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NETWORK PLANNING AND DESIGN

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Introduction

Public transport can become a much more useful and efficient service than existing services in most cities and regions (Currie & Tivendale, 2010; Walker, 2011; Spieler, 2018; Higashide, 2019). This is possible by making better, more goal-oriented and widespread use of some main principles of network planning and design. Securing high-quality network solutions is more cost-efficient and important for public transport success than new, heavy investment projects or many new technological solutions.

This chapter first explains why an integrated, seamless network is necessary to achieve significant improvements in the quality and market share of public transport, even when the resources devoted to transport in the area are strictly limited. To achieve the network effect, many detailed aspects of the system must be attended to.

The main body of the chapter presents some of the most important and consequential factors of network planning and design. This includes principles of line design, service frequency, speed of operations and right-of-way and complementary services as a part of a common network for all citizens. Attention to door-to-door travel also requires a strong focus on quality access by non-motorised modes and liveable places well integrated into the urban structure, with careful considerations of car access provision.

The principles presented in this chapter are relevant for all public transport modes. Since bus services represent the dominant and flexible part of travel networks and have the largest potential of improvement and fast implementation, they are the focus of attention here. Each piece of advice might seem rather obvious and well known. The overall conclusion is that if most of these solutions can be applied together as a total strategy in a city or region, they can become a “game-changer” in the passenger transport market.

The network function – necessary for public transport success

People want – and often need – to travel from almost everywhere to (all) other places and at different times, preferably as a direct journey from door to door.

However, the common idea of creating a motorised transport system that offers all-time, on-demand, direct travel between all origins and destinations in cities and elsewhere must be
recognised as an impractical utopia. The dispersed pattern of individual travel demand makes it very difficult to achieve an average vehicle occupancy of more than some 3–4 persons per journey. Many projects have revealed the limited potential of ridesharing (carpooling) in private cars (ICARO, 1999; Amundsen & Ryeng, 2019), despite there being a potential for using ridesharing apps to extend the reach of public transport (Wright et al., 2020). Low occupancy is also a key problem of demand-responsive public transport projects (Pettersson, 2019; Nelson et al., 2010; Westerlund, 2016).

The space- and energy-demanding private car solution cannot satisfy the economic, environmental and social goals of the 21st century (OECD, 2018; Lane, 2016; Marks et al., 2016; WHO, 2016). Instead, resource- and space-efficient transport requires it to be easy and attractive for people to travel together in the same vehicle, train or vessel, and transfer must be an inescapable feature of the system. In addition to direct connections between places of heavy travel demand, public transport must provide a network of interconnected services, and significant proportions of the journeys must include one or two transfers between lines and modes (Nielsen et al., 2005).

Many cities demonstrate that network integration, achieved where the network of lines and the interchange points are designed to accommodate easy and fast transfers, generates more public transport demand and higher modal share (Tazris & Last, 2000; Mees, 2000, 2010; Thompson & Matoff, 2003; Vuchic, 2005; Thompson & Brown, 2012; Curtis & Scheurer, 2017). An integrated network design strategy creates better opportunities for a more attractive, simpler and more efficient travel system for all citizens – a cost-efficient way to build larger public transport demand (Currie & Wallis, 2008) (see also Chapter 6).

**Clear objectives for a premium network and complementary services**

There are usually two competing objectives for the public transport system: to provide an attractive, competitive and resource-efficient alternative to car traffic and to offer mobility for all citizens irrespective of their economic, physical or mental abilities.

The first objective points towards fast, high-frequency and comfortable trunk-line services with appropriate modes and safe, direct and high-quality access routes. Connected in compact, easy-to-use interchanges, they should form the *premium network*.

The objective of access for all must be supported through the design of vehicles, stops, stations, access routes, information and travel payment systems. In addition, *complementary services* are needed to serve citizens and areas not within reach of the premium network service (see also Chapters 13, 17, and 22).

Attempts to combine the two objectives in a single service design tend to result in many low-frequency bus lines on slow and roundabout routes with short distances between stops. They usually fail to reach either of the objectives and can often explain the low level of patronage and inefficient operations in many cities and regions.

As noted previously, in all cities and regions with a high level of public transport demand, large proportions of the journeys include one or more interchanges. Compact, efficient and attractive interchanges are essential for the network function – just as important as the road junctions in the car system. Many places in the network must offer fast and comfortable transfers, not only the large interchanges that tend to get most of the attention and resources within a region.

To support the functional network and achieve all potential benefits, a number of other aspects must be appropriately dealt with, such as: full-day operations with relatively high frequencies, appropriate capacity, travel comfort and use of modes, simple integrated payment and supportive information systems and marketing. However, these functions are outside the scope of this chapter.
Network planning and design

Direct and simple lines

The line is the basic building block of the premium network, and how the different lines are designed and operated is crucial. For efficient operation and to attract as many passengers as possible, some key guidelines for the design of single lines should be attended to, even if pragmatic compromises must often be accepted (Nielsen et al., 2005). However, departures from the principles should rely on clear analyses of local circumstances.

*Make straight lines along main routes* with the highest demand, and improve access to the stops. To achieve this, investments in the road system might be needed, but the operational benefits will often make such investments profitable. Do not try to satisfy all citizens by making detours to shorten walking distances and serve possible customers along low-demand routes.

*Avoid circle lines and U- and V-turns of lines.* These solutions usually increase travel time and distances compared to more direct routes. Circle lines can also create the operational challenge of timetable adjustments at one or two points with delay for passengers in the vehicle.

*Avoid one-way loops at the end of lines* and very different routes in the two directions of a line. They tend to increase passengers’ total travel time, spread stops over larger areas and complicate the provision of attractive routes and passenger information.

*Avoid splits with different routes in the central sections of lines.* They complicate the network and hamper equal interval service along the line.

*Prefer the principle of one line per route.* This will facilitate operations with stable and equal intervals between departures and simplify the services and the network for the benefit of both passengers and operators. Several different lines on the same route will often get variable levels of crowding, causing delays and disturbances that spread more easily to other parts of the network.

*Prefer pendulum lines through centres and interchanges,* as opposed to terminating lines – a solution that is far too common in traditional public transport networks. Through-running lines offer more direct journeys between areas on opposite sides of the centre or interchange, and they make better use of the service capacity. They facilitate more efficient use of urban space in centres and close to interchanges. Long stopping time in the most valuable locations is avoided, and the number of lines will be reduced.

*Create fewer and more efficient lines* with high, optimal frequencies. Then investments to improve travel speed, stops and traffic regulations will be easier to justify, and the benefit-cost ratio of such measures will be improved. This will facilitate reliable operations of longer lines, thus limiting the number of lines and the need for transfers. Simpler networks are also easier to plan, operate and communicate. Market success depends strongly on these factors (Nielsen et al., 2005; Currie & Wallis, 2008; Walker, 2011; Norheim, 2017).

High and optimal frequency

High frequency is the key to travel freedom by public transport; users can travel without much concern for the timing of trips. In studies of travel preferences, high frequency consistently comes out as one of the most important qualities that induce people to travel by public transport instead of using a car (Balcombe et al., 2004; Currie & Wallis, 2008; Iseki & Taylor, 2010; Kottenhoff & Bystrom, 2010; Walker, 2011; Norheim, 2017; Higashide, 2019). Frequency is particularly important for network travel involving transfers between different lines and modes.

For infrequent long-distance journeys, people accept the fact that the total travel demand cannot support more than a few departures per day or week. But for shorter daily travel, long intervals between departures result in inflexible timing and long waiting time so that only captive customers will use the service.
Improving frequencies on all parts of the public transport network is a major task for system planning and design. But every new departure adds to the costs of service operation – the major cost factor of the whole system. Efficient network structure, appropriate use of different modes and smart frequency improvements are essential for the creation of an economically sustainable network.

For network design, the concept of optimal frequency is useful. Based on common sense, a guideline for practical planning is to aim for a design frequency between 6–12 and 30 departures per hour. The reasons for this indicative range must be explained.

When the frequency is high, most passengers do not bother about the timetable. They arrive randomly at the stop to catch a bus or rail service. With a perfect regular service, waiting time will equal half the headway between departures. This behaviour is common with headways of 12–15 minutes or less (Balcombe et al., 2004; Holmberg, 2013; Norheim, 2017). When the headway is longer, most passengers adjust their journey to the timetable. The waiting time becomes very dependent on service punctuality and reliability and how well customers are informed about timetables. Real-time information systems improve passenger experience (see also Chapter 25).

For many travel purposes, the time of arrival at the destination, or the time of departure at the origin, is fixed due to work or school times, appointments, shopping hours, meetings, cultural events and so on. With low-frequency services, users experience this as a “hidden” waiting time caused by the difference between the desired departure or arrival time and the start or ending of the activities (Holmberg, 2013). Extending the area and periods served by high-frequency services will significantly reduce the loss of “hidden” travel time and make public transport a more competitive alternative to flexible car travel.

Within typical ranges, half the interval is a practical indicator of the inconvenience of having to wait for the next departure. With passengers coming randomly at stops, an average waiting time of some 2.5 minutes (5 minutes headway) might be considered quite acceptable for short-distance journeys, and 5.0 minutes (10 minutes headway) for longer trips. The very simple relationship between frequency and the length of the interval shown in Figure 32.1 indicates that a desirable service frequency for a major line might be approximately 6–12 departures per hour. The cost-efficiency of this bus service level was confirmed in a study for Ruter, the public transport agency of the Oslo region (Norheim et al., 2011).

Larger headways than 5–10 minutes will give long waiting times, smaller chances of fast transfers and a need to consult the timetable before the journey begins. Conversely, more frequent departures will cost proportionately more to run but with only small reductions in waiting times.

Increasing traffic will gradually also cause growing problems of congestion and environmental conflicts. For capacity reasons, headways between trains, trams or buses often come down to 2 minutes or less in large cities and in networks with only one or two public transport corridors through the city centre. At this traffic density, congestion starts to develop on rail lines and at stations and tram and bus stops. Disturbances between vehicles; between boarding and descending passengers and between buses, trams, and pedestrians at level crossings tend to reduce service quality and reliability.

It is possible to operate the system at shorter than 2-minute headways with separate right-of-way and strict traffic control, more tracks and platforms at stops and segregation of buses and light rail in city streets (Vuchic, 2007). But in long-term planning, one should have some security margin for the occasional traffic fluctuations and small disturbances that will always be part of the daily operations of urban transport. Also, environmental concerns can restrict the desirable frequency, particularly with diesel buses in narrow streets and dense urban development.
When the travel demand requires very heavy traffic, one must consider other solutions instead of adding more departures on crowded routes with operational problems. Planners should look for opportunities for network restructuring that moves traffic from congested sections and interchanges to other routes where more departures will enhance service frequency without overloading the capacity. When this option is unavailable, the vehicles should be replaced with larger units, that is, standard buses to be replaced by articulated buses or light rail and light rail by metro or heavy rail.

Outside megacities and central areas of smaller cities, the most common challenge is to attract enough demand to justify the higher frequencies needed for public transport to become a competitive alternative to car use. A concentration of operational resources is often a prerequisite for high-frequency services. Lines that run at low frequencies near each other, serving much the same travel destinations, should be merged.

By having lines with optimal, high-frequency services, some strategic beneficial effects are achieved. With the concentration of services and passengers, measures that speed up the journey and improve the standard of stops become much more profitable. This will both reduce running costs of the service and make the system more competitive. The concentration of services to a few high-quality lines will also create opportunities for creating network interchanges that cannot be thought of when the lines are dispersed.

High-frequency services attract passengers from a larger area than those with long intervals between departures. Customers can save travel time even if they must walk longer to and from the stops. Some studies of customer preferences (Norheim, 2017) indicate that with a given total time for walking and waiting (half interval), users will prefer the alternative with the highest frequency and not the alternative with the shortest walking time.
As illustrated in Figure 32.2, one can replace two lines with 3–4 departures per hour and 300 metres walking distance with a single line with the double frequency and 600 metres maximum walking distance. This will reduce the average travel time and save costs of infrastructure and operations. In this way, society gets a better service for less money.

To facilitate smooth and efficient operations, high-quality services must operate on schedule with equal headways within each traffic period. To achieve this, the dwell time at stops must be as independent as possible of the number of passengers getting on and off at each stop. Vehicles should be accessible, low floor, with wide (often several) entrances, and efficient payment systems are required. With variable time between departures in peak periods, buses or trains tend to get very uneven passenger loads. This affects the time needed for boarding and descending and will often create a “convoy effect” and congestion at the stops. All this reinforces the delays and the overload of some of the departures. As a result, the total capacity is likely to be inefficiently used.

Fast and reliable speed

Public transport speed directly affects the travel time and therefore competitiveness with the car. Speed is also a major parameter influencing the costs of operation. Together, this makes operational travel speed a key factor for all public transport services, as shown in Figure 32.3.

Punctuality is also necessary for efficient network design and operation. Stable as well as fast travel speed is essential for customer confidence and to reduce the need for safety margins in users’ travel planning. Unreliable service is a common reason given for not using public transport (Balcombe et al., 2004; Holmberg, 2013; Norheim, 2017).

Minimal variation in speed is essential to keep down the need for large reserves of vehicles and personnel in the timetables and for backup operations. Punctual operation of lines is a prerequisite for seamless integration of services into a travel network. And the efficiency and passenger benefits of long pendulum lines depend on stable and efficient speeds independent of traffic disturbances. A network-wide approach to the analysis and assessment of speed improvement measures is needed. A single bottleneck with uncontrolled delays on one important line in the network can cause delays that propagate to lines and users in other parts of the system.
Simple observations of existing systems show that the potential power of speed and reliability improvements is often undervalued by planners and politicians. Poor performance for these two parameters is an important explanation for the low level of patronage found in cities and regions dominated by car traffic. The operational speed depends on the quality of the right-of-way, the regulated speed limit, the stopping pattern and the time needed for picking up and setting down passengers.

As a policy instrument, it is a good idea to register actual travel speeds and benchmark them against the theoretical achievable speed under optimal operational conditions (Nielsen et al., 2005). In most cities and regions, one is likely to find that 30–100 percent faster services can be achieved on many parts of the network if policy makers are willing to prioritise the goal of having a very competitive and efficient public transport system.

Solutions to improve speed should be studied and implemented for all modes, although divided responsibilities for different measures are a usual obstacle.

The distance between stops is a key factor that often causes discussion and conflict. A common pitfall is to simply apply traditional planning norms for the distance between stops along a line. In Europe, the usual distance between stops along urban bus routes has been 300–450 meters,

Figure 32.3 How a speed improvement policy can change the competitive position of public transport and start a positive spiral of development in demand, service quality and economic efficiency

Source: Gustav Nielsen
but it is often only 200–270 meters in US cities and even shorter in the city centres (Tirachini, 2014). The many stops mean that the operations are very slow and expensive, and they seldom attract travellers with the choice of going by car. Improvements of stop locations and access routes are likely to be a better solution than very frequent stops.

In most urban situations, bus lines with average distance between stops of some 600 metres result in more efficient and competitive services. Naturally, this requires somewhat shorter distances in dense city centres and longer distances in lower density suburban districts. Modern bus rapid transit (BRT) is usually planned with longer distances between stops; some 760 meters has been calculated as a global average. However, there will be large variations depending on the systems role in the overall network (Tirachini, 2014) (see also Chapter 13).

Obviously, for express and long-distance travel, far longer distances between stops are needed to achieve acceptable travel speeds. But too-short distances between stops on railway lines are a common pitfall, leading to much slower travel than by car and often inefficient use of expensive, high-quality infrastructure.

The time needed for serving passengers at stops can be reduced by switching from traditional tickets sold and controlled by the driver to prepaid tickets only and/or electronic systems of payment. With full use of mobile technology, it is possible to make travel payment just as convenient as free transport but without undermining the funding of the public transport services. Clear wayfinding and adequate information systems can relieve the driver from disturbances due to customers asking questions before they enter or leave the vehicles at stops.

The design of vehicles affects the time needed at stops. Low floor, wide doors – several if possible – and suitable interior layout of vehicles can contribute to efficiency and comfort as well as accessibility for disabled and elderly persons, people with prams and so on. Double-decker buses and trains cannot perform these functions without significant extensions of the dwell time at stops.

Stops with platforms fit for the type of vehicles, fixed places for entering and disembarking passengers and clear and concise signage also contribute to short stopping times. Some regions also run information campaigns to influence customers’ behaviour at stops and inside vehicles.

Lessons about how to reduce the amount of disturbances and travel time variations can be learnt from the impressive punctuality of the very safe and heavily trafficked rail services in Japan. This is achieved by a combination of hardware, software and “humanware” and a cultural enthusiasm for punctuality – not abundant use of extra crews and trainsets and additional tracks at stations. (Toomi, 2010).

Road traffic management

Obviously, the challenge of undisturbed speed and operations is much bigger for services running on ground level in mixed traffic than for rail systems on separate tracks. Most cities and regions have a long way to go to reach the highest possible speed and reliability standards of road-based public transport needed for the seamless and efficient network.

High-quality bus and light rail systems will often require some new, separate right-of-way on at least parts of their routes. But this can be an expensive and difficult solution involving the expropriation of property and the tearing down of houses. So these solutions are only applied on a minor part of the total network.

It is much cheaper to give priority for buses and light rail through changes in the use of existing road space and capacity. Through use of common traffic and parking signage and
control measures at all conflict points along bus or tram lines, the total effects on speed, service efficiency and reliability of the whole network can be significant. The operational savings will often more than offset the costs of the traffic management measures. But they often require detailed and controversial planning processes, changes in routes for car traffic and new solutions for pedestrians and cyclists.

Planning of the use of road capacity must focus on the number of persons and their travel time, not the number of vehicles. The social and network benefits of improvements in public transport efficiency and accessibility motivate extra priority for users of the space-efficient, non-motorised and least-polluting modes.

Passengers and operators of buses and light rail need priority on a minor part of the total street network and in most cases only for a small part of the total time. Even on a bus route with 12 departures per hour in each direction, the street will be free for other users for most of the time. The measures that are needed to give buses and trams safe, free-flowing access through city streets and urban roads are well known and have been recommended since the 1970s (Webster & Bly, 1976). Numerous practical examples of such measures can be found in European cities and elsewhere (e.g. Hass-Klau et al., 2003; Mundy et al., 2017).

Straight, in-lane kerbside stops should be preferred everywhere they can be accepted on the grounds of traffic safety. They take away the sideways movements and possible delays of the buses from passing car traffic, and they can improve space, safety and comfort of both passengers and passing pedestrians and cyclists. Straight stops are a simple method for giving buses and trams a high level of traffic priority over cars. If cars are held back while the bus or tram is serving passengers at the stop, traffic safety will be improved. By adding give-way signing along the whole route, a simple, trouble free solution for a whole bus or tram network will be in place – as opposed to the heavy investments involved in most modern bus rapid transit and light rail projects.

Priority systems at traffic signals can improve the journey speed and give the bus or tram additional advantage over the car. The signals give priority when a bus or tram comes to the junction, but the total green time needed for public transport will often be less than with the old, fixed interval controls. Surveillance of priority lanes and signals is important for the efficiency of these measures.

Even quite substantial rebuilding of the existing road system may be a good idea. By rearranging the use of existing road capacities, improved bus and light rail speed and reliability can be achieved. On a limited scale, this has been done in many cities around the world. More radical changes through highway conversion and deconstruction can have greater effect on modal split and reduce car traffic (e.g. Cairns et al., 1998; Cervero et al., 2017).

In discussions on traffic management, car travel speed is a major political concern and potential obstacle against the priority measures for buses and light rail. In this case, it may be helpful to remind citizens that the actual and optimal speeds of car traffic in urban areas are rather low (Brög, 1993; Amundsen et al., 2000).

**Complementary services for weaker markets**

For some parts of the travel network, the demand for public transport is so low that high-frequency operations are too expensive and a waste of resources. Various means of compensating for this are available for different market segments.

For long-distance and interregional transport services, customers usually accept the limited number of departures per day or week. In heavily urbanised countries, interregional travel and
main intercity services might have 1–2 departures per hour as a minimum standard, even up to 2–4 per hour in peak periods. Such service levels might induce former car users to prefer intercity trains or express buses for both business and private transport.

In rural districts and low-density suburbs, where there is strong competition from the private car, usually only low-frequency services are possible. For citizens without access to car transport, this can severely restrict their mobility and chances of taking part in work, public and private services and social life.

Complementary services in addition to the premium network, with simple and co-ordinated timetables and reliable, on-time operations, will help to compensate for a lack of high-frequency service. Fixed-hour or -minute services are appreciated by the customers, since they make it easier for people to plan and adjust their activities to the available public transport services. Such adjustments can be facilitated by encouragement of flexible and free working times and long opening hours for shops and services. Particularly in rural communities, adjusting school hours, service appointments, meetings and cultural activities to simple, fixed public transport timing can help to reduce actual and “hidden” waiting times.

It is common to have some lines that are operated only in peak periods. Others are only available in short periods on schooldays. Such services cannot be part of the premium public transport network needed to replace car use, but they can complement the premium network by serving smaller segments of the travel market.

In places and periods without scheduled operations, demand-responsive services might be offered as a general public service or a special service for certain groups or simply left to the private transport market.

Since the 1970s, numerous cases of special services for disabled citizens, and flexible bus operations in rural districts and low-density suburbs, have used all types of technical, operational and organisational ways to improve system efficiency and attractiveness. But, despite some exceptional projects, the key character of demand-responsive transport services remains the same: They are usually unable to collect more than a few customers per vehicle-kilometre or vehicle-hour of service (Pettersson, 2019; Weckström et al., 2018; Westerlund, 2016; Nelson et al., 2010; Enoch et al., 2004).

Special transport services for elderly people and citizens who, for medical reasons, are unable to use the ordinary public transport system, was legislated by Sweden in 1979 and soon followed by many other countries, for example, the United States in 1990. They are operated as demand-responsive services, but the high cost of public subsidy per passenger trip has become a major concern. In the United States, this is the case for the so-called ADA-complementary paratransit required by the Americans with Disability Act (ADA), which shows a very low service productivity, like that of the conventional taxi (Nelson et al., 2010).

However, complementary services in addition to the premium travel network are needed to fulfil the objective of transport for all citizens. To make them as efficient and user friendly as possible, the following system design requirements can be recommended (Westerlund, 2016; Nelson et al., 2010).

The services should be fully integrated as a part of the public transport network open to all citizens, designed in close co-operation with all stakeholders in the areas they cover and flexibly adapted to users’ changing demands. They should be operated as relatively short feeders to stops and interchanges on the premium network. To secure demand and productivity, special market segmentation should be avoided.

Adaptation to different user requirements should be handled through service variants and price differentiation with a pool of vehicles, drivers and operators within the service district.
For user-friendliness, information, booking and payment should be designed and operated as a one-stop service, preferably as a national or even international system.

**Quality access and liveable places**

Access and egress to and from stops and stations constitute significant parts of the generalised cost of the total public transport journey. The quality of these walking or cycling links affects the choice of mode, and they also influence the size of the catchment area of the stops (Norheim, 2017; Hillnhütter, 2016; Balcombe et al., 2004; Wardman, 2001).

Upgrading the local access routes will also support the previously recommended increase in distance between stops to improve the efficiency of the premium network. Of course, such measures give additional benefits for all non-motorised trips in the area, that is, a large part of the citizens’ travel activity. Positive effects on the population’s health and the liveability of cities are huge bonuses.

Making walking and cycling safer and more attractive should become an essential part of the policies to develop an attractive and competitive public transport network. This includes creating shortcuts and reducing the barrier effects of car traffic, traffic signals and other traffic management measures that slow down the travel speed of pedestrians and cyclists. Road traffic regulations from the days when free-flowing car traffic was the main concern must be replaced by solutions focusing on walkability and bikeability.

The Netherlands, Denmark and other European regions particularly promote the combination of cycling and public transport use. They improve access and egress by bicycle and build safe and attractive parking facilities at stops, develop shared bicycle systems and allow space for bicycles on board trains and metros.

Stop location and design should be an integrated part of urban development and design. By creating liveable environments and stimulating activities, the stops and stations can become natural meeting places for the local area. The otherwise tedious waiting time at inhospitable places can be spent at more interesting and busy places where travellers also feel safer and can combine their public transport journeys with useful or entertaining activities. This can support community liveability and stimulate car-free lifestyles.

In principle, stops and stations should be located in the middle of urban development and away from freeways and major roads with heavy car traffic. Environmental areas and superblocks (as promoted in Barcelona) are common in urban planning and development. However, usually public transport is treated as an environmental nuisance and therefore relegated to the edges of the area together with the main car traffic flow. But modern buses and light rail can be virtually noise and pollution free. Even busy routes have few vehicles per hour compared to local streets for car traffic, and practice has shown that they are acceptable in most pedestrianised streets and squares that are closed to car traffic.

Decision-makers should also recognise the potential of using the distances to car parking and public transport stops as instruments of transport policy and urban planning. It is not a law of nature that car users always should be able to park their cars very close to the entrance of their destinations. When the walking distance to public transport stops is shorter or similar than to car parking, more travellers prefer to use public transport. Walking and cycling are also more attractive choices inside car-free zones with parking on the edges. Car users who walk to and from their cars also contribute to the numbers of pedestrians and liveability of the area.

Redesigning the traffic system according to this updated neighbourhood model is one of the strongest policies that can be used to reduce the car dependency of most regions. This might
require that car parking be understood and financed as part of the road system and not as the integrated responsibility of buildings and their users.

**Public transport access by car?**

Park and Ride facilities to support access to public transport by car is a common solution, particularly in mainly car-based regions. In many low-density areas and small travel markets, individual motorised transport is still considered the most efficient and environment-friendly solution, particularly when the cars can be operated on non-polluting, renewable energy. However, this individual transport will not reduce the need for complementary services for the carless population (see also Chapter 7).

Catering to some demand for multi-modal travel with car to and from the public transport network will make public transport a more practical and attractive alternative for those who want to combine the rail or bus trip with activities by car.

Access by cars, or minibuses, takes several forms: Park and Ride, kiss-and-ride, rent-a-car, taxi, limousine and hire-bus services operated independently of the public transport system. On a small scale, all solutions can be quite easily integrated in the ordinary road traffic system close to the public transport stops.

But at bigger stops and stations, car access can be a design requirement in conflict with the needs of the majority of public transport users and the total system’s competitiveness towards car use. The space and capacity requirements of car parking and heavy car traffic mean that one must be careful about where the interchanges between public transport and car travel are located.

Park and Ride schemes can often divert passengers from using other public transport services, thus contributing to more car travel than before (Wiseman et al., 2012). A feeder system with timed transfer can instead provide a reduction in vehicle-kilometres. It has been found that Park and Ride stations at the periphery of an urban area have a negative environmental effect on the vehicle-kilometres, while “remote” stations can have a positive effect (Bruun, 2014).

Compared to solutions with a complementary feeder service to the premium network, Park and Ride is very space demanding. The area required to park one car in a car-park facility is 25–40 m². This is equivalent to the space needed for a small flat or an office for a couple of persons. Therefore, a better alternative for the generation of public transport demand will often be to replace the car parking space with more flats or offices and transport-intensive functions near the stations and stops. This will also support the design of compact interchanges and stops as meeting places.

Resources used for the investment, operation, and maintenance of large car parks at public transport hubs might have an alternative use through improvements of services that can make people less dependent on using cars to access the system. Then more people could let their cars stay in the garage at home. A socioeconomic calculation of this strategy should be made before deciding about creating large Park and Ride sites.

**Conclusion**

Taken together, the network design principles described previously can have a profound impact on the attractiveness and efficiency of the public transport system. Making the public transport system the dominant mode of motorised transport will of course also require appropriate transport policies and pricing of car use and parking. Furthermore, network planning and design
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should be well integrated with urban planning and development. Land use density and urban form have a profound effect on public transport demand and service efficiency.

When the public transport sector is able to make a clear, long-term network structure of services and communicate this to everybody, it will be possible for households, businesses, public institutions and urban developers to make locational decisions that reduce dependence on car transport and support further growth in public transport demand and services. Network planning and simplification is a prerequisite for such processes to take place.

More public transport research should be focused on network planning and design. To further verify the recommendations in this chapter, more detailed before-and-after studies could be made of demand and cost effects of major network redesigns. Such studies should cover various urban and regional contexts and identify the appropriate roles of different modes, types of service and supportive transport and land use policies. If possible, the “value” of simplicity in all aspects of system design should be quantified. Better understanding of the interaction and pay-offs between network accessibility; different service quality factors; operational efficiency and the effects on long-term demand, land use and modal share would be useful.

In reflecting on the experience with the COVID-19 pandemic, some considerations are offered about how future network planning and design might or should be affected when society is “back to normal”. First, the pandemic has been a reminder of how important public transport is as a crucial part of society’s basic infrastructure. This is a good reason for using public money to finance the system. Second, the need to keep social distancing can perhaps induce a revision of what is considered an acceptable capacity in public transport vehicles. Third, in most large cities, working from home and staggered hours are flattening the traffic peaks and saving resources that might be used to strengthen the basic, off-peak transport services. Differentiated pricing of both public transport and car traffic would support this development. Finally, the pandemic has also induced more walking, cycling and e-biking as replacements for short-distance travel in crowded public transport. Many cities have seen an opportunity to reserve more road space for these modes at the expense of other modes. Improved conditions for the active modes will support the network design recommendations in this chapter concerning greater distances between stops and faster, more direct and frequent services along high-quality routes.

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