Chapter 2
Public Transport in the Era of ITS: Forms of Public Transport

Kjell Jansson, Ingmar Andreasson and Karl Kottenhoff

This chapter describes the characteristics of public transport systems, seen as a *system*. With public transport system, we mean mainly the technical system of different modes of transport including vehicles and infrastructure as well as their characteristics, such as capacity in various traffic concepts. Maybe, most importantly, the concept of a system means that the various lines and modes are not self-contained entities, but they are used in combinations, where the travellers regard alternative ways of going between points. These combinations give rise to positive network effects, which can be taken care of in integrated systems.

A major distinction between PT and other forms of transport is on the provision of both facilities (vehicles and/or infrastructure) and services. Except for some hybrid types of PT [e.g., on-demand transport, dial-a-ride (DAR)] which are introduced in Chap. 8, most public transport services are scheduled. This means that operators publish timetables for various times of the day and various times of the year.

The integration of components forms the system. It is important to discuss first, in this chapter, aspects on organisation of public transport, as organisational forms determine the level of service, costs, fares structure, possibilities for service integration and for introducing ITS for integrated planning, ticketing, etc.

Forecasts of how many people will travel by public transport in the future are normally based on the development of population, social and geographical conditions, as explained in Chap. 1, but also on the structure of public transport, standard and passengers' valuations of the supply. In order to understand how to model and then forecast passenger flows, we need to have a basic understanding of how the service is designed, especially the forms of PT networks implemented in practice,

I. Andreasson
LogistikCentrum AB, Osbergsgatan 4A, 426 77 V Frölunda, Sweden
e-mail: ingmar@logistikcentrum.se

K. Jansson (✉)
Riksrådsvägen 22, SE 12838 Skarpnäck, Stockholm, Sweden
e-mail: kjsek@hotmail.com

K. Kottenhoff
Dept of Transport Science, KTH, SE-100 44, Stockholm, Sweden
e-mail: karl.kottenhoff@abe.kth.se

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and how to assess the performance of such networks. In order to plan for good service, we need to know in fact how people value travel, frequency, comfort, etc. If we start with the perception of public transport, it is not certain that we perceive the supply in the same way or even as it is in reality.

This chapter starts with the discussion on organisational forms and gives an overview of the products of public transport available in practice. An overview of the vehicle technologies available completes the description of the product types. Then, the chapter describes the network forms and design dilemmas arising from the interaction between products offered and urban and regional mobility patterns. Finally, it concludes with a high-level description of how infrastructure, network and vehicle technology choices translate into supply capacity offered to the PT users.

2.1 Organisation and Products

2.1.1 Regulation Versus Deregulation

Local and regional public transport is, at least in industrialised countries, owned or supervised by a local or regional public authority. The operation can be public or private, in the latter case, under free competition or procured by the authority through competitive tendering.

Three common types of organisational forms are as follows:

- Traditional: The authority defines and runs the services.
- Restricted competition: Authorities define the services that will be delivered by operators, who compete to get contracts (competition for the market).
- Deregulated system: The operators can freely establish PT services and thus compete for customers (competition on the market).

Some European countries still apply a traditional system where the authority itself operates the services (Fig. 2.1). This classical European solution is characterised by

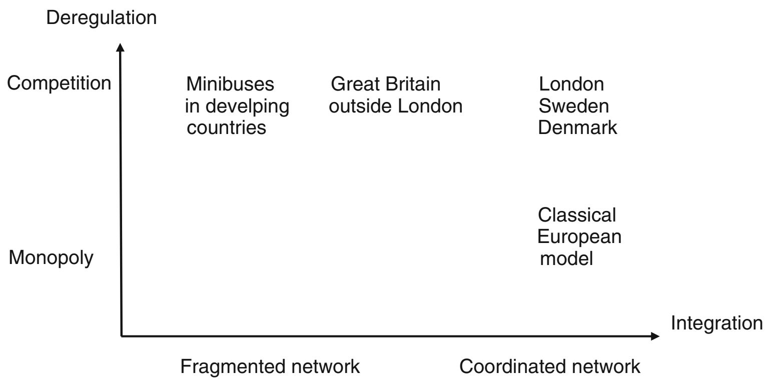

Fig. 2.1 Monopoly versus deregulation and fragmentation versus coordination

monopolies with good coordination, but often also with high operation costs. Other countries, and London, apply restricted competition through competitive tendering. UK, outside London, has a deregulated system of local and regional public transport. Even in Britain, there is restricted competition in cases where commercial operators do not provide service that the authority considers essential.

In local and regional transport, there is a variation with respect to fare competition. In some local or regional areas, there is one authority in charge of all public transport, allowing the passengers to transfer for free between any lines and modes. In other regions, several operators may compete. There may be one metro operator, one commuter rail operator, several bus operators, etc., between which transfers are not normally free of charge. This situation is common, for example, outside London (UK) in some other European regions, and especially in developing countries. There are examples where the regional authority has engaged in trying to make operators cooperate. In UK, there are examples where passengers can buy one pass for travelling with one operator, and another, more expensive pass, for travelling also with other operators.

The trend in Europe is to introduce more competition. A concession is a contract that is granting the right to operate a subsidiary business. It can be a form of less restricted competition, similar to a deregulated system, but with just one operator in each area.

Introducing deregulation does not always increase the efficiency and overall satisfaction from the PT users. It brings issues to the management of the whole system (i.e., guaranteeing standards and quality of all its components have reliable information of all sub-systems, etc.), economical (fare revenue allocation, subsidising), technical (duplication, reliability and permanence of services, services for special user groups, etc.), and societal (safety conditions may differ from company to company). The two sections below describe some experience from UK and Sweden, where deregulation has been most fostered.

2.1.1.1 Deregulation in UK

In 1984, the government of UK approved the London Transport Act, in which it was established that any transport company outside London city was allowed to obtain a bus service licence and therefore offer public transport service to the citizens. With this act, UK introduced for the first time the abolition of road service licensing and allowed for the introduction of competition on local bus services. The main motivation for introducing such a liberal policy was to remove the inefficiencies of the regional and interregional systems due to over-regulation, and due to lack of competition.

According to this act, two bus service types could be provided: commercial and subsidised. In 1985, the operation of new private bus services was established through a tender for the first time and, for a number of years, buses holding a variety of different colour schemes operated alongside those still operating in the traditional red paint. The variety of services was found to be confusing to users expecting to find red-painted buses and, after lobbying from the tourist board, it became a requirement when contracts were retendered that bus colours must be predominately red.

The integration of the different services was under the responsibility of the London Regional Transport, which in 2000 was replaced by the current Transport for London agency, as a consequence of a revision of the Act in 1999 (Greater London Authority Act), after an assessment of the previous deregulation principles was performed, which showed many structural issues.

Having no control on the commercial services, many lines, which were giving low profits to the companies, were discontinued, causing major issues for the citizens as geographical coverage was getting more and more uneven. On the contrary, tracks where high demand was observed were served by many companies, which were competing to offer the fastest and most profitable service. This was the case of the interregional service between London and Manchester, where buses of different companies were engaged in famous *bus wars* (fake inspectors sent in competitors' buses to push customers away, speeding to overtake each other, etc.), which required the intervention of the authorities to avoid the snowball effect of the dangerous situations happening.

Beyond the above issues due to competition, the results of deregulating the PT system were not positive as expected. Although operating costs were lowered by 42 %, PT users decreased dramatically (−27 %) and fares generally increased (+17 %). Negative outcomes were also observed in system performance measures, such as increased distances travelled due to more commercial services using minibuses.

Nowadays, with the Act of 1999, a softer approach is applied. There is first of all a "Quality Partnership" between road authorities and PT operators: the operator agrees to run or improve a service according to some targets and, in return, gets benefits in terms of infrastructure concessions, expansion and renovation investments. Such contracting sets also specific contractual terms aimed at offering multimodal services and assesses performance in terms of total passenger flow served, which forces services to cooperate and coordinate with each other.

2.1.1.2 Deregulation in Sweden

Since January 2012 in Sweden, the market for PT in regional transport has been opened for commercial operators who can compete with the operations in charge of the regional authorities, as consequence of the new Public Transport Act ("Den nya kollektivtrafiklagen", prop. 2009/10: 200). This Act means that any operator is allowed to compete with the operator in charge of the regional public transport authorities. The main objective of the Act is to benefit the passengers by providing a supposed variety of services.

In one sense, this new Act may be seen as following the British deregulation from 1986, but might also be seen as even more liberal, at least when comparing with the current applications of deregulation in UK. New commercial operators may announce entry or exit of the market only three weeks in advance. There are no requirements at all concerning fares integration.

The question is, whether this new scheme may be financially viable for the commercial operators and whether it may be a good idea from a welfare point of view. The Swedish Ministry of Enterprise, Energy and Communications has given to the government agency Transport Analysis (Trafikanalys) the task to evaluate the evolution. It was found from a simulation study that very strong conditions must be available for commercial lines to be profitable and provide a positive welfare effect. Moreover, the impact of new bus operation was found very marginal: with respect to ordinary regional public transport, there appeared in fact only one non-subsidised commercial line in operation, a bus line in Stockholm operating from February 2012 but laid down in January 2015 due to low demand.

Principles for a level playing field with respect to access to infrastructure—stops, transfer points, depots, etc., as well as models for more effective contracts, are being worked on in the industry. Nevertheless, tentatively the Swedish form of deregulation in local and regional public transport will probably be no great success, especially since private operators have to compete with subsidised services in the hands of regional authorities.

2.1.2 Integration Issues

The different forms of regulation/deregulation made it necessary to deal with the problem of integrating the different services. First and foremost, integration is needed to avoid competition on high-demand routes, at the expense of a sufficient level of geographical coverage. A second important reason is to guarantee that the users see PT as a seamless service, in order to increase the shift from the private car mode. PT integration is nowadays not only about sharing information about timetables, and coordination of services, but has also been extended to include the fares system. This is done to provide the users with a unified fare system and a unified image and in turn increase the efficiency of PT use and increase the total ridership.

Integration brings, however, a number of questions, which are not easily answered and depend on the specific case:

- How to determine an effective integration in terms of responsibilities, coordination, synchronisation, fair operating ratio, etc.?
- How to guarantee a reliable commitment between companies?
- How to assess the quality of each operator? How to control the data concerning their performance, and which indicators and metrics could be unbiased?
- How to fairly redistribute revenues?

It is easy to understand how complex the problem of assessing the performance of an integrated system and of redistributing the revenue is, especially in complex systems aiming to integrate local and regional services. One can think, for example, of their main functionality, which for some company can be to cover the main connections (e.g., interregional services), while for some other can be to act as complementary service (e.g., local bus lines). It is clear that the good performance of the latter strongly affects the attractiveness of the former, so the high passenger flows carried on by the main connections may not be achieved without the good performance of the local operators.

After ten years of deregulation in the UK, integration made a big return with the new Labour administration of 1997, but the progress towards seamless and integrated transport has not been smooth.

It has been argued that the short-term, non-strategic model of competition adopted in the UK inherently acts against integration. This suggests that current levels of integration are sub-optimal and that the implementation of integration measures would generally be beneficial.

Currently, the vision of many European countries (e.g., France, Sweden, Germany, Denmark, Belgium) is to split up the integration problem into two sub-problems, managed by two different authorities:

- Tariff and infrastructure integration is left to the infrastructure managers, in charge of distributing and allocating infrastructure capacity to the undertakings, who charge the users, elaborate safety regulations and technical standards, and analyse and assess the passenger flows to evaluate the efficiency.
- Operations are left to the operator managers, which provide commercial services to the customers according to tendering processes and agreements with the infrastructure managers, which are normally reviewed regularly (1–5 years).

2.1.2.1 The Asymmetric Demand Aspect

Apart from the integration issues, which arise in a competitive market introduced by the deregulation policies, the asymmetric demand makes the coordination of lines a very complex problem. Here is an illustrative example.

Assume that a welfare maximising public transport authority (PTA) and a private profit-maximising operator, respectively, are considering to invest the same resources on a new line, either line 1 (Fig. 2.2) or line 2 (Fig. 2.3). Assume also that the investments result in the same reduction of generalised cost, from G^0 to G^1, leading to demand increase from x^0 to x^1. For simplicity, prices are assumed to be the same on both lines. The operators' choices depend on expected demand response, partly due to transport substitutes.

Apparently the profit-maximising operator will invest in line 2, where the profit, equal to the dark rectangle, is much larger for line 2 than for line 1.

The authority on the other hand will invest in line 1. The reason is that a welfare maximising authority takes into account the sum of the profit area and the consumer surplus, the light area, and this sum is much larger for line 1 than for line 2.

Besides the welfare issue, there may also be distribution consequences. The private operator will invest in a line where passengers are sensitive to level of service. This may concern areas where many have access to car and may shift to public transport if the line is improved. The authority on the other hand invests in areas where passengers are less sensitive to level of service. The reason for which can be low car ownership or low incomes.

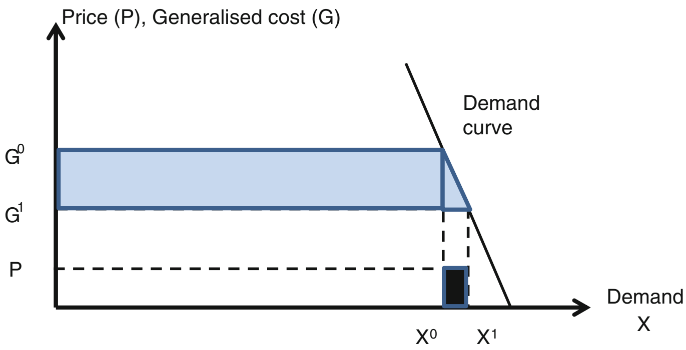

Fig. 2.2 Line 1 with low elasticity with respect to generalised cost

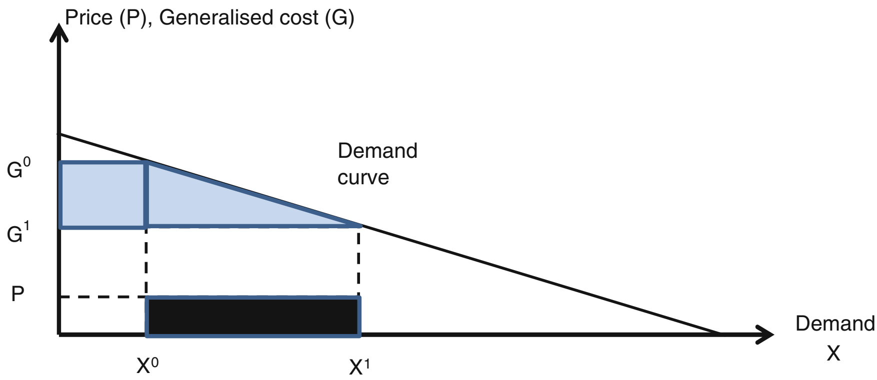

Fig. 2.3 Line 2 with high elasticity with respect to generalised cost

2.1.2.2 Competition Among Lines on a Network

Two examples are provided to explain issues that arise by connecting lines in a network.

With on the road competition, a private operator may leave out a section of a line it could operate profitably. Assume it operates *a*–*b* and *c*–*d*, but does not operate between *b* and *c* (Fig. 2.4). The PTA may find that this gap in service is not good from a welfare point of view, and decides to procure the section *b*–*c* by use of competitive tendering. It is then probable that the operator will win the bid rather than its competitors due to the advantage of already operating *a*–*b* and *c*–*d*. And its profit may be even higher than if they operated the section in the first place under "on the road competition".

Some people have argued that private profit-maximising operators would create a better functioning public transport than would a public authority. Nash (1978) questions this by comparing a welfare maximising and a profit-maximising operator, concerning one line. Here, the issue is analysed for a network, even though a

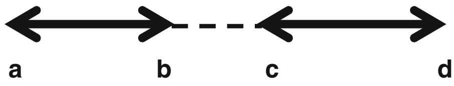

Fig. 2.4 A section left out of service

simple one, where the interaction between demands for various lines becomes a crucial matter.

We assume there is originally an existing line, E (which may be public or commercial and be thought of as part of a network), operating between points *a* and *c*, via point *b*. The question is, whether the introduction of a new commercial line, N, would improve welfare. This line N is partly "parallel" with line E, operating between points *b* and *c*. Some of the passengers, group E2, who travel on the section between point *b* and *c* on line E, are attracted by the new line, giving line N the demand N2. Figure 2.5 illustrates the network.

By use of a numerical example, Jansson (1997) found that the entry of the new line N may reduce the welfare level and yield profits for the two operators together that are smaller than the profits of line E before the entry of line N, even in the case the new line N would make a profit. This holds both if line E is public or commercial. The simple reason why this may occur is that when line N has "stolen" passengers from line E along the section *b* to *c*, the operator of line E finds it optimal to reduce the frequency of this line. This will harm the level of service for those who use line E and also reduce its revenues more than its costs.

2.1.3 *Public Transport Products*

A public transport product is a term that focuses on the offering that is put on the transport market. This offering includes a public transport supply with certain characteristics for the customers. Example of products is easily seen in the rail sector where *InterCity, Thalys* and *X2000* all are brand names for specific products. In local and regional public transport, the names often denote wider products such as *express, Metro, bus rapid transit* (*BRT*) and buses with high level of service

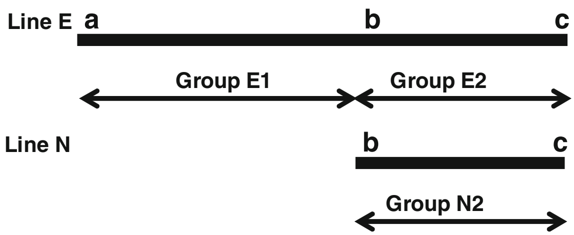

Fig. 2.5 A simple network with *lines* E and N

(*BHLS*). For example, *Metro* is an abbreviation of metropolitan, and the name of many products and services related to urban areas, especially public transport systems.

The PT system consists of vehicles which operate on an infrastructure; this consists of road or railway tracks, with stops/stations (Fig. 2.6). The operator offers its customers a combination of this system and the service and information provided to a certain level of quality, represented by the operating speed, the frequency of a service, etc. Finally, the service is offered at a certain price and complemented with additional services such as static and/or real-time information.

When a public transport product should be designed, there are four dimensions service providers need to define. These are set by answering these questions:

- Which vehicle technology to invest in?
- What infrastructure is optimal/feasible?
- Which network of lines and connections should be developed?
- Which service level to offer to the customers?

These questions are not easily addressed, and they represent the building blocks of the *design dilemmas*, which will be described more in detail in this chapter. Usually, these dilemmas are solved by local (national) authorities, and often solutions are country-specific.

2.1.3.1 Local and Regional

The local and regional public transport market includes, for example, trips to school, work, purchasing and health care. These markets aim to cover two broad categories of trips:

- Local trips, e.g., trips within the same urban area, typically shorter than 10 km and with an average trip duration of no more than 30 min. Typically, everyone takes at least one local trip daily. In European cities, the distribution of local trips is shared between car, public transport, walking and cycling.

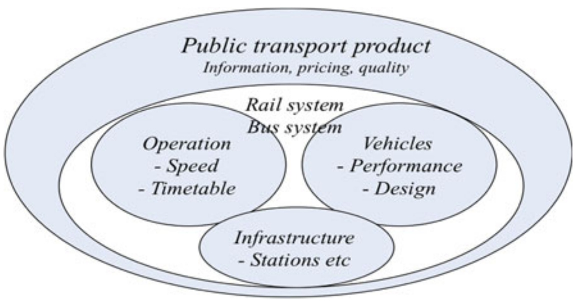

Fig. 2.6 Public transport products, See (Kottenhoff 1999)

- Regional trips are trips from one urban area to another within a region. These are trips that are almost always less than 100 km with a maximum of 1-h travel time. In broad terms, about 40 % of the population in Europe makes a regional trip daily. The average travel length is 20–30 km and the car dominates as mode of transport in this range. The bus dominates among public transport, but the rail has a strong position in some areas where train, metro or light rail services are attractive.

In medium and big European cities, each citizen makes about 200–400 public transport journeys per year (look back at Fig. 1.7). The capitals often have about 350 journeys, one way, per inhabitant and year, but some Swiss cities have even higher public transport use. The public transport share is higher to and from the city centre than for other journeys in the urban region. For example, in Stockholm the share for public transport in comparison with all motorised journeys is almost 80 % for journeys towards the inner city, in the rush hour. For other journeys in the Stockholm region, it is much lower. In some cities, there is significant competition from biking, for example, in Holland and Denmark and biking share is growing in many European cities. There are also attempts in Europe to integrate different forms of transport, for example, bike and public transport or car sharing and public transport. For this reason, so-called Mobility Centres are established in some places.

2.1.3.2 Interregional

The interregional (long distance) market can be defined in different ways: according to the actual demand, according to case, geography, competition, etc., the market can be defined on the basis of the following:

- Travel need, for example commuting, services, leisure.
- The person's time budget, which imposes restrictions.
- The transport systems that provide opportunities to satisfy travel needs in different ways.

Interregional travel can be defined as travel that takes more than an hour and almost always involves journeys of more than 100 km (about 300 km on average), and journey time is usually 3–6 h, which means that no one makes an interregional journey daily. The distribution of interregional trips by transport mode varies both with the traffic base and with the standard of public transport in the various counties. Even if there is a general correlation between increasing size of population centre and increasing travel by public transport, there is also a wide variation depending on supply, tariffs, etc.

The car is the most widely used means of transport due to the high proportion of leisure and holiday journeys, but public transport has a strong position over longer distances, where also rail, air and bus compete with each other. The train is the predominant form of public transport. Interregional travel by public transport is mostly recreational and business travel. Interregional public transport mainly serves travellers a few times a week or a few times per year. The distances are longer, and the vehicles used are different from those used for local/regional transport. Here, we have intercity trains, high-speed trains, coach services and airlines with higher speeds and fewer stops. Dependent of purpose of journey, stop pattern, valuation of travel time and available income, travellers choose mode or combinations of modes.

To manage an interregional journey over a day and have time to do a work-related activity at the destination lasting at least 6 h (e.g., a meeting during office hours), the trip must take no longer than 6 h in order for all this to be done in the time one is awake is usually awake, i.e., between 06.00 and midnight. An interregional journey over a weekend may take slightly longer and a holiday of course even longer.

Interregional public transport is sometimes privately owned and commercial. But even if it is private and commercial it is, as mentioned, a system, irrespective of whether the various operators of lines and modes compete or sometimes cooperate. Cooperation may mean that operators offer combination tickets.

2.1.4 Multimodal Transport

2.1.4.1 Competition Between Modes

The choice of transportation for local, regional and interregional travel varies greatly; the choice of the right vehicle technology to invest on is clearly dependent on the length of the journey. Variations are also due to supply, price, quality, service, etc. Quite naturally, the train and air travel increase their market shares the longer the distance, while the car decreases. The bus has its largest market share over medium distances. In long-distant transport, the various public transport modes, such as rail, coach and air often compete with each other for customers. There are also often several operators within each mode that compete with each other. Competition can appear in terms of ride time, comfort, frequency of service and fare. With respect to fares competition these are often based on revenue (yield) management, which means that fares can vary substantially between days and even within days.

The so-called path-time diagram can illustrate the competition between modes in terms of speed. In a path–time diagram, the path is represented by the distance on the horizontal *x*-axis and the journey time by the time on the vertical *y*-axis. By adding in typical terminal times and the average speeds of different modes of transport, we can see which mode is the fastest over different distances and also in a simple way illustrate changes in supply in the transport system.

Competition for interregional travel between 100 and 600 km is broadly shown in Fig. 2.7. At the starting point, the train travels in the backbone network at an average speed of 85 km/h, and we estimate 50-min total access time to get to and from the train. This means that in 3 h, one can travel 200 km between origin and destination. The car has a very short access time, i.e., only 5 min to fetch and leave

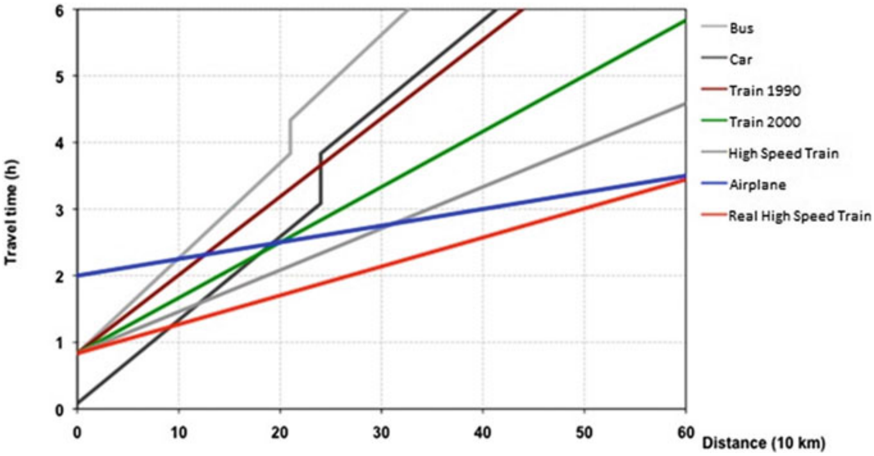

Fig. 2.7 Journey time competition between modes of transport as function of the distance

the car in a parking space and then drive at an average speed of 80 km/h over a certain distance. In 3 h, one can thus travel 240 km. After 3 h, however, we add a break of 45 min before resuming the journey; here the train can thus overtake the car over longer distances. By air, access time is very long; a total of 2 h, of which 1 h 15 min at the origin with feeder transport, watching the time and checking in, and 45 min at the destination. Once on the plane, however, the journey is fast, averaging 600 km/h, which means that one can travel about 400 km in 3 h, or twice as far as by train. We can also see that planes are relatively insensitive to distance; another 600 km can be covered in 20 min. For interregional journeys, the bus has the same access distance as the train; access time is then 50 min, and the average speed 70 km/h if the bus stops a few times along the way. After 3 h, we add a break of 45 min. It is clear that the bus is the slowest means of transport; after 3 h, we have travelled only 150 km. One can also see that the car is the fastest means of transport over distances of up to slightly more than 200 km.

Figure 2.8 presents a similar competition but on within a local area. Price, frequency of service and comfort, which all vary between the different means of transport, are also important. Journey times, however, are crucial to establishing travel habits. It is often the fastest means of transport that generates new travel—once it was the railways, then the car and, most recently, air transport. The fastest means of transport also become market leader most easily, which means an opportunity to charge sufficiently high prices and thus also achieve good profitability.

There seems to be a stable relation between travel time by train and the rail–air market share. A selection of 105 rail–air routes was identified in Europe (and Japan) in a study, which has a maximum speed of at least 200 km/h. Of these, 30 could be identified with market shares from which a statistically significant regression curve was produced. This analysis confirms that there is a very strong correlation between

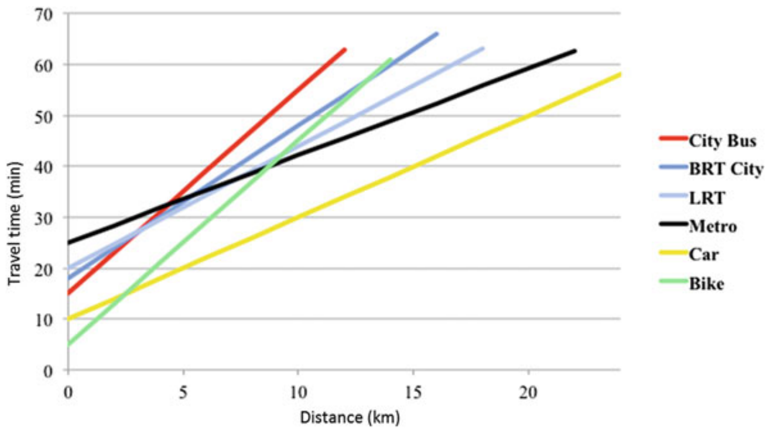

Fig. 2.8 Local journey time competition between modes of transport, as function of distance

the train's absolute journey time and its market share. The relative journey time between rail and air, the journey time ratio from city centre to city centre, was also analysed and showed a clear correlation. A three-dimensional analysis also showed that there was also a correlation between relative journey time, distance and the train's market share. The correlation between the train's frequency of service and price was also studied but proved to be weak. The conclusion is that journey time from city centre to city centre is by far the most important factor when choosing between train and plane.

Introduction of high-speed rail in many countries have changed the competitiveness of the rail mode quite dramatically. More up-to-date figures for the air–rail mode split show that where rail journey times are reduced below 4 h, rail share of the rail–air market increases rapidly with further journey time reductions, and rail tends to have a market share of at least 60 % and sometimes effectively drives air out of the market when rail journey times are below 3 h. Future trends are found to depend on a wide variety of factors including the introduction of environmental charges on air transport and trends in air and rail costs.

2.1.4.2 Intermodality

Intermodality integrates two or more transport modes on the same journey. Aim is to make this interchange as seamless as possible with common information, an integrated ticket and a multimodal station where passengers feel safe, secure and comfortable. If successfully implemented, intermodal passenger transport will give more options to the traveller, is user-friendly and adds to the overall efficiency of the transport system. To achieve seamless intermodal travel, many transport stakeholders have to cooperate closely, which is not evident in a system of increasing competition. Past studies found that the fragmentations of transport operation occurred by privatisation made the seamless inter-regional transportation difficult.

The importance of intermodality in general public transport systems means that models applied should be able to take all combinations of lines and modes into account, not only main modes, but also to regard different forms of public transport as a seamless system. This also means that more sophisticated choice models need to be developed, which are able to handle different service types, different modelling paradigms (e.g., scheduled services, frequency-based systems, etc.) and their respective connections, plus access and egress costs. These models will have a central role in Part 2 and 3 of this book.

2.2 Vehicles

2.2.1 Trains

Passenger trains can be divided into three major groups:

- *Long-distance high-speed and Intercity trains*: connecting cities in the fastest time possible, bypassing intermediate stations.
- *Fast trains/Interregional trains*: calling at larger intermediate stations between cities, serving large urban regions.
- *Regional trains*: calling at many intermediate stations between cities, serving all inside communities. There are also regional express trains with higher average speeds.
- *Local trains*: calling at all intermediate stations.

There are also local rail systems that are not referred to as train, but rather metro, light rail and tram as well as some guided bus and beam transport systems.

The distinction between the types can be thin or even non-existent. Trains can run as Intercity services between major cities and then revert to a fast or even regional train service to serve communities at the extremity of their journey. Long-distance trains travel between many cities and/or regions of a country and sometimes cross several countries. They often have a dining carriage or restaurant carriage to allow passengers to have a meal during the course of their journey. Trains travelling overnight may also have sleeping carriages.

2.2.1.1 High-Speed Rail

One notable and growing long-distance train category is high-speed rail. Generally, high-speed rail runs at speeds above 250 km/h (155 mph) and often operates on dedicated track that is surveyed and prepared to accommodate high speeds. Japan's

Shinkansen (“bullet train”) commenced operation in 1964 and was the first successful example of a high-speed passenger rail system.

The fastest wheeled train running on rails is currently the French TGV (Train à Grande Vitesse, literally “high-speed train”), which achieved a speed of 574.8 km/h, under test conditions in 2007 (Fig. 2.9). The TGV runs at a maximum revenue speed of 300–320 km/h, as does Germany’s ICE trains, Italian ETR and Spanish AVE trains as well as the TGV-based EuroCity service trains from London. The largest high-speed network as well as the highest speed currently attained in scheduled revenue operation is in China with 350 km/h.

In most cases, high-speed rail travel is time- and cost-competitive with air travel when distances do not exceed 500–600 km (311–373 mi), as airport check-in and boarding procedures may add as many as two hours to the actual transit time. Also, rail operating costs over these distances may be lower when the amount of fuel consumed by an airliner during take-off and climb out is considered. As travel distance increases, the latter consideration becomes less of the total cost of operating an airliner and air travel becomes more cost-competitive.

Some fast and high-speed rail equipment employs tilting technology to improve stability in curves. Tilting is a dynamic form of superelevation, allowing both low- and high-speed traffic to use the same tracks. Examples of such equipment are the Pendolino, the N700 Series Shinkansen, Sweden’s X2(000) services, Amtrak’s Acela Express and the Talgo (Fig. 2.9).

In order to achieve much faster operation over 500 km/h (310 mph), innovative magnetic levitation (Maglev) technology has been researched for years. The Shanghai Maglev Train, opened in 2003, is the only commercial operation, operating at speeds of up to 430 km/h. The conventional high-speed technology is cheaper, it can also reach very high speeds, and it is compatible with existing rail infrastructure.

The European Commission is currently also in discussions with the rail sector concerning a major initiative for research and innovation for rail during the coming financial period (2014–2020), called Shift-2-Rail. The European Rail Research Advisory Group (ERRAC) has identified seven priority areas for the future

Fig. 2.9 European high-speed trains: TGV duplex (*source* Wikipedia) and Talgo (*photograph* Kottenhoff)

development of the European rail sector, for example, intelligent passenger information systems, increased the energy efficiency of trains, increased safety speeding up product approval procedures, improved interoperability and attractiveness, cost management and forecast models and finally developing less costly infrastructure maintenance methods. Among the many EU projects can be mentioned as an example the MODTRAIN project, which worked on standardising the numerous components that make up a train.

The EU Framework Programme for Research and Development is contributing to the development of high-speed rail in Europe, focusing on all elements of the system: vehicles, power supply, track bed and sub-structures, tunnels as well as traffic management and signalling. The challenge is to modify a highly unstandardised system due to different technologies and power supply systems at the national levels, into a seamless network. The development of a European Rail Traffic Management System (ERTMS) is co-funded by the European Union and will inter alia contribute to improve interoperability for cross-border traffic, which represents an important (actual and prospective) market for high-speed rail traffic.

2.2.1.2 Local Rail Systems

Different forms of rail-based technologies are designed especially for the urban and regional markets. The most popular are *city rail*, *metro/undergrounds*, *trams* and *cable rails*. Both Metro and tram systems most often have the steel track—steel wheel technology, but even concrete track—rubber wheels exist. These vehicle (and infrastructure) technologies differ significantly from each other in terms of operational speeds, acceleration/deceleration power, maximum slope, minimum technical distance between stops, etc. Most of light rail transit (LRT) systems have a separated infrastructure, apart from the tram, which often shares its infrastructure with other PT types, and sometimes with private cars.

There are today about 150 metro systems and even more LRT systems in the world. Just in Europe, there are more than 170 systems and the number is increasing.

Modern rail systems can be driverless. This is especially practical for metro and other fixed rail systems including cable rail and other rail systems operating in tunnels and on elevated beams.

2.2.2 Buses and Coaches

Buses are the most popular PT service in cities, as it well operates on conventional road infrastructures and offers different opportunities in terms of size/passenger capacity, speeds, combustion technology, etc. The latest trend is specially designed vehicles for "BHLS". Double-decker buses are also increasing their market share where either seats comfort or capacity is important (Fig. 2.10).

Fig. 2.10 Example of bus types. A double-articulated BHLS bus, a regional double-decker and a long-distance tourist coach (*photographs* Kottenhoff)

Buses can be guided by various technologies, either mechanical guidance in concrete or by steel tracks or electronic guidance by magnets, camera and GPS technologies. Examples of mechanical technologies are the German "Spurbus" and the French "Tram-on-Tire" (It can also be called tram).

Long-distance bus/coach services run in many national and international relations. Private companies most often operate these services. Beside these scheduled interregional public transport services come a great number of long-distance chartered coaches. Companies that run these charter services often also run scheduled bus services.

2.2.3 Aircrafts

The air mode is growing mainly on longer distances, while rail serves as feeder systems to the airports. The market has been developed and changed by low-price airlines.

There are numerous variants of aircrafts, for regional, national and international flights. There is no important reason to go into detail on these in this context. While old aircrafts had rather high relative energy consumption, modern aircrafts are down at levels similar to cars if there are two persons in the car and the aircraft has a high-load factor. The CO_2 emissions are still problematic for a sustainable future.

2.3 Infrastructures and Networks

There are modes that operate:

- on streets (buses and trams);
- partially separated on ground (light railways or light busways);
- fully separated, either elevated or on the ground (heavy railways or heavy busways); and
- underground (subways).

The runway categories show various infrastructures and their position as public transport technologies in cities. In Table 2.1, X denotes *applied* and (X) *applied to some degree*.

The public transport categories and infrastructures are unorthodox and open for further discussion. An example is the common capacity distinction in transports (light vs. heavy), where heavy means always complete or full separation regardless if it is a bus or rail system, whereas light attribute is for systems that anchor on partially separated, or are partially on street or partially fully separated (Fig. 2.11).

2.3.1 Right of Way

Local and regional public transport systems are traditionally planned for the commuting market. Rush hour travel data are used. The pressure on the transport systems is hard during rush hours with congestion in both private transport modes

Table 2.1 Public transport systems and infrastructures

Mode	Runway				
	On streets in mixed traffic	Dedicated lane on streets	Partially separated on ground	Fully separated on ground or elevated	In tunnel or underground
Bus system	X	X	(X)		
Busway system		(X)	(X)	X	(X)
Tram	X	X	(X)		
Light rail transit (LRT)	(X)	(X)	X	(X)	(X)
Heavy railway (HRT)			(X)	X	(X)
Subway/metro				X	X

Fig. 2.11 Lundalänken in Lund, Sweden, is a partially separated “light busway”, here passing under an ordinary road. There is a parallel bikeway (*photograph* K Kottenhoff)

and public transport, at least in bottlenecks. For this reason, PT systems can be designed with different right-of-way (RoW) rules:

- RoW A: fully controlled without any grade-level or shared access: these types have no influence of other modes, therefore guaranteeing high-reliability and high-quality services.
- RoW B: longitudinally separated from traffic, with at-grade crossings, normally physically separated by curbs barriers. These are partially influenced from grade crossing with traffic or pedestrians. There is limited interference from other modes, normally occurring at the intersections.
- RoW C: shared surface streets with mixed traffic and reserved lanes. These are strongly influenced by traffic affecting travel time reliability, and vice versa they reduce the capacity of car lanes as often stops are placed on the carriageway.

Clearly, the transport systems with an own right of way can better compete to the performance of private cars. Travel times for going to work with car or public transport show that it mostly takes longer to use public transport. Usually, it takes 1.5 times longer or more, but as mentioned when there is congestion in the streets, public transport with its own RoW can reduce or eliminate this gap. For example, fast regional trains can offer travel times lower than a car journey if the origin and destination are not too far from the stations. The same is true for, e.g., express buses in prioritised lanes.

2.3.1.1 Target Lanes

If car traffic is dense, it can be hard to follow a timetable. There is often an advantage if public transport can be given its own RoW, for example, in the form of reserved target lanes. Very common examples in cities are the bus lanes (e.g., Fig. 2.12). Curb lanes can be used somewhere, but will be almost worthless if cars are parked in them. Curbstone lanes work quite well on streets without berthing. For tram operation, there will be a total stop if anyone parks in the way of the tram.

Fig. 2.12 Public transport reserved lanes in the middle in one direction at Sturegatan, Stockholm. This particular lane also serves as a "queue jumper" (*photograph* K Kottenhoff)

Reserved lanes in the middle of the street are often better for public transport, due to the decreased risk of being impeded by other traffic. Stop islands makes so the vehicles do not need to pull into the dock at curb stops. The trip will be faster and more convenient and faster than for curbstone stops.

A *bus jumper* or queue jumper is a reserved bus lane short before a crossing where there is regular congestion. By having a reserved bus lane, the buses can pass ("jump") the car queue and be at the crossing before or in front of the cars. It is also known as a bypass lane or queue bypass. The buses are often let first by the help of traffic signal priority.

2.3.1.2 Bus Streets and Busways

Bus streets are used for different reasons. In some cases, it is to make the line more direct and thus faster, cheaper and more attractive. In other cases, it is to serve areas that are closed to automobile traffic, for example, in residential areas. To prevent car traffic, sometimes only traffic signs are used, but often are automatic booms, gauge barriers or such used. Busways can be seen as a "runway" for the bus. Cities that have invested in high-level service busways are Almere, Amsterdam, Runcorn.

Figure 2.13 shows three ways to serve a district by a public transport line. The first sketch shows the most efficient route that can serve the area. It often requires a rail- or busway straight through the quarter. The third sketch is the most expensive way to lie out a route for the quarter. It was often designed for cars, for traffic safety reasons.

Bus and tram streets can be built in city environments. Entire roads can be designated as bus streets, such as Oxford Street in London as well as in Amsterdam

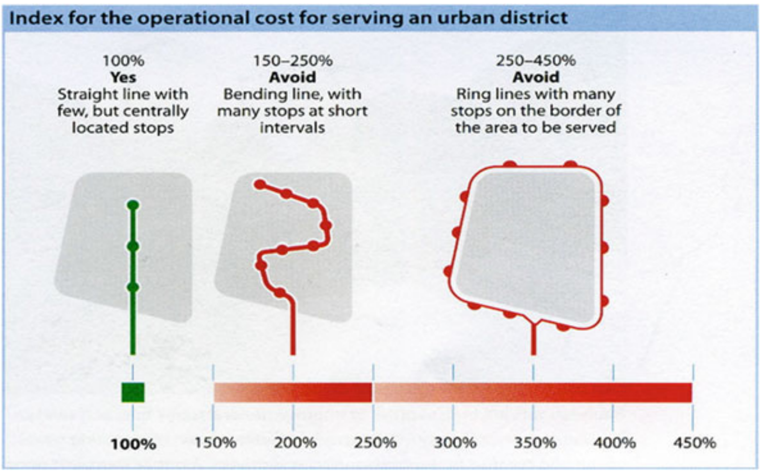

Fig. 2.13 Short and central lines save costs (*Source* Hitrans 2)

Fig. 2.14 Busway in suburb, south of Amsterdam (*photograph* K Kottenhoff)

(Fig. 2.14), allowing buses, taxis and delivery vehicles only. Sometimes bikes and buses are mixed, but a safer solution is to have separate bike lanes.

Bus lanes are normally created when the road in question is both likely to be congested and heavily travelled by bus routes. *Contraflow bus lanes* can allow buses to travel in the opposite direction to other vehicles. Some bus lanes operate at certain times of the day only, usually during rush hour, allowing all vehicles at other times, and it is common to have bus lanes in only one direction, such as for the main direction of the morning rush hour traffic, with the buses using normal lanes in the other direction.

A special form of "public lane" is seen on American highways in urban areas, i.e., the *HOV—high-occupancy vehicle lanes*, where buses and cars with at least 3–4 people may run in a reserved lane.

2.3.1.3 Prioritisation at Traffic Signals

Traffic signals make it difficult to obtain high average speeds and to run by a timetable which assumes that all trips take the same time, as delays encountered are highly variable. Prioritising in traffic signals is an effective measure to increase public transport speed and regularity.

Bunching is a problem to bus, and to some extent tram, operations; if a bus has a delay due to traffic, for instance at signals, there will be more passengers waiting at the next stops, resulting in longer dwell times, which make the bus later and so on. The following bus will have a shorter headway and therefore fewer passengers at the stops and may even catch up with the late bus. The bus bunching leads to an ineffective use of the bus fleet and causes delays and crowding for the passengers. Much would be gained if the initial small delay could be handled before it has grown and caused bunching. Conditional bus priority only giving priority to late buses can reduce the bunching significantly with relatively small delays for other traffic.

PT priority is easier to arrange in isolated signalised intersections than in coordinated systems, where the “green waves” may be disrupted and it may be necessary to make green time compensations. However, compensations made locally in the signal controllers may have negative impacts on the performance of the coordinated system if they are not carefully timed. Bus priority can have a negative impact not only to traffic that crosses the prioritised bus route, but also to other movements following the bus route.

PT signal priority can be passive or active. In passive signal priority, signal timings can be set favouring approaches with PT, and the speed of the progression can be adapted to typical PT—speed including time at stops. Passive priority is often good when the PT frequency is high and the dwell time at stops is short and predictable. Active priority measures can give larger benefits to PT vehicles than passive measures since they are only applied when they are needed, and can therefore be allowed to give more negative short-term impacts to other road users.

Active signal priority can be Unconditional or Conditional. Unconditional priority is mostly used for trams and will always favour the PT vehicles without consideration of negative impacts for other road users. Conditional methods may apply PT priority so that the overall intersection delay is minimised. It can also be arranged by:

- setting limits for extension lengths;
- restricting the priority to uncongested time periods;
- only giving priority to late/not-too-early buses, which will also improve PT regularity.

Too aggressive signal priority can also be counterproductive, if the negative impacts to other traffic cause oversaturation, the queues may spill back and block the buses. There are two main methods for conditional active signal priority:

- local signal timing adaptations with restrictions in a fixed-time system;
- self-optimising methods that minimise an objective function (e.g., minimises total road user costs).

It can in some cases be adequate to give priority only to some public transport vehicles, or different priority to different vehicles, in order to minimise the impacts on other traffic or to handle conflicting requests for priority. In Stockholm, signal priority is only given to trunk bus routes (blue buses) and not to local (red) buses. To this end, all buses in Stockholm are equipped with an AVL system that keeps track of the bus position and scheduled position according to timetable. The system is used for real-time information to passengers and gives the drivers and bus dispatchers, dynamic information on the timetable adherence. Buses that are more than 2 min ahead of schedule, according to the AVL system, will not call for priority. Conflicting calls for priority are handled according to the first come, first served principle.

Here are the four examples of active priority:

- Extension of the ongoing green phase (often the most effective);
- shortening of the red phase;

- insertion of an additional green phase (for public transport);
- switching back to green.

There are different ways to detect buses at traffic signals. The most important are as follows:

- Detection using loops in the road;
- passive loops, for example, long-loop detectors that sense big low vehicles;
- active loops that is receiving a signal from the vehicle;
- infrared detection or other form of transponder;
- computer–radio communication, which sends information to the steering device if a bus is approaching. The position can be given by, for example, GPS; and
- radar detection.

The methods that are developed for the prioritisation of public transport must take into account other traffic modes so that the traffic does not get congested entirely. There are different ways to do this. PT priority settings are usually conducted on the basis of traffic engineering experience. Microscopic traffic simulation is often applied to assess the impacts.

2.3.2 Nodes

2.3.2.1 Bus/Tram Stops

The location of stops should connect to the natural footpaths. At the same time, there are trade-offs with the requirement for a fast and straight bus route. Winding bus routes are neither convenient nor fast, and they are difficult to understand for those who do not use them every day. Slow bus routes make public transport more expensive. The footpaths to stops have importance for the accessibility, especially for children, the elderly and the disabled.

In rural areas and at streets with 70 km/h or higher speed limit, the stops are designed as pockets, where the bus stops are beside/outside of the roadway. For bus stops on highways there are specific design rules.

Curb stops at the sidewalk (footway) are simply arranged by making marks for the stop near the curbstones. With demand on accessibility for disabled, this is a serious matter. The sidewalk should be rebuilt with a proper height and constructions like the “Cassel Curb” can help the driver to “dock” tightly into the curbside. There should also be facilities for sight-impaired people at stops of all kinds.

For many reasons, it might be better with *bulb stops* (Fig. 2.15), where the sidewalk is built out into the street so that the bus does not need to pull into the stop. Comfort for the travellers is improved, the required stopping time decreases slightly and the bus calls adjacent to the curb. Another advantage is that the possible parking distance becomes longer and the risk of parking cars wrongly decreases. The capacity for all traffic on the street is, however, decreased. If priority for public transport is a goal, this makes it.

Fig. 2.15 A bulb or heel stop in Stockholm with a prototype VanHool/Scania BHLS vehicle (*photograph* Scania)

2.3.2.2 Stations and Terminals

The proportion of journeys that involve interchange ranges from less than 10 % to more than 50 % looking at different cities. Terminals are located at key interchanging sites in the traffic network or to key destination points in the region or the urban area. There might sometimes be reasons, including environmental concerns, not to let regional buses into the central part of an urban area. The terminals are in these cases located where interchanging sites give good connections in the local traffic system.

Major bus terminals are often organised in order to have a common stop for clustering alighting operations from all lines. After that, the bus goes to a parking space, which should be close to the staff facilities. Shortly before departure—normally 5 min before—the bus drives up to the boarding stop to take on passengers. Each boarding stop can serve multiple routes, which departure times are coordinated for a maximum utilisation of space.

The lamella terminal is a traditional form, which may have some traffic safety and logistic problems. A terminal type that is much used in Europe is the *Island Terminal*. It is traffic safe if one comes to the island without passing over the roadway. *Docking Terminals* provide short walking distance and high convenience for travellers, but are forcing buses to back out from stop (Fig. 2.16). They are used more often for buses in long-distance service. There are some good examples of underground docking terminals in, for example, Helsinki, Madrid and Stockholm.

Bus terminals often require a fairly big space. One reason is that each route often has its own *post*, a fixed departure stop. One way to get a more compact terminal is to use ITS with dynamic information signs that allow a dynamic allocation of stop points so that buses can depart from the stop locations where currently there is space. Ideally, all buses and all rail stops should if possible be arranged at one island (berth) or platform, which mean transfers over the platform in the same level are preferred. A closed passenger area allows for boarding of vehicles without

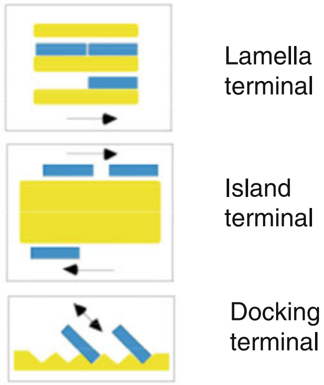

Fig. 2.16 Different types of layout of a bus terminal; Lamella, Island and Docking

validating your ticket once again. This is the typical system in metros and can be used also in advanced bus systems.

At terminals with connection between rail and bus services, the coordination should be in real time between trains' arrival and the departure of buses, which adds to the timetable coordination. A different integrated system with information for the bus drivers shows the number of minutes to the train's actual arrival, allowing the bus driver to determine whether or not he can wait for a delayed train.

2.3.2.3 Multimodal Hubs and Travel Centres

Multimodal terminals or hubs have an essential role in achieving a significant modal split to multimodal journeys. The origin of multimodal terminals results from the fact that transport operators were originally private and not at all interested in collaborating with other operators. Once public administrations started to coordinate public transport and integrated transport tickets consequently appeared that hubs became key elements in public transport networks.

Hubs allow for coordinated action on the part of different modes of transport with differing capacities, both the trunk and branches of the same tree. The various modes should be achievable within convenient distance and without passing any car traffic. Another advantage of integrating several modes is that travellers have, in a very little space, all the information about all the modes.

A good example of this design concept is the multimodal terminal of La Défense, Paris, which handles among the largest volumes of passengers, around 450,000 people per day. It is used both by commuters going into the business centre of La Défense and also by others using the station as an access point for the city of Paris and its public transport network. Also to be highlighted is the *observation centre* of La Défense, which controls the movements of the different modes of transport operating there and can act quickly in the case of disturbances.

As natural extension/generalisation of the multimodal hub concept, *travel centre* has become a name on a main terminal in the city, mostly railway station combined with a bus, tram and/or metro terminal, taxi station and bicycle and car parking. A travel centre should have closeness between the various modes. The stations are nodes in the entire travelling networks. Short walking distances are important. At travel centres, extra services should be added such as restaurant, the opportunity to rent a car, post office, bank/ATM and tourist information/hotel reservation. The aim is to gather all possible service for travellers, but also to create a complement to the town centre.

2.3.2.4 Park and Ride Facilities

Park and Rides (P&R, or P + R) are specific kinds of hubs where passengers change between their private vehicle and public transport. These nodes are designed to provide easy access to modes of public transport for those people living in areas far from stations within the transport system, thereby dissuading them from using their private vehicle when going into the city. In most cases, Park and Rides are associated with railway or bus stations with fast, high-frequency services. In addition to the spaces allocated for parking in general, they can also have areas reserved for those with limited mobility, to drop off and pick up passengers (*Kiss and Ride* and *Wait and Ride*) and to park motorbikes or bicycles.

In general, Park and Rides are owned by public administrations and, in fewer cases, by the underground or railway operators; however, it is always each country's public administration that determines the location and properties of the Park and Ride; hence, it is chiefly responsible for the investment. The purpose of the Park and Ride is to encourage travel by public transport for passengers with long walking distances from home to the nearest stop. Incentives include the following:

- A Park and Ride facility is locating normally outside of the inner city and is in direct connection to the public transport by which the onward journey to the city can be undertaken (e.g., located close to railway stations). To make the park and ride attractive, the walking distance between car park and PT stop should be short (preferably <300 m).
- Normally, car parks are reserved for those using the public transport. However, on certain occasions, to guarantee economic viability or obtain permits from the local administration, not all parking spaces are reserved for public transport passengers as some are also permitted for residents, workers in the area, etc.
- Fee for the parking lot is very low (ideally, zero). Some charges are integrated within the transport tickets. Users are generally offered the chance to buy seasonal tickets at a lower rate than daily ones, and rates charged for parking are lower than those of car parks in the city centre.
- Travel time with PT should be less than by car (due to, among other things, the congestion on the road for the car to the inner city), and frequencies of the public transport should be high.

- Signage and guidance to Park and Rides is considered to be one of the most effective ways to attract Park and Ride users. Some cities use dynamic information panels to indicate the closest facility, as well as the car parking spaces available.

2.3.3 Topological Structures

2.3.3.1 Regional and Urban Structures

A metropolitan area may in principle have one (or more) city centres, sometimes called central business districts (CBD).

In places where the rail services development is recommended, the planning should be focused on locations with good opportunity to organise effective connections between different public transport services. In the first instance and in all the smaller station locations, the goal should be that the station should be reachable by pedestrians or cyclists distance. Medium-sized towns can be linked with fast regional trains.

In many European agglomerations, new or upgraded rail lines and services trigger regional expansion. Even high-speed trains with top speeds up to 200–300 km/h are being used for work commuting. The radius can be 100 km or more with on-board travel times of up to 1 h.

It is difficult to get enough load and utilisation rates of the public transport if settlements and roads do not fit. Therefore, buildings should lie around corridors or "bands" (Fig. 2.17, left). An appropriate structure is, for example, the linear city, with businesses and residents concentrated in a not-too-broad band or corridor. Through this structure, one can create one line (or more lines) with high frequency and satisfactory economy.

In the USA, an old planning idea has come back in form of "TOD"—transit-oriented development. It means that planning of (dense) settlements, working places, etc., is made in public transport corridors and that the environment is nice for walking and biking. This is to encourage people to use public transport and to walk to the stations. For example, some cities permit commerce and multi-storey apartment buildings only within one block of train stations and multilane boulevards and accept single-family dwellings and parks farther away. In

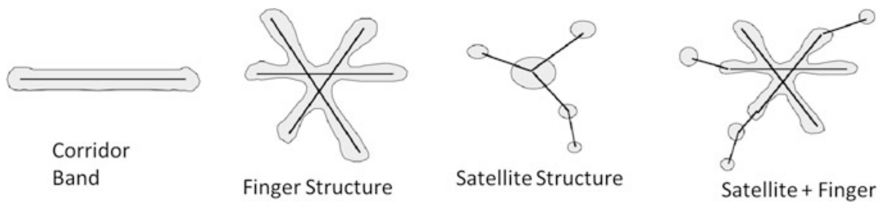

Fig. 2.17 Examples of well-suited metropolitan structures for public transport

Europe, TOD has been used for long. Good examples can be found in many European cities and in special projects like Vällingby in Stockholm, Runcorn in Britain, Almere in Holland and in Freiburg, Germany.

New dwelling and work areas should, if possible, be built in existing public transport corridors, not in between them. In some cases, the expansion of the local rail network and the metropolitan structure has been tightly linked. Such an example is the Stockholm region with a satellite and finger structure (Fig. 2.17, right). The Stockholm metro corridors form the fingers, while the satellites have been located around local and regional railways. An idea that may work well for public transport in mega cities is to complement the central core with a number of regional cores. This policy is encouraged by, for example, the Stockholm region.

2.3.3.2 Network Structures

The main public transport structure is in many large European conglomerations traditionally formed by rail lines (railway, metro, tram), while the bus systems are more complementary. In these cities, buses act as feeders to rail, for direct lines as trunk lines to areas without a close rail corridor. Medium and smaller cities on the other hand are often dominated by bus systems. It is more unusual in large cities in Europe that bus forms the core public transport. In principle, it is possible to build very heavy bus corridors, as have been made in the South American BRT systems. One example is the BRT system in Bogota, where a peak hour capacity of over 40,000 passengers has been reported.

The design of a PT system therefore begins with the identification of the most suited main network structure. Figure 2.18 shows the typical categories of structures used in practice. Examples of European cities with these network structures are as follows:

- *Diametrical system*: Helsinki, Warsaw
- *X-system*: Brussels, Amsterdam, Stockholm
- Radial/cross-system: Rome (Stockholm)
- Circle-radial system: Madrid, Moscow
- Intermeshed/ grid system: London, Paris, Berlin
- *Air-bladder system*: Lille, Rotterdam, Nuremberg.

Fig. 2.18 Examples of rail network structures: diametrical with branching (X-system), radial (cross-system), circle-radial system, intermeshed-system and air-bladder system

This classification should not be interpreted as strict, while it gives an example of different ways of designing network structures.

Once the most opportune main network structure is identified, a number of design parameters needs to be defined to optimally use the PT system. These parameters will affect the functionality and performance of the PT system, how easily it will be able to be integrated with complementary services (e.g., the bus network), and how the customers will use it.

A first fundamental design parameter is the *node frequency*, expressed, for example, in terms of average distance between stops. This parameter is clearly dependent on the vehicle technology used, as explained previously in this chapter, but also on the overall system performance. A higher density of stops has in fact a positive impact on PT system accessibility, but it has a negative effect on the total travelling time for the travellers, as well as it affects the reliability of the system as the number of vehicles stopped for boarding/alighting operations increases with respect to those running in between stops.

An interesting second aspect is the centrality of different nodes and stations in the network; in some network structures, one can reach many destinations from many origins, while in other structures more interchanges and even detours are needed. Figure 2.19 shows schematically the design dilemma represented by the *network density of lines*. Higher densities of lines as in the left example imply on average a lower number of transfers between lines for the travellers to reach any node, thus lowering the total travelling times. Providing this service, however, requires the introduction of a significant amount of extra lines for the same connectivity, and in general each line will be used by a relatively smaller flow of passengers.

The benefit of an integrated network is illustrated by the connectivity effect illustrated by the two networks in Fig. 2.20.

In the left network, every line runs in parallel to the other lines. In the right part, twice as many lines form a network. If interchange is possible in every crossing, the travel demand will be 550 % greater than when lines are operated fully independent without shaping a network.

A third design dilemma is on the *line density*, i.e., on the trade-off between increasing frequency of a line, and increases the number of lines. This is shown with the schematic example in Fig. 2.21, where lines and frequencies are traded off. In the first case (left picture), the crossing corridors can be served by just one route

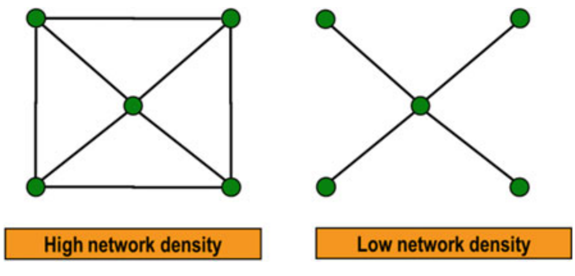

Fig. 2.19 Network density dilemma

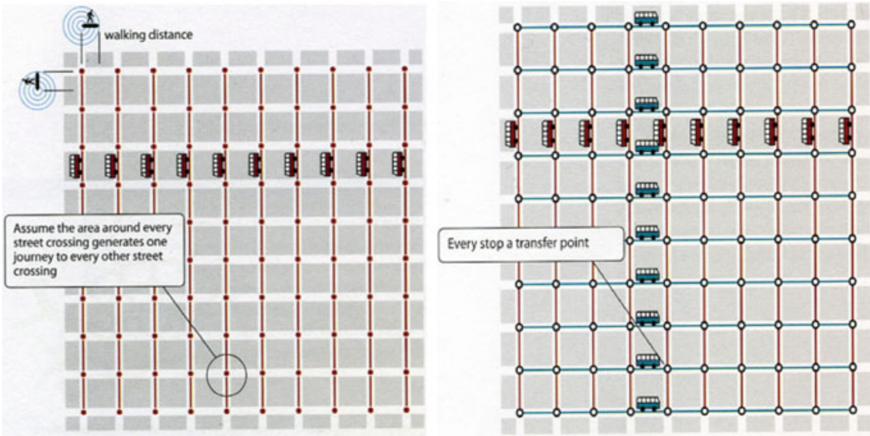

Fig. 2.20 The “network effect” (HiTrans 2)

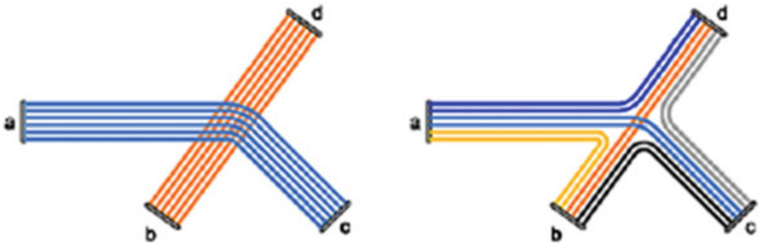

Fig. 2.21 Two network principles for crossing public transport corridors (HiTrans 2)

each. This enables a regular and stable operation on each of the two branches, but many passengers have to make an interchange. The alternative is to make several routes creating direct connections between destinations in different corridors. This, however, reduces the line frequency of each line and travellers may experience longer waiting times if they want to avoid a transfer. The crossing-lines system is often used in highly reliable systems, where synchronisation of vehicle arrivals at the stations is possible, thus reducing the disutility of transferring operations.

Systematically synchronised timetable operations are used both in interregional operations by railways, for example, in the Bahn 2000 system in Switzerland, and in local public transport. Often smaller- or medium-sized cities have a central node—bus terminal—where all lines meet at regular times (e.g., Fig. 2.22). To facilitate even further these operations, transfers are very often done at adjacent platforms. Corridors with heavy travelling exist in most cities. A good example is Wuppertahl in Germany with ordinary rail, bus and *Schwebebahn* along the corridor. The city can also be planned with a number of corridors radiating from the centre in a so-called finger structure. If there are spaces in the corridor it becomes a pearl-finger structure.

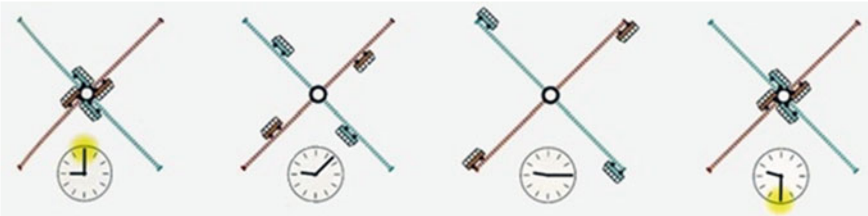

Fig. 2.22 Principle for systematic (pulse) timetable operations (HiTrans 2)

The above design dilemmas provide indications of qualities such as *spatial* and *temporal availability*. Space availability is related to the localisation of stations or stops, while temporal availability has to do with the period of time in which the service is offered. Frequency and headways are always very important indicators for users to evaluate the level of service and quality of a transit system, and partly determine the temporal availability.

Attractive headways are always dependent on the time on board the vehicle: short headways are satisfactory for short trips, while for long trips, lower frequencies are accepted. At this point, in the case that the demand is not high, a trade-off must be defined: whether to give priority to the space accessibility and the number of stops, or to the frequency. The mentioned trade-off offers two opposite limits: the traditional transit service with a high number of stops but large headways, and feeders, serving few points with high demand. Experience determines that high frequency is preferred over access time to a pickup point.

2.4 Service Performances

Public transport can, as we have seen, be run with different types of vehicles, on road, rail, but also beam and water. Seen from the operational point of view, there are more relevant ways to assess the performance of public transport, and to evaluate whether the choices of infrastructure, vehicle types and network type are efficient for the potential demand for PT.

2.4.1 Service and Stop Capacity

Many city buses do have an average speed of 12–18 km/h. In suburban operation, the average speed can be higher, but it is seldom over 25 km/h if not operated on a motorway. Traditional trams on streets are also quite slow, but when operated on their own RoW the average speed can be 25–30 km/h or more. Metro with a station spacing of one kilometre has an average speed of about 35 km/h (e.g., the red and blue lines in Stockholm).

Capacity is often a main decisive factor for the choice of a mode. When choosing mode capacity, the network design is indirectly chosen, while high-capacity lines often need feeder lines.

The definition of capacity for PT services may have different facets. The two main definitions are as follows:

- *Vehicle capacity*: maximum number of seats and standing places offered.
- *Line capacity*: total number of passengers for all vehicles of a line per unit of time.
- *Passenger capacity*: total number of passengers between two points considering all lines.

These two definitions are related by the simple formula: $C = C_v \times n \times f_{max}$, where C is the line capacity, C_v the vehicle capacity, n the vehicles per unit of time (e.g., 1 h) and f_{max}, the line frequency (TCRP 2003).

Other important terms to distinguish capacity concepts are *offered capacity* in relation to the actual *utilised capacity*. These two terms differ mainly because of the actual load factor/capacity utilisation coefficient, i.e., the percentage of offered capacity that is actually utilised. Finally, during the design of a line, trade-off is done between *peak capacity* and *practical capacity*.

Table 2.2 shows that most transport modes can be designed with low, medium or high capacity. Generally, it is possible to get more capacity on a line with rail, because rail vehicles are easy to connect to trains. An expression that is sometimes used for heavy public transport (rail) systems (in USA) is “mass transit”. Buses can haul a trailer, but this is rarely done nowadays. Instead bi-articulated buses are made with one or two joints and up to 25 m in length.

However, rail systems tend to be expensive in low capacity applications. On the other hand, the bus mode needs large-scale corridors with its own right of way, as in South American full BRT systems, to reach high-capacity levels. It should be mentioned that European cities are often more compact and “narrow” than cities in

Table 2.2 Public transport modes and capacity levels

Mode	Capacity		
	Low capacity	Medium capacity	High capacity
Rail modes	Tram in mixed traffic	Light rail with ROW Local train	Metro Regional express trains Interregional trains
Bus modes	Bus in mixed traffic City bus, Suburban bus Express bus on motorway	Bus on busway (ROW) BHLS BRT Light	Full BRT (e.g., Busmetro, Istanbul)
Other modes	Bus-on-demand STS	Personal rapid transit	

America and comfort demands by Europeans are higher than for people in newer economies in South America and Asia. Therefore, achievable capacity levels are in practice lower in Europe.

Regular buses have two axles and are about 12 m long with about 6 m wheelbase. The number of seats in a normal bus varies from about 20 to 50 depending on use and local practice/tradition. Italian city buses have very few seats and many doors, while the regional and interregional coaches in most countries usually are filled with about 50 (rather cramped) seats. The permitted number of standing passengers is restricted by weight and space limitations as well as safety rules. The permitted axle load restricts the length of a bus. Two axle buses can be built to over 13 m length, but often a so-called bogie (two interlocking rear axles) is needed for buses over 12 m. Bogie buses of 14.5 m take nearly as many seated passengers as articulated buses. One problem is that they require more space in curves.

Short buses, *mini- and midi buses*, are relatively rare in many western countries because they are almost as expensive in operation as normal buses. Based on car or truck components, the buses can be cheap but the bus driver cost makes the traffic almost as expensive as for normal-sized buses (Fig. 2.23).

In old, crowded, cities in Europe, sometimes shorter (mini or midi) buses are used for access reasons.

Articulated buses (with one joint) are about 18 m long and the number of seats is often around 60–70. In other countries, there are even larger articulated buses with two joints. Volvo has, for example, produced double-articulated, 25 m long, buses for many modern bus systems (Fig. 2.24). Another way to increase capacity is to use buses with two decks, i.e., the *double-decker*. Often the number of seats is increased significantly, while the capacity of total number of travellers is not so much higher than of an ordinary bus with one deck.

The vehicle capacity figures vary with a number of factors: seat/standing ratio, if it is a low floor design, the permitted weight restriction and more. For vehicles with new propulsion systems, the weight restrictions might be limiting the permitted vehicle capacity. The given space per standing passenger also affects a lot. This can vary from 4.0 to 6.0 passengers/m^2 and even more, at least in practice in metros, commuter trains and buses to high transport demand in mega cities. Table 2.3 shows figures from Stockholm local transport.

Fig. 2.23 Battery-operated small bus in Paris on narrow streets (2003) and Midibus in Leeds (that offer free trips in the city), 2006 (*photographs* Karl Kottenhoff)

Fig. 2.24 Double-articulated bus in Switzerland (*photograph* Segunda-Feira, 2011)

Table 2.3 Maximum capacity for various public transport vehicles

Mode	Capacity		
	Seated	Standing	Max per vehicle/train
Normal bus, 12 m	32–42 (35)	35	67–77 (70)
Bogie bus, 14.5 m	46–56 (50)	45	91–101 (95)
Articulated bus, 18.5 m	44–68 (55)	60	104–128 (115)
Tram/LRV, 30 m	80	105	185
Metro train, full length, Stockholm	400	800	1200
Commuter train, full length, Stockholm	750	850	1600

Source SL Planning Handbook, 2008, available in Swedish, with rounding in parenthesis by Kottenhoff

Practical capacity is far lower with maximum capacities where about 50 % of the standing places can be used in an average rush hour, as a rule for planning. In practice, certain vehicles will be crowded and over-filled if one tries to plan for 100 % capacity, because of statistical variations, daily variations, weekday variations, seasonal and weather variations, part of the route variations, passengers changing from high-capacity rail systems, etc. In the rail modes, some carriages may be laid out to have more standing room than seats, or to facilitate the carrying of prams, cycles or wheelchairs. Some countries have double-decked passenger trains for use in conurbations. Double deck high-speed and sleeper trains are also becoming more common in mainland Europe.

The space and time allocated for stop operations are in relation to the bus frequency, to the average number of passengers that are observed in the boarding and alighting operations, and to the number of accesses that the vehicles offer. If buses arrive with high frequency and many passengers board at the stop, more than one bus is likely to be served simultaneously. With even higher capacity demand, different lines should have different stop areas, or stops. Maybe all lines do not have to serve all stops. For example, express services and trunk lines may skip some stops. This is also a method used for rail services, metros and local rail operations.

2.4.2 *Systems Speed—Boarding, Alighting and Travel Times*

Speed is a key indicator in the modal share of a territory. However, a person deciding to make a trip compares the travel time among the available alternatives. As a result, it is not only the speed involved in the time spent on a trip, but also the design of the lines (routes), the localisation of stops and the frequency of service. Short travelling times require high average speeds including stops. Low-speed systems are used mostly for local transport, medium-speed systems for regional and high-speed systems for interregional services (Table 2.4).

Boarding and alighting operations vary significantly in Europe. While British buses often have just one door, in the front, Italian city buses sometimes have four wide doors along the side of the bus. These conventions have an impact on the internal distribution of the passengers in a vehicle, as well as their circulation within the bus (Fig. 2.25).

The choice of the type of boarding and alighting system depends also on the ticketing system and control. In some countries, it is possible to purchase tickets

Table 2.4 Speed levels of various modes

Mode	Speed		
	Low speed	Medium speed	High speed
Rail modes	Tram in mixed traffic	Light rail with ROW metro Local train	Regional express trains Interregional trains High-speed trains
Bus modes	Bus in mixed traffic City bus	Suburban bus Bus on busway or bus track (ROW) BHLS, BRT	Express bus on motorway
Other modes	Local ferries	Personal rapid transit Ferries	Air

Fig. 2.25 City bus with five wide doors. Presented by MAN in the EBSF project (European bus systems for the future 2011)

from the driver or by a vendor at the front entrance, while in others the purchase is allowed only in vending services outside of the vehicles. Clearly, the first system requires on average longer boarding time operations.

Rail modes mostly practice boarding and alighting at the same doors. There are often many doors in trams, metro cars and local trains. Most long-distance trains have coaches with two doors for a 26-m coach. Buses are different. The number of doors varies between countries and traditions. For example, Italian 12-m city buses have up to four doors, while their British analogues have just one or two doors.

Service speed and boarding/alighting times are main determinants of the travel time of a vehicle. From the operator's perspective, travel times must add also operations that are not perceived by the customers (*deadhead times*), but are ought to be included to define the rolling stock, i.e., the total number of vehicles used during operations, while in maintenance, stopped for checking operations, etc.

2.4.3 Reliability, Punctuality, Regularity and Robustness

There is no doubt that the transit operator must define a trade-off to assure an attractive service, while assuring it is economically efficient. A set of variables should therefore be designed by the supplier: localisation of stops or stations, routes, RoW category, speed and capacity are certainly the main performance measures that define the overall level of service. Passenger, however, value qualities that are less related to the form of PT offered, such as flexibility, safety and security, costs and attractiveness. Considering the quality of service perceived by users, other variables that have to be previously determined are comfort, convenience, security and safety, and the cost. Quantitative features may indirectly measure some of them.

Literature has determined reliability to be an essential feature of the quality of a transit service. Reliability can be defined in PT services as the degree of trust in the service. This is a significantly different concept than punctuality, which is often the quantitative indicator to evaluate reliability and is measured as per cent of vehicle arrivals within a previously defined period of after the schedule time. Customers depending on the headway of the service differently perceive punctuality: reduced waiting times due to high frequencies lessen the inconvenience of delays. However, low punctuality is often related to longer times on board due to traffic conditions in transit services with no exclusive lanes or pathways.

Stability and regularity can be seen as the analogous of reliability and punctuality, but from the operators' view. Stability can be seen as a measure of the capacity to effectively dispatch the scheduled services in the planned time. High stability of the system implies that the service has also high regularity, i.e., adherence to maintain the frequencies/headways planned. Highly irregular services are often characterised by frequent bunching of vehicles from the same line arriving at a stop.

If reliability and punctuality are qualities that are often related to a specific service (e.g., a line, or the total PT system), robustness refers to the design and operational strategies adopted by the PT service to cope with incidents or network disruptions. Currently, there is no universal definition of robustness, as it still remains a relatively fuzzy concept in transit systems. Increasing robustness has to do with reducing the negative effects of an unpredicted event to the system, and this can be achieved in different ways. For instance, this can be achieved offline by carefully designing timetable in order to absorb the effects of delays or avoid that unpredicted delays propagate along lines and between lines, or online by preparing flexible strategies and backup plans to apply once a disruption occurs (e.g., rerouting vehicles, providing emergency services like substitutive buses in case of a rail disruption, etc.).

2.5 Conventional and Unconventional Services

Conventional services are conceived for a wide public of users, ranging from commuters to students, from inhabitants to tourists. They are organised in lines that serve a fixed sequence of stops with a given frequency and/or a published timetable. Lines using traditional vehicles for public transport on different infrastructures are possibly integrated in a transit network, where some stops are shared. Short pedestrian transfers may be required among different stops and intermodal terminals.

In unconventional services, some of the above assumptions do not hold. For example, they may be devoted to a particular category of users, or may be operated with non-typical transit vehicles, or without a fixed route, or they may be conceived for a particular function.

2.5.1 Complementary Services

2.5.1.1 Feeder Lines

In the case corridors are served by rail feeder buses, they often complement them. But there are also pure bus corridors. Two methods for network planning, which take into consideration both trunk bus lines and so-called feeder lines from smaller counties/towns, can be found in the literature (Fig. 2.26):

- **Trunk-Feeder technique**—larger buses utilise lines in the main network, while smaller buses utilise the more detailed lines in the local network. The main network changes to a more detailed network at the terminals where even the travellers are forced to transfer. The upside with the "Trunk-Feeder technique" is that one can adapt the bus size to the flow of travellers, while the downside is that the travellers are forced to transfer in many cases.

Fig. 2.26 Two techniques for network planning: “Feeder-Trunk technique” and “Convoy technique” (HiTrans 2)

- **Convoy technique**—more bus lines run parallel to the main network and then they branch out to the city’s periphery/suburbs. The advantage with the “Convoy technique” is that the main network is utilised by many bus lines, resulting in a high frequency of service and few transfers for those travelling from the network periphery. The disadvantage is the risk for the service on the main network to become over-dimensioned and difficult to understand.

Direct lines, often with buses, take passengers from an origin area to a destination area directly, without a lot of stops in between. Such lines often complement trunk lines by rail (Fig. 2.27). Wrongly made, this competition threatens the economy of scale for the transport system. Properly made, for example, when planned by a PTA, it can increase the travel standard and social economy.

Sometimes direct lines express lines and motorway buses are mixed with respect to terminology. Even newer concepts like BRT are confused with the other terms.

2.5.1.2 Shuttle Services

In many occasions, there are clearly defined patterns of trips for which feeder and shuttle services are the best option to deal with the demand requirements. These requirements sometimes come from the excessive number of automobiles in a train station or transfer point car park, or excessive car trips on the same route from an origin to a destination at specific times of a day. Shuttle buses commonly serve trips between an origin and destination characterised by a high demand with no stops in between them and are usually designed along a fast route. When the destination is a transfer or intermodal point, shuttle buses serve as feeders of other modes.

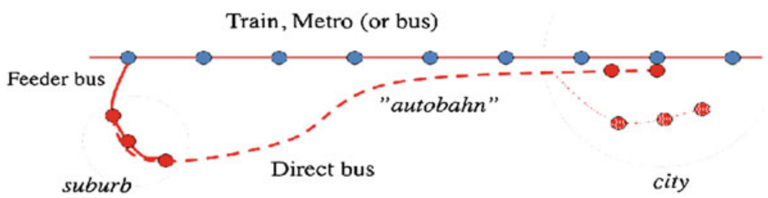

Fig. 2.27 Trunk line with feeder bus and direct bus: the trunk line can be rail or bus, e.g., BRT

The fleet size of a circular shuttle route is assessed taking into account the road network attributes, the average travel time for a vehicle to make a round journey and the time of the day, since the demand distribution may fluctuate. Once the fleet requirements have been considered, the vehicle chains must be designed. The next phase deals with the route strategy. The extreme shuttle service is designed with no stops but the origin and destination. However, this restriction may be relaxed as much as it is required.

Fixed or flexible routes and schedules, together with direction (fixed or bi-directional routes) and the possibility of short turns and cuts (direct shortest path to the destination or back to previous stops instead of an established number of stops and a fixed path) lead to strategies comprised of combinations of the mentioned characteristics. The strategies could successfully be implemented as long as the capacity restrictions are considered and the potential demand has been assessed.

All in all, the aim of the previous phases is to achieve minimum waiting and travel times with the minimum number of vehicles. In the case of a shuttle service to a long-distance bus/train station, the on-time or established arrival should be assured.

2.5.1.3 Differentiated Route Networks

Contrarily to rail-based systems, bus networks can adapt to changing needs rather quickly. Earlier, in medium-sized cities, there was a kind of basic networks that would cover most travelling needs by public transport. Differentiated bus service networks for different customer groups started during the 1980s. Therefore, new forms of network have arisen.

We may speak of a "differentiated networks" with different kinds of routes created to satisfy different needs. Some examples of such route types are as follows:

- *Base (trunk) routes*: fixed routes which run a large part of the day and night.
- *Peak routes*: routes run in the peak hours, in (partial) other relationships.
- *Off-peak routes*: often operating during evenings and holidays instead of base routes.
- *Night service routes*: often a few routes at low frequencies.
- *Express tours (routes)*: go in parallel with other routes but avoiding intermediate stops.

Trunk routes can also describe the biggest and most important routes among the base routes. The most extreme form is BRT routes in dedicated corridors on exclusive right of way.

Some types of routes are tailored to needs of specific groups:

- *Working trip routes*: sometimes created between large residential and work areas.
- *School trip routes*: connect to schools on school hours.
- *Service routes and flex routes*: meet mainly the needs of disabled people.

The concept "service routes" appeared during the 1980s in Sweden. Mini- or midibus networks connect areas where elderly live and where they have to go: city, shopping, hospitals, etc. A newer travelling variant for the elderly is "flexi routes". Here, the small buses drive past a predetermined location. These more specific services are described later in this chapter, together with other non-conventional frequency- or schedule-based services.

2.5.2 High-Level Bus and Rail-Like Systems

2.5.2.1 Buses with a High Level of Service (BHLS)

Of particular interest in recent years has been the creation of a trunk network for buses. The intention has been to get part of the rail service qualities but to a lower cost. An example is the Stockholm's "blue buses", which are serving as trunk. Route 4, the heaviest route, had in 2005 about 60,000 passenger journeys a day.

The following elements can be employed to construct a trunk network:

- Reserved lanes and priority at traffic signals;
- boarding and disembarking at all doors with another type of tariff control;
- real-time display of waiting times, delay information and "next stop" signs;
- straight and direct routes linking areas of high base;
- slightly longer stop distance and sparser networks with higher frequency in return.

Many of the elements are already familiar—priority for buses in traffic, higher quality vehicles, improved comfort at stops, improved information to passengers, integrated ticketing, intelligent transport systems to improve operations management and planning, etc. However, BHLS differs from the conventional approach in three main respects:

- The elements are combined in a holistic way, to achieve a total product improvement rather than just improve specific aspects.
- The BHLS is usually packaged as a concept, given a distinct label and marketed to the high market.
- The BHLS usually serves urban and transport policy or strategic objectives, and there are not just technical or operational improvements.

BHLS means buses with a high level of service which is not a fully developed BRT system but a French/European version suiting the European cities. It may be called light BRT. CERTU (2007) defines BHLS as "BHLS is a public road transportation concept for the structuring services of the network that meet a set of efficiency and performance criteria, coherently integrating stations, vehicles, circulation lanes, line identifications and operating plans in an on-going manner".

2.5.2.2 Bus Rapid Transit (BRT)

BRT is a system operating on its own RoW infrastructure either as a full BRT with high-quality interchanges, integrated smartcard fare payment and efficient throughput of passengers alighting and boarding at bus stations; or as a system with some amount of dedicated RoW (light BRT) and lesser integration of service and fares. This system can cost four to 20 times less than the LRT system and 10–100 times less than a metro system. BRT combines the flexibility and lower cost of bus, and the speed and reliability of rail.

BRT originated from Latin America. During the 1970s, there was a rapid growth in the urban centres placing a high demand on the transport sector for public mode of transport. With a fast population growth and limited resources, people were dependent on the public transport only which led to the development of a rail-based infrastructure in the form of BRT. Examples of highly efficient bus services, BRT, are seen in several places in South America, e.g., in Curitiba, Brazil and Bogota, Colombia but also in Ottawa, Canada, and in a growing number of Asian cities. It has in some cases reached very high capacity in traffic, up to 40,000 passengers per direction in rush hours.

There is no system yet in Europe with 100 % heavy busways. BRT in the urban model and in practice in Europe revolves around light busways.

BRT can assume different forms, ranging from dedicated bus lanes to a complete network of BRT lines in corridors. The infrastructure design must encompass a wide range of system components, including busways, stations, intermediate transfer stations, terminals, depots, control centres, traffic control signals, integration facilities, public utilities and landscaping. Likewise, depot areas must be designed to handle a range of tasks including refuelling, cleaning, maintenance and repair, and vehicle parking. A control centre allows system controllers to ensure a timely service to the customer as well as the ability to respond to any problems or emergencies.

Radial BRT traffic is substituted in large cities lacking a metro system. We can take the example of Curitiba, where a number of radial corridors were developed. More examples are available in other developing countries. Even in America there are certain cities almost completely without rail-based traffic, like Ottawa. Department of transportation (DoT) in USA has issued a report, which highlights a form of BRT system which was called “Light Rail Lite” and described as a cheap alternative of modern light rail. Light Rail Lite is run with lower average speeds and lower passenger volumes.

In cities with a well-developed (rail) transit system which accounts for most of European big cities and exists a need for better tangential and feeder traffic. Amsterdam, Paris and Sydney have developed integrated tangential “rail” corridors based on the BRT concept. In medium-sized cities, the complete transit system can be based on BRT. This idea is being followed by some French and Dutch cities such as Rouen and Eindhoven.

Fig. 2.28 Volvo concept bus for the EBSF project (Volvo Bus) and Translohr rubber wheel tram, "Tram on Tire" in Padua, Italy (*photograph* Kottenhoff 2008)

Many BRT systems are built on trunk lines in corridors with feeder lines. This can prove to be a good solution if the trunk lines are much faster than bus services without the need for transfer.

Both BRT systems as well as the European BHLS concept favour new vehicle designs. The applications vary from ordinary, but distinctively designed buses to buses on tracks and "trams on tyre" (Fig. 2.28).

2.5.3 Demand-Responsive Services

The dominant form of public transport is schedule-based. Buses, trams or trains are running—or trying to run—according to a published timetable. Timetables are designed to meet expected demand (during periods of high demand) or to offer a minimum level of service (at low demand). This means that operators publish timetables for various times of the day and various times of the year. Passengers plan their trips based on the timetable information and/or information on perturbations. If the headways are small enough (below 5–10 min), passengers may not bother about timetables.

In contrast, the idea of demand-responsive traffic is to operate when and where there is demand. Their purpose in relation to scheduled traffic is usually one of the following:

- saving cost in areas or at times of low demand;
- improving access by coming close to points of demand; and
- offering individualised service of high standard.

2.5.3.1 Dial-a-Ride

DAR services are the alternative for regular trips starting or heading to those areas that traditional public transport does not serve due to high private car ownership or inadequate conditions of roads or streets. Together with other paratransit services such as route deviation or flex-routes, DAR is designed to fulfil the lack of service of regular transit and to provide a cheaper alternative compared with taxis. It commonly serves rural areas, towns and peripheral neighbourhoods.

This hybrid mode is a system operated by a company that owns the vehicles (cars or small buses) and serves a predefined area. In most cases, users reserve a trip by telephone, informing about their transport needs, but systems exist where users arrange the trip with the driver. DAR is also an alternative for regular and arranged trips. An increase in the demand of DAR causes a decrease in flexibility by increasingly fixed routes.

Compared to taxis, DAR is a cheaper service as a result of trip sharing but, on the contrary, inconveniences come from excessive waiting times or uncertainty of arrival time to destination.

DAR is without any doubt a demand-responsive transit (DRT). The hybrid nature of this type of transit leads to difficulties when intending to efficiently meet demand requests. Literature defines two types of routing: many to many or one (or several) to many. This last option is expected to operate as a shuttle/feeder service. Advanced technology such as AVL and GIS provides instantaneous data that reduce the routing-scheduling problem when the fleet exceeds the possibility of manual planning.

DAR is the optimal mode to supply mobility to disabled persons, in areas where regular transit does not serve, at off-peak times of the day or in small cities and towns.

New Paratransit or hybrid modes are based on many-to-one DAR services where routes are fixed. In this case, if the vehicle can deviate from the route to pick up passengers by demand, then the service is called route deviation. However, services may not operate with a schedule but by request: on-call services, which may provide mobility as a feeder service to a train station.

2.5.3.2 Bus-on-Demand

Bus pickup ordered by telephone goes by different names, such as Dial-a-bus, Ruf-Bus, Tele-Bus or Flexi Line. They exist in many European countries. The concept has been around at least since the early 1970:ies with manual order-handling and order-dispatching. Now, of course, these functions can be made automatic.

Common applications include pickup and distribution to/from a major destination such as a service centre or a transit terminal. Pickup stops are ordered (not destinations) and all orders are for the next scheduled tour. Distribution trips from the terminal need no order, and the driver usually does the route planning to verbally requested stops. Without orders, the next trip will be cancelled.

Bus-on-demand is typically introduced in areas of low demand. The area served can be a sector from a terminal or a service centre or it can be a corridor between two nodes. The route can be fixed but the concept allows additional possible stops over an area since not all of them need to be visited. Advantages are cost reduction from cancelled trips and improved area coverage and short walking distances. The vehicles are often minibuses or contracted taxi vehicles.

With handicap-adapted vehicles and stations close to buildings, this scheduled service can serve some demand which otherwise would have required more expensive transport for handicapped.

2.5.4 Paratransit

Paratransit is a term for forms of transport that lie between ordinary public transport and conventional taxi. It denotes services that do not follow fixed routes or schedules. They vary considerably in the degree of flexibility, and the term is used differently in different parts of the world. It can denote jitney and minibus services in developing countries, handicap services in North America or generally Bus-on-Demand services.

Vuchic (2007) defines Paratransit as urban passenger transportation service mostly in highway vehicles operated on public streets and roads in mixed traffic; it is provided by private or public operators, and it is available to certain groups of users or to the general public, but it is adaptable in its routing and scheduling to individual user desires in varying degrees.

The oldest Paratransit mode to be known is the taxi but other hybrid modes have been designed to meet semi-public transport demand: jitney, DAR and subscription commuting service. Their main attributes are flexibility and demand-responsive performance, whereas regular transit services lack these characteristics. Among the alternatives of Paratransit are the following:

- Exclusive-ride taxi
- Shared-ride taxi
- Children’s services
- Subsidised general public transportation
- General public DAR
- Fixed-route feeder services
- People with disabilities
- Subsidised medical care receivers
- Other social service clients.

Four characteristics are claimed to define Paratransit modes: the type of usage, the fleet ownership, the routing and the accessibility. This service may be supplied either to the general public with a regulated fare or to people involved in an organisation (school, factory, office). The provision of vehicles may come from a transport agency, an individual owner (taxi or jitney driver) or any other organisation. Hybrid modes of transport may provide door-to-door service, a fixed route or an alternative between them. From the availability point of view, the service may follow a prearranged schedule or it may be designed to provide specific service to individuals after a phone call. Needless to say, the combination of this group of attributes leads to different capacity constraints.

Among semi-public Paratransit modes are vanpools, subscription buses and car sharing. Public alternatives are taxis, jitneys, DAR and other hybrid services.

In short, Paratransit involves specific mobility and low passenger volumes. Therefore, besides the specific situations where hybrid modes are suitable, these also offer short-term solutions to deal with mobility requirements before the implementation of a regular service. These modes should be considered part of the mobility in coordination with other public transport systems. Regulation of quality of service, security and safety is greatly recommended for these modes to appeal to the entire community and to avoid the use of private vehicles in those towns or neighbourhoods with high rates of car ownership. However, marketing is essential and information should be clearly delivered. To conclude, commuters, schoolchildren, air passengers and people with disability (PwD) are the first targets of the various modes involved in Paratransit.

The denotation demand-responsive transport does include not only road transport but also guided systems like many PRT (personal rapid transit) solutions. In the following, some forms of demand-responsive traffic are described.

2.5.4.1 Vanpools

Commuter vanpools consist of medium to big vans driven by one of the commuters, and the driver is free to use it for personal purposes too. Unless this driver wants to purchase the van, the operating and maintenance costs are shared among the commuters involved. This mode is recommended for large factories or working destinations which are not served by regular transit.

Subscription buses are used in a similar way as vanpools but are provided by the company or institution or by a transport agency. Subscription buses require a higher number of participants and can provide several runs during the day but are generally operated on fixed route and schedule.

Charter vans as in Buenos Aires offer subscribed luxurious commuting from distant suburbs to the city. Air-conditioning, working space and parking in the city are attractive features.

2.5.4.2 Car Sharing

Car sharing is an option for non-regular trips and people who do not own a private vehicle but need one in specific situations where the transit conditions do not meet their needs. As a result, they are designed to complement public transport. Users have to subscribe and are given a personal key. Whenever such service is required, it can be booked online or by making a call.

2.5.4.3 Taxi Services

Taxis are complete individualised modes of public transport and are offered either at specific stops or on the streets. Vehicle assignment is possible by radio and automatic vehicle location (AVL) systems. The main characteristic of this mode is its availability: everyday and anytime service which provides rides to any destination. Consequently, taxi is a very attractive alternative at specific moments, situations or destinations. Regulation of taxis has traditionally been a matter of discussion. Therefore, fares, stop locations and entry conditions for new licences may or may not be controlled by the public administration. Non-regulated services generally lack security. However, even with regulated fares, there is always an uncertainty of the amount of money a trip would cost since it is a function of the travel time and time-of-day.

2.5.4.4 Jitneys

Jitneys stand for popular taxis or minibuses and have been an alternative of public transport in many developing countries. The vehicle is driven by its owner and has a capacity of as many as 15 seats. This specific mode of transport shows a mixture of advantages and disadvantages over regular transit: whereas frequency and speed are higher, regularity and reliability are not. Jitney performance is good at peak hours, but the level of service is low at off-peak periods of time. Vehicles sometimes are owned by different companies in a city and might be coordinated in routes and schedules (fares are established by public administration). It is a general fact that those cities in which jitneys are not regulated end up lacking security and proper conditions and mostly cover the same commonly used routes at the same highly demanded periods of time. The major inconvenience with jitneys is that even when there is a great number of vehicles around a city, they do not provide transport as a system. Consequently, road occupancy is high due to these vehicles. Moreover, if this service is not under any control of the public authorities, they will never be eliminated when a broader and more organised service is required to be implemented. International experience shows that jitneys succeed when regular transit fails to provide convenient services.

2.5.4.5 Paratransit in Developing Countries

Paratransit systems in many developing world cities are operated by individuals and small business (Fig. 2.29). An entrepreneur often owns a number of vehicles, which are leased to individual drivers who have to earn a sufficient amount every day. Therefore, the minibuses wait until they are full. The fragmented nature of the industry makes government regulation and control hard. Government authorities have cited problems with unsafe vehicles, etc.

Fig. 2.29 Paratransit vehicles in Jakarta, Indonesia (*photograph* Kottenhoff)

2.5.4.6 Corporate Transport Services

Large organisations such as factories, hospitals, universities and schools may prefer to arrange services for their commuting members to and from the workplace. These services are called "corporate/company services", "service vehicles" or just "services". They can operate on a fixed schedule and route. Each bus has a predetermined path to follow and pick up points along this path. In the mornings, the service usually collects the registered members (i.e., employees, pupils) from these certain pickup points to bring them to the work place. In the evenings, after work, it takes them to their home zones.

Modifying the system by introducing more flexibility may offer promising benefits with the help of contemporary IT solutions. Rather than a fixed list of members, opening the service vehicles to the use of non-registered employees of the company will attract more demand. Secondly, rather than a fixed schedule, a more dynamic timetable, in line with varying demand, will also make the system more attractive. Thirdly, rather than a pre-booked registration, designing an IT-based infrastructure which receives bookings electronically over Internet or mobile phones will greatly improve the system (as they can determine the coordinates of the user and calculate the optimum path to serve the optimum number of users, and send messages to the driver of the service vehicle).

2.5.4.7 Special Transportation Service (STS) for Elderly or Handicapped

In Sweden, Canada, USA and some other countries, there are special transportation service (STS) for the elderly or the PwD. This demand-responsive public transport is run in part by taxi and partly by the local PT companies. In some cases, taxi cars are being used, and in other cases, small buses are being used.

In some cities, disabled passengers who cannot use ordinary buses are entitled to transport with special vehicles and assisting drivers. Sometimes, two persons are needed to assist a passenger in stairs. These services are often contracted out to companies with special vehicles and trained drivers/assistants. These services are labour-intensive and expensive, so their scheduling and routing need to be efficient.

A comprehensive STS is much more expensive than ordinary public transport. In Stockholm, it costs more than 15 € per trip.

Known trips are scheduled or pre-ordered the day before the trip. That allows consolidated routes to be planned during the night with multiple passengers picked up and delivered. The time of return trips is often not known in advance, so they need to be scheduled in real time, typically by inserting them into planned routes. Several computerised systems are used for this problem.

As a measure to cut high cost, SL in Stockholm had introduced midi buses on-demand for elderly people (Fig. 2.30). These attract people that otherwise would have used taxi vehicles, but the midibus services are also open to the general public. Each midibus covers a predefined part of the city and runs every hour from 9 to 16 on weekdays. The driver can plan her/his route in real time with limited help of basic ITS, so there is potential for product development.

Service routes run mostly by special buses for 10–20 persons. They are built with low floors. The same vehicle can also be used for "flexi lines", which are a kind of service lines that do route deviations to pick up people at specific pickup locations.

To get low entrances, all or part of the buses and trains today are built with a low floor. The buses that have only partially low floor are usually called *low-entrance buses*, the other are called *low-floor buses*. The low floors make the wheel arches protrude into the passenger compartment and the buses are harder to furnish. Low-floor buses are often difficult to furnish and when the engine is in a cabin, even more seating options disappear.

The platform heights still vary a lot between countries and even between lines and stations in each country, but standardisation has been initiated, for example, in Sweden (550 mm for interregional lines).

Fig. 2.30 Vehicles used by the STS in Stockholm: low floor minibus, Taxi and Midibus. The latter for bus-on-demand services (*photographs* Hans Adeby, SL Stockholm, Public Transport Authority SLL)

2.6 Automation and New Transport Systems

Automation can help in making demand-responsive transport and in making systems where the drivers' role is limited. Automated metro systems are in use in many places. These give possibilities to run shorter trains and denser services in off-peak times without driver costs. There are also forms of automated smaller systems like automated light rail systems and people movers.

2.6.1 Advanced Control for Rail Systems

Railway safety systems are based on four major components. Track-free detection system (track circuits or axle counters), monitors the occupation and releases of track sections. The infrastructure and interlocking safety requires that movements are done only if all points (switches) are properly set and locked, conflicting routes set and locked, flank protected, and requested tracks are clear. The occupation status of block sections ahead is transmitted to trains by a signalling system, among which conventional trackside signals are the most common ones. Automatic train protection (ATP) guards against driver errors, by supervising operations and intervenes in case of driver errors. Those basic functionalities are implemented in traditional legacy systems that greatly differ between countries.

Control of rail operation is also done by manual intervention. In principle, this intervention function should not at all affect the safety function of the traffic management system, but the systems are to some respect integrated. A big challenge for European rail is that each national railway has its own technical solution, even when the supplier of the systems can be the same in some countries.

The ERTMS is the Europe-wide standard to enhance cross-border interoperability of train operations. The overall ITS scheme aims at improving safety, capacity and performance of a railway network. Main components of the ERTMS are the European Train Control System (ETCS), a standard for signalling, control and train protection system, and communication standards among which GSM-R.

ETCS is specified at four different levels:

- L0: ETCS compliant vehicles interact with non-ETCS compliant trackside equipment and signalling
- L1: ETCS is installed trackside (possibly together with legacy systems) and on board (cab signalling); data are transmitted from track to train at prespecified locations via ETCS balises
- L2: as level 1, but ETCS data transmission is continuous; the currently used data carrier is GSM-R
- L3: as level 2, but train location, track-free detection and train integrity are determined on board rather than by trackside equipment.

ETCS L2 is the most advanced system currently available for deployment. ETCS L2 is a fixed block system with track-free detection that the interlocking system uses to set routes.

The interlocking receives track-free status to set routes and communicates those to a Radio Block Centre (RBC), which then translates this information into Movement Authority (MA). The MA, together with a track description, is sent to the ETCS L2 computer on-board trains. The train determines a dynamic speed profile based on the MA, train characteristics and all track speed restrictions. The MA and speed profile are displayed to the driver in the cabin, without the need for trackside signals. The train sends its position and speed to the RBC, including routes requests.

The on-board computer supervises that the permitted speed at each location is within safe braking; an emergency mechanism handles the case when the driver does not react promptly and exceeds the braking curve.

2.6.2 Automated Rail and Metro Systems

A further step forward might arise from automatic train operations (ATO). Vehicles will compute the best speed profile to match the current MA. Such an arrangement is currently used mostly for closed systems such as subways. Automated metro systems are in use in many places worldwide.

The earliest ATO were used in operations in the 1960s in metros, and more modern services are continuously developed and applied to metro systems worldwide. Among the different arrangements, the automation can vary from driver supervision, to driverless operations but with a driver or attendant on board, and going as far as being remotely controlled, or completely automatic. There are also forms of automated smaller systems such as automated light rail systems and people movers. For example, a cable-drawn minimetro operates in the small city of Perugia with headway of 1 min.

Benefits of ATOs consist in an extremely high level of reliability in realised departure, running and arrival times. This results in a much higher capacity of the link, as the distance between successive vehicles can be controlled with a high level of reliability, and headways can be safely lowered to 90 s or even less. These give possibilities to run shorter trains and denser services in off-peak times without driver costs. In fact, the cost structure of a driverless system is completely different than when needing a driver. To adapt to variations in demand, a variable amount of vehicles can be sent and operated for a smaller headway time and increased frequency. Applications of ATO in metro have a target reliability result of 98 % of less than 2 min delay; up to 99.4 % service availability has been reached in Copenhagen metro.

2.6.3 Cable-Propelled Transport (CPT)

Vehicles pulled by cables have been around since the nineteenth century. Initially, running on rails at grade but later also elevated and suspended. An example is Perugia automated Minimetro in Italy running on rails partly elevated and partly tunnelled. LaPaz "Linea Roja" opened in 2014. Most recent applications use a continuously running cable with detachable grips. Cable-propelled transport (CPT) lines can have speeds up to 45 km/h, although typically 15–25 km/h. Vehicle capacities and headways range from 12 passengers every 20 s to 180 passenger trains every 2.5 min. Typical transport capacities range from 2000 to 5000 persons per hour and direction.

2.6.4 Personal Rapid Transit (PRT)

The idea of PRT is to offer "car quality" within a public transport system. PRT offers automated taxi service over a network of dedicated rights of way. PRT can run on elevated guide-ways, in tunnels or at grade between fences. Each vehicle takes 2–6 passengers. According to some visions, it would be possible to construct beam transport systems with both PRT and scheduled public transport on the same infrastructure.

Transport is on-demand and non-stop along the quickest path to each passenger destination. Since trips are individual or made with a chosen company, vehicles can be small, allowing slender guide-ways. Stations are offline so that stopping vehicles do not delay passing traffic. Typical PRT travel speeds are 35–45 km/h which is often faster than car traffic. Safe headways as low as 3 s between vehicles allow for line capacities up to 1200 veh/h. Ridesharing is encouraged for passengers with the same destination. Guide-ways are one direction with merges and diverges but no intersections.

PRT complements scheduled transit in many respects:

- serves areas as opposed to only corridors;
- vehicles wait for passengers instead of the opposite;
- many stations are possible without slowing trip times;
- travel times are typically half of those with scheduled transit; and
- automation allows all 24 hour service.

One factor that may be crucial for traffic on elevated beams to get a major breakthrough is whether it can fit in the visual environment. It is thus very important to get sleek beams and columns. The biggest problem is often terminals and stops, which may be bulky and ugly in the urban environment with its raised position. So far four PRT systems are in operation; in Morgantown (USA), Heathrow (UK), Masdar (UAE) and Suncheon (South Korea) as of April 2013 (Fig. 2.31).

Fig. 2.31 Personal rapid transit systems (Vectus) in Suncheon S Korea and at Heathrow airport (*photographs* Yonrap News and Kottenhoff)

2.6.5 Automated Road Transport

Development of self-driving vehicles is ongoing, and these may be allowed on at least some motorways within some 10 years. It may also be possible within cities or certain areas in cities. An example of automated minibuses already operates on a route in a business area in Rotterdam (Fig. 2.32). These operate on a closed busway with a number of small stations. Similar technologies can also be used for full PRT systems.

The full use of automated cars can be attractive for some people who get stressed when driving personal vehicles. Private cars can adopt some of the advantages for bus and rail. They could become more like mobile offices in which people can text, talk by cell phone, send emails, or sleep without worrying about the dangers of distracted driving. Many transit passengers today use transit because they can engage in electronic communications without worry of causing an accident. Much of the advantage public transit now enjoys in attracting choice riders would be gone with automated cars.

Perhaps the biggest, and no doubt the most controversial, question would be how it would affect the position of bus drivers. If they didn't have to drive the vehicle, would their role become more of a customer service person, providing passenger

Fig. 2.32 Automated minibus in regular service on special busway in Rotterdam (Kottenhoff, June 2014)

assistance, information and security? Is it possible that the position of bus driver will not be necessary?

Self-driving cars can be used in taxi fleets (aTaxi) offering cheaper rides than manually driven taxis. Routing, ride-sharing and empty running can be optimised with ITS. Depending on ownership, regulation and pricing a Taxi can be a complement or partial substitute for other public transport.

2.7 Reference Notes and Concluding Remarks

Organisational forms have changed over the last decades. Different forms of deregulations have in many countries gradually replaced PT services based on pure monopoly, i.e., one transport operator, normally linked to the PTA. As consequence of these deregulations, lack of integration has become crucial, especially how it affects the users in terms of an easy understandable and seamless view of PT and operational efficiency. Intermodality and a seamless journey are of great importance for the public transport travellers.

Rail system types that increase their market share in Europe are high-speed trains and regional train services with modern EMUs (Electric Multiple Units). Even Metro and LRT are expanding. Modern rail systems can be driverless. This is especially practical for metro and other fixed rail systems. But now technology for driverless operation without conventional tracks is emerging with a first driverless minibus line in Rotterdam. Even older technologies like cable-propelled transport may get a new application in driverless minimetros.

Right of way for public transport is of utmost importance for public transport efficiency and attractiveness. Various forms of bus lanes, busways and dedicated infrastructure with and without rail can increase average speeds and regularity. Public transport nodes can made efficient and customer friendly by good design and by using modern traffic management and information systems. Close integration of rail and bus connections enhances the ease of use.

The regional and urban structures are to some extent integrated with the needs of efficient train and public transport system designs. This is better in Europe than in, for example, the USA, where planners start making “TOD”. Rail or BRT systems are today integrated with development of the cities. For example, cities, or parts of them, can be built in public transport corridors like linear cities. This partly solves the dilemma of having many direct lines with lower density or fewer networked lines with higher density. Today a system with many lines may be hard to understand, but with IT system, it can be easier to communicate the system design and offer real-time travel information.

Regarding capacity, different technologies and different system designs have different maximum capacities. An ordinary bus line in the city may have a capacity of about 1000 passengers per hour, but a BRT line with dedicated infrastructure, as line 34 in Istanbul’s BusMetro has a practical capacity of almost 20,000 passengers per hour and direction. This is similar to many European metro systems. Rail systems also have a great span, varying from about 2000–50,000 passengers per direction and hour in a corridor. The local and cultural demand on comfort and privacy affects how many people should be transported together in a public transport car, and this also affects the practical capacity.

The infrastructure design and standard not only affect the capacity but also the speed for various modes. Regular buses and trams have low speeds, while Metro, BRT and LRT should reach medium speeds. In relative scales, regional express trains and interregional high-speed trains have competitive door-to-door travel times with car and air.

Public transport should also be reliable and punctual, and departures should be regular. Besides good infrastructure design, passive and active traffic management systems are used both for rail and bus operations. Efficient traffic signal priority is crucial but also systems for efficient use of rail and bus terminals and stops. For local rail and bus traffic, there is a variety of active traffic control and management systems. Information can, for example, be presented to the driver continuously, showing how his/her vehicle is positioned in relation to the vehicles is front of and behind. This is especially important for high-frequency trunk services as Metro, LRT, BRT and BHLS. For bus operations in corridors, the trunk-feeder and the convey technique both put demands on active traffic control for coordination and regular operation. Shuttles and a variety of route types, for example peak services that take people to work on routes that operate only a few times in the morning and afternoon, complement the trunk corridors and routes. The magnitude of differentiation is always a trade-off between simplicity and customer demand adaption. Rail, BRT and BHLS are examples of the former, while demand-responsive services represent the other end of the scale. In between, there are scheduled local minibus services and special services for old or impaired travellers. There are also various forms of DAR and bus-on-demand.

There exist so-called Paratransit services of various forms. In developing countries, Paratransit is operated by smaller or bigger private companies operating Jitneys on semi-fixed routes, while in USA and Europe, some Paratransit systems are heavily assisted by an ITS for transport management and control. There are also vanpools, car sharing systems, taxi and corporate services.

In rail operation, computer-controlled safety systems are everyday technology on most lines, and advanced traffic management systems have also been in use for long. The next step is to integrate national systems into a European system ERTMS. Full ATO are not yet on the agenda for long-distance rail, but already in operation for metros and other local rail systems. Higher operational quality is expected. It then also becomes economically feasible to operate off-peak periods with higher frequency.

The idea of PRT is to offer as many as possible “car quality” within a public transport system, such as no waiting times and journeys without transfers. PRT offers automated taxi service over a network of dedicated rights of way. Small “podcars” can run on elevated guide-ways, in tunnels or at grade between fences. In the near future, we will probably also see route-fixed and not route-fixed on-demand services with automated small-bus-like vehicles. These technologies are very dependent on advanced ITS including a high level of traffic safety control.

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