# URBAN PUBLIC TRANSPORTATION SYSTEMS

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## Contents





## Summary

Cities and metropolitan areas are centers of diverse activities, which require efficient and convenient transportation of persons and goods. It is often said that transportation is the lifeblood of cities. High density of activities makes it possible and necessary that high capacity modes, such as bus, light rail and metro, be used because they are more economical, more energy efficient and require much less space than private cars. Moreover, public modes of transportation provide service for all persons, while cars can only be used by those who own and can drive them. Thus, cities need and benefit from public transportation services, which offer greater mobility for the entire population than people in rural areas can enjoy. Transit systems are also needed in urbanized areas to make high-density of diverse activities, such as residences, business offices, factories, stadia, etc., physically possible, while keeping cities livable and attractive for people.

Urban transportation is classified into private, for-hire and public transportation or mass transit. This chapter covers public transportation systems. Transit modes are defined by their right-of-way (ROW) category, technology and types of operations. **Three ROW categories** are:

- **C - urban streets with mixed traffic**: Street transit modes include mostly buses, but also trolleybuses and tramways/streetcars.
- **B - partially separated tracks/lanes**, usually in street medians. Semirapid Transit, using mostly ROW B, requires higher investment and has a higher performance than street transit. It includes Light Rail Transit - LRT, as well as semirapid bus.
- **A - paths used exclusively by transit vehicles** comprise rapid transit mode or metro system. Its electric rail vehicles are operated in trains and provide the highest performance mode of urban transportation.

**Buses** are the most common transit mode. They operate on streets and have an extensive network of lines. In some cities they have been upgraded by provision of exclusive bus lanes and provision of bus preferential signals.

**LRT** represents the most common mode of semirapid transit. Its articulated electric vehicles operated in short trains on largely separated tracks provide more attractive and permanent services than buses at a much lower investment cost than metro systems require. LRT is presently being developed in many cities around the world that want to make transit services more efficient and largely independent of traffic congestion.

**Metro** systems have by far the highest performance - capacity, speed, reliability - of all transit modes. They require very high investment, but in the long run they are essential for efficient functioning and quality of life in large cities.
Rail transit modes have a strong ability to influence urban form and contribute to a city's livability.

Other modes, such as **Regional Rail** and **Automated Guided Transit**, are mentioned. Brief descriptions of **transit line scheduling procedure** and the **general approach to transit planning** are also presented.



## 1. Classification of Transit Systems

Urban transportation consists of a family of modes, which range from walking and bicycles to urban freeways, metro and regional rail systems. The basic classification of these modes, based on the type of their operation and use, is into three categories:

**(a)** ***Private transportation*** consists of privately owned vehicles operated by owners for their personal use, usually on public streets. Most common modes are pedestrian, bicycle and private car.
**(b)** ***Paratransit or for-hire transportation*** is transportation provided by operators and available to parties which hire them for individual or multiple trips. Taxi, dial-a-bus and jitney are the most common modes.
**(c)** ***Urban transit, mass transit or public transportation*** includes systems that are available for use by all persons who pay the established fare. These modes, which operate on fixed routes and with fixed schedules, include bus, light rail transit, metro, regional rail and several other systems.

***Urban public transportation***, strictly defined, includes both transit and paratransit categories, since both are available for public use. However, since public transportation tends to be identified with transit only, inclusion of paratransit is usually specifically identified.

Another classification of travel categorizes transportation as individual or group travel. ***Individual transportation*** refers to systems in which each vehicle serves a separate party (person or related group); ***group transportation*** carries unrelated persons in the same vehicles. The former is predominantly private transportation, the latter is transit, and paratransit encompasses both.

This chapter covers urban mass transit or public transport systems. First, basic characteristics of transit modes are defined, then their physical components are described. Further, operations and scheduling are presented and illustrated, followed by a brief review of transit planning and a discussion of the present and future role of transit in cities and urban regions.

### 1.1. Definition and Characteristics of Transit Modes

***Right-of-way (ROW) Category***, or type of way on which transit vehicles operate, is the most important characteristic of transit modes. There are three ROW categories:

- **ROW Category C** are public streets with general traffic.
- **ROW Category B** represents transit ways that are partially separated from other traffic.

Typically they are street medians with rail tracks, which are longitudinally separated, but cross street intersections at grade. Bus lanes physically separated from other traffic also represent ROW category B. This ROW requires a separate strip of land and certain investment for construction.

- **ROW Category A** is fully separated, physically protected ROW on which only transit vehicles operate. This category includes tunnels, aerial (elevated) structures or fully protected at-grade tracks or roadways. Thus, vertical position of the ROW is not as important as its separation from other traffic, because total independence of TUs allows many physical and operational features that are not possible on ROW categories B and C. Therefore, the modes with ROW category A are guided (rail, exceptionally rubber-tired) systems with trains, electric traction and signal control which offer very high capacity, speed, reliability and safety.

***Technology*** of transit systems refers to the mechanical features of their vehicles and travel ways. The four most important features are:

- **Support**: rubber tires on roadways, steel wheels on rails, boats on water, etc.
- **Guidance**: vehicles may be steered by the driver, or guided by the guideway; on rail, AGT and monorail systems drivers do not steer vehicles/trains, because they are mechanically guided.
- **Propulsion**: most common in transit systems are internal combustion engine - ICE

(diesel or gasoline) and electric motor, but some special systems use magnetic forces (linear induction motor - LIM), cable traction from a stationary motor, propeller or rotor, and others.

- **Control**: the means of regulating travel of one or all vehicles in the system. The most important control is for longitudinal spacing of vehicles, which may be manual/visual by the driver, manual/signal by the driver assisted by signals, fully automatic with driver initiation and supervision, or without any driver at all.

***Type of Service*** includes several classifications:

- By **types of routes and trips served:** Short-haul, City transit and Regional transit.
- By **stopping schedule:** Local, Accelerated (Skip-stop, Zonal) and Express service.
- By **time of operation and purpose**: All-day, regular service, Peak-hour service or Commuter transit, and Special service for irregular events (public meetings, sport events, etc.).

Transit system technology is often the most popular aspect of transit systems: people usually know what is a bus system, trolleybus, tramway, rapid transit or metro, regional rail, etc. Actually, among the three characteristics - ROW, technology and type of service - ROW is the most important element, because it determines the performance/cost relationship for the modes. It is the main criterion for the definition of three generic classes of transit modes, defined in the next section.

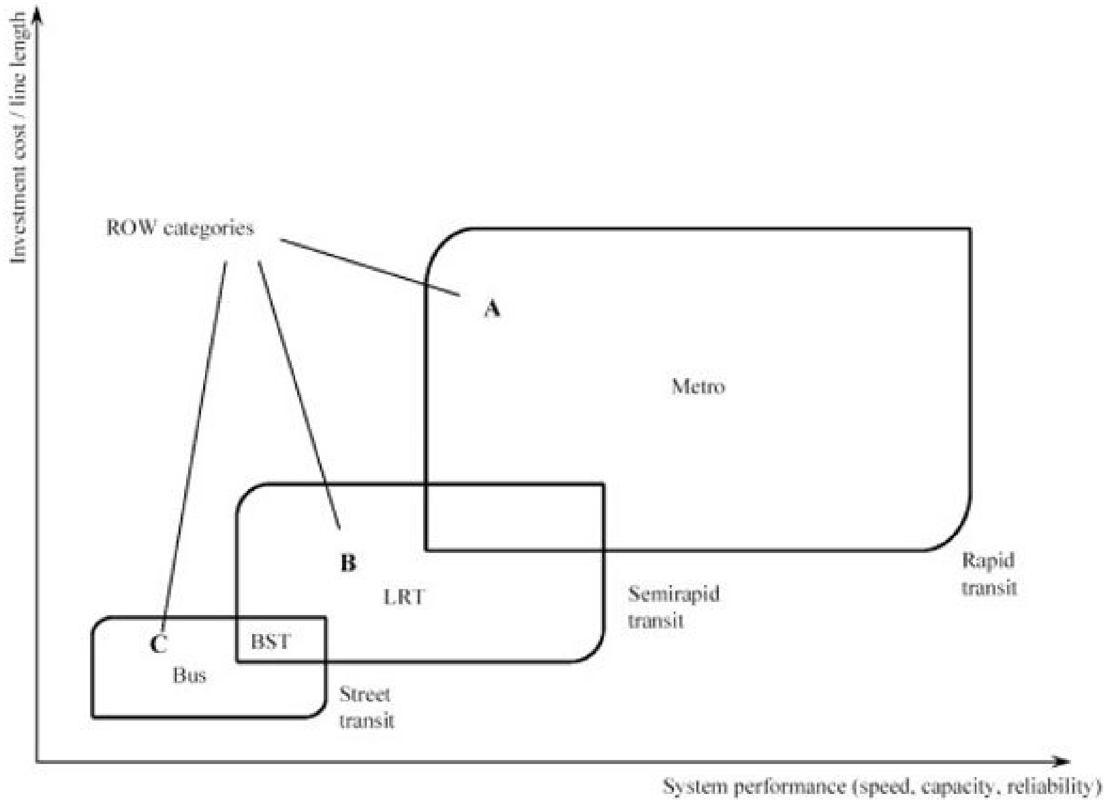


Figure 1: Right-of-way categories and generic classes of transit modes

### 1.2. Street Transit, Semirapid Transit and Rapid Transit

As described in the preceding section, the three ROW categories - C, B and A - define three generic classes of transit modes, respectively: Street Transit, Semirapid Transit and Rapid Transit. The diagram in Figure 1 illustrates this: it shows performance of transit modes on the abscissa, and their required investment cost on the ordinate. Performance is represented by the product of line capacity and operating speed; investment cost is in $/line-km. On this diagram it can be seen that street transit modes which have ROW category C require very low investment. They offer relatively low performance, however. Modes with ROW category B, semi-rapid transit, have a significantly higher performance, but they also require higher investment. By far the highest performance, as well as the highest investment characterizes modes with ROW category A: rapid transit or metro systems.

**Street Transit:** Most **buses, trolleybuses** and **tramways/streetcars** belong in this generic class. With operations on streets or ROW category C, transit requires very low investment (mostly for transit stops). However, quality of street transit services, particularly speed and reliability, depends on traffic conditions. Being slower than general traffic, transit can not compete effectively with private cars, unless other conditions discourage car use.

**Semi-rapid Transit:** With partially separated ROW, category B, the most common transit modes in this class are **Light Rail Transit - LRT** and **Bus Semi-rapid Transit - BST**. The latter has recently been named Bus Rapid Transit - BRT. This is an inaccurate designation because “Rapid Transit” represents by definition transit modes that have ROW category A on their entire routes, which is never the case with buses.

LRT tracks are usually in curbed medians or in reserved lanes, in park areas, sometimes on short flyovers or underpasses at major intersections, or in tunnels through high-density areas. Construction of these partially separated tracks, redesign of intersections to give preferential treatment to transit vehicles, separate stop or station areas, as well as special bus roadways, require considerable investment.

However, as a result of the separation and independence of transit from general traffic, its performance is distinctly higher: operating speed and reliability of semirapid transit service are greater than performance of street transit, and it is often competitive with or even superior to car travel. Moreover, operation of larger TUs is possible. TU or “transit unit” is a term designating a set of vehicles coupled together; it includes single vehicles - bus or rail - as well as trains of any length. **Rapid Transit**: By far the most dominant mode in this category is **Rail Rapid Transit - RRT, or Metro systems;** others are **Rubber-Tired Rapid Transit - RTRT, Light Rail Rapid Transit** (LRT with ROW category A only), **Automated Guided Transit - AGT** and **Monorails**, which may have different technologies, such as supported, suspended and others.

Due to fully protected ROW, category A - regardless of whether it is in tunnels, aerial or at ground level - rapid transit is by far the highest performance transit system. Independence from streets allows operation of trains with up to 10 cars, having capacity equivalence of 2-4 LRT trains or 15-25 buses. Operating speed is as high as the alignment of ROW physically allows, typically 2-3 times greater than the speed at which street transit operates. Consequently, rapid transit represents the highest performance passenger transportation in urbanized areas. Correspondingly, the investment cost for rapid transit is very high, typically several times higher than for semirapid transit.

Transit services on lightly traveled routes cannot justify large investments. Such services, typical for small cities and suburban areas, are generally operated by buses on streets (ROW category C). When passenger volume is greater and better service is needed, ROW category B is more effective. Once the investment in partially separated ways is made, it is logical to use a higher performance mode - electric rail transit. The logical choice is usually LRT, because it is more efficient in operations for large passenger volume, it attracts more riders, and its operating costs do not increase linearly with passenger volume (as is the case with buses).

Finally, for very large passenger volumes, which usually exist in big cities where there is no space for separate ROW on the surface, tunnels or aerial structures must be constructed. This is justified by the high usage of transit, required high performance and the need to use the limited land intensively. Once ROW category A is provided, the only logical technology to use is rail rapid transit: electrically powered trains can carry much greater passenger volumes at higher speed, comfort and safety than short trains of LRT; buses would be even less effective. Moreover, they are physically infeasible for use in tunnels because of the exhaust gases they produce.

Consequently, ROW category is generally a function of the quantity and quality of transit service required, and it dictates the technology and type of service that will be most effective to use. In other words, technology of transit systems is largely influenced by the ROW category: it changes from dominant buses on ROW category C to a greater use of trolleybuses and tramways as the passenger volume and required quality of service (performance) require. On ROW category B use of buses diminishes as compared to rail technology in the form of LRT. Finally, when transit systems with ROW category A are required, buses are eliminated because electric traction is needed, and long trains -- metro systems -- become a more logical choice than lower capacity, shorter LRT trains.

The positive impact transit has on the areas it serves is generally proportional to the required investment. Semirapid and particularly rapid transit have a much stronger image and attract more passengers than street transit, which is not strongly distinguishable from general traffic. With their permanence, rapid transit systems have a strong interaction with urban design and they often stimulate investments in areas around transit stations.

The following description of transit modes will be based on technology because their physical characteristics -- buses, rail modes and special systems -- will be described in separate sections. Each technological family of modes will be described by its components -- vehicles, ways, terminals -- and their operational characteristics will be defined, particularly as they differ due to the different ROW categories they operate on.

## 2. Bus Transit System

Buses represent the most widely used transit technology. Virtually every city in the world that has transit service operates buses. Large cities with rail transit also operate extensive bus networks, usually on lines with lower passenger volumes or as feeders to rail lines.

Bus service is easy to introduce or modify: basic service requires only purchase of vehicles, garage and maintenance facilities, and organization of service. Stops along the lines can be simple. Therefore, buses represent the most economical transit mode for lightly traveled lines. This flexibility of bus routes is an advantage for any necessary changes, but it is a disadvantage for major bus lines: they lack permanence, efficiency in carrying heavy passenger volumes, and image of permanent, physically fixed routes desired by passengers.

Compared to paratransit modes, bus transit is very labor-efficient: one driver operates a vehicle with capacity of 50-150 spaces. Compared to rail transit, buses are labor-intensive and have no economy of scale: on heavily traveled lines, for every additional 40-120 passengers, one bus and one driver must be added to the service.



### 2.1. Bus Vehicles

There is a range of bus vehicles by their size/capacity and body type. Main types are defined here.

A **minibus** is a 6-8 meters long vehicle, which has a capacity of 15-40 seats and standing spaces. It is used for lightly traveled lines, short shuttle lines, services in residential neighborhoods, etc.

A **regular bus** is 10-12 m long, 2.50 m wide. It has 30-50 seats and 60-20 standing spaces (minimum number of seats corresponds to the maximum number of standing spaces).

An **articulated bus** is a vehicle with the main body on two axles and an articulated section with the third axle. These buses are 16-18 m long and have a capacity approximately 50 percent greater than a regular bus. With their greater capacity, articulated buses are suited for heavily traveled lines. In a few cities with very heavy ridership double-articulated buses, with three body sections and four axles, are used.

**Double-decker buses** have two decks, the upper being for seated passengers only. Like articulated buses, double-deckers have a greater capacity than regular buses, but take less street space. They involve passengers climbing stairs, which is inconvenient. Riding on the upper deck, however, offers nice views for passengers. They are used extensively in the cities of the United Kingdom and many British Commonwealth countries, as well as in Berlin and a few other cities.

In selecting buses for a specific service, expected passenger volume is critical for vehicle design. Maneuverability and riding comfort are also considered. Thus, for lightly traveled bus lines in suburban areas with many narrow residential streets, or on hilly terrain, a minibus may be best suited because it is least expensive per vehicle-km, its small capacity is adequate and it can negotiate such alignments better than large buses. On the other hand, heavy passenger loads make regular or high-capacity buses more economical and superior in offering the required capacity. Average trip lengths influence the number and width of doors, as well as seating arrangement.

Relatively short trips and intensive exchange of passengers at stops requires two double channel doors on regular, 3 - 4 double channel doors on articulated buses, and single rows of seats on each side. For lines with moderate passenger loads and longer trips, 2+1 or 2+2 seating may be used. In the latter case, standing should be expected only in exceptional cases. In all cases access for passengers in wheelchairs is legally required to be provided by lifts, "kneeling bus" which can be lowered in the front, or by low-floor bus design.

**Low-floor buses**, perfected during the 1990s, have become standard in several industrialized countries. These buses have floors 35-40 cm above ground, so that entry from a curb is nearly flat, or a plate is provided for wheelchairs. Low-floor buses offer considerably greater comfort for passengers and speed up their boarding-alighting. Mechanical equipment on these buses is stored mostly on the roof, while the motor is in a compartment in the rear, where the floor is ramped up.

Most buses are powered by 4-, 6- or 8-cylinder diesel engines. To reduce air pollution, a number of new propulsion systems have been developed: "clean diesel," ethanol, methanol, propane and other propulsion is used. Some new engine designs, such as propane, are rather quiet, but noise and odor do remain disadvantages of diesel buses.

### 2.2. Bus Travel Ways

The vast majority of buses operate on regular streets, ROW category C. Being in mixed traffic, their speed and reliability of service depend on traffic conditions. Their average speed is lower than the average speed of cars because they stop to pick up and drop off passengers. Buses are therefore not very competitive with car travel in the same corridor with respect to speed and reliability. Their advantages are much lower cost and convenience of not having to drive and park.

To make buses more efficient and attractive to passengers, bus preferential measures can be introduced. These include the following:

- **Preferential signals**: buses in a separate approach lane at intersections get the green signal before other lanes, so that they can proceed through the intersection ahead of other traffic;
- **Alternating stop locations** at near- and far-side of intersections (before or after cross street) so that buses clearing one intersection on green signal use the green at the following intersection before they make the next stop. Also, spacing between bus stops should typically be about 250-400 m.
- **Exclusive bus lanes**, which may be curb lanes or lanes in the median - ROW category B. This is the most significant improvement measure because it makes buses

independent of traffic conditions on the same street.

- **Buses on high-occupancy vehicle (HOV) lanes or roadways** are used when bus lines with frequent service follow freeway alignment for a rather long distance. HOV facilities usually have traffic control that prevents congestion, but they do not provide the image of an exclusive, independent transit facility.
- **Busway** - special roadways reserved for buses only (ROW category B or A). Since busways require very high investment costs, they are used for some sections of lines. If ROW category A is required for a large section of line, it is usually better to introduce a rail system, so that the investment in high quality ROW is better used for electrically powered trains, rather than single bus vehicles.

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**Biographical Sketch**

**Dr. Vuchic** is a UPS Foundation Professor of Transportation in the Department of Electrical and Systems Engineering at the University of Pennsylvania. He obtained his diploma in Transportation Engineering from the University of Belgrade in his native country of Yugoslavia (1960) and then the M.Eng. and Ph.D. degrees at the University of California at Berkeley (1966). In 1960-61 Dr. Vuchic worked for the Transit Agency in Hamburg, Germany, then for Wilbur Smith and Associates in New Haven, CT. In 1967 he joined the University of Pennsylvania and initiated the graduate program in Transportation Engineering. He is a member of ASCE, ITE, TRB and UITP. Dr. Vuchic has been consultant to US Department of Transportation, cities of Belgrade, Edmonton, Lima, Naples, Perth, Philadelphia, Rome, as well as to many transit agencies (Buffalo, Caracas, Chicago, Manchester, New York, San Francisco, Toronto and others). Dr. Vuchic has presented major seminars to Ministries of Transport, lectured at about 70 universities, at many professional conferences and scientific institutions. He made presentations in major transit agencies, at the Congresses of the International Union of Public Transport, annual meetings of APTA and its German counterpart, VDV. Dr. Vuchic has authored about 140 reports, book sections and articles published in the U.S. and foreign countries, mostly on various aspects of urban transportation. His book *Urban Public Transportation Systems and Technology* (Prentice-Hall 1981) contains descriptions, analyses and design aspects of bus, rail and other transit modes. In 1982 he became the first recipient of the "Dr. Friedrich Lehner Medal" in Germany, given to "persons who have dedicated a life work to urban public transportation and excelled in that effort". In 1990 he was awarded the University of Pennsylvania's UPS Foundation Chair in Transportation. In 1994 he was elected Foreign Member of the Serbian Academy of Sciences and Arts. His latest research, focusing on an international comparison of urban transportation systems and policies, has been published in the book *Transportation for Livable Cities* (CUPR, Rutgers University, 1999).