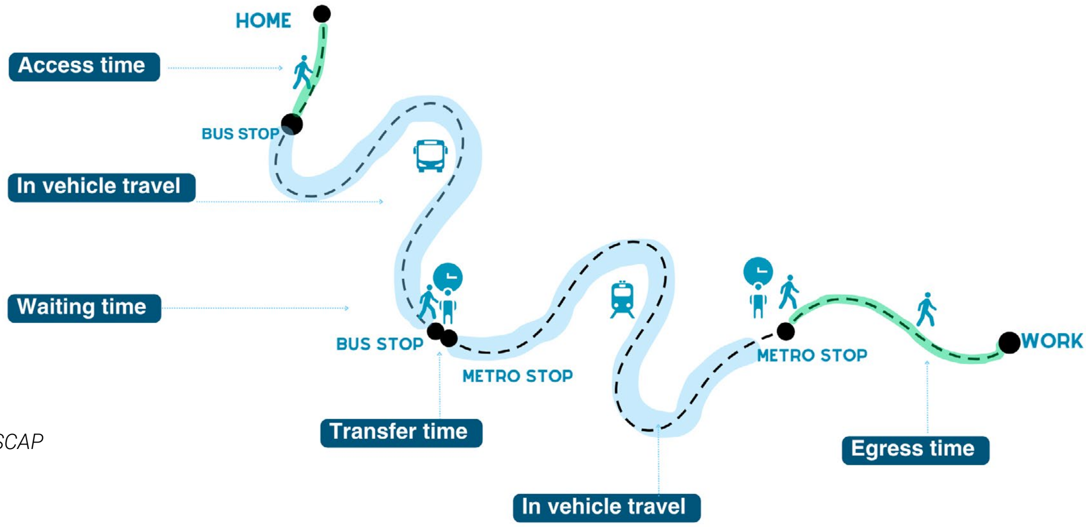
- Bus performance capability of the transit vehicle (acceleration/deceleration)
- Permissible speed limit (cruising speed)
- Number of stations and dwell times (door opening/ closing, boarding/alighting time)
- Number of intersections and delays at intersections
- Distance between stations and traffic conditions (street network location, time of the day)
- Terminal turnaround time (based on the schedule).

In multi-modal journeys, passenger travel times include several components (Figure 5.4). These include:

- Access time (time taken to reach the station)
- Egress time (time taken from destination station to final destination)
- Waiting time (waiting time at the transit station)
- Transfer time (time taken to transfer from one mode to another)

- In-transit time (travel time on board the public transport vehicle)
- Total travel time (time taken by the passenger from origin to her/his point of destination, i.e., access time + waiting time + in-transit time + in-transit time + egress time).

FIGURE 5.4 Illustration of a passenger journey



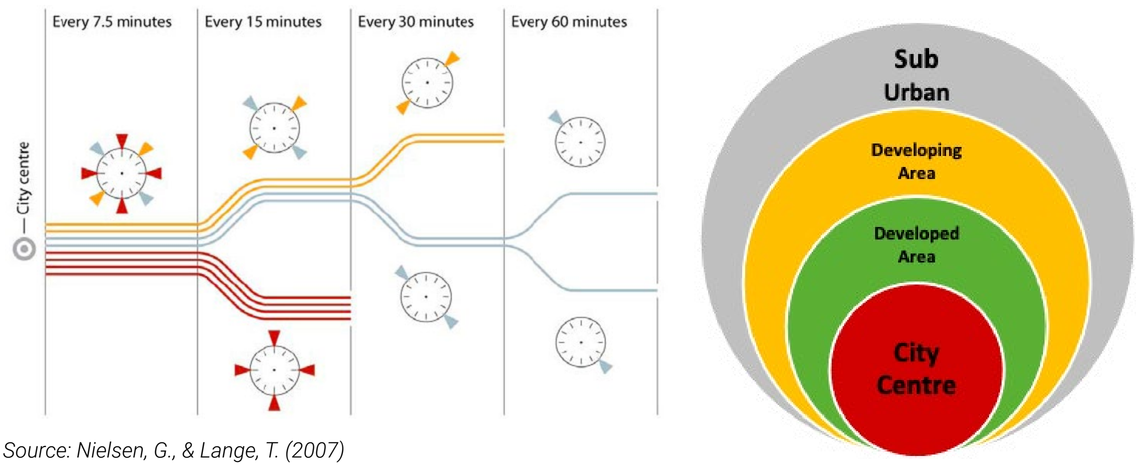
Source: ESCAP

5.3.6 FREQUENCY/HEADWAY

Service frequency is the number of public transport scheduled per hour. Headway is the time gap between the services, which usually varies according to the demand, i.e., by the time of the day. Figure 5.5 shows a generic example of how service timings differ by the type of area they serve. In the case of the Government of India, guidelines for urban bus operators are:

- Maximum headway prescribed for an urban transport service is 20 minutes
- Desirable headway during peak period is 5 to 8 minutes.
- Desirable headway during off-peak period is 8-12 minutes.
- Minimum headway during early morning and late evening (first and the last hour) may be 15 to 20 minutes.

FIGURE 5.5 Timetable of frequency by distance and type of area



Source: Nielsen, G., & Lange, T. (2007)

For bus operations, a headway of less than 5 minutes is not advisable as it would cause bus bunching, adversely affecting the reliability of operations. If the demand is higher, higher-capacity vehicles or modes should be chosen. For example, it is technically feasible to operate BRT, metro and rail-based systems with a minimum headway of 90-120 seconds.

5.3.7 CAPACITY AND UTILIZATION CONSIDERATIONS

Lastly, the above factors depend on the actual capacity and utilization of the vehicles for the mode selected. Bus systems will have a single unit vehicle while metro/mono/LRT systems will have multiple coaches. Capacities vary by vehicle capacity, or the maximum number of passengers a vehicle can accommodate (both seating and standing), as well as line capacity, as measured by passengers per hour in peak direction (PPHPD) and peak hour peak direction trips (PHPDT).

Operators must also use their assets efficiently. Oversupply can be as bad as undersupply in terms of balancing costs and revenues. For example, they will be looking at the following indicators to design their services:

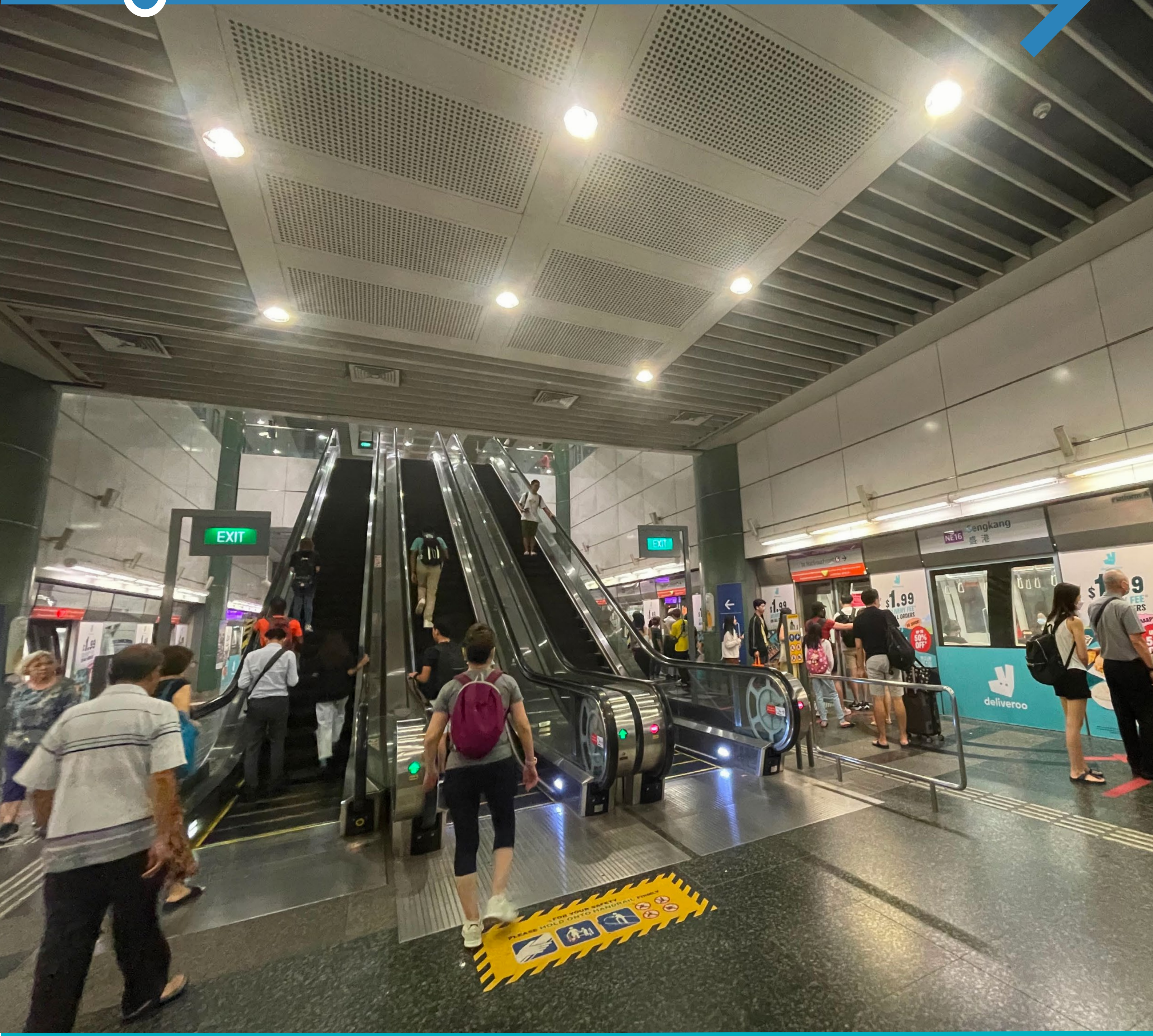
- **Vehicle utilization:** the number of km a vehicle is effectively used in a period, e.g. day. **Non-revenue / dead km** is the distance travelled from the first/last terminal to the depot. Minimising dead km is achieved through the careful selection of depots and terminal locations. Meanwhile, **revenue km** is the revenue per km earned on a scheduled service transporting passengers.
- **Fleet utilization:** ratio of the number of vehicles deployed on-road daily to the total fleet.
- **Capacity utilization:** capacity utilized to the total capacity offered; also referred to as load factor (LF).

5.4 SUMMARY

An effective operational strategy for public transport involves designing and structuring various elements like networks, routes, stops and services to meet diverse mobility needs. Transit networks are coordinated sets of lines providing integrated services with routes connecting different origins and destinations. Achieving efficient transfers between services requires due consideration to be given to the design of physical interchanges. These are discussed in more detail in the next chapter. For a selection of good practices on operational strategies, please refer to Chapter 5 of the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

6

Interchanges



Sengkang Transport Hub, Singapore. Photo: Canh Do

6.1 WHAT ARE INTERCHANGES?

Interchanges are the connectors between modes and services which help form an integrated public transport network. Well-located and designed multimodal interchanges are essential to delivering a seamless experience to the customer. The interchanges distribute passengers across regional and urban transport modes, such as airports, railway stations, port terminals, metro, buses, taxis, bicycles, and so on. Approaches to planning and designing interchanges can be considered at two levels:

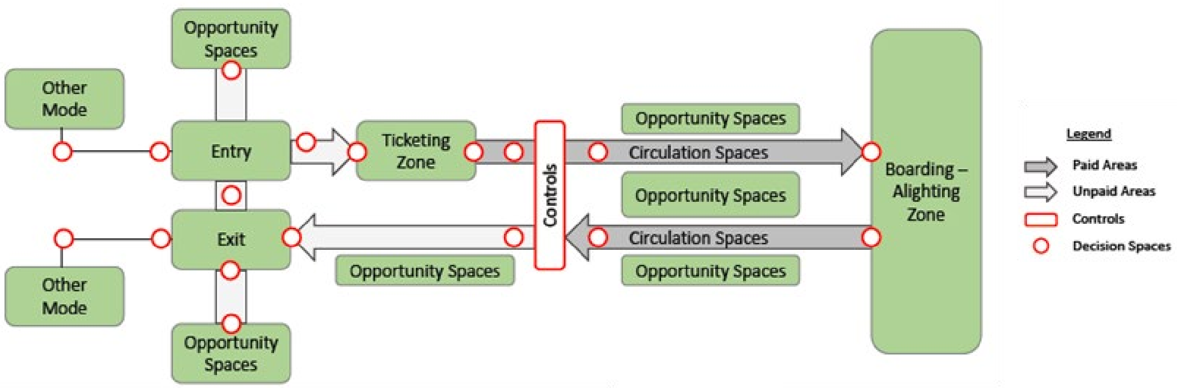
- Design of the station or terminal
- Design of the area around the station.

6.2 STATION DESIGN

Moving from one mode to another requires a physical interchange facility. This should be built with the appropriate dimensions, taking into consideration current and potential uses for the future. The spaces in stations must make transfers between modes fast, comfortable and safe for users, embodying the shift from the idea of bringing people to services to the idea of bringing services to people.

As walking is the key mode for transfers in a journey, the transition must be seamless and take place in enjoyable spaces, such as retail, green or recreational spaces. In this regard, areas in the station can be categorised by purpose: circulation, decision-making and creating opportunity (Figure 6.1). These are described in more detail below.

FIGURE 6.1 Major zones of an interchange station



Source: CEPT/ ADB (2023).

Circulation Spaces: Circulation spaces refer to areas or zones that are designed for pedestrian movement as well as connections to various modes of transport. They are typically free from obstructions, ensuring that people can flow smoothly and efficiently as they navigate through the interchange (Figure 6.2). Some principles for designing circulation spaces are to minimize transfer distance between modes, prioritise passenger safety, avoid conflicts, and ensure clear navigation, information, wayfinding and barrier-free access. The circulation spaces connect the decision and opportunity spaces.

FIGURE 6.2 KL Central Interchange, Kuala Lumpur

Photo: iStock/Sergio Delle Vedove

Decision Spaces: As the passenger enters the station, several decision points are present where the passenger decides on activities related to the trip. These decisions can be choosing between modes of transport, selecting the appropriate platform or gate, deciding on ticketing options, or changing directions or levels. Decision spaces are strategically designed and marked with clear signage to help passengers make informed choices and navigate through the interchange efficiently. For example, Figure 6.3 shows the signage in a Tokyo metro. Different lines have a letter and colour ID, while each station has a unique identifying number to help passengers, especially tourists, navigate the vast network.

Opportunity Spaces: Opportunity spaces are areas or zones within the interchange where various activities or services are provided to travellers. These spaces are designed to enhance the overall experience of the journey and can include amenities that make the interchange more than just a transit point, such as retail, waiting lounges, information centres, green spaces and so on. These spaces can also generate revenue through concessions and commercial activities. In some cases, the railway company will create its own retail shops or lease the space to private enterprises (Figure 6.4).

FIGURE 6.3 Signage in the Tokyo Metro

Photo: Jenny Yamamoto

FIGURE 6.4 Retail shops in Surabaya Gubeng Stations

Photo: Setyo Nugroho

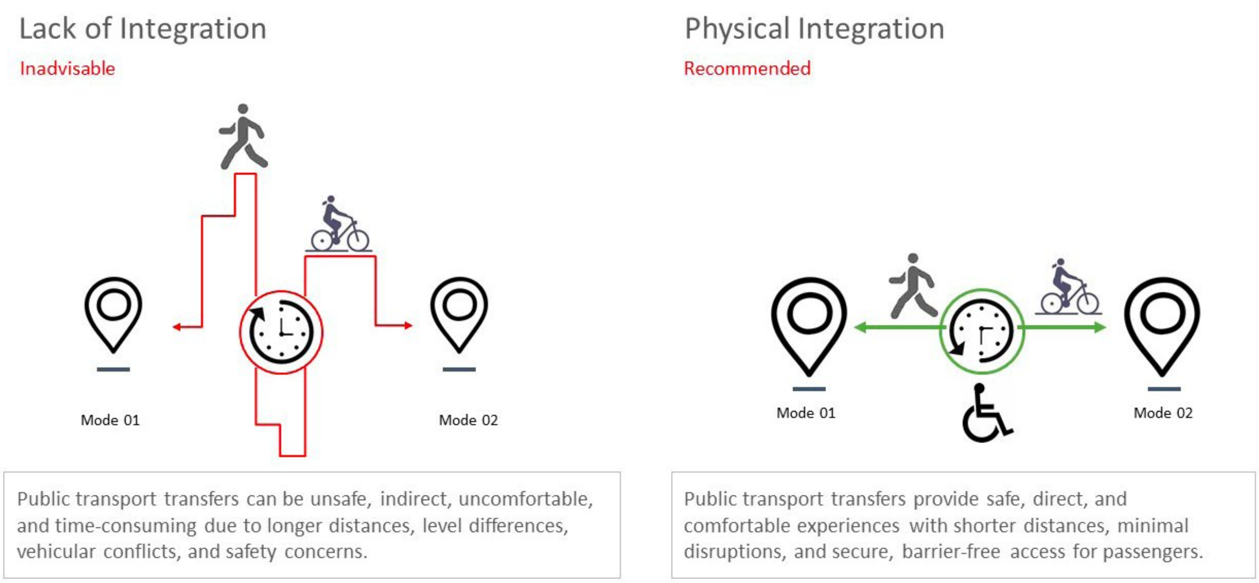
6

6.3 AREAS AROUND THE STATION

Station area development is usually focused on built environment aspects. It is based on principles such as creating a walkable urban street, promoting a comprehensive street network, managing parking, ensuring the integrity of natural systems and the environment, conserving built heritage, preserving affordable housing close to the station, involving stakeholders, and generating value for financial sustainability.[23] The location and character of the surrounding area are important considerations when developing stations, as they can influence the level of ridership of the public transport services.

Passengers shifting between modes during a journey have to be safe and comfortable. The extent to which this transfer can be done smoothly depends on the design of the transfer hub (Figure 6.5). The hub should bring the various access points closer to different public transport, such as bus stops, platforms, car parking, cycle parking, drop-off areas, and so on. Priority should be given to public and non-motorised transport which cause fewer externalities. To ensure passenger safety and comfort, last-mile connecting modes like feeder buses, paratransit, and private vehicles should incorporate features such as shaded areas, seating, rest spaces, wayfinding and barrier-free accessibility.

FIGURE 6.5 Act of Transfer

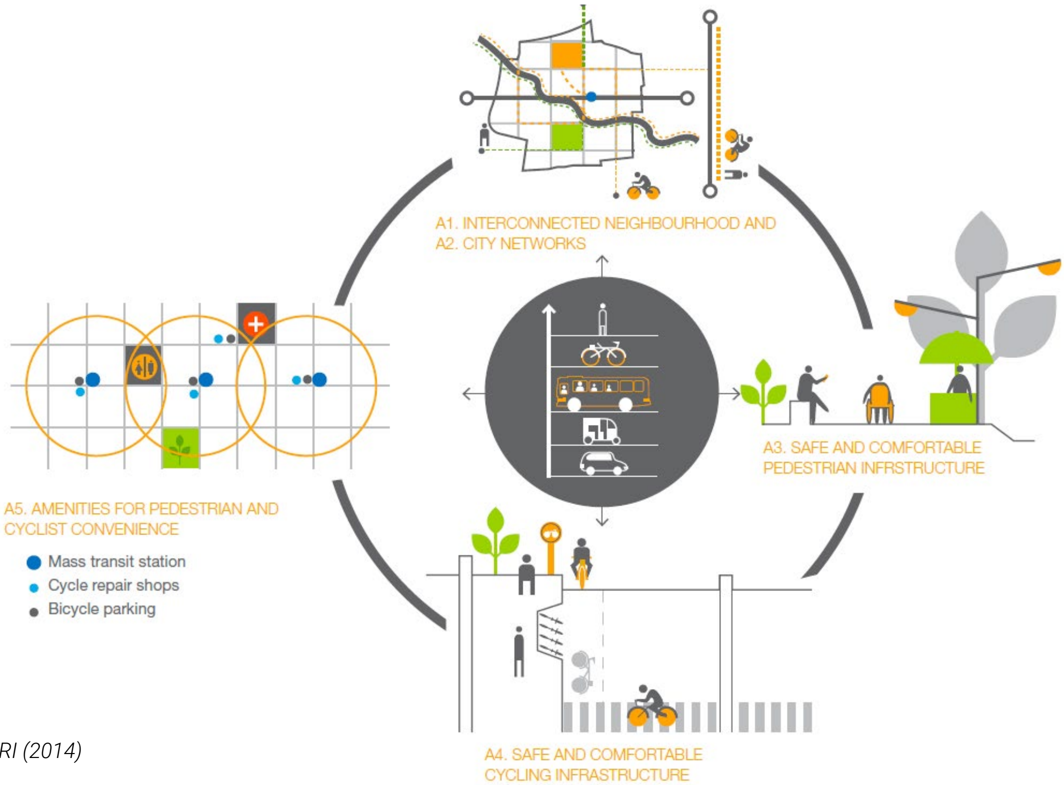


Source: Lokre, A. and Paul, S. (2022)

Achieving impactful integration depends on the seamless and well-coordinated execution of modal transfers. The design elements of a station area include[24]:

Accessibility: In interchange areas, passengers may transfer directly to another mode or spend some time between trips. These areas experience heavy pedestrian traffic, so offering secure, spacious walkways, along with opportunity and public spaces, improves the quality of pedestrian transfers. Connections to the streets around the station should also be safe and accessible with barrier-free design (Figure 6.6).

FIGURE 6.6 Strategies to give pedestrians and cyclists priority



Source: WRI (2014)

Safety and Comfort: The primary concern of a station is to offer a safe and comfortable environment. The streets leading to the interchange area and the pathways within it must be designed to accommodate large numbers of pedestrians. To enable people to pass each other easily, pedestrian paths should have a minimum width of 2.5 meters, free from obstructions. Additionally, the use of shading devices can protect passengers in weather conditions like heat and rain.

Activity Zones: Planning activities in the area around the interchange can improve the quality of the transfer experience and attract public footfall. Creating special activity zones may encourage people to use public transport and engage in various activities.

Last-mile Connectivity: Last-mile connectivity refers to the ease and convenience of getting passengers from the interchange station to their final destination, which can be a home,

FIGURE 6.7 Floor Markings in Tokyo Station

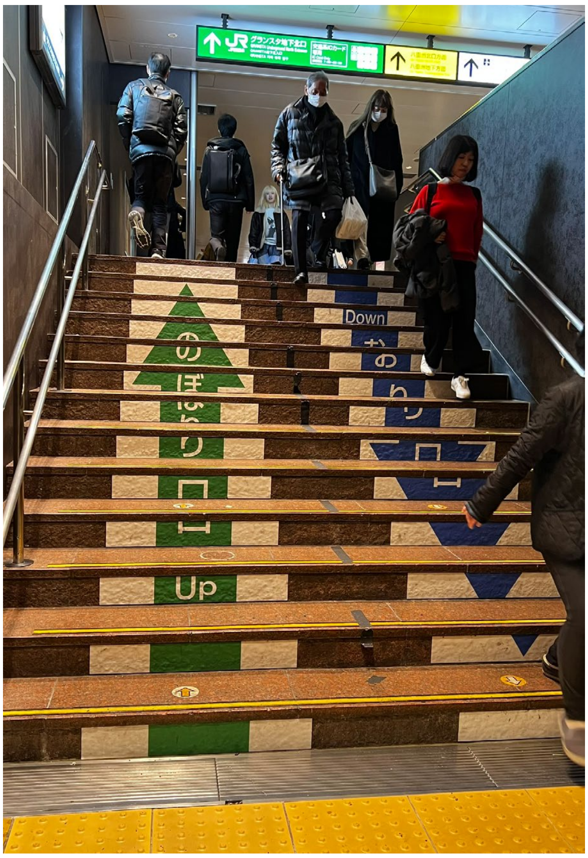


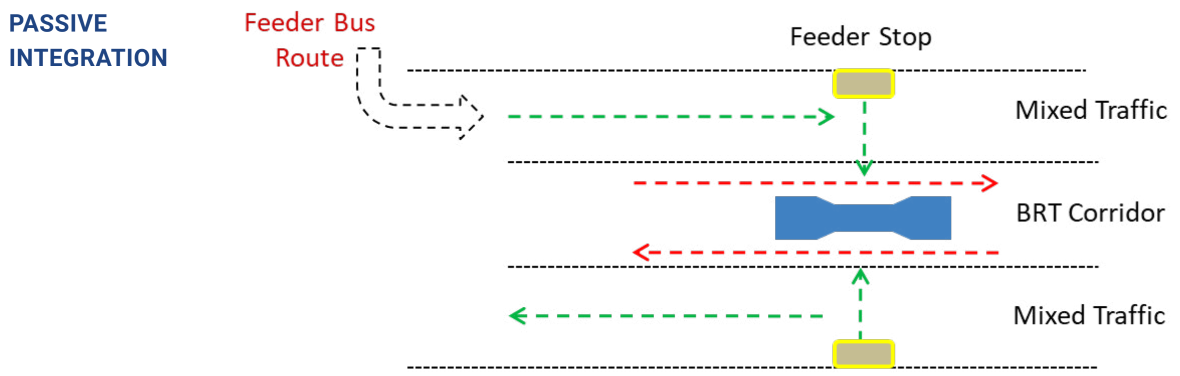
Photo: Jenny Yamamoto

workplace, school, or any other place they want to reach. Interchange stations often link to last-mile modes such as feeder services, taxis, cycle, or personal vehicles. Some options of transit modes include feeder bus services, taxis, cycles, bike-sharing systems, paratransit, or personal vehicles, including “kiss and ride” systems whereby passengers are dropped off or met by a family member driving a personal vehicle. The varying degrees of safety and convenience are demonstrated in Box 6.1, which describes the differences between passive and active integration between modes.

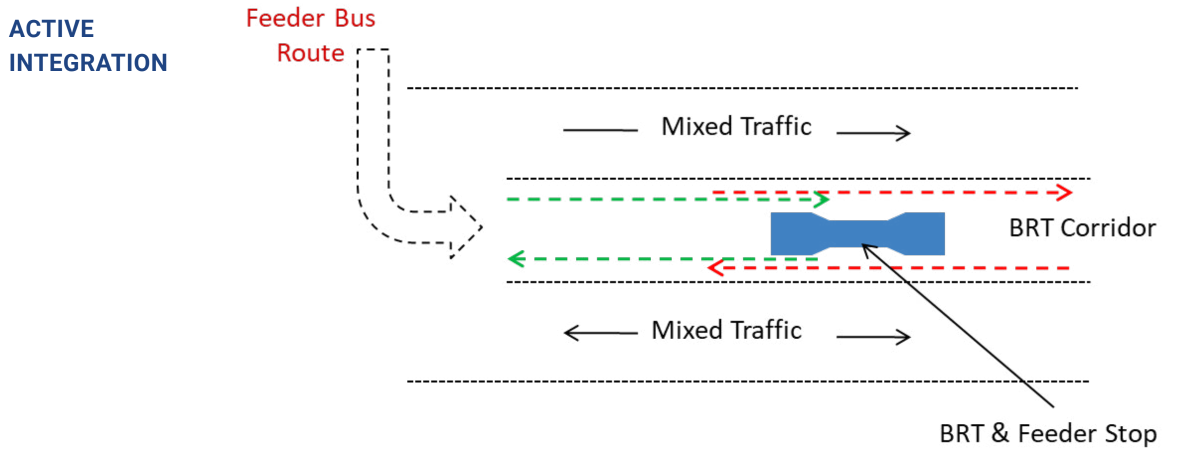
Wayfinding: Signage helps passengers to find their way easily to their intended destination. Its placement and legibility are important elements to ensure smooth navigation within the interchange area. Clear signs, information kiosks, maps, symbols, floor markings, digital displays, and directional signs are useful for wayfinding. Figure 6.7 shows the use of floor markings to direct the flow of pedestrian traffic in Tokyo Station. Yellow tactile paving blocks guide people with visual impairments throughout the station.

BOX 6.1 Comparison of passive and active integration: the case of BRT and bus services

The following case depicts two approaches to integrating BRTS with feeder bus service. In passive integration, concerns arise about pedestrian safety while crossing streets. If fares are not integrated, passengers also have to purchase multiple tickets. Moreover, the buses stopping in mixed traffic can impact overall traffic flow.



In contrast, active integration involves strategic planning to enhance connectivity. If feeder buses can access the BRT corridor, passengers will be able to board and alight seamlessly. Single ticketing simplifies the process, ensuring that transfers are efficient and hassle-free. Boarding and alighting through BRT stations can also enhance safety.

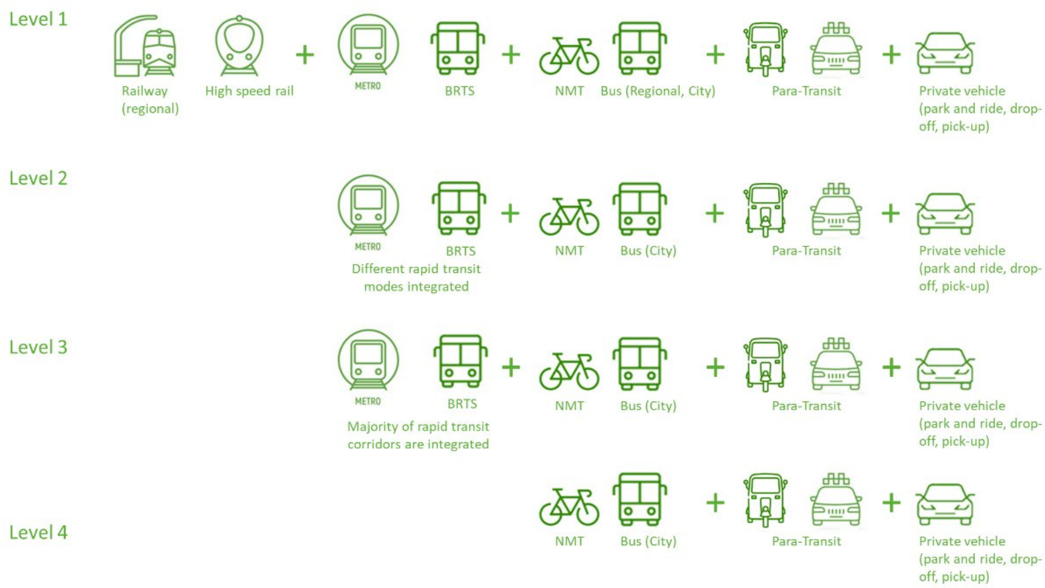


6.4 HIERARCHY OF INTERCHANGES

Interchange classifications vary in different research papers as well as in practice. For example, guidelines by Dublin National Transport categorize interchanges into four classes, with Class 1 comprising integration between a pair of bus stops to Class 4 representing major multimodal interchanges. Meanwhile, a study by Monzon et al (2016). classified interchanges as cold-hot, partially integrated, and fully integrated[25]. Both studies considered factors such as the passenger demand served; the number and types of transport modes, services and facilities; location within the city and surrounding urban area; and land use. The CETP/ADB (2023) manual for training transport officials from Bengaluru proposed the following hierarchy to help classify different types of interchanges (Figure 6.8).

Level 1 interchanges offer barrier-free and direct transfers between regional services and urban services. These interchanges are typically located in central business districts (CBDs) and are well-connected through other transport services. Examples of Level 1 interchanges include the large transport hubs found in most major cities with high speed rail systems, such as Beijing Station, Seoul Station, Tokyo Station, King's Cross St Pancras Station, London, Leningradsky Station Moscow, and Hong Kong West Kowloon Station.

FIGURE 6.8 Different Levels of Interchanges



Source: CEPT/ADB (2023)

Level 2 and Level 3 interchanges are both designed for transfers between two or more services of the same mode or different modes. They offer barrier-free transfers and are often situated in sub-centres like employment hubs. Many railway stations are either Level 2 or Level 3 interchanges. For example, the Sengkang Transport Hub in Singapore is an example of a modern interchange with excellent connections between modes as well as many shops. Level 3 interchanges primarily serve as connections between rapid transit services and urban bus services.

Level 4 interchanges are intended for transfers from feeder services or last-mile connectivity to urban bus services. They are typically located in residential areas. The vast majority of stations and bus terminals in the world are Level 4 interchanges. Figure 6.9 shows the busy bus terminal next to the main market in Suva, Fiji.

Further examples of interchanges can be found in Chapter 6 in the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

FIGURE 6.9 Main bus terminal in Suva, Fiji

Photo: iStock/ymgerman

6.5 SUMMARY

Interchanges play a crucial role in connecting modes and services for a seamless customer experience. These spaces must make a transfer from one mode to another fast, comfortable and safe. To make interchanges attractive, accessibility challenges should be removed and both stations and the areas around them should be designed with care. Interchanges are also a potential source of revenue for transport operators, which can be used to support the upgrading of infrastructure. Such multi-purpose uses of interchanges can be expected to grow in the future, especially as local governments pursue compact city development strategies. For examples of existing and new interchanges currently being built, please refer to Chapter 6 of the ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

7

Data and Digital Applications

Command and control centre, Ahmedabad BRTS. Photo: CEPT

7.1 GROWING IMPORTANCE OF DATA AND DIGITAL APPLICATIONS

Digital technology applications in urban public transport systems can improve the safety and effectiveness of services by allowing them to integrate with other existing and emerging services. In particular, digital technologies are being actively used in three areas of transport management, namely:

- **Digital applications for traffic management:** digital systems designed to manage and optimize the flow of traffic, including public transport vehicles, on public roads and highways.
- **Digital applications in public transport:** a range of innovative and integrated technologies and services that are designed to enhance the efficiency and reliability of public transport operations including real-time passenger information.
- **Emerging digital technology applications and services:** a range of innovative and integrated technologies and applications impacting urban mobility.

7.2 DIGITAL APPLICATIONS FOR TRAFFIC MANAGEMENT

Advanced Traffic Management Systems (ATMS) manage and optimize the flow of traffic on roads and highways.[26] Real-time data is collected from traffic sensors, cameras, GPS tracking, and other data collection devices and used by a traffic management centre to monitor and resolve traffic problems. In the context of public transport, ATMS help to optimize the flow of buses and other public transport vehicles, thereby reducing congestion, improving on-time performance, and enhancing the passenger experience. ATMS also provide real-time information on traffic conditions to bus drivers, allowing them to adjust their routes and schedules to avoid delays and improve efficiency. The different components of ATMS are briefly described below.

- **Traffic Management Centres:** The key tasks of traffic management centres are to monitor traffic, manage traffic operations, manage incidents (such as crashes or road works) and planned disruptions, and disseminate traffic information to media and service providers.[27] Road networks are monitored in real-time from a central location by network monitoring technologies. For example, VicRoads in Australia operates 24 hours a day and handles over 400,000 calls a year.[28] When incidents occur, the VicRoads Centre staff respond immediately by taking actions such as closing lanes, reducing speed limits, and programming electronic information signs to warn drivers of incidents further up the road.
- **Advanced Traffic Signal Control:** Advanced traffic signal control refers to technologies that monitor and asses real-time traffic demand data to optimise traffic signal operations.[29] This process helps to tailor traffic flows to live demand. Key benefits of advanced traffic signal control include fewer traffic accidents, reduced fuel consumption/pollution, up to 50 per cent faster traffic flow and 25 per cent reduction in travel times.[30]
- **Automatic Traffic Enforcement System:** An automatic traffic enforcement system enforces traffic laws using devices such as red-light cameras, speed cameras, and mobile phone and seatbelt detection cameras. These cameras detect violations of traffic laws and can "reduce fatalities and injuries by preventing and reducing traffic collisions and violations along with modifying aggressive drivers' behaviour."[31]

- **Electronic Road Pricing Systems:** Several cities are adopting pricing as a tool to manage traffic congestion. With digital technology evolution, charges can be collected without stopping the road user, which in turn improves the speed and efficiency of traffic flow. Singapore was the first to introduce congestion pricing as a tool to control traffic volume in 1975.[32] Such charges are also used to discourage the use of private vehicles and attract more people to public transport.

7.2.1 ADVANCED TRAVELLER INFORMATION SYSTEMS (ATIS)

An ATIS keeps travellers updated with pre-trip and enroute traffic information such as information about schedules, delays, route changes, and other relevant information about real-time traffic conditions. Data is collected from various devices (surveillance cameras, fixed sensors such as loop detectors and vehicle detection systems, probe cars and mobile phones), analysed and then disseminated through the Internet, radio, VMS, mobile/online services, and navigation devices.[33] Multiple applications are used as a part of ATIS.

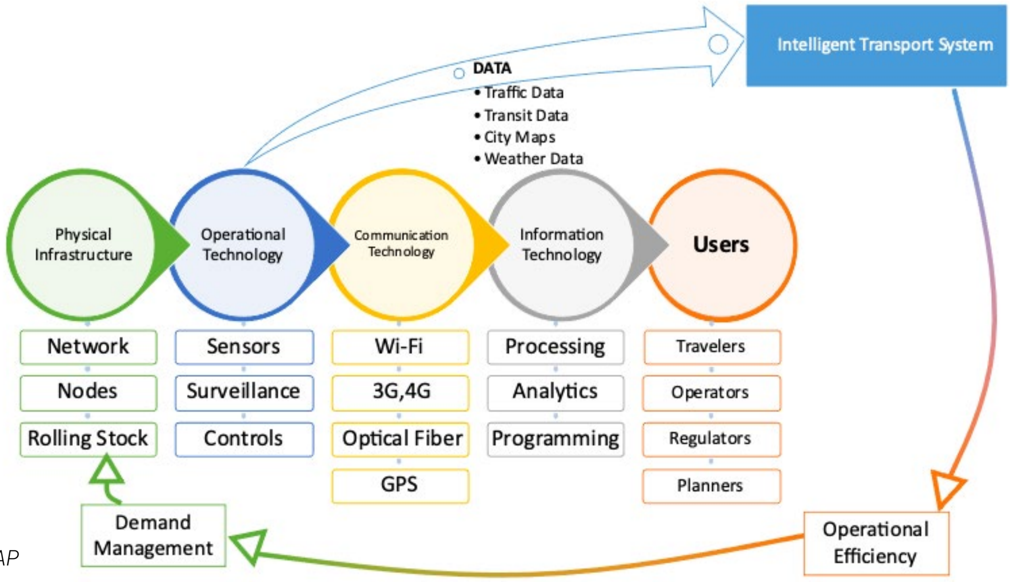
- **Mobile Applications:** Mobile applications can serve the dual purpose of providing real-time information about traffic flows and population mobility to traffic monitors, as well as distributing information back to road users.[34] With an estimated 6.89 billion active smartphone mobile network subscriptions worldwide as of 2023,[35] using these devices to help manage traffic is appealing, especially compared with other systems which require investments in infrastructure.
- **Variable Message Signs (VMS):** VMS are electronic roadside signs which convey real-time traveller information to road users.[36] Messages can include information on incidents, travel times, weather conditions, detours, events, and other relevant information. Variable message signs are controlled via traffic management centres.
- **Road Weather Information Systems:** Road weather information systems use environmental sensor stations located in the field to monitor atmospheric, pavement, and/or water level conditions.[37] This information is processed and conveyed to road users. Some systems, such as that used by the North Dakota State Government, are open source and provide live road weather information on a public Geographical Information System (GIS) map.[38]

7.3 INTELLIGENT TRANSIT MANAGEMENT SYSTEM (ITMS)

An Intelligent Transit Management System (ITMS) is a comprehensive platform that integrates various components and functions to efficiently manage public transport planning and operations. This platform allows data and process exchange protocols to be documented, ensuring that bus transport systems can easily adopt new initiatives in the future. Further, these solutions can leverage advances in hardware, software, interfaces, and algorithms as they evolve (Figure 7.1).

Many countries and cities across the world have developed strategies for ITMS. For example, the Ministry of Transport and Infrastructure of the Republic of Türkiye developed the National Intelligent Transportation Systems Strategy Document and 2020-2023 Action Plan to help guide ITS progression and implementation in the nation.[39] This plan focuses on ITS technologies and applications to increase efficiency in all sectors at the national level. Meanwhile, cities like Surat, India, have implemented city-wide ITMS (Box 7.1). Some areas where ITMS is applied in bus-based public transport systems are given in Table 7.1.

FIGURE 7.1 Components of an Intelligent Transit Management System



Source: ESCAP

TABLE 7.1 ITMS Functions and Devices for Bus Systems

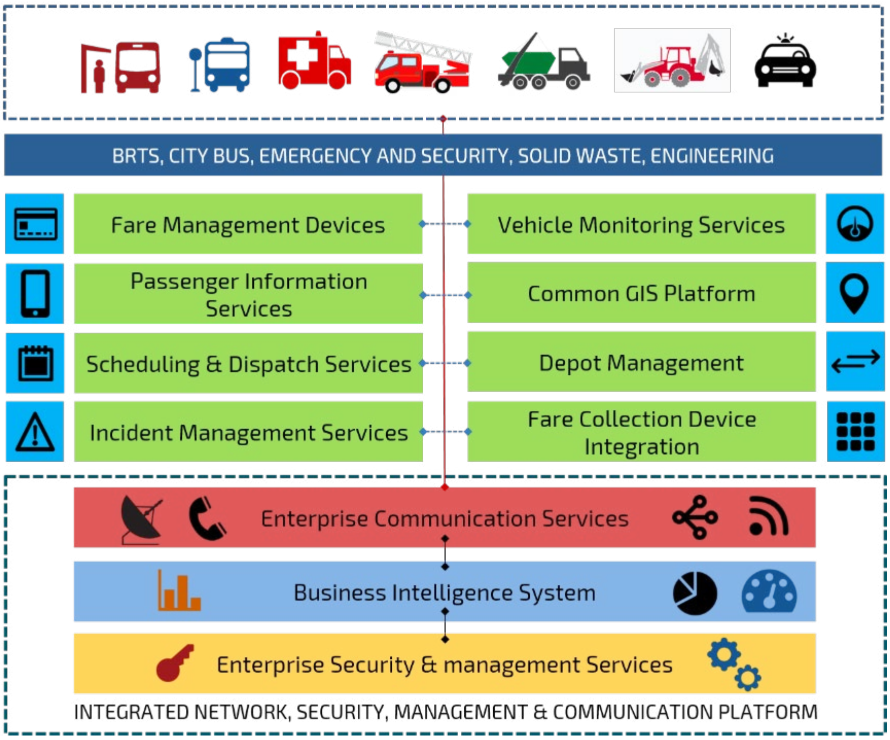
SL. NO	TYPICAL SPACING	REMARKS
Operations Management including Driver Aids	• Automatic Vehicle Location System • Automated Scheduling and Dispatch System • Vehicle Identification • Vehicle Health Monitoring	• Vehicle Tracking Device • On-board Integrated Controller • RFID Sub-system • Driver Management Console
Passenger Information System	• In-vehicle Display Units • At-station Display Units • Web-based Passenger Information System • Mobile-based Passenger Information System Applications	• LED/LCDs in buses • LED/LCDs at bus stations/bus stops • Mobile devices • Personal computers
Fare Collection System	• Fare Media • Devices to read/write media • Back-office systems • Depot/Station ICT equipment and infrastructure • Central Clearing House	• Electronic Ticketing Machines • Ticket Vending Machines • Smart Card Issuance counters • Ticket Office Terminals • Fare Gate (in the case of BRTS) • Stand-alone Validator • On-vehicle Validator
Security System	• In-bus surveillance • At-station surveillance • At-depot surveillance • Surveillance through the Command and Control Centre • Support Infrastructure	• In-bus and at-station Closed Circuit Television (CCTV) cameras • At-depot CCTV cameras • Digital Video Recorder • Storage of video feed at Data Centre

Source: India, MoHUA (2020)

BOX 7.1 City-wide ITMS in Surat City, India

Surat has implemented a city-wide "Intelligent Transit Management System" (ITMS), to manage a diverse set of transport needs for the city. This includes: (a) public transport, and (b) vehicles related to civic services like solid waste management, drainage, heavy engineering, emergency services, and so on. ITMS integrates various departments of Surat Municipal Corporation for better operational efficiency and optimum utilization of resources. The project is envisaged to reduce travel time, improve the reliability of public transport, and bring operational efficiency to various departments in providing their services to citizens of the Surat city. Similar efforts are underway in Ahmedabad, Indore, Bhubaneswar, Hubli-Dharwad, Bengaluru, and several other smart cities in India.[53]

Integrated Transit Management System Framework for Surat City



Source: NIUA (n.d.); NIUA (2018).

7.3.1 AUTOMATED VEHICLE LOCATION SYSTEM

The Automated Vehicle Location System (AVLS) primarily uses GPS-based location tracking devices mounted on vehicles. The location and associated data acquired from the vehicle units become inputs for tracking and operational processes required by user-executing functions. Information is made available across various devices such as mobile phones, fixed displays, web, etc. in the form of text and voice. The in-vehicle system includes systems and devices (hardware and software) that are placed in buses to support AVLS, passenger information, and other in-vehicle functions. A typical onboard device stack would include an On-Board Unit (OBU), Driver Display Unit (DDU) with built-in RFID connected to a speaker and microphone, Passenger Information System (PIS) with LED displays, public announcement systems (PA System), antennas and GPS/network connectivity 4G, cameras and panic alarms.

7.3.2 AUTOMATED FARE COLLECTION SYSTEM

An Automated Fare Collection System (AFCS) is a technology-driven solution implemented in transit systems to automate the process of fare collection from passengers. It replaces traditional manual fare collection methods, such as paper tickets or cash transactions, with electronic and contactless payment methods. Two commonly employed fare collection methods are on-board collection, in which passengers buy tickets from conductors upon entering the vehicle or use smart cards to tap on fare validators, and off-board ticketing, where passengers tap in and out on turnstiles or fare gates at transit stations (Figure 7.2).

AFCS allows for faster boarding processes through contactless payments, which in turn can improve revenue collection. Moreover, smart technology enables data collection and analysis that contributes to improving the overall efficiency and financial viability of public transport systems.

FIGURE 7.2 Phrom Phong station, Bangkok Mass Transit System

Photo: Madan Regmi

7.3.3 PASSENGER INFORMATION SYSTEM (PIS)

Passenger information systems (PIS) are integrated services that utilize tracking data from vehicles to estimate arrival and departure times. A central PIS system can deliver estimated time of arrival (ETA) and estimated time of departure (ETD) information on a schedule or request basis, depending on the type of end application or device. The central PIS delivers ETA / ETD to fixed display devices installed on bus stations at a set frequency or on a bus movement basis. The PIS information on buses is driven by a local geo location-aided controller which can deliver information in visual and audio formats. In Seoul, the government has introduced "smart shelter" bus stops which provide information about bus arrivals (Box 7.2).

BOX 7.2 Smart Shelter Bus Stops

The public transport authority in Seoul is rolling out ‘Smart Shelter’ bus stops.[54] These self-contained glass cube shelters feature air conditioning for summer and heating for winter, ultraviolet light sterilisers, surveillance cameras, Wi-Fi, power points for charging personal devices, and digital screens to notify users when buses are approaching. As they were designed in response to the COVID-19 pandemic, some stops also have hand sanitiser and heat visualisation cameras which prevent the admission of passengers whose body temperatures exceed 37.5 degrees Celsius.[55] The bus stops also share real-time information with emergency services using data from surveillance cameras, alarm signals, and smart noise sensors.

Photo: Haein Namgung

Source: Chenchulin, D., Mohr, D., Pokotilo, V., Woetzel, J. (2021). Urban Transport Systems of 25 Global Cities.

Transit information can also be delivered to commuters via other electronic means like websites, mobile apps, or short message services (SMS). This multi-channel commuter interface reassures citizens and promotes the image of public transport as a safe and reliable system. Information is disseminated through the following units:

- **Web portal/mobile apps** enable passengers to get information about the bus and train schedules and ETA based on real-time data from the central PIS system (Figure 7.3).
- **Bus display units on the front windshield and the back window** display bus route information, while the internal display shows real-time information about stations and routes, e.g., next stop, via text and voice interface.
- **PIS display systems** at transit stations show real-time information about the route and estimated time of arrival using a communication system installed within the station (wired / wireless) with the central AVLS / PIS application (Figure 7.4).
- **Voice information systems** derive information about the next station based on the location information of the GPS unit and have the capability of playing pre-recorded voice information on the bus. This system may be used by the transit agency to deliver marketing or outreach information to consumers.
- **A call centre** is usually maintained by the service provider on behalf of the bus transport system for passengers to call for information on bus routes and schedules as well as for any issues related to transit service.

FIGURE 7.3 Interfaces of Journey Planner mobile application of Hong Kong MRT

FIGURE 7.4 Multilingual sign on platform in Tokyo

Photo: Jenny Yamamoto

7.3.4 VEHICLE SCHEDULING & DISPATCH SYSTEM

This system can optimize service delivery by developing the route network and publishing final timetables and rosters, generating statistical summaries and MIS from the system, trip and vehicle planning, crew schedules, roster and dispatch (operations), crew kiosks, performance monitoring, workshop and fleet management systems, fuel management, tyre management, procurement and inventory management, and fleet management. Dynamic rescheduling is a facility within a Computer-Aided Dispatch / Automatic Vehicle Location System (CAD/AVLS) system that allows the schedule to be adjusted in real-time or semi-real time in response to prevailing circumstances, including the following situations:

- Smoothing the schedule or headway pattern when a vehicle is missing
- Recalculating the schedule or headway pattern when one or more additional vehicles are operated on a route (e.g., in response to unusually high demand)
- Recalculating the schedule when a route diversion takes place
- Recalculating the schedule based on overall or sectional running times
- Creating an alternative schedule in case of a disruption.

In some cases, the revised schedule is transmitted to in-vehicle devices and real-time travellers' information channels. The system also features an integrated Optimization Tool for vehicle and crew management based on various constraints and preferences, allowing for the generation of "what-if" scenarios. Moreover, the system considers labour award conditions and preferences, and can present the costs associated with each service option. For performance analysis, the system provides trip time deviation analysis and constraint analysis to identify critical trips and constraints. Furthermore, it can store and manage documents related to staff, such as birth certificates, education certificates, licenses, and appointment orders.

7.3.5 DEPOT MANAGEMENT SYSTEM

For bus transit systems, depot management plays a very important role in ensuring the availability and safety of transit buses. The depot management system (DMS) primarily manages vehicles, routes, crew, and schedule management. Depot resources are also required to carry out day-to-day maintenance of vehicles, and preventive and predictive maintenance schedules. DMS helps manage activities such as body repairs, Fitness Certificate Renewal, reconditioning of assemblies and engines, retrieving of spares, tyre re-treading, and repairs and reconditioning. The application provides a query function for viewing and updating the fleet status. The application can track progress by type of workshop activity (e.g., accidents, engine rebuild, fitness certificate), as well as report vehicle-wise insurance claims, road permits, and so on.

7.3.6 INCIDENT MANAGEMENT

Generally, strategies for managing emergencies and incidents are formulated at an organizational level and involve multiple stakeholders. These situations can be classified into three levels, each requiring a different level of response:

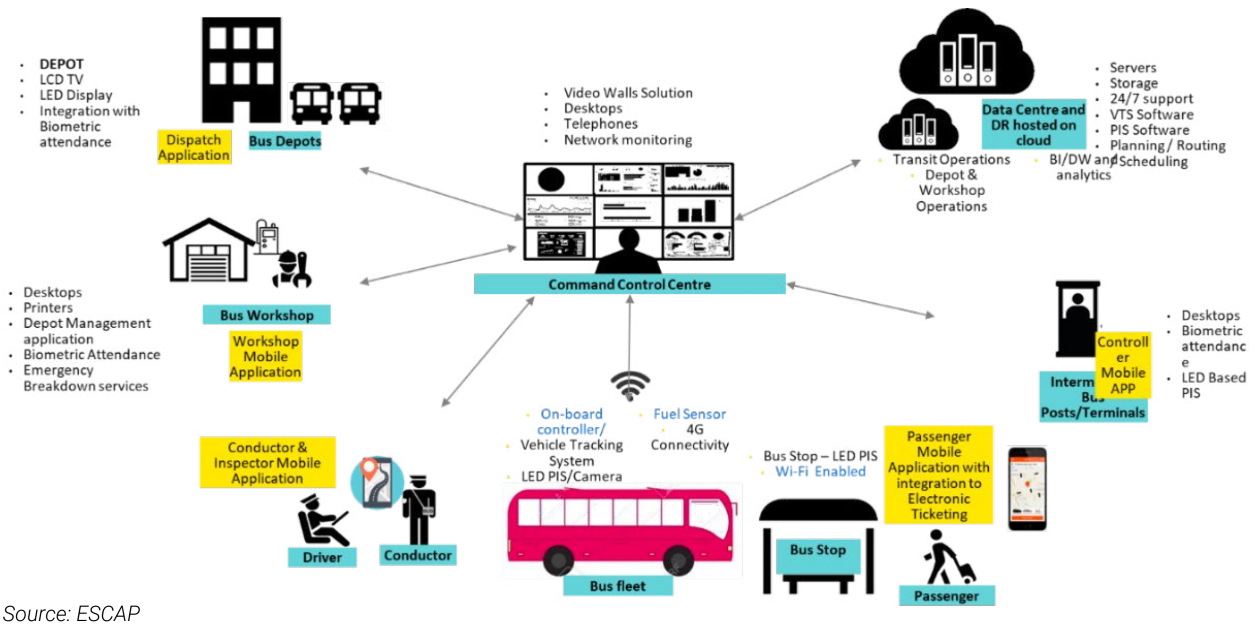
- Incidents that involve individual vehicles or specific locations.
- Incidents that impact only public transport services.
- Incidents that affect the entire urban area and its utilities, including public transport systems.

Incidents may include vehicle breakdowns, collisions necessitating technical assistance or vehicle replacement, medical emergencies, assaults or security incidents requiring police response, pre-advised diversions or restrictions due to road construction or repairs, unplanned diversions or restrictions, weather-related events and restrictions, and events that demand diversions or additional services. The effective management of incidents reduces their adverse impacts on public safety, vehicle delays, and the local economy, particularly by reducing response and clearing times. The CAD/AVLS system also facilitates data exchange among transport and security agencies and allows for traffic signal adjustments near the affected areas.

7.3.7 TRANSIT COMMAND AND CONTROL CENTRE (TCCC)

The various systems described above are connected to the Transit Command and Control Centre via a wireless communication system. The central control centre serves as the operational hub for the transport service, utilizing the AVLS application system to handle inputs from various field devices, scheduling systems, bus-stop databases, and the radio system for tasks like vehicle dispatch and dynamic scheduling. Real-time passenger information services are provided by the PIS application, which processes information accessed from the onboard AVLS devices. Data communication needs to be secure. In-bus components such as GPS modules can be equipped with 4G/LTE connectivity to communicate data in real-time for live tracking and operation monitoring of fleets through the command and control centre.

FIGURE 7.5 Command and Control Centre is at the centre of operations management



Source: ESCAP

Transit controllers, incident managers, and technical staff in the control centre are responsible for ensuring the smooth delivery of business services. Their responsibilities include receiving, interpreting, and transmitting information while determining appropriate responses to incidents and ensuring the security of individuals and infrastructure, and maintaining an electronic reporting facility. Staff need to be trained to operate security systems to monitor activities, coordinate incident responses, and implement relevant procedures through standard operating procedures (SOPs).

7.3.8 BUSINESS INTELLIGENCE TOOL (BI)

Some public transport operators use BI platforms to conduct multi-dimensional analysis and generate reports for informed business decisions. To achieve this, the BI platform should offer interactive visualizations that allow easy comprehension of data, along with options to create reports in various formats for sharing. To enhance the user experience, the BI tool offers view-management tools, zero-programming mashup capability for data integration, and intuitive visual filtering and sorting options. The platform's interactive visualization plays a crucial role, displaying key performance indicators with colour-coded status and offering drill-down capabilities for different views. Diverse chart types, GIS map extensions, and integrated calendars also provide insights into the spatial and temporal aspects of the system.

By closely monitoring the data, transit authorities can gain valuable insights into how the system operates, how passengers use it, maintenance requirements, and where potential issues or bottlenecks may arise. By tracking vehicle location, ridership, vehicle health data and other performance metrics, transit agencies can schedule services, plan preventive maintenance and reduce the risk of breakdowns. For example, by tracking their passengers at different times of the day, service providers can adjust schedules or increase service frequency. Similarly, monitoring identifies areas with low ridership, which helps the transit authorities to reconsider route planning. This process of continuous monitoring ensures that transit services remain responsive to changing demographics, commuter preferences, and urban developments.

7.4 EMERGING TECHNOLOGIES AND APPLICATIONS

Emerging technologies and applications represent all transport technologies and mobility services that attempt to solve critical issues facing current society. Such innovations ensure the competitiveness and efficiency of public transport operations and management in the longer term, with sustainability, reliability and safety as central objectives. Some technologies which are expected to play an ever-increasing role in integrated public transport systems are described below.

7.4.1 AUTONOMOUS VEHICLES

Autonomous Vehicles (AV) are vehicles that use sensors, cameras, and other technologies to operate without human intervention.[40] Autonomous vehicles are predicted to have a radical effect on the transport sector, with benefits such as improved fuel efficiency of 4-30 per cent, improved safety with a potential 90 per cent reduction in crashes, and a reduction in traffic congestion.[41] AV can be used for various public transport applications, such as buses, shuttles, and trains. AV sales are estimated to exceed 33 million per annum by 2040, enabling autonomous mobility in more than 26 per cent of new car sales.[42] To quantify AV autonomy, the Society of Automotive Engineers International has developed an autonomy classification system based on a six-level continuum.[43] These levels range from Level 0, "fully manual", to Level 5, "fully automated". Recent technologies have advanced AV to level 3 autonomy, which allows the vehicle to observe the environment and handle crises with functions such as emergency braking.[44]

7.4.2 BIG DATA

In the context of smart public transport, Big Data refers to the vast amount of data generated by various sources such as sensors, GPS, ticketing systems, social media, and other sources. The collection and analysis of Big Data can provide valuable insights into the performance of transport systems, including passenger flows, congestion levels, and the utilization of public transport services. By analysing Big Data, transport authorities can optimize routes, schedules, and operations, improving the efficiency and reliability of public transport services. Big Data can also help to identify patterns and trends in passenger behaviour, enabling transport authorities to improve services and provide personalized travel experiences.[45]

7.4.3 FIFTH GENERATION (5G) INTEGRATION

Fifth Generation (5G) wireless technology is a revolutionary communication network connecting everyone and everything. 5G provides the necessary communication infrastructure required by various smart transport applications. C-ITS is one of the many smart city applications that can be realized by 5G technology.[46] 5G is gaining ground in several Asian countries. For example, it is being used in Guangzhou, China, to assess the physical conditions of metro tracks and the driving patterns of bus drivers (Box 7.2).

7.4.4 ARTIFICIAL INTELLIGENCE

Artificial Intelligence (AI) can be defined as intelligence – perceiving, synthesising, and inferring information – demonstrated by machines, rather than by humans or other animals. While still an emerging technology, it is used to tackle problems that are challenging to address by traditional computational techniques. Issues regarding public transport arise when the system and users' behaviour become too complex and too difficult to model to predict their travel patterns. AI is deemed to be a good fit for use in wide applications within transport systems to overcome such challenges, as well as challenges of increasing travel demand, CO2 emissions, safety concerns, and environmental degradation.[47]

7.4.5 INTERNET OF THINGS

The Internet of Things (IoT) is a system of interrelated computing devices, mechanical and digital machines, objects, or people with the ability to transfer data over a network without requiring external interaction.[48] The IoT is an emerging concept that when integrated with other emerging technologies like C-ITS, artificial intelligence, cloud computing, and Big Data, has the potential to drastically alter the world we live in.[49] IoT enables organizations to implement new services more rapidly and at lower risk.

BOX 7.3 Guangzhou, a 5G Smart Transportation City

In Guangzhou, China, the Guangzhou Municipal Transportation Bureau is incorporating 5G-enabled smart transport systems into the Guangzhou public transport network. 5G-enabled monitoring of the Guangzhou Metro can assess the physical track conditions, presence of fire, waterlogging, or unauthorised intrusion, significantly reducing the rate of incidence and consequent cost of maintenance. As digital infrastructure in metro stations is 5G-enabled, methods such as AI flow analysis or abnormal behaviour analysis can shorten processing times by up to 20 per cent during peak hours. In addition, 5G technology can provide early warning systems for trains, reduce manual train suspension inspection times from 2 hours to 2 minutes through camera-assisted AI-driven inspection, reduce the number of front-line production staff required, and increase the average daily processing capacity. Buses also benefit from 5G-enabled technology. For example, by analysing bus drivers' driving behaviour and driving records, back-end systems can improve the safety of bus operations, reduce the time needed to schedule bus lines and increase bus system capacity.

Photo: iStock/Zhonghui Bao

Source: GSMA (2022).

7.4.6 DIGITAL TWINS AND MODEL

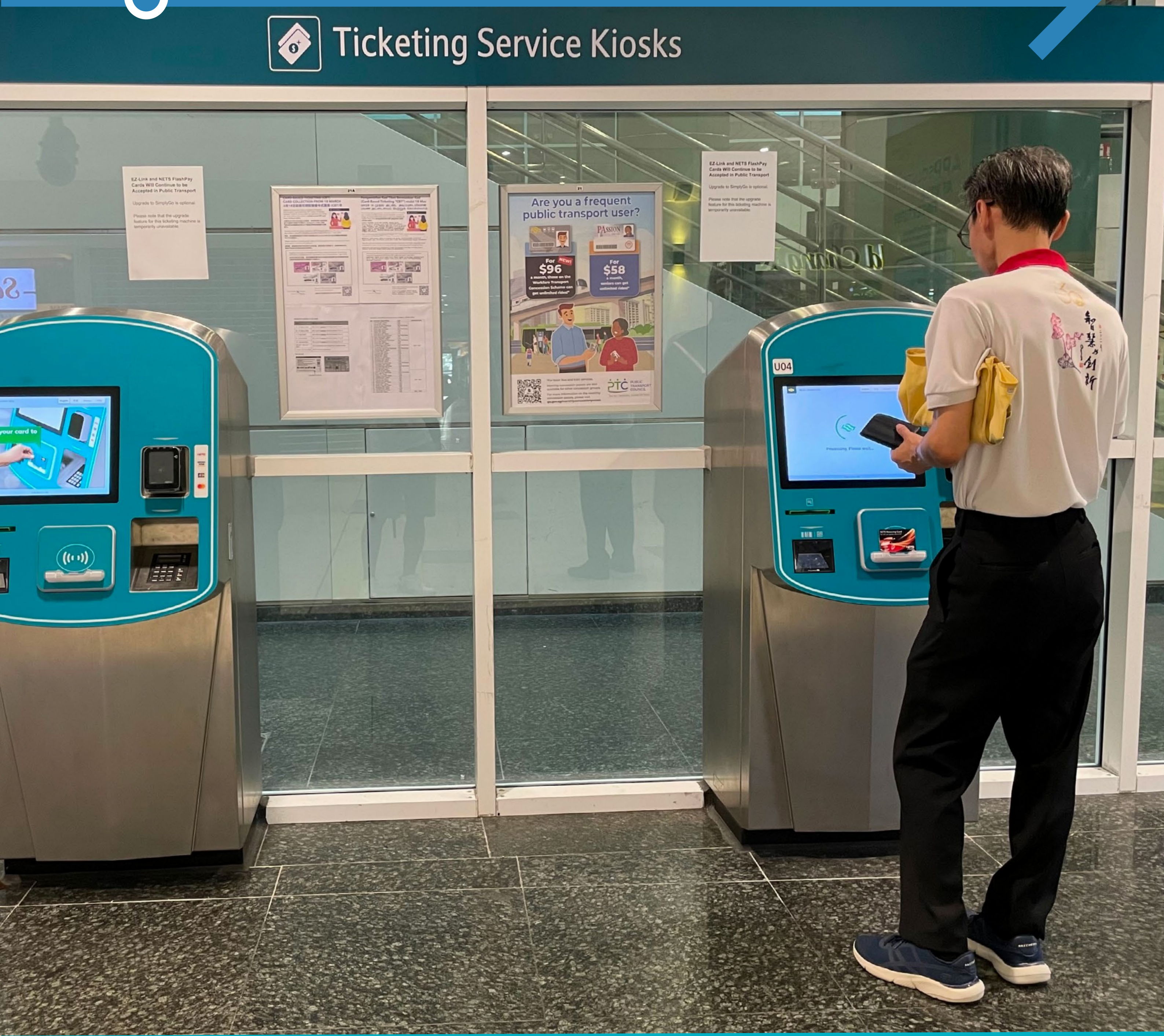
Digital twins use data from sensors, cameras, and other devices to create a virtual model that accurately represents the physical system or product and simulate their performance in real-world scenarios.[50] This model can be used to test and optimize performance, predict outcomes, and identify areas for improvement. For public transport systems, digital twins can be used to simulate the behaviour of vehicles, traffic flows, and transport infrastructure. This can help transit operators to optimize routes, schedules, and resource allocation, and to identify potential problems before they occur. It also allows designers and operators to test models before deploying them in the real world. For example, digital (virtual) twin technology is being used to plan a sustainable transport system in the new capital of Indonesia, Nasuntara.[51]

7.5 SUMMARY

Digital applications in urban traffic and transport systems are helping to make public transport safer, cleaner, faster, and integrated. These technologies are evolving so the adaptation of technology is an ongoing exercise. As cities continue to evolve and urban mobility demands grow, it is becoming necessary to embrace ITMS. While some ITMS systems for public transport can require significant upfront investments, this is balanced by the fact that they can decrease the costs of operating public transport over the long-term. For more examples of how data and digital applications are being applied for integrated public transport, please refer to Chapter 7 in ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

8

Integrating Fare Systems



Ticketing kiosk, Singapore. Photo: Canh Do

8.1 WHAT IS FARE INTEGRATION?

Fare integration refers to the creation of a unified fare structure to access multiple forms of public transport systems using a single form of payment. The aim is to simplify the fare payment process for passengers, encourage the use of public transport systems and enhance the overall efficiency of the transit network. Fare integration can be implemented at various levels, such as within a single transit agency, between multiple transit agencies in the same region, and even across different modes of transport.

Public transport users are not only sensitive to the overall pricing of the journey, but also the number of times the fare must be paid and tickets are purchased. Paying multiple times for a journey is very inconvenient and it increases the negative impression that the use of public transport costs more in a single journey compared to driving one's vehicle unless tolls or parking is charged. Fare integration can reduce the cost of travel by eliminating transfer penalties. This cost reduction may reduce the burden on low-income users who are unable to afford multiple tickets on their travel to work, schools, health centres or other facilities. Moreover, fare integration enhances passenger convenience and simplifies transit, making public transport a more appealing option.

The approaches that govern fare integration include:[52,53]

- **Fare policy** involves the development of a fare policy, strategy and structure for standard pricing systems among the modes, and distribution of revenue across the operators.
- **Fare technology instruments** are technological and involve the standardisation of media used and the collection of fares.

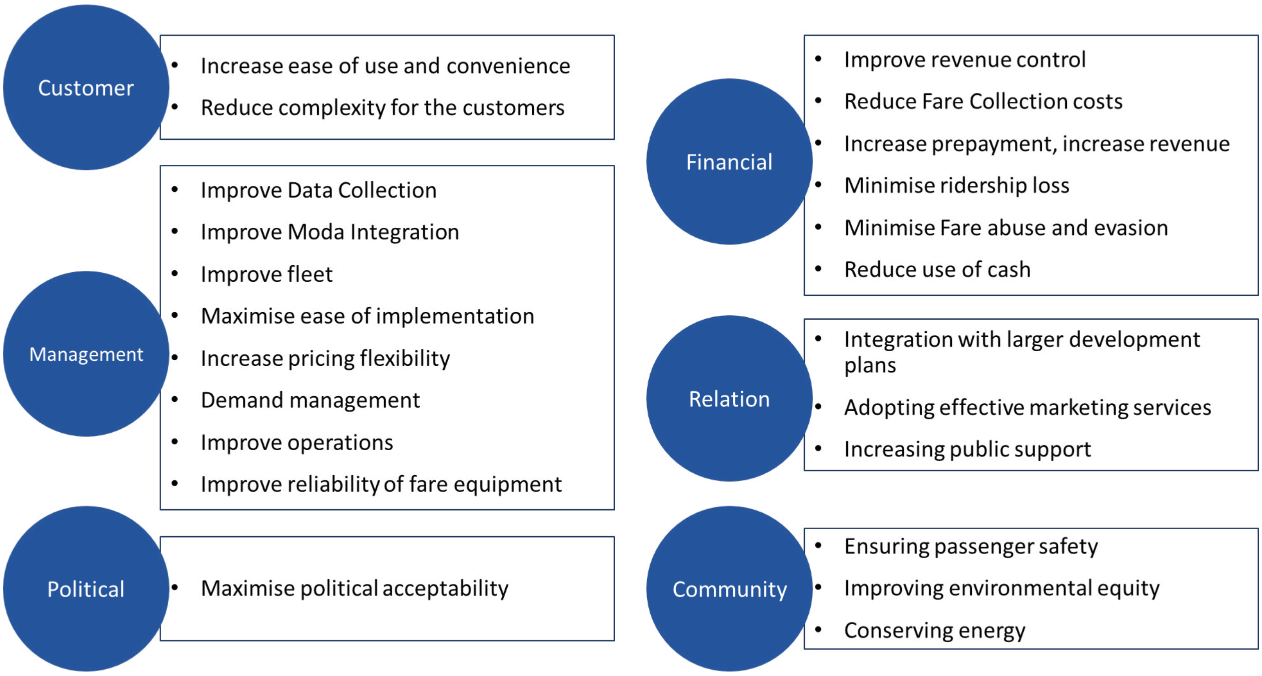
8.2 FARE POLICY

The fare policy is based on the policies set by the transit agency to attain specific goals. It should have a well-formulated strategy and fare structure.

8.2.1 FARE POLICY ENVIRONMENT

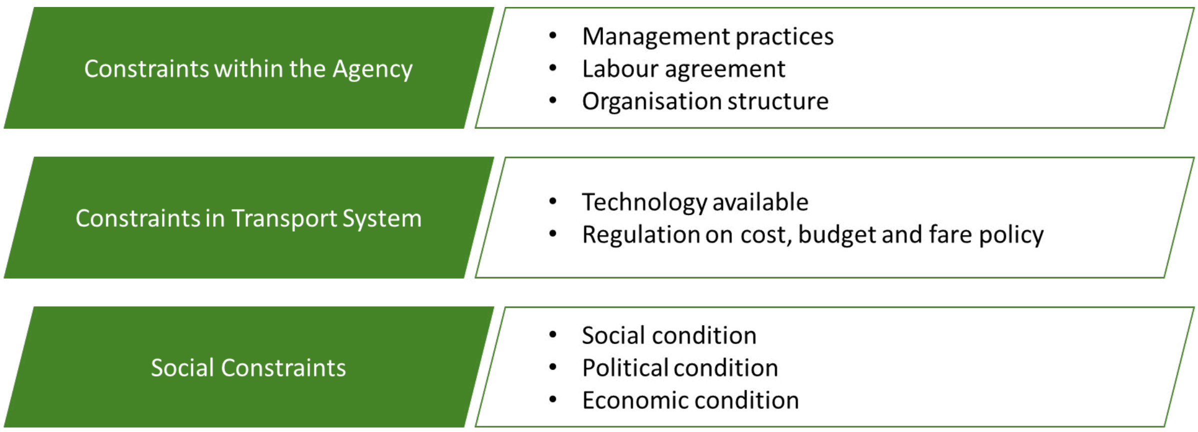
The fare policy environment encompasses a range of factors, including both goals and constraints, that influence the formulation and implementation of fare policies within a transit agency (Figure 8.1). The goals refer to the desired outcomes that the agency aims to achieve through its policy decisions. The transit agency's goal can be related to improving customer service, financials, management, politics, relationships and community. Meanwhile, constraints are limitations and challenges that transit agencies must consider while developing their fare policies (Figure 8.2). They can be related to the agency, transport system and society.

FIGURE 8.1 Goals of transit agencies that influence fare strategy



Source: Roy, S. (2013)

FIGURE 8.2 Constraints faced by transit agencies that influence fare strategy



Source: Barr, J. E. (1997)

The fare policy must strike a balance between meeting the goals of the transit agency while navigating these constraints. Policymakers need to carefully analyse and understand the fare policy environment to create a well-rounded and successful approach that benefits both the agency and its passengers.

8.2.2 FARE STRATEGY

The fare strategy encompasses various elements, such as fare levels, fare structure, integrated system and transfer pricing. The strategy is "to determine a tariff structure that reconciles the user's need for an affordable public service with the commercial interests of the operators while at the same time pursuing the authority's social objectives."[54]

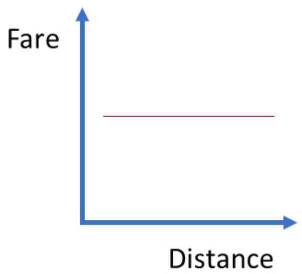
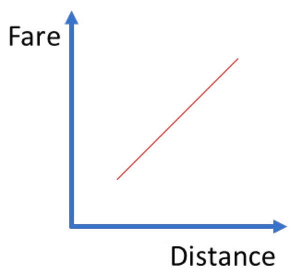
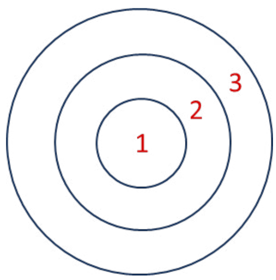
Fare Levels: Fare level is the amount of money charged to the customer for their journey from origin to destination, i.e., the unit fare to be charged per passenger kilometre. This is based on the overall policy of the organization about the level of system cost recovery expected, such as:

- Full cost recovery (both capital and operating expenditure)
- Full operating cost recovery (capital is funded by the government)
- Partial cost recovery (partial operating costs)
- No cost recovery (zero fare policy)

Affordability is an important criterion in fixing public transport fares. Carruthers et al. (2005) define affordable fares as when the amount spent on transport for 60 monthly trips as a percentage of average per capita income is less or equal to 10 per cent for the poorest 20 per cent of the population. Hence, government subsidies are very common in public transport.

Fare Structure: The fare structure refers to the way fares are applied based on different journey types. The fare structure should strike a balance between simplicity and fairness, encouraging ridership while ensuring a sustainable revenue stream for the transit agency. Generally, the fare is comprised of two components, the base fare and the incremental fare, which is charged based on distance. Three standard fare types are applied in public transport systems, as shown in Figure 8.3 below.

FIGURE 8.3 Types of Fare Structure

FLAT FARE	DISTANCE-BASED FARE	ZONAL FARE
		
The same fare is charged to the customer regardless of the distance travelled.	The fare is charged based on the distance travelled. The route is generally divided into slabs, known as stages. The fare increases with each stage is crossed.	The fare is distance-based. The city is divided into different zones. The fare within the zone is fixed and increases as zones are crossed in a journey.

Source: EMTA (2016)

In addition to these fare structures, certain aspects such as time-based fares (peak/off-peak hours), days of the week (weekday/holiday), service-based (air-conditioning/non-air-conditioning, express), market-based, consumer-based, or a combination of these approaches are considered while structuring fares. Furthermore, social or political considerations may lead the transit agency or local municipality to provide subsidies so that certain groups can have fare concessions or discounts, such as senior citizens, students, journalists, police, military personnel and veterans, and the differently abled.

Integrated Fare and Transfer Pricing: Integrated public transport systems may have uniform fares across all services or have varying fares for different types of services. The transfer pricing strategy should consider factors like the operational costs of different modes, the goal of encouraging seamless connections, the overall financial sustainability of the transit system, and the impact on passenger behaviour. In most cases, the base fare is more than the incremental fare, by an amount that is called the boarding fee. For an integrated fare, three types of transfer pricing can be applied for transfers from one mode/service to another:

- No transfer penalty (free transfer)
- Low penalty transfer (difference in the boarding fee)
- Transfer with a full penalty (full fare boarding in each boarding)

The fare strategy and structure are closely tied to the fare policy. For example, the full fare boarding structure is more profitable but may discourage users. However, fare-related decisions may not always be under the control of the transit agency. In some cities, fare-setting committees collaborate with transit agencies in formulating the fare strategy, and final approvals are sometimes sought from elected bodies at the state and local government levels. These committees play a crucial role in communicating vital information to decision-makers and obtaining the necessary approvals.

8.2.3 FARE DISTRIBUTION

In an integrated fare system, the fare is collected by a single entity for all journeys, so a mechanism to distribute collection is needed. Usually, the total fare collected would be less than the fare collected by individual operators during independent operations. Many public transport systems therefore use revenue allocation formulas to distribute fare revenue among different operators within an integrated network. These formulas take into account factors such as passenger volumes, distance travelled, service quality, and operational costs. Revenue sharing is considered after deducting 5 per cent administrative exchange. The equation governing the sharing of revenue is known as the Apportionment Ratio, which is the ratio of the fare on a particular service to the total fare on both services, which is then multiplied by 95 per cent of the integrated fare.

8.3 FARE COLLECTION TECHNOLOGIES

Fare payment systems for public transport typically involve various options and media to facilitate easy and convenient travel for passengers.

8.3.1 FARE OPTIONS

Fare options refer to the different types of tickets, passes, or payment plans available to passengers when using public transport. These fare options are designed to cater to various travel needs and preferences. Some common fare options available to passengers in public transport systems are:

- **Single trip** – The passenger purchases one ticket at a time for one trip. In many cases, this ticket would be purchased at the time of boarding and involves payment in cash.
- **Multiple trips** – The passenger can purchase multiple numbers of tickets at a time. This increases convenience for the customer, as he or she does not need to stand in the queue and purchase tickets every time they travel.
- **Period pass** – The customer is provided with a card or pass that allows them to conduct unlimited trips across the system or a route over a specific period, such as weekly, monthly or annually. Similar to multiple trips, this pass is convenient and is generally linked with concessions.
- **Stored value** – In the case of a stored value card, a certain number of rides or a certain amount of money is encoded on the card and deducted when a trip is made.
- **Post payment** – The passenger is charged by billing method for the journey after the trip is completed. This type of option is widely accepted by the transit industry with ITS technology development.

8.3.2 FARE MEDIA

Fare media refers to the various forms of payment that passengers can use to pay for transport services in public transit systems. Fare media can be physical or digital (Figure 8.4). Table 8.1 below compares the characteristics of different media.

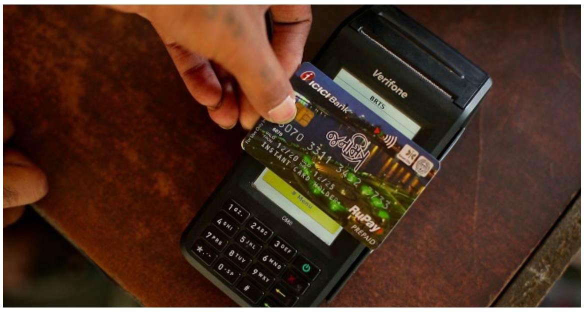
- **Cash** – Cash is still the most common medium of paying in most cities in Asia, but cash handling and providing exact change requires an interface such as a ticket machine or a person selling tickets.
- **Token** – Tokens are used for a single journey as an alternative to cash.
- **Paper tickets** – Paper tickets are widely used for single or multiple rides. Information can be encoded visually through a bar code, QR code, etc.
- **Magnetic ticket** – This type of ticket offers extensive flexibility to operators and passengers. It is generally used in systems which have gates and turnstiles to control access and egress.
- **Smart card** – This is becoming widely accepted media and facilitates fare integration. Debit cards, credit cards and transit vouchers may also be used as smart payment media.
- **Mobile Ticketing**–- Mobile tickets are digital tickets stored on a passenger's smartphone or mobile device. They are usually accessed through dedicated mobile apps or digital wallets. These tickets are shown as QR codes or digital barcodes that are scanned at fare gates or validators.

TABLE 8.1 Characteristics of Ticketing Media

CHARACTERISTICS	CASH	PAPER TICKET	TOKEN	SMART CARD	DEBIT/ ATM CARD	MOBILE TICKETING
Ease in using it multimodal transit system				√	√	√
Cost-effectiveness and sustainable				√	√	√
Service provider compatibility		√	√	√		
Ease of infrastructure implementation		√		√		
User-friendly to occasional users	√	√	√			

When evaluating various technological tools, a crucial factor to take into account is whether they operate in a closed-loop or open-loop manner. A closed-loop instrument functions exclusively within its system, while an open-loop instrument utilizes accessible tokens and processes that are not exclusive to the specific transport network. Historically, smart card systems have mostly been closed-loop. However, there is a growing preference for open-loop systems because they offer the advantage of integration with other systems. Figure 8.5 shows a ticket barrier in a Japanese metro station which accepts several different media.

FIGURE 8.4 Travel Card of Ahmedabad BRTS



Source: Centre of Excellence in Urban Transport, CRDF, CEPT University

FIGURE 8.5 Ticket reader in a Japanese metro station for IC card, ordinary paper ticket, smartphone ticket, and QR code ticket

Photo: Jenny Yamamoto

8.3.3 FARE COLLECTION

Fare collection in public transport is done through two methods. The on-boarding method involves passengers purchasing fare tickets from the conductor when they board the vehicle. In the case of smart card payments, passengers must tap their cards on the fare validator while entering and exiting the vehicle. On the other hand, the off-boarding method requires passengers to tap in when entering the transit system and tap out while exiting, typically using turnstiles or fare gates.

- **Fare Collection Equipment:** various devices and hardware used in public transport systems to collect fares from passengers. This equipment is designed to facilitate efficient and secure fare payment and validation.
- **Ticket Vending Machines (TVM):** self-service portals that are operated by passengers from where people can purchase various kinds of fare media by using cash, credit or debit cards. These can be used for any public transit mode to vend different types of fare media like tokens to smart cards. An automatic teller machine (ATM) can also be used as a TVM.
- **Ticket Validators:** equipment to validate or cancel a previously purchased ticket or pass. In the case of a ticket, the validator cancels the ticket so that the passenger can't use it later and for a pass, it will indicate the date when it can be used.
- **Ticket Office Machines (TOM):** used by agency personnel at locations where tickets are sold. TOM will take input from the operator about the fare that is being purchased and encode necessary information into some type of fare media (mainly paper tickets). It speeds up the sale process and helps in accounting.
- **Ticket Processing Units (TPU):** issue and accept magnetically encoded tickets, which are usually attached to the fare box. TPU can make the operator more reliable as a fare medium acceptor and improve the quality of passenger data.

- **Farebox:** used on vehicles to accept fare medium from the passenger, which is then deposited into a locked vault to secure it from theft. Most modern fare boxes are electronically registering fare boxes (ERFs), which count the fare medium deposited and verify that the appropriate amount has been deposited.
- **Fare gates:** control access to the transit system (rapid transit system). These comprise flap gates or turnstiles that accept the fare medium and store all medium deposited in a secure location within the equipment. Once the fare medium has been counted and/or verified, a gate is released or opened, providing access to the system.
- **Hand-held devices:** developed for the sale, acceptance, and verification of fare media by personnel on the system, such as ticket collectors/conductors/ ticket inspectors.

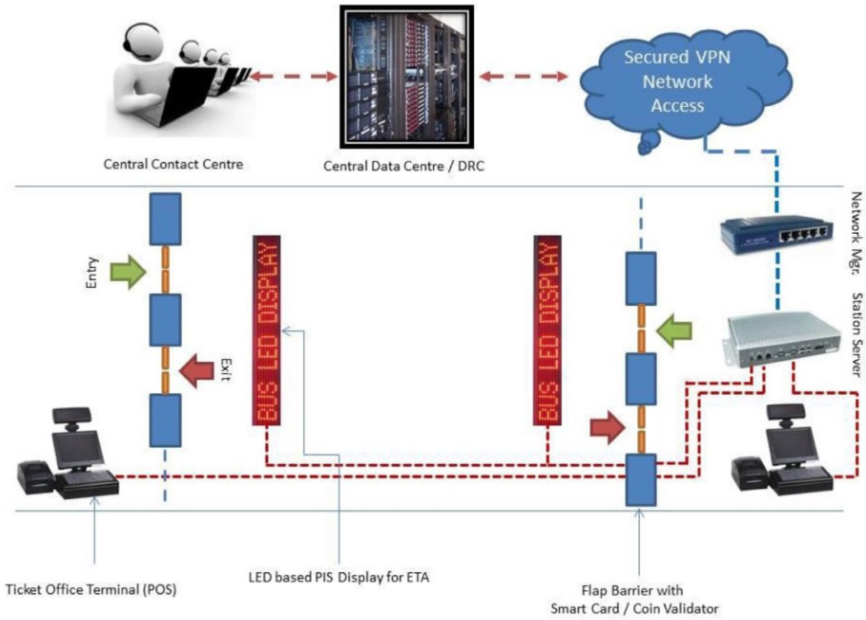
Automated Fare Collection System: An automated fare collection system (AFC) is a sophisticated and integrated set of technologies and processes used in public transport to automate the fare payment and ticketing process. It is designed to replace the manual fare collection method. Automated fare collection (AFC) provides an integrated system for managing tickets issued to commuters using various modes of public transport, including buses, metros, and railways (Figure 8.6). In addition to facilitating financial transactions, this system gathers valuable data that aids in monitoring performance and enhancing decision-making related to operational aspects. AFCs span different types of fare media, including:

- **Card-based:** The card-based AFCs can be either open or closed-loop. These used to be generally closed loop earlier, however, in recent years, open loop cards are also available.
- **Account-based:** Passengers no longer need to purchase tickets in advance. Instead, fares are calculated after the trip, providing the transit agency or operator the flexibility to implement fare capping or best fare-finding rules. The account-based ticketing system calculates the most cost-effective fare for each customer based on their travel, ensuring they are never charged more than necessary. This enhances the attractiveness of public transport, offering greater travel flexibility and the assurance of fair pricing for passengers.

AFC systems often consist of the following:

- **Fare media:** Printed tickets, tokens, magnetic cards, smart cards, contactless cards and wearable media.
- **Devices to read/write media:** Used for reading and writing the fare media such as ticket vending machines, ticket office terminals, fare gates, ticket validators, standalone validators, ticket processing units, handheld devices, etc.
- **Depot/station computers:** Used to concentrate data communication with the devices in the station or the depots and are generally used in the case of older AFCS systems, where communication lines are slow and unreliable.
- **Back-off ce systems:** Servers and software to manage the AFCS system. These include fare management, media management (which provides support cancelling lost or stolen cards) and reporting system (wherein periodic reports are made on the performance of the system in terms of the revenue details, messenger counts and movements).
- **Central clearing house:** When multiple operators share an integrated ticketing system with interoperable media, the central clearing house provides a system for the clearing and settling of funds, common reporting and revenue apportionment between the operators.

FIGURE 8.6 Components of the Automated Fare Collection System



Source: Swamy, H., and Ogra, V. (2016)

The automated fare collection system is not only to generate revenue, but it enables understanding of the travel behaviour of customers, which helps transit agencies and operators to improve the system and services. Smart ticketing enables us to combine various modes of public transport and offers users a seamless experience. This platform information is based on data gathered using artificial intelligence and conveys better options for travel, discounts and areas of interest in the vicinity of transit stations.

8.4 MARKET APPROACH TO FARE INTEGRATION

With technology advancing at an unprecedented pace, traditional cash transactions are being phased out in many cities across the globe in favour of electronic and mobile ticketing systems. The need to adapt to these shifts in technology is evident. Having one digital card that seamlessly works across all public transport systems seems like an ideal solution, but achieving this entails dealing with different service providers and significant technology and infrastructure upgrades. This highlights the necessity for a mobility card to streamline and standardize fare systems. For example, the National Common Mobility Card (NCMC) launched in India can pay for travel, toll duties (toll tax), retail shopping and also be used to withdraw money. It is expected that in the future, all transactions will be completed using mobile devices. In addition to mobile devices, fare validators, pole-mounted systems, and self-validation via mobile apps are emerging technologies that can streamline the fare collection process. Over the next few years, technologies will enable more passengers to self-validate, reducing the reliance on touch-based validation systems (Box 8.1).

However, this transformation requires meticulous planning as multiple transactions may accumulate over a day, necessitating end-of-day settlements. Interoperability of information is crucial for a successful fare integration system. Platforms like the Open Network for Digital Commerce (ONDC) can enable this by providing comprehensive details about transport services, retailers, and more. The effectiveness of such a platform depends on how well it can serve the public.

Fare integration must be taken beyond transport and integrated into our daily lives. Market players can add value to society by creating opportunities for seamless integration and making inventory visible to the market. This holistic approach can redefine the way we perceive and use the public transport smart card for various services apart from transport such as retail, leisure facilities, parking and so on. To fully realize this transformation, mobile platforms should be viewed as tools for meaningful change, rather than limiting our vision of technology.

8.5 MOBILITY AS A SERVICE

Fare integration is a key feature of Mobility as a Service (MaaS), a transport concept that is based on the idea of providing access to public transport, taxis, car-sharing, bike-sharing, and other modes, through a single digital platform.[60] Users can choose the most suitable mode of transport based on various factors, such as cost, travel time, comfort, and environmental impact. MaaS platforms also provide real-time information on the availability, location, and pricing of various transport options, making it easier for users to plan their journeys. While not a traditional public transport service, elements of MaaS can potentially be packaged with public transport services in partnership with private organisations, in particular to bridge "first and last mile" access issues.

8.6 SUMMARY

By unifying ticketing and payment methods, fare integration offers passengers the convenience of using a single ticket or card for various modes. This approach simplifies travel for commuters, encourages multi-modal trips, and enhances the overall passenger experience. Fare integration involves careful planning and coordination between transit agencies, operators, and other stakeholders to ensure smooth implementation and optimal revenue management. It can be achieved through various methods, including account-based ticketing, contactless smart cards, mobile ticketing, and fare capping to ensure that passengers are charged fairly and never pay more than necessary for their journeys. Overall, fare integration plays a significant role in modernizing public transport, promoting sustainable mobility, and making urban travel more accessible and efficient. For further examples of fare integration, please refer to Chapter 8 in ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Pacific.***

BOX 8.1 Will fare collection using biometric data ever become the norm?

Multiple Chinese cities, including Beijing, Shanghai, and Shenzhen, are utilising facial and hand recognition technology in public transport systems to enable payment via biometric data. Passengers can have their face scanned while passing the turnstile to enter the public transport network, and later the fare is automatically debited from their personal account, which is linked to their biometric data. A similar system is being tested at underground stations in Japan and the Republic of Korea. In Osaka, the metro is piloting a new device where the passengers walk through the gates without showing their tickets. While this new technology is said to improve efficiency a large amount of personal data is required from the user, prompting the need for a strict privacy policy. Its success will largely depend on what type of data will be collected by the operator and the willingness of passengers to share this data.

Sources: Chenchulin, D. et al. (2021); Lin (2019)

Photo: Ko Sagawa

Automated turnstile using face recognition technology in Osaka.

9

Gender and Social Inclusion

Female staff of Tashkent's metro system. Photo: iStock/Wirestock

9

9.1 PUBLIC TRANSPORT THROUGH A GENDER AND SOCIAL INCLUSION LENS

Mobility has a significant role in socially sustainable development as it supports access to health, education and employment for everyone, regardless of gender or physical attributes. However, many public transport systems can exclude certain individuals or groups due to the lack of attention given to their needs in the design of the system. For example, research has shown that limited transport options affect girls' attendance at school more compared to boys, as well as women's access to healthcare and other essential public services, contributing to higher rates of maternal mortality.

To promote equity in the integrated public transport system, it is crucial to acknowledge the role that gender plays in an individual's decision to make transfers[58]. Without addressing these requirements, women and other groups are prevented from accessing the full benefits provided by an integrated system. While the current chapter focuses on gender, many of the issues are common to other groups at risk of exclusion, such as children, the elderly, and people with disabilities.

9.1.1 WOMEN'S TRAVEL NEEDS AND BEHAVIOUR

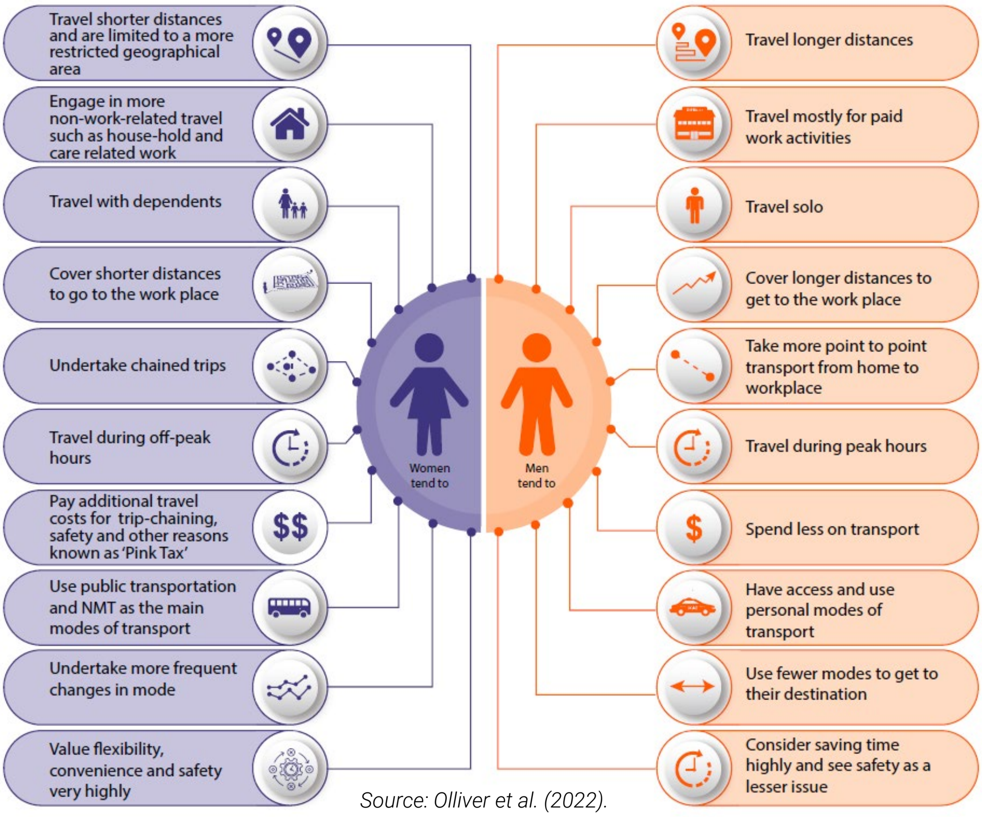
Past research has found that the travel patterns of women and men often differ (Figure 9.1). For example, in societies where women are expected to be the primary caretaker, a significant proportion of trips conducted by women are associated with maintaining the household. As a result, women structure their daily schedules around their work, the needs of their dependents, and shopping for household necessities. This is reflected in their trip patterns, which are more likely to be characterised by trip chaining compared to men, i.e., travelling to multiple destinations within a single journey. For example, in societies where women bear the main child-rearing responsibilities, women may drop off or pick up their children at nurseries and schools before or after going to work. As they undertake multiple trips, they tend to utilise various modes of transport and the expenses of their journeys increase. A study conducted by the Inter-American Development Bank in Latin America and the Caribbean states that over 50 per cent of public transport users are women, and more than half of their trips are for caring purposes and only 15 per cent conducted for work.[59]

9.1.2 WOMEN'S SECURITY AND SAFETY CONCERNS

Personal security is identified as one of the important factors in women's travel decisions as it can influence their mode choice, route selection and time of travel.[69] Public transport systems are sometimes "gender blind", in that they are designed without taking into consideration gender-specific barriers during access and egress, waiting times and experiences at stops, transfers, and when boarding and alighting, and their safety and comfort inside the vehicle.[61]

Women face violence and harassment in verbal, visual and physical forms while using public transport. A recent study conducted in Delhi indicated that 51 per cent of women have experienced harassment inside public transport vehicles, and 42 per cent experienced it while waiting at bus stops or stations). And ADB study of Tbilisi, Karachi and Baku found similar results.[62] As a result, the fear of harassment or victimisation of women and girls can influence their travel patterns. Women make minor modifications in their travel due to fear such as getting out of the vehicle at an earlier stop, moving to a safer space in a station or vehicle, standing with other women and using mobile

FIGURE 9.1 Differences in mobility patterns for women and men



Source: Olliver et al. (2022).

phones while passing through unsafe places.[63] Such fear can lead to completely avoiding the use of public transport and walking at particular times of the day, specifically at night, which can also limit their access to education, employment and other opportunities. The risk factor is related to the quality of public transport services: overcrowded services and unsafe waiting areas, stops and stations provide chances for harassment.

Safety is a concern for all genders in terms of safety of vehicles, traffic management, driving behaviour and infrastructure construction norms. Women who have dependents are less inclined to take risks when conducting journeys, which either discourages them from travelling altogether or compels them to rely on their private vehicles. In some countries, theft and other petty crimes are more likely to be reported than cases of sexual harassment because women are not confident to come forward and lodge complaints. Moreover, women who deal with multiple household responsibilities often lack the time to visit a police station and dedicate several hours to advancing their complaints. Also, women are sometimes discouraged from reporting due to the attitude of police forces.

9.1.3 SOCIO-ECONOMIC INFLUENCE IN TRAVEL PATTERNS

Socio-economic factors that influence travel patterns include age, gender, income, household size and car ownership. The travel needs and patterns of women from low-income households vary significantly from women in high-income households, pointing to a strong correlation between gender in transport and poverty in urban mobility.[65] An overarching concern present in every developing city is the cost of transport. In certain instances, disadvantaged individuals are compelled to choose transport options that are less convenient, comfortable and community-friendly due to their lower cost.

Poor women and children are more likely to forego the opportunity to travel if transport costs are high, which ultimately affects their livelihood. Transport services provide access to employment opportunities, especially for those travelling longer distances. However, affordability and increased transport costs are likely to restrict the geographic range of employment opportunities. A social evaluation conducted in Ashgabat, Turkmenistan, revealed that there were significant turnover rates in employment, prompting women to seek jobs closer to their residences to minimise longer commutes. It was observed that women were more likely than men to decline higher-paying job opportunities if the commuting conditions such as timing, duration and cost do not align well with their lifestyle.

9.2 ELEMENTS OF GENDER-RESPONSIVE TRANSPORT

9.2.1 SAFETY AND SECURITY

Improving infrastructure like walkways, cycling paths, and traffic calming measures to slow down traffic all contribute to increasing road safety. Safety can also be enhanced with good lighting and pathways with sufficient landscaping on approach streets and around stations and terminals (Figure 9.2). Mixed land use, commercial spaces and active spaces around the stations encourage people to utilise the area, thereby reducing isolated spaces. The presence of mixed-gender staff in metro, buses and stations and an effort to overcome overcrowding in transit systems would encourage women and other genders to utilise public transport.

FIGURE 9.2 Women walking along elevated walkway, Mumbai

Photo: Brett Cole

Segregation of men and women is another solution to tackle physical harassment. Several cities have introduced women-only bus services, coaches in trains, taxi and autorickshaw services, but these solutions should be seen as temporary, and efforts should be continued to address the underlying problems (Box 9.1). Technological solutions, such as journey planners, ride-hailing services, bike renting, transit ticket booking and so on, are expected to become more important to help women to access transport safely. In addition, an efficient complaint redressal system builds trust in the system and encourages people to report cases of harassment and others. Educational initiatives and raising awareness on gender sensitisation and transport-related applications should be implemented within communities, particularly targeting those who lack access to such resources but stand to benefit from them.

9.2.2 ACCESSIBILITY

Across the world, research has shown that women often conduct multiple trips in a single journey, with some part of the journey on foot. In developing countries, however, pedestrian infrastructure is poorly maintained, discontinuous and often encroached by other vehicles or users, so people are compelled to walk on the streets, increasing the risk of accidents. Hence, gender-sensitive transport

BOX 9.1 For women, by women – pink autorickshaw services in Indian cities

Following regular reports of sexual harassment and several shocking attacks on female passengers, "Pink Auto" (autorickshaw) services have been launched in several South Asian countries and cities, including in Kathmandu, Delhi, Mumbai, Surat, Pune, Bihar and Assam. These services are generally run exclusively for women and children, with either male or female drivers. The vehicles are equipped with panic buttons and GPS tracking services to enhance their safety.

For example, Surat Municipal Corporation (SMC) launched Pink Auto services in 2017. Through the Deendayal Antyodaya Yojana-National Urban Livelihoods Mission (DAY-NULM), SMC supported the Urban Community Development (UCD) by providing jobs for women. Ward-wise UCD community organisers visit and hold meetings with NGOs and community leads to promote the Pink Auto Project. SMC covered the cost of the training and licensing process, and also helped Pink Auto drivers to connect with aggregator service providers, thereby enhancing the lean period demand of the system. According to one estimate, the drivers can earn a fixed of Rs 8000 to 10,000 per month.

While the Pink Auto has been deemed a success in some cities, it has also faced several challenges. One report from Delhi described how the services were so popular that the waiting times drove people back to ordinary bus services. In other cities, services moved away from only serving female passengers due to lack of demand. In Pune, the President of Baghtoy Rickshaw Women's Union also questioned the government's focus on pink rickshaws, noting that it created disparities by treating female drivers differently from male drivers. But as long as women feel unsafe on ordinary autos, it is likely that the pink autos will continue to ply the streets of India's cities.

Photo: CEPT

Source: Swamy, H.M.S., Sinha, S., Hari, G.P., Jose, D. (2021); Review of Women-Only Auto Rickshaw Service in India (2023); Indian Express (2017); Indian Express (2024)

planning is needed to improve the entire travel experience of users. Well-lit and clear passages and social areas encourage women to use public transport as they perceive it as safe and convenient. Women travel with dependents more often than men and may be carrying children or packages while travelling, so escalators, lifts, reserved seats near doors, spaces for luggage, strollers and handlebars are useful. These facilities will also benefit other less able-bodied users, such as the elderly and people with disabilities. Public toilets and rooms for breastfeeding should be seen as part of public transport infrastructure. In addition, transit stops can also offer various amenities such as grocery stores, convenience shops, and childcare facilities.

9.2.3 OPERATIONS

To improve safety of public transport services, operators can ensure compliance with safety standards, provide training to frontline staff on customer service and safety protocols, and implement measures to address issues such as overloading and route deviations that may impact passenger safety. Moreover, emergency services such as emergency buttons, helplines and mobile-based reporting systems for emergency complaints, can enhance safety and provide reassurance to passengers. Regular audits may be required to ensure that they are in working order. Additionally, deploying rapid response teams at key locations can ensure quick intervention in case of emergencies or security incidents, thereby increasing the sense of security for all passengers.

9.2.4 WOMEN IN THE TRANSPORT SECTOR WORKFORCE

Gender diversity in the workplace not only benefits women, but also benefits societies, economies, the environment and enterprises themselves.[66] While it is becoming more common to see women in jobs such as taxi drivers, auto-rickshaw drivers, bus conductors and metro staff across the Asia and Pacific region (Figure 9.3), the management of the sector continues to be dominated by men while women tend to work in the lower-paid jobs. Jobs such as cleaning, which do employ many women, played a critical role in providing safe and healthy transport services during the COVID-19 pandemic. However, to achieve a more gender-balanced workforce and attract more women to the industry, operators should provide equal pay for equal work, flexibility to schedule working hours, basic amenities, space for social interaction, and managerial training programmes. They should also remove some of the major barriers to entry, such as limited access to capital, discriminatory attitudes, and unfriendly work environments, such as a lack of female restrooms in bus depots or offices.

FIGURE 9.3 Staff at Aluva Metro Station, Kochi

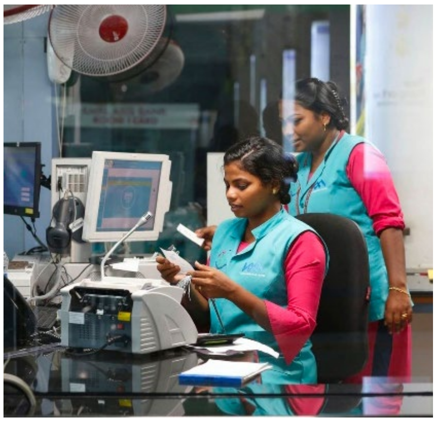


Photo: CEPT

9.2.5 DATA COLLECTION AND RESEARCH

Gender-based disaggregated data enables policymakers and stakeholders to understand the differences in mobility patterns and develop strategic actions for a gender-responsive system, including mitigation measures where the impact of new transport infrastructure or services negatively affect women and other genders. As women represent a diverse group, it is important to further disaggregate the data by age, socio-economic status, family composition and level of mobility.[67] Data can be collected through methods such as household surveys, surveys of users and non-users, traffic surveys, origin-destination surveys, electronic ticketing machine data and so on. Focus group discussions are useful for capturing differences in perceptions of safety.[68] Meanwhile, safety audits at stations and IPT stands can provide insights into the diverse needs, preferences and experiences of women, men and other genders. All new transport projects should systematically collect disaggregated data to see how they are affecting accessibility, safety and convenience for different user groups.

9.3 SUMMARY

A gender-inclusive transport system prioritizes the safety, accessibility and equitable treatment of all passengers, regardless of gender identity. Measures such as enhanced safety protocols, improved accessibility features, and gender-sensitive planning, create a more welcoming and secure environment for everyone. Through education and awareness campaigns as well as meaningful engagement with stakeholders, transport systems create greater equity and social inclusion within communities. These efforts can help build more resilient, sustainable and empowering transport networks that benefit individuals of all genders. For more examples of gender-sensitive transport initiatives, please refer to Chapter 9 in ***Integrated Public Transport Systems: A Compendium of Good Practices from Asia and the Paci ic.***

10 Way Forward for Integrated Public Transport Systems

Inside the Shanghai Metro. Photo: Jill Tip

10.1 KEY MESSAGES

Transport is key for a nation's development, fostering wealth, development, equality, and wellbeing. Public transport in particular offers mobility to all, regardless of socio-economic standing. The more widespread access to mobility is in a city, the more opportunities people have for contributing toward economic growth and increases in national GDP. Without efforts to develop integrated public transport networks, there is a danger that people's mobility will be oriented towards private transport modes, creating additional barriers and mobility inequality for people who are less able to access such modes, such as people from lower income groups.

Drawing on the chapters presented in this Guidebook, the key messages for policymakers are summarized below.

Customise Institutional Structures for Integrated Urban Land Use and Transport Solutions

Several models of institutional structures to develop integrated land use and transport solutions for urban areas were presented in the Guidebook. The first entails merging all agencies into a single unified authority, although this demands substantial political commitment and administrative restructuring. Alternatively, a more pragmatic approach is seen in the second model, where a single authority acts as a regulator, organiser, and coordinator of urban transport planning, allowing existing agencies to adapt their functions. In cases where local bodies handle planning and management, they must be legally empowered. Lastly, the fourth model relies on transit alliances to facilitate coordination without extensive restructuring. It is crucial to understand that there is no universal model. The choice should be tailored to each city's unique context, considering historical factors, governance structures, city size, modes and operators, political values, and administrative cultures. Customization is key to effectively addressing urban challenges.

Enhance Urban Development Through Integrated Land Use and Transport Planning

To cultivate a more efficient and harmonious urban environment, it is imperative to implement reforms that promote a cohesive relationship between land use and transport planning efforts. This can be achieved by treating urban and transport planning in two ways as a unified plan or reinforcing one another. Furthermore, encouraging Transit-Oriented Development (TOD) should be a key focus, by seamlessly incorporating it into local area plans and redevelopment strategies. To ensure that progress is both sustainable and equitable, it is essential to establish mechanisms for capturing the increased value that results from improvements in both land use and transport infrastructure. Additionally, it is important to create viable systems for distributing these benefits among the various agencies involved.

Optimize Urban Transport Planning for Long-Term Sustainability and Inclusivity

An effective approach to integrated urban transport planning involves a concentrated effort to identify and construct transport modes and networks that closely align with the current demand. However, it is equally important to consider the long-term suitability of these systems, as they are expected to serve the city's transport needs throughout their lifespan. Transitioning between rapid transit modes can be disruptive and time-consuming. Acknowledging that transport demand evolves gradually over time, it becomes essential to tailor the system to the right scale. In this regard, the introduction of a national framework for both bus-based and rail-based rapid transit systems can greatly aid in selecting the most appropriately sized transport mode for a given area.

Plan Effective Transport Operations and Leverage Interchanges

Operation strategy planning in transport is a dynamic process that involves the allocation of transport modes in a way that effectively matches the ever-changing demand, which can vary significantly across different spatial and temporal contexts. It is essential to acknowledge the vital role of interchanges in ensuring the success of integrated multimodal transport systems. These hubs serve as critical connectors, facilitating seamless transfer of passengers between various modes of transit. To maximise the benefits of these interchanges, it is imperative to foster the development of the areas surrounding them. This approach not only encourages higher public transport ridership but also presents opportunities for creating and capturing added value, ultimately contributing to the overall efficiency and sustainability of urban transport systems.

Revolutionize Public Transport with the Intelligent Transit Management System

The Intelligent Transit Management System stands at the core of all integrated public transport systems. By leveraging cutting-edge technologies and data-driven insights, ITMS empowers transit authorities to optimize resource allocation, enhance service efficiency, and elevate the passenger experience. Real-time monitoring, predictive analytics, and adaptive decision-making enable seamless coordination of various transit modes, reducing congestion, boosting ridership, and promoting a sustainable transport network. In the face of evolving urban landscapes and increasing mobility needs, adopting ITMS is essential for nurturing a smart, interconnected, and future-ready public transport system.

Fare Pricing for Balancing Cost and Affordability

Fare pricing in public transport transcends mere cost-efficiency considerations; it fundamentally represents a facet of public policy. While ensuring the cost-effectiveness of public transport is important, an equally significant factor is affordability. Striking a balance that allows for accessible fares while also sustaining the operational costs is crucial. Moreover, it is vital to recognize that the impact of public transport extends beyond its users alone. The benefits ripple through the entire community, contributing to reduced traffic congestion, environmental preservation, and enhanced urban accessibility. Therefore, examining the question of who pays for public transport becomes paramount. Policymakers should explore potential strategies to recover costs from non-users, ensuring that the financial burden is equitably distributed, and that the system's sustainability is maintained.

Integrating gender and social inclusion dimensions into planning processes and policies benefits everyone

Enhanced mobility for women and other gender groups can catalyse empowerment, enabling them to seize opportunities and surmount societal obstacles. Good access to transport opens doors to education and employment, fostering an uplift in their quality of life. Facilitating their movement not only expands their horizons but also promotes gender equality and socio-economic advancement. In this regard, all genders should have access to the same transport choices and services. Simplifying modal changes and increasing the presence of mixed staff on services can improve security and accessibility, while providing adequate facilities such as shelters and reserved seating at bus stops, stations, buses and metros can improve safety. Gender disaggregated data is needed to help policymakers gain insights into different customer groups and to identify the impact of new projects and interventions. Sufficient investment in public transport, infrastructure, digital technologies and planning can help make transport inclusive for everyone, including people with disabilities, different genders, elderly people, and children. These experiences should be captured and shared so that other policymakers and transport operators can learn from successful initiatives.

10.2 CONCLUDING REMARKS

Integrated public transport is a crucial strategy for achieving sustainability in cities. This Guidebook has introduced the main elements of an effective integrated public transport system. As discussed above, the process of integration involves several challenging tasks and is best approached incrementally, recognising the unique characteristics and needs of the local context. Critical issues include road safety and security, demand management, last mile connectivity, affordability, climate, environmental impact, universal accessibility, gender, social inclusion, health and well-being. It is also important to acknowledge that certain aspects of integration may entail financial investments. Policymakers will have to balance these financial considerations with their broader sustainability goals.

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