NETWORK DESIGN FOR PUBLIC TRANSPORT SUCCESS – THEORY AND EXAMPLES

Gustav Nielsen
Institute of Transport Economic

Truls Lange
Civitas group of consultants
Oslo, Norway

INTRODUCTION

This paper is about the design of public transport service concepts and networks in urban and rural districts. An attempt has been made to define some basic concepts that are useful for public transport planners and decision makers when they want to create high quality public transport services in their region.

The paper is based on the authors' work for the HiTrans Interreg III-project (Nielsen, Lange et al. 2005), recent work on a good practice guide for public transport system design in rural and small town regions for the Norwegian Ministry of Transport and Communications (Nielsen and Lange 2008), earlier literature studies and consultancy work for various public transport bodies in Norway. The ideas are still under development, so comments and suggestions will certainly be appreciated.

Network design – an undervalued success factor

We consider the importance of the design and planning of network structure for public transport success to be underrated, and are surprised that the topic is more or less neglected in standard texts on public transport or transport policy. The paper will draw attention to the key role of network design, irrespective of the mode of public transport.

Getting the network right is usually more important than the often debated and studied choice between bus and rail systems. Mode selection for new parts of the network should normally come after an overall network strategy has been created. Then the roles of different bus and rail systems can be conceived as specialized tasks within the network, and the different advantages of the various public transport modes and types of lines may be more easily exploited.

Proposals for the structuring of multi-modal public travel networks in different types of urban and rural districts will be presented. The focus will be on the principles for the design of such networks in small and medium sized urban regions and their rural hinterlands. Examples of "good" practice will be chosen from different regions and countries. We do not deal with all the details of network design, but the main concepts that we recommend public transport planners to sort out before they start the detailed planning of the public transport system.

Some key terms

We must clarify our use of some key terms. Our concern here is only about local and intra-regional travel, and how to create attractive, competitive and efficient public transport services inside various types of regions.

By region we mean the commuting and service district surrounding an urban or rural centre. The size of the region may vary a lot, in terms of land area, population size and functional role in the hierarchy of settlements. The size of the hinterland will depend on topography, population density and the regional pattern of the country. In terms of travel time by car or local rail services we think of journeys of up to 60–90 minutes from the regional centre to the outer edges of the region. Public transport networks for interregional and long distance travel is a different matter, and will not be discussed here.

We use the term line, and not the more commonly used English term” route” (see below). By this we follow the GUIDE project (Tarzis and Last 2000) as well as the Scandinavian and Continental professional practice of distinguishing between the line as an operational element of the public transport system and the route that the bus or rail vehicle follows through the city. Normally in English the terms route, operational route, service, etc. are used. But then it is easier to mix up our line concept with the other meanings of the word route. ”Line” is also used for rail services in the UK, such as the different lines of the London Underground, e.g. the Circle line or the Piccadilly line. In rail systems the operational term line should also be distinguished from the infrastructure term of rail track, even if common English often mixes the terms of railway line and track.

A further discussion of the definition of a line is given in the HiTrans report (Nielsen, Lange et al. 2005). This includes a look at the different ways a line may be presented to the public. Simplicity in the design of the main lines is a “golden rule” for the creation of a public transport system that is attractive and easy to understand and operate. In many regions this rule is overlooked, which has made the system diffuse and its services difficult to understand. The need for information about geography and timetables becomes a heavy barrier to users and synergies between different modes and operators are very difficult to achieve.

A line must have a timetable, which also should be as simple as possible. Under ideal operating conditions the driving and stopping times would be the same at all times. Then it will be possible to operate with fixed departure times at every hour during the service period. However, large fluctuations in demand, congestion and insufficient priority measures will often force the introduction of peak and off peak running times. High frequencies will offset some of the disadvantage in the peak, but outside peak periods a fixed-minute (clock face) timetable should be the norm. Lines that are not operated in large parts of the general service period (peak services, night services etc) should not be included in the main network structure, but dealt with as a part of the supplementary access service.

The term route we use to describe the series of road or rail links that a public transport vehicle follows through the city and/or region. The public transport services are operated on lines (as above) that may or may not follow the same routes. This is different from common English practice, where a ”bus route” is the normal term for what we call a ”bus line”. This is because we need to use the term line – the key unit for public transport service production - as a common term for both rail and bus services.

Transfer is the act of changing from one public transport line to another line that may be of the same or different mode of transport. Usually passengers transfer (or change) at a designated interchange. The noun interchange is used for all places in the public transport network that are specifically designed to facilitate transfers between lines and/or modes. Changes between vehicles may also take place at ordinary stops, but we designate stops as interchanges only when they offer clearly different travel directions and have physical facilities and information systems that support passengers when they transfer from one line to another.

SUCCESS FACTORS FOR HIGH QUALITY PUBLIC TRANSPORT

From international research we know that a large number of factors are important to bear in mind when designing systems and networks for public transport at the local and regional level (Nielsen, Lange et al. 2005).

Organisation and transport policy

At the policy and organisational level, institutional factors may strongly affect the opportunities for overall planning of the network (Mulley, Nelson and Nielsen 2005). Under the regime of on-the-road competition, such as in Great Britain outside London, there will be great difficulties in the implementation of the type of network design that we recommend. But even under other institutional frameworks, network planning requires the right organisation of planning duties and powers, as well as appropriate forms of incentives to the different players of the game.

Empirical evidence suggests that good practice seems to have four interrelated factors in common (Colin Buchanan and Partners 2003, ECMT 2002). These are:

- Regional organisation. The existence of some kind of regional structure is the element that many authors have argued as essential.
- Funding. A willingness to commit funds to both operations and infrastructure by relevant stakeholders is a pre-requisite and by itself would appear to be able to generate public transport patronage, but not modal shift from car.
- Supporting policy. Complementary policies that reinforce the underlying transport policies in their achievement of modal shift.
- Land use and transport co-ordination. Successful co-ordination between land-use policies and transport policies in recognition of their conjoint spatial attributes.

Long term stability

At the strategic level of planning the public transport system, long-term stability of a high service quality is required for the public transport system to influence urban development and create more sustainable transport patterns. At the same time, one must recognize the need for the system to adapt dynamically to the changing demands of the citizens and the economic circumstances of public transport operations.

The request for network stability can only be satisfied if the network is robust enough to incorporate the need for short term adjustments in frequency, capacity, connecting and disconnecting lines and branches. The network should also have the ability to be extended into new areas of urban development without having to redesign large parts of the existing structure. Even conversions of transport corridors between bus and rail should ideally be possible without completely altering the network structure of the urban region.

Robust and simple structure for major market segments

The required robustness is most easily achieved when the public transport system is built up as a simple network of as few, clearly defined lines as possible. The network of only a few lines for each mode of public transport has a number of advantages compared to the much more complex networks that very often characterize urban regions today, for historical, institutional and other reasons. The robust simplicity will provide a public transport service that is easier to perceive and remember for the users, easier to market, brand and sell, and simpler to plan and operate. All this will support the aim of making public transport more efficient and decisive in the development of new infrastructure, urban development and land use planning.

These recommendations are supported by HiTrans' case studies of how medium-sized cities have delivered high quality public transport. Rye et al. (2005) analysed ten different cases of urban networks and five transport corridors in different north western, European urban regions. In order to increase usage amongst both existing users and current non-users of their public transport systems, medium sized cities should (p. 92):

- "Speed up their core services, preferably by converting them to some form of segregated rail-based mode, or otherwise by simplifying the routes and introducing bus priority.
- Simplify routes more generally; focus on high frequency on core corridors.
- Start with corridors, because these are easier to grow than networks as a whole.
- Both the above measures will improve reliability, which is also a key quality factor.
- Cut fares through the provision of integrated season tickets.
- Integrate services across modes.
- Provide high quality modern, clean, safe vehicles, stations and stops.
- Reduced parking availability/increased parking prices, traffic calming, traffic congestion on key road corridors paralleled by rail-based services and a land use planning framework that works to assist public transport will all lead to greater patronage increases and modal shift, although they may not necessarily be defined as what the citizen would want from their public transport system."

Serving all citizens

In order to succeed in the market competition with the motorcar, much of the resources of the public transport system must be directed towards the main transport corridors. But this concentration of resources in a region must be balanced with the need to provide a minimum transport service to all citizens irrespective of car availability, physical abilities and area of residence.

Lines that are only operated a few times per day, and lines that do not follow fixed routes, will not be included in the main line structure planning. This means that areas with little public transport demand must have other transport solutions to give access to the stops, stations and interchanges of the main public transport network. Local access may be provided by various forms of low frequency bus lines, demand-responsive services, service lines, minibuses, taxis, school buses and special transport services for the elderly and disabled. Even special solutions such as night buses, work buses and other market-adjusted services will supplement the main public transport network. Obviously, local access is also provided by walking, cycling and private cars.

But the development of a strong, attractive travel network open to all members of the public and designed for universal accessibility, will reduce the need for special, tailor-made solutions. Too extensive use of special services may divert resources from the task of creating a basic, high quality public system. However, special services may also be used to test new markets and give impulses to the further development of the regular public transport network.

A two-tier public travel network similar to the road network

In order to combine efficiently the two rather different tasks of public transport – attracting people away from cars, and giving accessibility to all citizens – we suggest a two-tier public transport system which should be defined as a fundamental part of the regional infrastructure. As for hospitals and schools, this must include the operational part of the service, since empty infrastructure without operating services is useless. Further, the service should be designed as a single system from a user point of view, and it should ideally be as easy to understand and use as the road network for car traffic.

The main concept that emerges from the preceding considerations, is that different modes, lines and service concepts should be integrated into a single, user-friendly, and two-tier public travel network, with a combination of:

- a stable and simple network of lines with fix-scheduled services and frequencies high enough to satisfy large sections of the travel market, and
- a flexible, demand-responsive service catering for all other public transport services that are needed to satisfy customers in low density areas, at quiet traffic periods, and for people that are not able to use the scheduled line services or who have certain defined citizens' rights to public transport services to schools, studies, health services, social institutions, etc.

At the operational level there are numerous details that should be kept in order so as to reach the service standards required for a high quality public transport service. Many factors must be "right" and "correctly" designed in order to move towards the vision of a public transport system that is easy to use for everybody. However, between the strategic and the operational levels of planning, network design is the key factor, which is the main topic of this paper.

PROPERTIES OF A SUCCESSFUL PUBLIC TRAVEL NETWORK

We will now discuss some of the most important properties of the travel network we propose to become the backbone of urban regions in the future. In the course of this discussion, we will comment briefly on some points from the extensive literature on the various factors that influence the demand for public transport. We restrict our comments to the factors of greatest importance when the network structure is decided, with reference to the research reviews on the topic of public transport demand from the Transport Research Laboratory (2004), the Institute of Transport Economics (Stangeby and Norheim 1995), and a few other references.

Of course, the design principles for the public travel network must be adjusted to the actual urban and regional structure, and the level of public transport provision that one is aiming at for the region in question. We will briefly discuss this, but have in mind that further application studies are desirable to confirm or modify our recommendations.

The importance of service frequency

A line in the main public travel network should not only be a line on the map; it must provide a significant travel service. Market studies in many places have revealed a strong demand for higher frequencies in public transport services. The importance of high frequencies for public transport patronage is also found in comparative studies of different cities. When the policy objective is to attract people away from the use of cars, a high frequency service level is particularly important. However, the relationship between frequency and demand is not as simple as often assumed in practical planning.

The Transport Research Laboratory (TRL 2004, chapter 7.7.) concludes in its review of 27 different measurement studies of the service elasticity of bus demand, that the short run elasticity of demand (in an urban, British context) is 0.38, with a standard deviation of 0.14. The long term elasticity of bus demand is significantly greater, 0.66 with a standard deviation of 0.28. They also found that the short term demand elasticity for rail travel was almost the double of that of the bus services, 0.75 with a standard deviation of 0.13.

From this one might conclude that it is uncommon to find average demand elasticities in relation to service frequency above 1.0. The figures from TRL mean that doubling the frequency of an existing public transport service on average might only result in some 40–70 percent increase in the patronage. From a business point of view, this very often implies that the costs of increased frequencies will not be covered by increased traffic income from the fares. The benefits of higher frequencies will be reduced waiting times for the public transport users and the indirect effects of new journeys being made, and of any reduced car use. But the social benefits not reflected in increased fare revenue must be paid for through public support, and this will often be a strong barrier to such service improvements.

However, the level of frequency that is considered acceptable by the customers differs a great deal according to what the public has been used to; for instance between a person living in the central part of a large city versus a suburbanite or inhabitant of a small town. The time of the day, journey purpose and length of the journey also affects the experience of frequency and acceptable waiting time. Through good knowledge of the market and appropriate design of the travel network one can find market segments that are more responsive to service improvements than the average figures indicate.

Furthermore, the relationship between service frequency and demand is not likely to be linear. As we will later illustrate, when frequencies are increased within an existing line structure, we have a case of diminishing returns in relation to demand. Instead of increasing frequency on existing lines, perhaps many with quite short headways, one might use the extra service production to strengthen the weakest parts of the network or create new lines if the services manage to satisfy new groups of customers.

This leads to an aspect of frequency and network design that tends to be overlooked or not fully understood: high frequency lines can create a network of travel opportunities. This is especially important for the public transport system's attractiveness in relation to the motor car. With adequate service levels on both radial, centre-oriented lines and orbital, suburban lines, the public transport system might become a more realistic and attractive alternative to the use of cars, or at least to the users of the second or third car in family households. Therefore we followed Paul Mees' (2000) advice, and started to look for the ”network factor.”

The network factor

The implications of the network effect for the planning of public transport are so great that it is necessary to clarify what this concept implies. Figure 1 illustrates the basic idea. With only low frequency lines, waiting times at transfer points become far too long to make public transport journeys with one or more transfers between different lines an interesting travel option for others than those who are forced to make this type of journey. With some high frequency ”trunk lines” the situation improves, but it is only when you have a network of high frequency services the system really stands a chance to compete with the car as a real travel alternative for other journeys than direct, radial trips to and from the central area of the city or region.

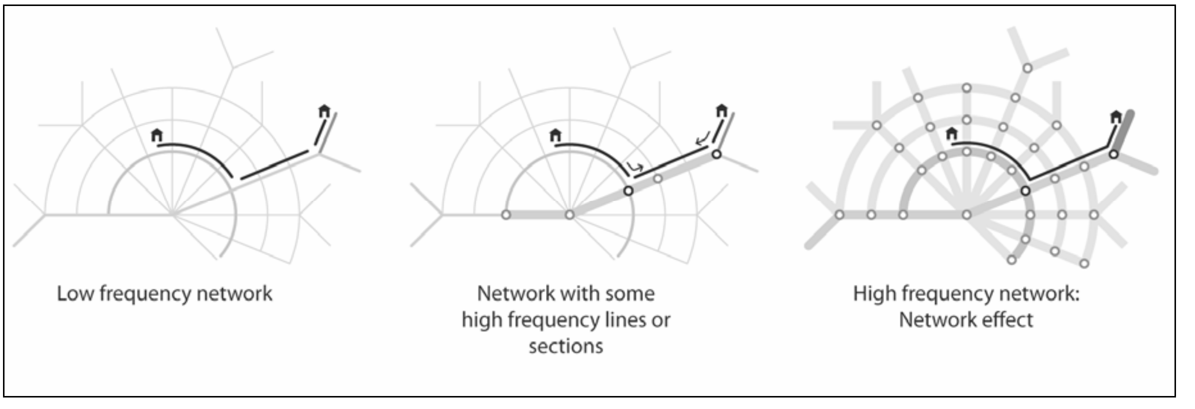


Figure 1: The network effect

How the network effect might significantly influence travel demand, is probably best understood through Mees’ (2000) theoretical example of “Squaresville” (adapted by us in Nielsen, Lange et al. 2005).

Squaresville – the ideal case

As shown in figure 2, the hypothetical city of “Squaresville” has a grid-iron street pattern. The streets are well suited for a bus service since they are 800 meters apart. “Squaresville” is a homogeneous city with a travel demand that is entirely dispersed. Assume that the area around each of the city’s street crossings generates one journey to every other street crossing; 9900 trips per day in total. For the whole of “Squaresville”, the ten bus lines can only serve 900 trips in the city, which is less than 10 percent of the total trips of 9900. Assume that the public transport service presently attracts one-third of the journeys it can theoretically serve. This gives 300 trips per day by public transport, which is a modal share across the whole city of only 3 percent.

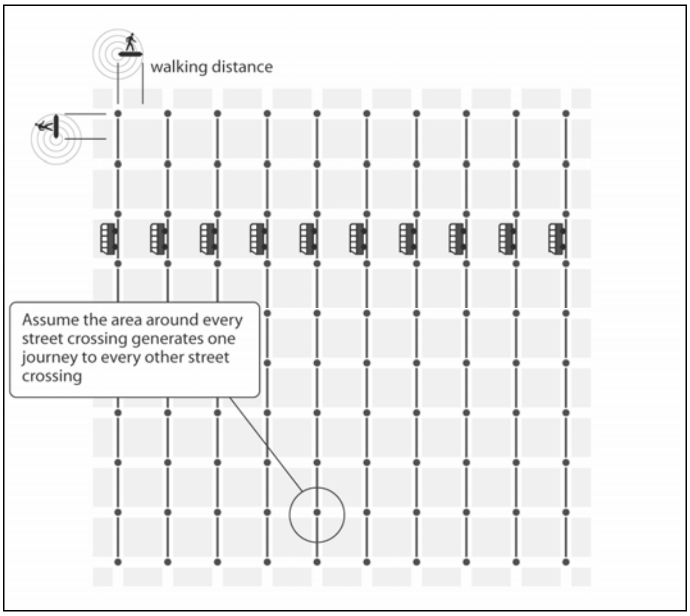


Figure 2: "Squaresville" with ten bus lines running north–south

Imagine that services on the existing bus lines are doubled in order to induce more people in "Squaresville" to use public transport, figure 3. According to traditional transport demand modelling the elasticity of demand might be assumed to be some 0.5. This means that a 100 percent increase in service will produce a 50 percent increase in demand. The result will be 450 public transport trips per day and a modal share of 4.5 percent. Since the operational costs are likely to increase by more than 50 percent, the cost-recovery through fares is likely to fall.

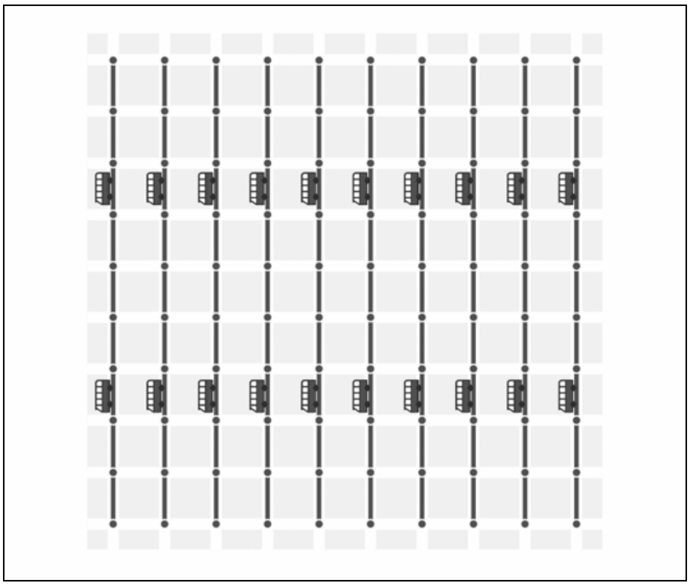


Figure 3: "Squaresville" with ten bus lines running north–south, double frequencies on all lines

Imagine that the extra operating resources instead were used to run ten new bus lines in the east-west direction, as shown in figure 4. This would create a grid network of twenty lines. The number of trips that are directly served would double to 1800; the 900 initial north-south journeys and the 900 new east-west journeys that can be made without transferring between lines. But if passengers are willing to transfer (we will later return to this condition), then all 9900 trips between all blocks can be served by this network; 1800 directly and 8100 by transferring. Assume that the modal share for journeys involving a transfer is half of that for direct journeys, i.e. one-sixth of these trips that can be attracted to public transport. This gives a total number of 1950 public transport trips per day (1800/3 + 8100/6). The modal share has increased dramatically from 3 to 20 percent.

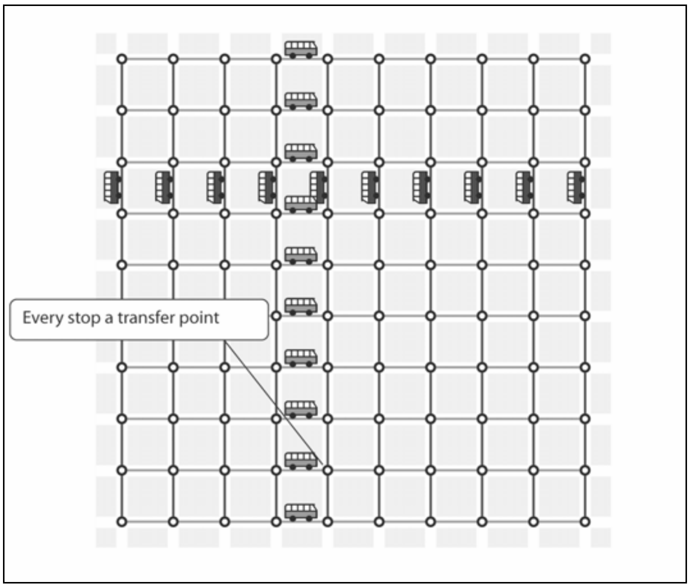
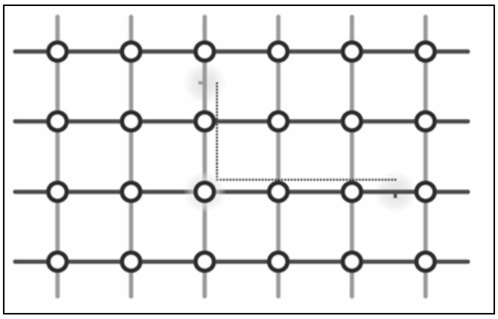


Figure 4: "Squaresville" with twenty bus lines running north–south and east–west

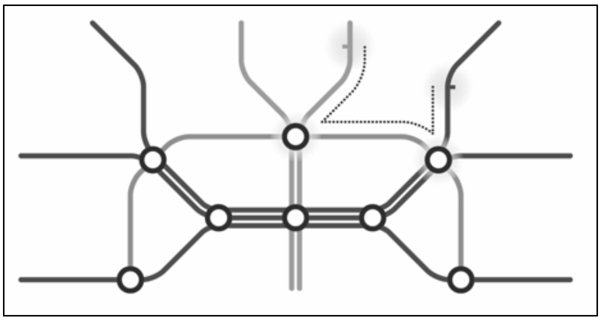
This gives a theoretical elasticity of demand that is 5.5, rather than the traditional figure of 0.5. Increased revenue from the fares should more than cover the extra costs of operation and vehicle occupation would rise. We will by no means claim that this ten-fold increase in demand is a figure to be found in the real world. Nevertheless, it illustrates the significance of the network effect for public transport demand; if at least some of the theoretical potential is exploitable in a real situation.

Regional size, density and urban structure

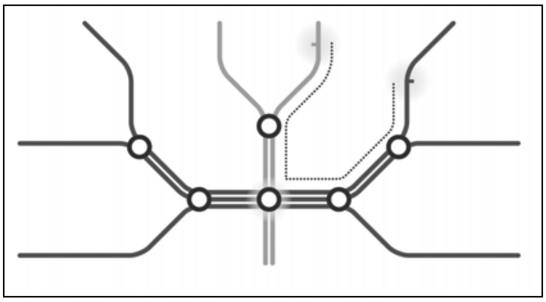
We will argue that the network effect is not only achievable in big cities, as indicated by the following examples of typical network structures, see figures 5 a – f. In addition to the illustrated patterns of urban development and infrastructure, one must consider the questions of scale and density of demand. The practical catchment area of a bus stop or rail station is limited, even if one includes a demand-responsive service as a supplementary access system as recommended for the overall system design.



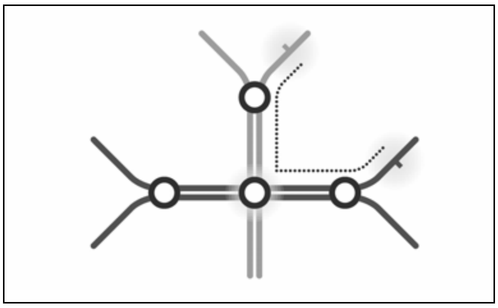
a. Squaresville



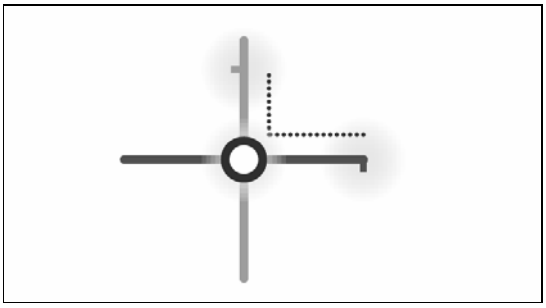
b. Medium sized city



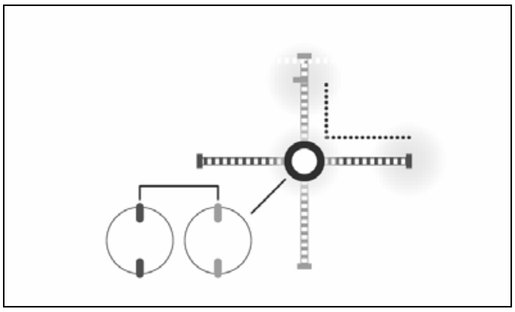
c. Large town



d. Small town



e. Village



f. Station or express bus stop

Figure 5 a–f: Travel possibilities in different urban structures

However, by presently ignoring the more detailed aspects of scale and variations in the density of urban development, we have a few comments on some typical urban structures and how they might be served in order to achieve much of the network effect indicated by the ”Squaresville” example:

- The theoretical concept of ”Squaresville” shows a grid pattern of high frequency lines where all journeys may be done with one transfer only. Very large cities and agglomerations may have the possibility to develop their public transport network according to this principle.
- In many cities with a population of some 100,000–200,000 or more, the urban structure and travel demand might allow for one or two ring lines. If possible, the

ring line(s) should have a frequency and travel speed that makes it attractive to travel across the city without having to travel all the way to the city centre. By developing high quality interchanges at strategic locations with a concentration of activities, a fairly attractive network may be achieved.

- In smaller cities, including most cities with less than 100,000 inhabitants, most journeys are short, and the demand for public transport is insufficient to support a high frequency ring line outside the central parts of the city. Then all public transport journeys between different suburbs must be made through the city centre, either directly on a through running "pendulum" line, or by transfer in the city centre. A network effect may still be achieved if the service frequencies are high in all major corridors of the city region, and the interchange is a high quality one.
- In small towns, there are few corridors with sufficient demand for high-quality public transport, so here the coordination between regional and local lines will become more important for the possible creation of a network effect. The town centre is the only major interchange in the town in addition to the common stops of several lines in each of the transport corridors.
- In even smaller towns and villages there is no basis for a separate local network. All public transport (except service lines, etc.) is based on the regional lines serving the rural district and connecting to the nearest larger town and/or transport hub. Here frequencies are so low that time table co-ordination is necessary to achieve a network effect in the regional system.
- Time table coordination through the creation of integrated pulse schedules is even more important at bus or rail stations in areas where the frequency of services is low.

A real-world confirmation

Mees' (2000) description of Squaresville and the network effect was supported by rather clear evidence from his detailed, comparative study of the public transport systems of Melbourne and Toronto over several decades of urban growth up to 1990/91. The 1990 population of Melbourne was 3.0 million, and Toronto had reached 3.9 million.

In the period 1960 – 1990 the number of annual per capita public transport journeys increased by 22 percent in Toronto, and decreased by 56 percent in Melbourne. The public transport share of all motorised trips was stable at 33 percent in Toronto between 1964 and 1986, in Melbourne the percentage fell from 42 percent to 19 percent in the same period. Mees investigated a number of possible explanations for this very significant difference in policy results, including differences in urban structure, service levels and public transport structure. He concluded that the main explanations for the relative success of public transport in Toronto compared to Melbourne, were:

- The high quality of bus services in the suburbs and their excellent integration with rail in Toronto, and the poor bus service and lack of integration with rail in Melbourne.
- The integrated system of Toronto also resulted in a much more intensive and cost-efficient use of the rail infrastructure, when compared to the more extensive Melbourne rail system.
- The bus and rail combination in Toronto proved more attractive to the population in Toronto than the more extensive park & ride facilities that had been developed in Melbourne, partly as a result of the poor bus and rail integration.

The conclusions are supported by the internal variations in patronage and service qualities in both urban regions, which showed that the network effect was at work in those suburban areas of the city were it is likely to be most important. To Europeans with experience from the integrated public transport systems of urban regions in Germany and Switzerland, the conclusions are no surprise. But it is interesting that Mees has demonstrated the importance of the network effect in cities with a medium to low density, and with a more car-oriented urban structure.

The key role of transfers and interchange points

Obviously, the network effect depends on the assumption that travellers are willing to transfer between lines. In cities and places where both the line network and the transfer points are designed to accommodate this, such changes are being made in large numbers.

But in regions without the same level of network integration, it is common to argue that a system of direct lines is the only strategy that is able to attract car users. As described by Mees (2000), the idea is that the motor car is the ideal mode of urban transport, and that public transport should try to offer a service as similar to the car as possible. The idea usually leads to a large number of bus lines running parallel and in all sorts of directions in a very complicated tangle of low-frequency services, but with heavily congested bus routes in the city centre in order to serve all suburbs and rural districts with their own direct lines to the city centre. Unfortunately, much of the research on willingness to transfer tends to confirm this network strategy, through studies of hypothetical, stated preferences among users of systems where transfers between lines are unattractive and complicated.

These results have encouraged a common misunderstanding of the nature of public transport, a point stressed by the GUIDE project (Tarzis and Last 2000). They ascertained that transfer between services is an inescapable feature of public transport. The essence of a public transport system is the concentration of passenger flows onto specific lines of movement. It is almost inevitable that the network of individual lines – bus routes or rail services – cannot serve all combinations of passenger origin and destination. Operational resources must be concentrated to achieve the economy of scale that creates most of the benefits of public transport compared with the car.

In practice, public transport works by concentrating passengers into selected corridors, and inevitably this leaves some journeys without a direct connection. Transfer is an inescapable feature when it comes to providing comprehensive linkages within an urban area. Furthermore, there is a range of public transport modes, each of which offers a different combination of characteristics such as speed, capacity, ride quality, ability to penetrate different types of areas, and cost. Letting different modes and types of lines (e.g. express and local services) play different roles in the total network is an important way of getting value for money in public transport. It can also be highly advantageous for passengers to substitute a fast mode (such as rail) for part of their journey, instead of a slow mode (such as bus). Indeed, only by doing so will public transport offer an acceptable alternative to the private car for longer journeys.

Reducing barriers to transfer will enable individual passengers to gain more benefit from the public transport system, and will increase the attractiveness of the public transport 'offer' relative to the car. Consequently, how interchanges are designed and presented, and the processes through which passenger expectations are moulded and satisfied, is at the heart of the overall strategy of improving the public transport offer. There are a number of factors concerning location, design and information of interchange points that may be used to improve network connectivity, but further comments on this is outside the scope of this paper.

Data gathered by Tarzis and Last (2000) suggest that there is an association of higher levels of transfer with higher public transport modal shares, which possibly may be interpreted as a network effect.

The fact that most urban regions still have very few high-quality interchanges means that most of the survey respondents in customer preference studies have little experience of situations with travel in properly integrated networks. A Swedish study of passengers travelling by bus to Arlanda airport Stockholm (Sjöstrand 1999) concluded that the experiences of travellers are of great importance to their evaluations. The group of respondents who were used to changing buses at a high-quality interchange evaluated it as 7 minutes extra travel time, while those who were used to direct travel evaluated a transfer at 22 minutes extra travelling time in a bus. This was a study of rather long journeys, but in a market where many of the travellers bring some luggage.

We see this study result as a confirmation of the importance of network creation and interchange design. But further research is needed to quantify the effects on demand that could be referred to as the network effect.

Optimum frequency?

Even if high frequency is an important condition for market success, there is no need to go beyond all bounds. There are clear limits to how many departures per hour one has to have in order to offer passengers short waiting times. We suggest 6–12 departures per hour at working daytime as a suitable frequency level to aim at for middle sized cities. This takes account of the fact that shorter headways would not radically reduce waiting times.

The diminishing return of increased production is illustrated in figure 6, which sets the average waiting time at half of the interval between departures. It shows that larger headways than 5-10 minutes will give long waiting and transfer times, and a need to consult the timetable before the journey begins. Especially for journeys that include transfers between different lines.

On the other side, shorter headways will cost proportionately more to run, but without giving significant reductions in waiting times. In addition, the tighter traffic may gradually cause increasing problems of congestion and environmental conflicts, especially if the line is operated by standard diesel buses in narrow streets in high density (residential) areas.

We find some support for the idea of this basic service level as some sort of a threshold between “forget the timetable” and a “fixed-minute timetable” (see below) in the TRL review of how service factors affect public transport demand. They report effects on travel behaviour of a change in a bus service in North West London from 20-minute headway with large buses to 10-minute headway with minibuses. In the first case most customers planned their journey departure time, while in the latter most of them arrived at the bus stops independently of the timetable (White et. al. 1992). Further evidence from different cities and regions, and at various changes of service levels, would be useful in finding the right service level to aim at.

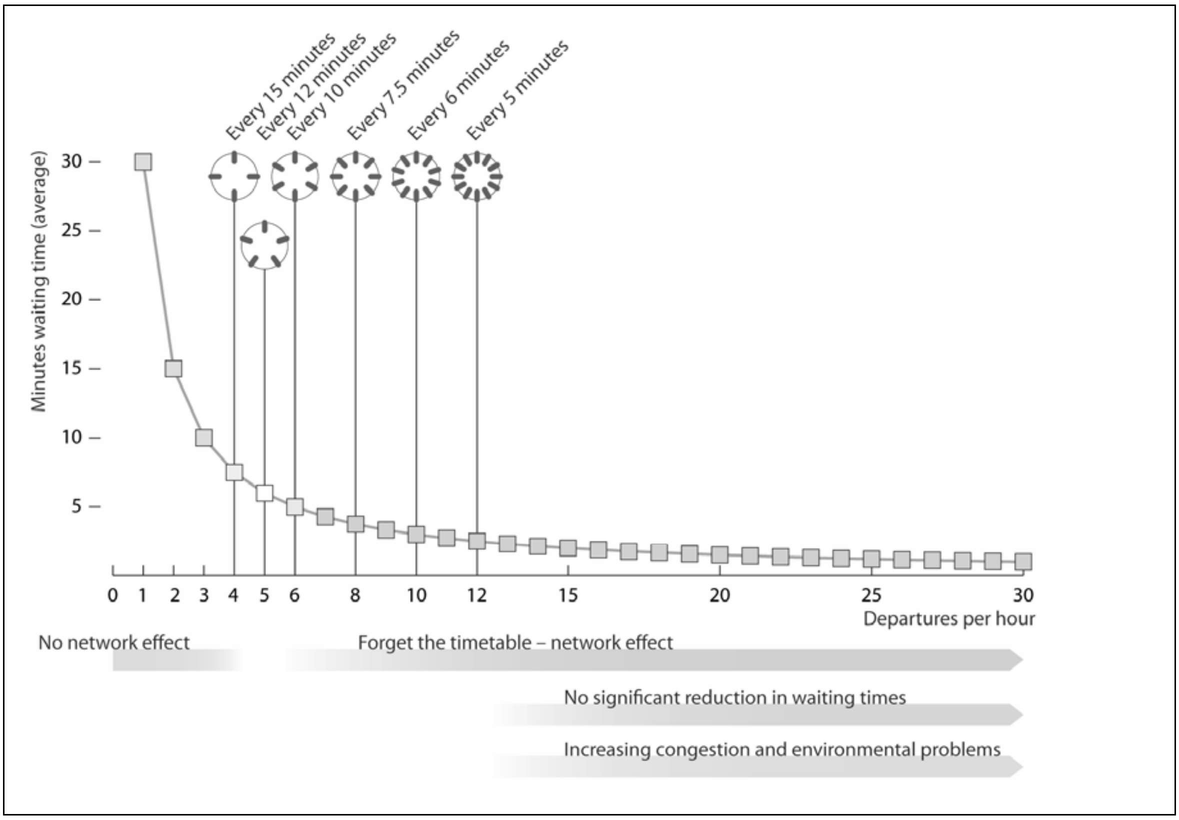


Figure 6: The simple relation between service frequency and average waiting time defined as half of the headway between departures

Three classes of service level

As a tool in the planning and design of the simple and easy-to-use public travel network, we suggest that one should divide public transport services in three different classes in relation to service frequency:

- Forget the timetable.
- Fixed minute timetable.
- Service on demand only.

It would be useful to have some empirical knowledge to support the choice of definitions of these service levels, and probably there is more evidence in the research literature than we have come over without a proper review. The London study already mentioned is only one case which supports the idea that the border between service level 1 and 2 will be at 6–12 departures per hour.

We also have a piece of evidence to suggest that the border between service level 2 and 3 should be at one departure per hour. In Norway we have some very positive experiences from introducing fixed hourly services in rural districts and small towns ("Timebuss" in Norwegian). In some areas with low density development and little existing demand for public transport, the provision of a fixed-minute, hourly bus service was able to generate sufficient new traffic to support a service level well above conventional expectations, both in local small town traffic and in the regional express bus market. Obviously, this effect is associated with the system simplification of the all day, fixed-minute scheduling.

The three service levels have different challenges in the daily service operations. At service level 1, it is important to operate with equal intervals in order to avoid overcrowding, delays and convoy formation. For such lines one should introduce a strict traffic control system to secure even intervals between buses, both at bus stops and at crossings with other street traffic. This will also help to smooth out traffic flow in congested streets. A separate right-of-way will very often be justified, on rail or on rubber wheels.

At service level 2 the challenge is to keep the service to the fixed timetable, which often will require separate bus lanes and/or priority signalling at junctions. At service level 3 travel demand is too weak, and the public subsidy too small, to justify fixed services with large or small buses. A more flexible, demand-responsive operation will be the most cost-effective type of service. More research and practical tests are needed to establish the various conditions and reasons for preferring such services instead of a fixed service with more than one hour between departures.

Long distance services are a different matter, not dealt with here.

The standard urban service level

The definition of a standard urban service level is another tool we have found useful in practical, strategic network planning, see figure 7:

Full frequency is defined as the standard work day service aimed at, i.e. headways of 5-10 minutes as discussed before. This will be experienced by the users as a “forget-the-timetable” service and the time loss for transfers between lines will be limited at this level of service. The frequency may be strengthened in peak hours according to demand, possibly only on the sections of the lines carrying heavy traffic. Designing lines with this frequency, will make the network effect possible if appropriate interchanges are created.

Half frequency will characterize lines with approximately half the number of departures per hour, i.e. headways of 15–20 minutes. For these lines the users will prefer to know the departure times, and there is a clear need for timetable co-ordination in order to facilitate transfers between lines.

Double frequency (or better) will occur on sections of the network where two or more lines follow the same route. On these sections the users can forget the timetable most of the service period, and transfers can be made without much waiting time.

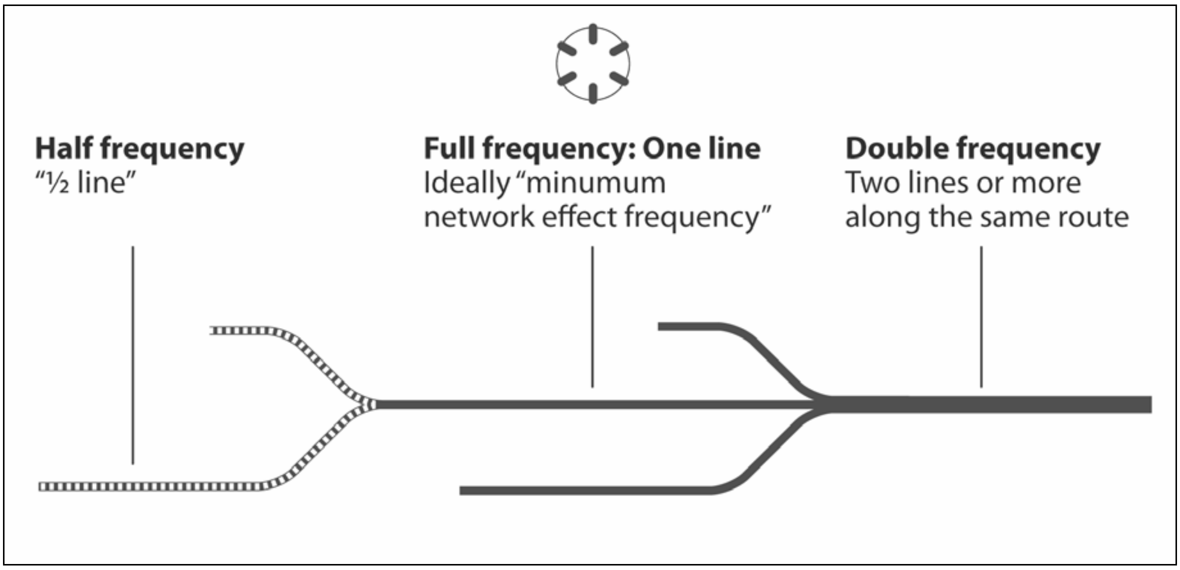


Figure 7: Three frequency classes

By the term full frequency as the standard level of service, we include the use of a low traffic frequency to accommodate demand variations over the day and week. However, as a contribution to the simplification of the system, we suggest that the network should standardise the service level and time settings for normal and low traffic periods, as indicated in figure 8.

This means that the ability to handle short peak periods of heavy demand should be secured through flexibility in the use of space inside vehicles, instead of more or less continuously adjusting service frequency to demand variations, which is a common strategy in many cities. Comfort quality will be higher in low traffic periods than in the peaks, and this may also contribute somewhat to a smoothing out of traffic variations.

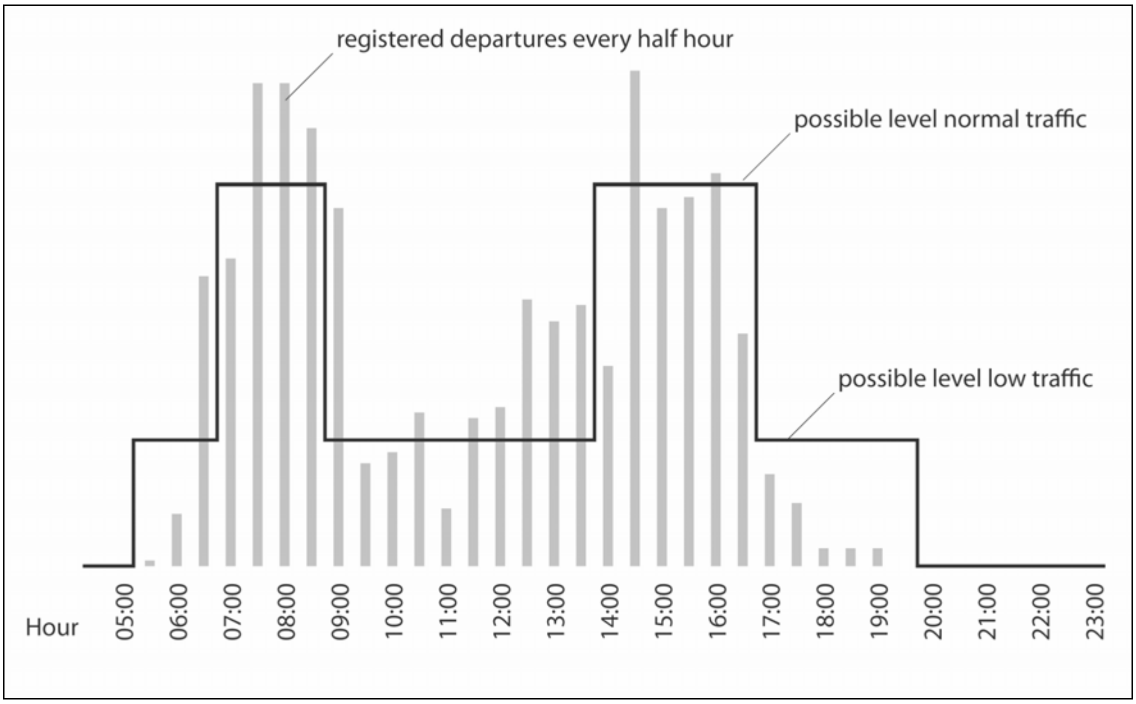


Figure 8: Example of a day's variation in the number of departures per half hour in conventional operations and in a simplified system

The challenge of congestion and network structure

In peak periods the recommended level of service might give too little capacity. Then our advice is to consider whether the traditional solution of increasing frequency further is the right answer to the problem, or whether a change in network structure is a better long term response.

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 is a problem on rail lines and at stations, tram- and bus-stops. There are disturbances between vehicles, between boarding and ascending passengers and between buses, trams and pedestrians at level crossings.

With separate right-of-way and segregation of buses and trams in city streets, and strict traffic control in heavier rail systems, it is possible to operate the system at very short headways. But system planning should also have some security margin for the occasional traffic fluctuations and small operational disturbances that will always be part of the daily operations of public transport.

A normal strategy to deal with the congestion problems in city centres is to spread out the location of bus- and tram-stops. But this makes the system more complicated to use. The central interchanges, which have the best service level in terms of destinations and frequencies, become the worst places for the transfer between lines as far as walking distances, orientation, traffic and safety conflicts, etc. is concerned. Cities try to make heavy investments in their central interchanges, but very seldom manage to overcome the problems of a lack of physical space to incorporate the complex mixture of too many public transport lines and vehicles and people at the same time.

Also considerations of the local environment and safety along the bus or rail corridors might help to define the upper limit for the suitable service frequency, especially in central parts of the city. This may include traffic noise, local air pollution, traffic safety and barrier effects on crossing pedestrian and other traffic. For such reasons many cities try to limit the number of buses (and trams?) that are allowed onto the inner city streets, or they develop stronger restrictions on vehicle emissions than elsewhere in the region.

In some cities, for instance Karlsruhe and Freiburg in Germany, considerations of congestion and environment have been decisive in the design of public transport networks with virtually no regular buses running through the city centre. Obviously, these decisions are linked to the cities' choice of making the tram system the backbone of their public travel network.

In Karlsruhe this has included extensive use of the tramtrain concept in order to connect large parts of the surrounding region with light rail services all the way into the pedestrianized main street of the city. However, this main section of the network has become overcrowded, resulting in plans to build an underground track for the regional services beneath the pedestrian and local tram street. In our opinion, when such congestion in the public transport system becomes a problem, a better strategy will often be to reconsider the network structure.

Extending the areas of high quality service outside city centres

It is our advice that planners should consider adjustments in network structure when the demand exceeds the capacity of the standard service level with 5–10 minute intervals for several hours during weekdays. Perhaps they can find one or two new routes for high quality service through the inner city that will take some traffic pressure out of existing routes and provide some new travel opportunities in the network.

Through such a strategy one might be able to accommodate with style and comfort more public transport vehicles in the city without building heavy new infrastructure, and simultaneously create some new areas of the city that have a similar high-quality service as the city centre. Partly for historical reasons, many cities have a highly centralised public transport network focused on the city centre, where lack of street and parking capacity always will secure a large market for public transport. With the suggested new network strategy, more operational resources will be aimed at catching car users in areas outside the city centre which today generate much more car traffic and congestion.

However, when studying the alternatives, one must be careful not to miss important main interchanges and connections to other corridors. The network effect must be taken care of – as traffic planners automatically do when they deal with the road network for car users. Improvements in the technology for vehicle power, fuel systems, and traffic safety and control, are likely to reduce some of the problems connected with high frequency public transport in city centres. The idea of the optimum frequency level will nevertheless be useful for the planning of the public network concept.

The importance of network simplicity

The last quality aspect of network design we will mention, is the importance of simplicity and ease of use for the potential customers. This too is a factor that has been underrated in conventional bus operations, especially under institutional regimes with weak network planning powers and functions. Because of the high costs of the specialized infrastructure and the limited number of routes and lines, this challenge is far easier with rail systems, except for the very big city systems such as the London Underground and the Paris Metro.

We believe that simplicity is one of the main reasons for the common notion that rail manages to attract more passengers than a similar buss service can do. We will not go into the bus-versus-rail debate and the so-called ”rail factor” in demand estimation, but only point out some very good motives for making a public transport system that is simple to understand and use. Here is our short list of reasons:

- Peoples’ knowledge of the services offered is important for their possible use of the system, and those who seldom use the system represent the greatest potential for more journeys.
- Car users that one wants to attract to public transport often base their travel decisions on misconceptions of the system, and they normally lack the insight into the total system one often needs to consider public transport as an alternative to car use. Ease of use is a very common explanation for people going by car, even when a reasonable public transport alternative is available.
- Public transport users are transient customers. The total volume of demand might be rather stable, but this hides the very large turnover of persons using the system. People move, change work, shopping habits and leisure activities, etc. Some customers even die! So there is a continuous need to explain the system to new customers just to stay in business.
- The simpler the system is designed, the easier the product is to market and inform about, and the cost-effectiveness of all such measures will increase.
- ”Less is more” is a usual slogan for products that are successfully branded in a mass market such as that of an urban and regional population and community.

Because of these points (and more detailed explanations) the design of a network that is as simple as possible should be a major consideration. If necessary, this aspect should be given priority over other design aspects, such as short walking distances, direct travel to the city from all suburbs or between all urban districts, etc. However, more research on public transport demand and preferences is needed to confirm this view and possibly to quantify how far one should go in order to simplify the system at the expense of other network design criteria.

Properties of lines that support network development and design

In order to facilitate the creation of a simple network of lines, there are some line design solutions that should be aimed at. The principles are discussed in greater detail in the HiTrans Best practice guide (Nielsen, Lange et al. 2005), but some main points are worth mentioning here.

First, in order to simplify the network and support the creation of high frequency services, a concentration of lines and operational resources to high quality routes is necessary, see figure 9. Even if this in many cases will result in longer walking distances for some customers.

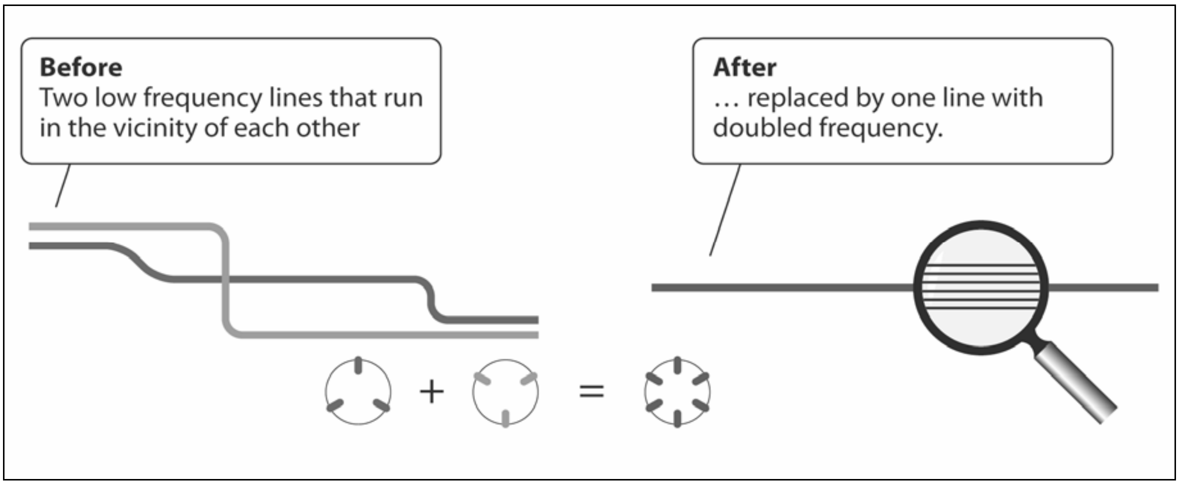


Figure 9: Concentration of lines and operational resources

Second, one should aim for a network according to the ”one section – one line” principle, see figure 10. In practice, this is likely to be a question of much discussion among public transport planners, as it has been in our home city of Oslo for the design of the tramway network.

To go deeper into the arguments pro and con in different urban and regional situations is not possible within the framework of this paper. However, the main motives for this principle are to simplify the network, to make operations more stable and efficient, and to avoid the barriers to proper high frequency services and timetable coordination caused by the timetable interdependencies created by several multi-line sections in the network.

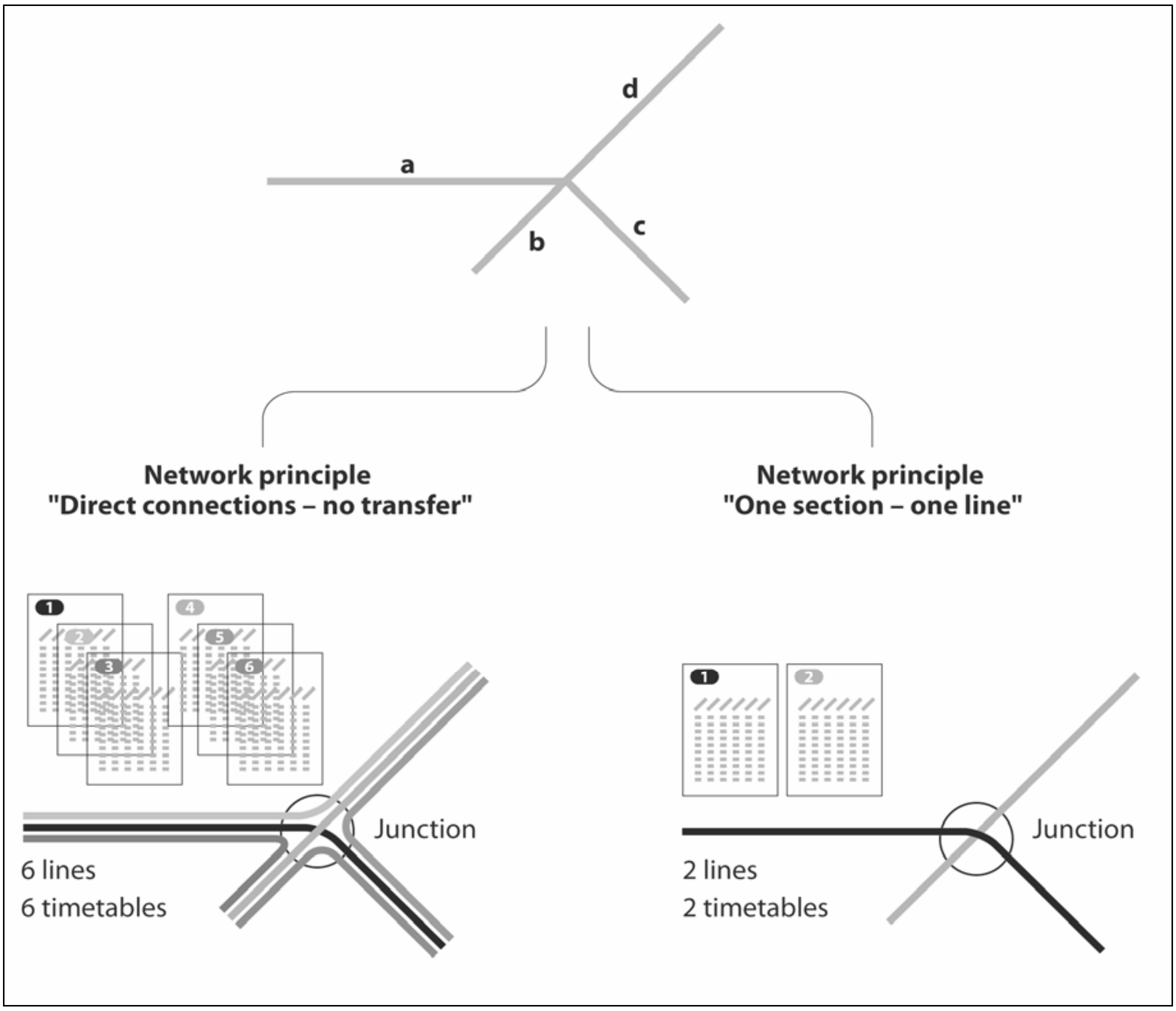


Figure 10: Two very different network design strategies; the principle of ”direct connections, no transfer”, and the principle of ”one section, one line.”

The third principle worth mentioning is the principle of making as few lines as possible, because this will make the system easier to understand, market and operate, and even reduce the need for transfers. This means that lines should be as long as possible, on the condition that they offer a high level of punctuality and represent an efficient use of resources. Avoiding short lines will usually reduce the system’s time losses for timetable adjustments at the start and end of lines.

Creating pendulum lines through city centres and other local centres and interchanges will significantly reduce the number of lines and create new direct travel opportunities, see figure 11. In the city of Oslo the creation of pendulum lines through the city that connected two different parts of the metro system released much potential travel demand in the 1980’s. The pendulum principle in large cities also has the advantage of reducing the demand for traffic space and large terminals in urban centres, where the costs of such infrastructure and land use are at the highest.

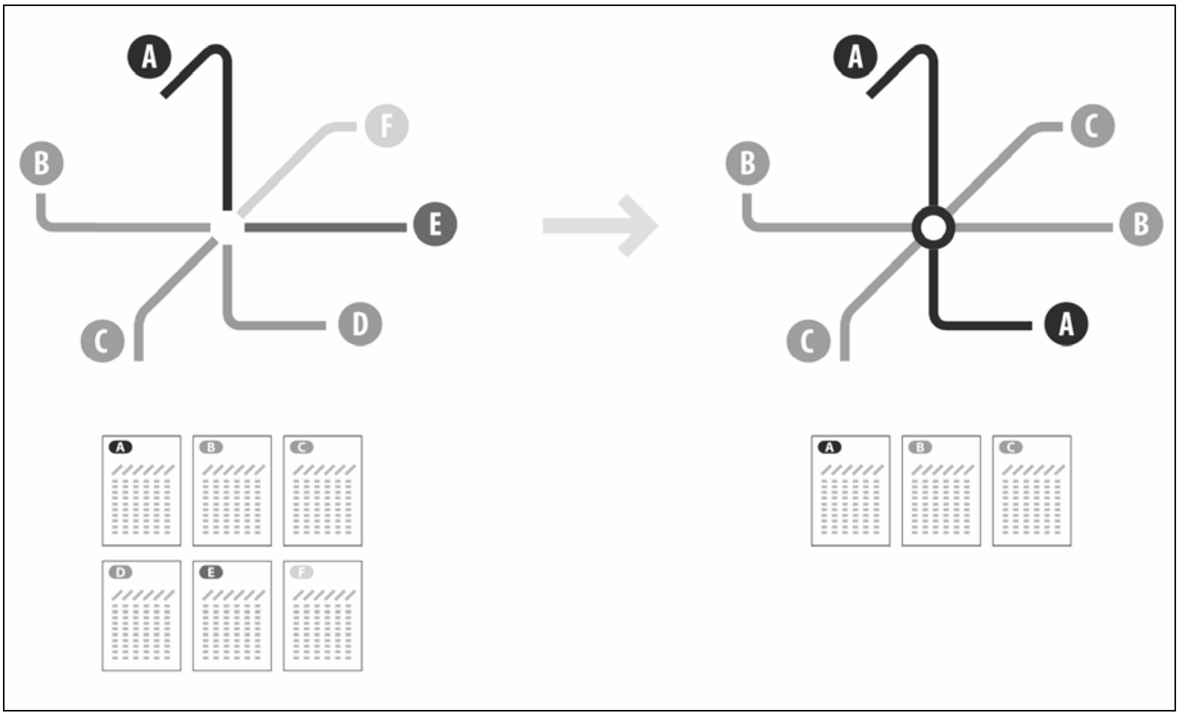


Figure 11: Connecting feeder lines to create ”pendulum” lines

Choosing between direct and feeder lines

A classic topic of discussion is the choice between direct lines to the regional centre or a combination of feeder and radial lines with interchange at a smaller centre or local hub. The main argument usually put forward in favour of the direct line approach, is that bus passengers have a strong resistance to transfers, due to the extra time and inconvenience of having to change modes in the middle of their journey. In many cases the introduction of a forced transfer will make the users switch to the car instead of travelling by public transport. Often it is also claimed that the direct bus solution is cheaper and more flexible to operate than a combination of local feeder bus and a rail service to the regional centre.

The normal objections to the direct bus solutions are that parallel running of bus and rail into the regional centre is a waste of resources due to under-use of train and rail capacity, that too many buses create congestion and environmental problems in the city centre, and that the journey by direct bus is slower and less comfortable than the alternative train journey on the main leg into the centre.

The main argument in favour of the feeder solution are that this system creates a more integrated network with better local travel opportunities by the transfer of operating resources from parallel bus and rail operation to a more economic division of roles between bus and rail. It is also pointed out that travel speed on rail is faster, more comfortable and more reliable than buses on the main roads into the city centre, and that the upgrading of the bus system in the corridors into the city centre is difficult and costly compared to the operation of trains on segregated rights-of-way. It is also claimed that feeder services are needed to make good use of the high capacity of the train system and support high frequency services in the main corridors. A feeder service can often provide a more frequent and useful local service and thus generate more local journeys if there is potential in the market.

Similar arguments may be used in the discussion of feeder lines to trunk bus services as to rail services, but the argument tends to be more heated when the alternatives also imply that different operators are loosing or gaining business opportunities in the market.

The importance of the network effect for overall public transport use has been stressed already. But obviously the best answer to the choice between direct and feeder bus depends on a number of considerations and local circumstances. For short journeys, the forced need to transfer is a substantial disincentive to use public transport. For longer journeys, the best solution for the user depends on a number of factors:

- Are there any cost or time savings or changes in comfort by choosing either the transfer or direct line service?
- How punctual and reliable are the different alternatives?
- How is the interchange designed? Is there a direct and coordinated five-step distance in a clean and nice environment under protection from the weather? Or is it a more typical low status, uncomfortable and complicated interchange point, possibly also demanding the crossing of car traffic and the negotiation of stairs and lifts?
- What are the service frequencies of the different alternatives, both at peak hours and in weak traffic periods?
- Does the system design, information and ticketing systems support “seamless” travel, or is the journey very complex and without through ticketing?
- What sort of place is the interchange? Is it a simple bus or train stop with no extra services, or is it a major service and employment centre?
- Are there other important travel destinations on the same local feeder lines?

Research into the perceived travel penalty for the users due to interchanges has given some interesting results, briefly mentioned already. Users with experience of high quality interchanges have much smaller resistance than those direct bus users that are asked of their likely reactions to hypothetical, forced transfers.

Common trunk line sections in small cities

In small and medium sized cities very often the demand for public transport is insufficient to have many high frequency lines running through the central city and out into the suburbs. The solution can then be the creation of a public transport network where several lines follow the same, common route through the central parts of the urban area.

Common trunk line sections make it possible to offer a high frequency service, at least for journeys between destinations along the trunk section, see figure 12. However, these sections should not be designed through the simple collection of different line routes to one or several main corridors through the central parts of the city. In practice this will normally not achieve the required even headways between vehicles running on different lines, and one may easily run into the problems of queues and convoy formations in the corridor.

In some cases, the best solution is to plan the network with only one main line on the common section, and have different branches of the main line in one or both ends of the common section. The alternative is to have two or three lines with strictly coordinated timetables to achieve the same effect of even headways. In practical operations this is very difficult to achieve if the lines are run by different operators.

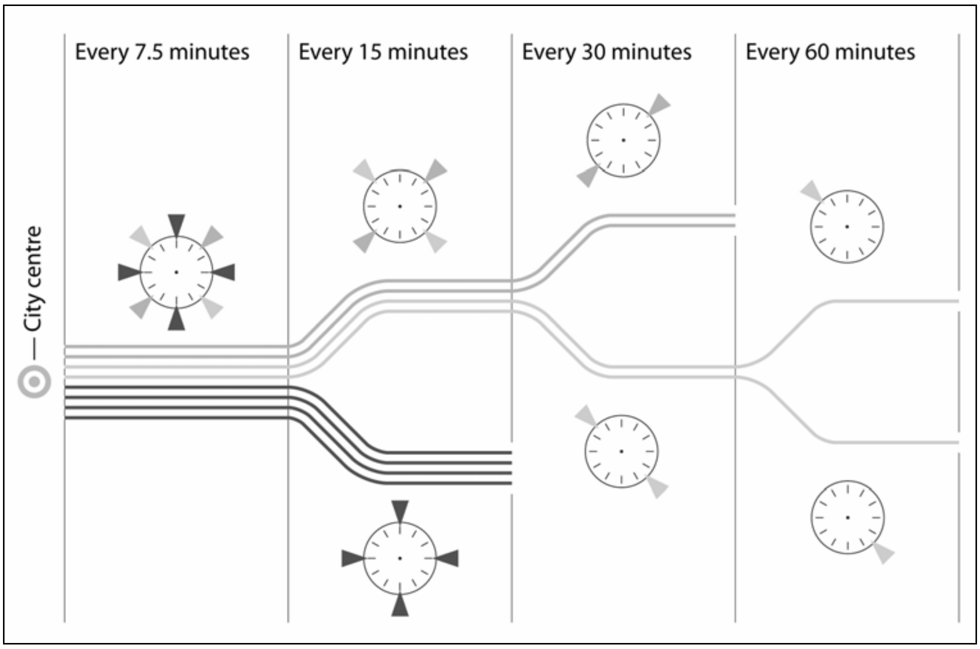


Figure 12: The principle of a common timetable for several lines on a trunk route section

In all three Scandinavian countries we have examples of small towns that have been developing their bus networks according to several of the principles suggested in our paper: Jönköping in Sweden was first with their “think tram – drive bus”-concept, and later Kristiansand in Norway and Aalborg in Denmark have put into operation their so-called “bus metro”. The first has been the most successful and object of rather thorough evaluation, so we will concentrate on this case.

“Think tram, use bus”

Jönköping, on the southern shores of Lake Vättern in Sweden, is a city with 81,000 inhabitants (including the integrated town of Husqvärna) and 120,000 in the administrative commune of Jönköping. A completely restructured, modernized bus network was introduced in 1996. The network is now organised around three main pendulum lines that cross the urban area. All other lines have many connections with the main lines, which are the “arteries of the network”, se figure 13.

The main routes (the ”City buses”) have been developed according to the principle of ”think tram – use bus” by creating short, direct, fast and punctual bus routes all the way through the built up area. This is achieved through a consistent use of all available measures, such as traffic management, new bus only road links, dedicated bus lanes, signal prioritisation at street crossings, optimised locations of bus stops with modern equipment and real time information to passengers based on GPS technology. New, low floor articulated buses with four wide doors (two for embarking passengers, two for disembarking), electronic ticketing and a simple fare system contribute to the fast, comfortable and reliable travel by bus in Jönköping.

The core bus services, with local and rural feeder routes represented a relatively radical change, since previously most areas of the town had low frequency but direct services to the town centre. These were in some cases replaced by a feeder route and an interchange. The fast and efficient operation of the main routes attracts so many passengers that the services are run with 5- and 10-

minute intervals most of the day. This also induces many suburban passengers to make transfers between local and main line services for journeys within the city. Most of the local bus lines have two departures per hour most of the day.

The results have been impressive, even if there has been some complaints from some customers with forced interchange in the suburbs. Patronage has increased by 15 percent (1996–2002) where it had been declining by a rate of –1–2% on an annual basis prior to the launch of the program. Comparable Swedish cities without a similar network restructuring continued their decline in the same period. The market share for public transport has increased from 19% to 22%. The level of patronage is higher than most comparable cities; 143 journeys per inhabitant per year is much more than most similarly sized cities in Scandinavia. The fare box recovery ratio is 68 percent (2000) compared to 32% in 1986 and up 13% since 1996. The new bus system also helped to revitalise its town centre, which had been suffering competition from a major out of town centre. (Sources: Council of European Municipalities and Regions 2003, Marie 2001, Rye et al. 2005, and study visit by the author).

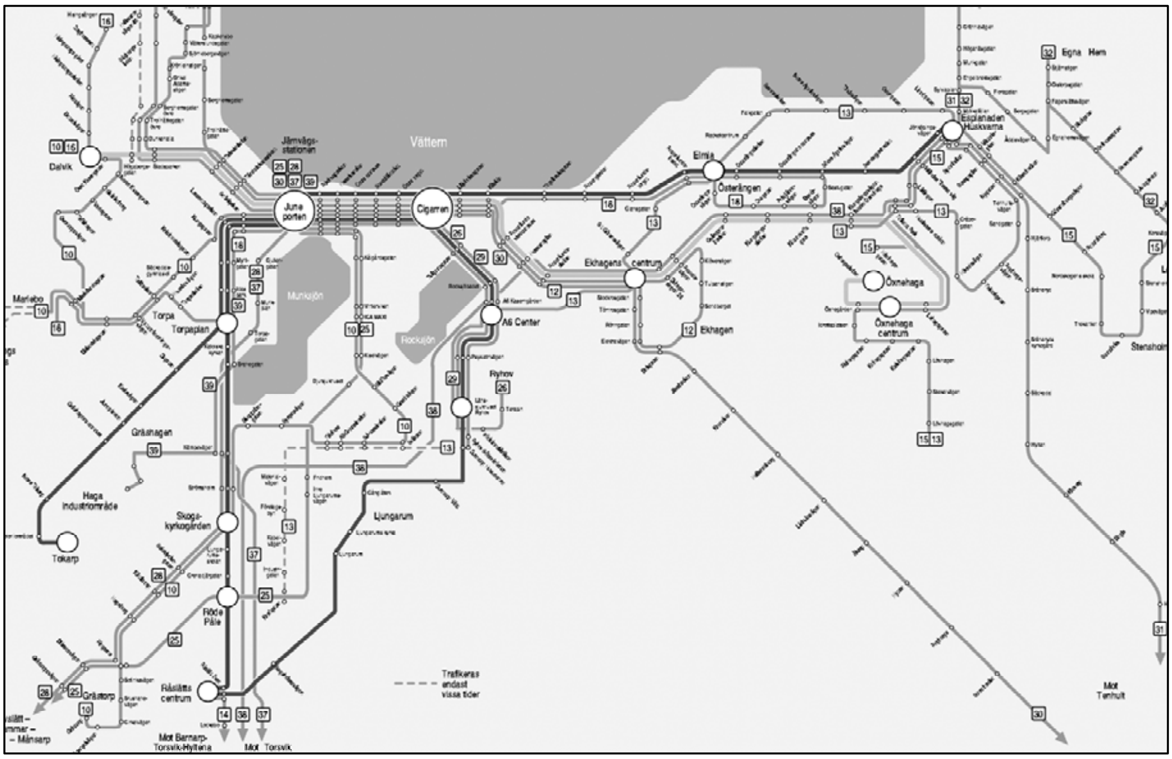


Figure 13: The public transport network of Jönköping, Sweden

Although many different factors have contributed to the good results in Jönköping, we will claim that also this case is a real world confirmation of some of the network design principles forwarded in this paper.

Integrated pulse scheduling

In most small towns, and in the outer suburbs of larger cities, the demand for public transport is too dispersed to run high frequency services. A service with only one or two buses per hour will in many cases be the best that can be achieved, even when there are significant public subsidies available for the services.

Even if a full “forget the timetable” service is not possible, significant improvements over traditional low quality networks can be made through the introduction of pulse timetables. This is a principle of network operation that is being used at the national level for the main line railway system in Switzerland, as well as in several small urban regions, mainly in Switzerland and Germany. The line structure of the network and the departure and running times are coordinated according to a pulse time table. At certain important stations and nodes in the public transport network arrivals and departures of all lines are synchronized in order to facilitate passenger transfers between lines with as little time loss as possible.

A typical example would be the main railway station in a small town, or a suburban centre on a light rail or express bus service. The station is served by a local bus network with all lines going past the station and connecting the different parts of the town or suburban district. For example, every hour, or half hour, all train and bus lines meet at the station. The buses arrive shortly before the train, and leave the station as soon as transfer passengers from the train have reached the right bus. Also transfers between bus lines are made in the same interval. See figure 14.

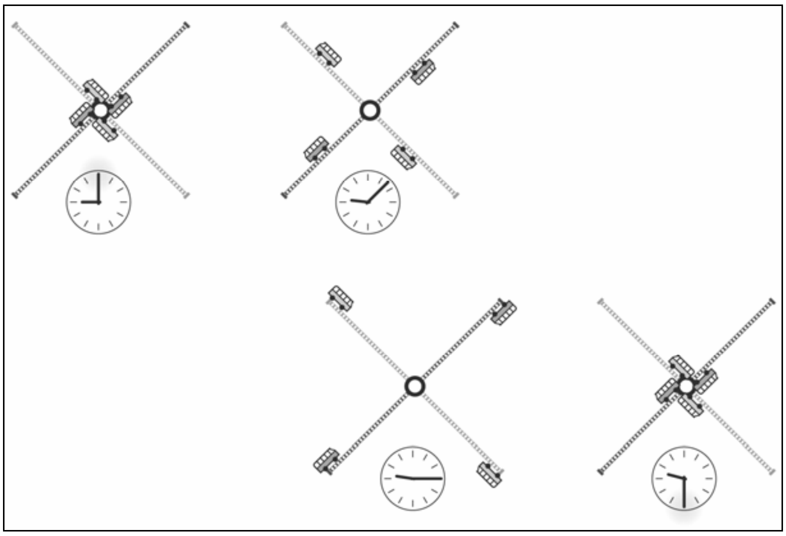


Figure 14: The principle of integrated pulse scheduling

Often the whole town or suburb can be reached within less than 15 minutes’ bus journey from the station. When the main station is close to the town centre, a simple and efficient local bus service can in this way cater for a large part of the local travel demand, and at the same time provide feeder services to the regional or national public transport system.

The pulse timetable operations can only be successful when running times of trains and buses are stable and reliable. The waiting time for buses at the interchange is a key factor for the efficiency of the local bus operation. This time element is determined by the time the transferring passengers need to walk between train platforms and the buses. When the crossing lines have a high frequency service, this element is less important since a late transferring passenger will have an acceptable waiting time for the next departure. When the lines have only 1–2 departures per hour, the extra waiting time will be a strong disincentive to the use of the public transport alternative.

If a high quality interchange with short walking distance between the different lines and modes cannot be built, this should affect the choice of line structure for the local buses. Due to the long waiting time for buses at the station, one has to decide which travel demand should have first priority; either the feeder service to and from the regional services, or the local connections between different areas on either side of the station. In both cases, the final solution will be a less cost effective operation, than what can be achieved when all elements of the highest quality solution are in place.

A large number of such bus systems are in operation in Switzerland, Germany and other countries. Three cases are worth mentioning here.

In Schaffhausen in Switzerland, a pulse timetable bus system has for many years been serving a population of some 70.000 inhabitants. There is little doubt that the network effect created by this system is a significant contributor to the very high level of patronage achieved (Stangeby and Norheim 1995); some 180 annual journeys per capita, which is almost double of the figure reported by Mees (2000) for the city of Melbourne with 3 million inhabitants in 1990!

In the Gothenburg (Sweden) suburb of Västra Frölunda a change of the local bus system from a conventional service to a pulse timetable operation resulted in 8 percent growth in patronage in the course of two years (1996–98), while the general traffic growth in the rest of Gothenburg was 2 percent (Wassenius 1996).

Lemgo, with some 42,000 inhabitants, is one of the most successful of the modern small city bus systems in Nordrhein-Westphalia (Land Nordrhein-Westfalen 1999 and Marie 2001). A corporate image and information design enhances the simplicity and stability of the bus service and facilitates long-term marketing. No commercial advertising disturbs the image of the system. Three pendulum lines run through the town centre, and a fourth line serves an external industrial area. Each pendulum line gives some 8000 inhabitants short walking distances to a 30-minute basic full day service, with double frequency in extended peak periods on workdays. Late in the evenings a demand responsive taxi service replaces the city bus service.

The city centre interchange terminal has a compact, middle platform layout and a public transport information centre. The bus service is operated with a pulse timetable schedule, so that the buses on all lines meet at the central meeting point every 15 or 30 minutes, depending of the time of the day.

The new bus system was introduced in 1996 because of very little demand for the traditional service, despite a modest renewal of the system in 1992 with four lines at 1-hour intervals. Before- and one-year after-effects of the restructuring of the city bus service:

- 960,000 new customers and 240,000 old customers travelling more
- 80 percent of the passengers on the new system where new public transport customers
- The public subsidy per passenger was dramatically reduced from 7,50 DM to 0,45 DM
- 70 percent of the bus operation costs are covered by the fares

A survey among visitors to the inner city revealed that the bus service had a significant effect on shopping trips to the city centre. The bus passengers shopped more often and used more money on city centre shopping than the car users.

Integrated regional network combining pulse scheduling and demand responsive services

In rural regions, the pulse principle may be used to connect a much larger district to the local centre, railway station or major bus interchange, as illustrated by the line scheduling diagram in figure 15.

It is easy to understand that there are some aspects of journey time, length of line, travel speed and frequency that combine to create some basic "rules" for how the different lines and the total network should be designed to optimize the use of operational resources.

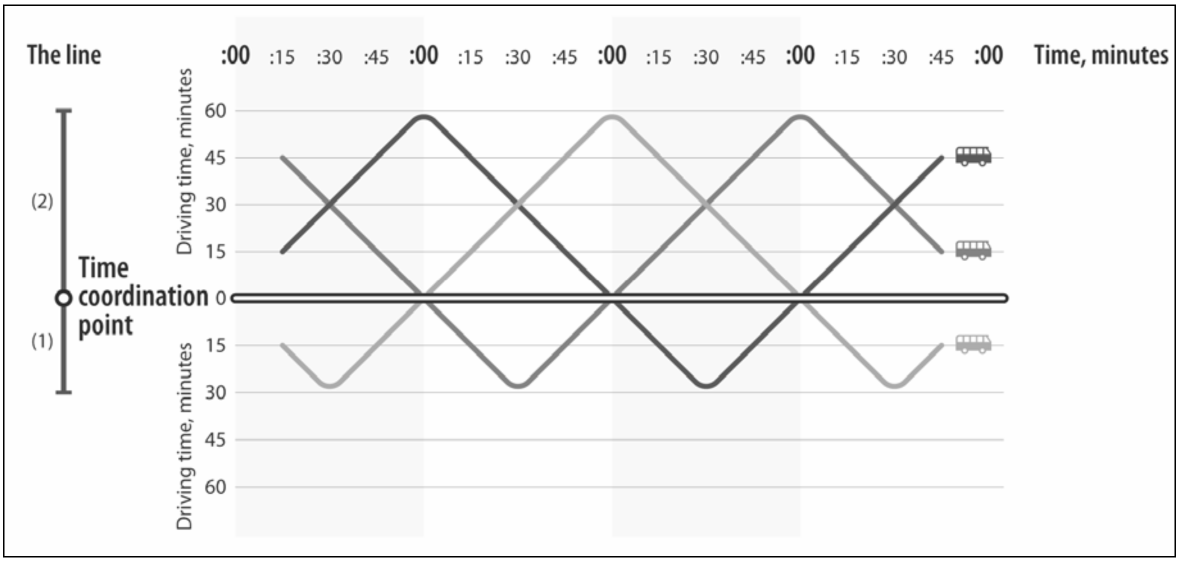


Figure 15: Example of a possible schedule for a bus route serving areas at a running distance of (1) 30 minutes to one side of the interchange point, and (2) 60 minutes to the other side

However, particularly in rural districts, but also in low density urban areas, the demand for public transport is so little that traditional scheduled bus services are very costly and inefficient. Therefore demand responsive services should be preferred.

This paper will not deal with this part of the total public travel network we recommend, but it is necessary to be aware of this option for areas that fall outside the immediate catchment areas of the main network of scheduled services. As mentioned earlier in the paper, we define this as the service level 3 to be aimed for within the total travel network.

To finally illustrate the idea of the combined regional travel network for a small and mainly rural district, we show the example of the new planned concept of a public transport service in the former Olympic region of Lillehammer, Norway. This is based on experiences from earlier projects in Norway and abroad, and the Lillehammer case illustrates the advice recently given for rural and low density regions in our country (Nielsen and Lange 2007 a and b).

The main objective of the service concept is to make public transport easy for everybody to use. The concept is illustrated in figure 16, and it combines:

- a simple, integrated scheduled service with pulse timetable focused on the regional centre, and
- a demand responsive service in areas with insufficient demand to support regular public transport.

A travel dispatch centre will coordinate all demand responsive services and transport tasks of public responsibility, and provide customer information to users of the complete travel network in the region. The first stage of implementation (with practical adjustments) will take place in January 2008.

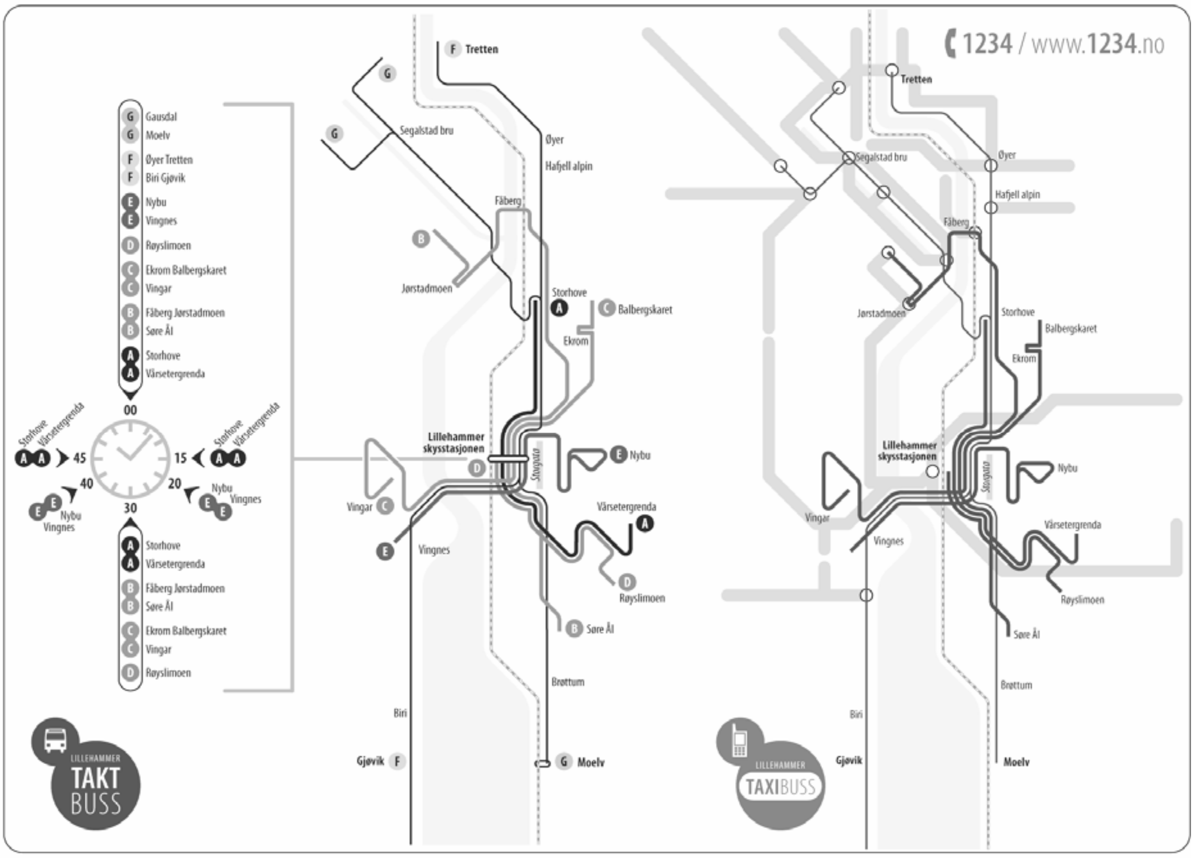


Figure 16: An illustrative version of the planned concept for the public travel network in the region of Lillehammer, Norway (Nielsen and Lange 2007b)

CONCLUSIONS AND FURTHER WORK

In this paper we have tried to demonstrate the importance of network planning and design for the possible success of public transport in both urban and rural districts.
We have also presented some principles of line structuring and network design which are likely to forward development of an efficient, high quality public travel network with focus on customer satisfaction and the creation of an attractive alternative to car use for all citizens.
However, the principles are under review, and there are a number of aspects that need further verification, such as:

- More studies of how various service factors and network properties affect travel demand and customer satisfaction are desirable.

- More studies of the possible network effect in different real world situations would be useful.
- Better understanding of the "value" of simple service design is needed, because often one has to pay a little extra for "simplicity" in service design, and then one should now more about how much resources one might use in this respect.
- Comparative analyses of various network solutions in different types of urban and rural regions might also be used to verify, modify and develop further the set of principles of network design that we have presented.

If any other public transport planners or researchers have any special interest in this field of public transport planning and development, please take contact.

REFERENCES

Colin Buchanan and Partners (2003). Transferability of Best Practice in Transport Policy Delivery. Final Report. Scottish Executive, Transport Research Planning Group. Edinburgh, July 2003.

Council of European Municipalities and Regions (2003). European Public Transport Award 2002/2003. Bruxelles 2003. Internet site: www.ccre.org.

ECMT (2002). Implementing Sustainable Urban Travel Policies. Paris, European Conference of Ministers of Transport. OECD/ ECMT.

Land Nordrhein-Westfalen (1999). Neue Chancen für den Bus. Aufwand – Nutzen – Perspektiven. Düsseldorf, Land Nordrhein-Westfalen, Ministerium für Wirtschaft und Mittelstand, Technologie und Verkehr. (In German)

Marie J. H. (2001). Emerging trends in European public transport – Intermodalism: Facilitating modal transfers. Paper presented to the ENO foundation.

Mees, P. (2000). A Very Public Solution. Transport in the Dispersed City. Melbourne, Melbourne University Press.

Mulley, C., Nelson, J.D. and Nielsen, G. (2005). Network planning for high quality public transport. 9th Thredbo Conference on competition and ownership in land transport. Conference proseedings.

Nielsen, G., Lange, T. et al. (2005). HiTrans Best practice guide no. 2. Public transport – Planning the networks. Stavanger (NO), HiTrans, c/o Rogaland County Council. ISBN 82-990111-3-2.

Nielsen, G. and Lange, T. (2007a). Improved public transport in low density regions. Advice on service design. Oslo, Institute of Transport Economics, Report 887/2007. (In Norwegian)

Nielsen, G. and Lange, T. (2007b). The Lillehammer network. A concept to make it easy for all to travel by public transport in the Lillehammer region. Oslo, Institute of Transport Economics, Report 882/2007. (In Norwegian)

Rye, T. et al. (2005). HiTrans Best practice guide no. 5. Public transport – Citizens' requirements. Stage 2 Case studies. Stavanger (NO), HiTrans, c/o Rogaland County Council. ISBN 82-990111-6-7.

Sjöstrand, H. (1999). Värdering av kvalitet i lokal kollektivtrafikk med Stated Preferences-metoden. Lund, Lunds Universitet, Institutionen för Teknikk och samhälle. Licenciatavhandling, Bulletin 175. ISSN 0346-6257.

Stangeby, I. and Norheim, B. (1995). Fakta om kollektivtransport. Erfaringer og løsninger for byområder. Oslo, Institute of Transport Economics. (In Norwegian).

Tarzis, G. and Last, A. (2000). Urban interchanges – A good practice guide. Woking, MVA limited.

Transport Research Laboratory (TRL 2004). The Demand for Public Transport: A Practical Guide. Crowthorne, TRL report 593.

Wassenius, B. (1996). Stjärntrafik. Utvärdering av stjärntrafiken i Västra Frölunda. Gothenburg. Trafikkontoret, City of Gothenburg. Report 8:1996.

White, P. R. et. al. (1992). Cost-benefit analysis of urban minibus operations. Transportation, **19**, pp. 59–74.