

The Principles of Public Transport Network Planning: A review of the emerging literature with select examples.

Jago Dodson, Paul Mees, John Stone and Matthew Burke



Urban Research Program

**Issues Paper 15
March 2011**

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ISBN 978-1-921760-36-5

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Table of contents

Introduction	1
The policy significance of public transport	2
Public Transport Network Planning	2
Strategies of public transport network planning	5
Radial network strategies	7
Dispersed network strategies.....	8
Design principles for the public transport network effect.....	11
Key practice 1: Simple and direct network structures:	11
Key practice 2: Plan a hierarchy of lines into a network.....	12
Key practice 3: Plan for speed, consistency and reliability:	13
Key practice 4: Coordinate convenient transfers	13
Key practice 5: Provide clear, ubiquitous and consistent information and marking	15
Planning line structures for improved network function	16
Specify the full network	16
Simplifying line structures.....	16
Simplify network structures.....	17
Coordinating timetables	19
Fare systems.....	20
Institutional Design for Public Transport Network Planning	21
Transition points in network reconfiguration	22
Conclusions.....	24
References	26

List of figures

Figure 1: Diagram of the London underground tube network	5
Figure 2: Conceptual radial network strategy	7
Figure 3: Radial strategy in practice, Melbourne (rail only).....	7
Figure 5: Radial network strategy in a poly-centric city.....	8
Figure 6: Conceptual dispersed network strategy.....	9
Figure 7: Conceptual dispersed network strategy indicating transfer opportunities.	9
Figure 8: The Zurich regional public transport network.....	10
Figure 9: Intersecting rail and bus services in a Vancouver sub-region.	14
Figure 10: Connecting buses at Joyce-Collingwood Skytrain station, Vancouver.....	15
Figure 11: Standard stop design, featuring information and full ticketing pre-purchase, Zurich. .	15
Figure 12: Direct and indirect line structures	17
Figure 13: Line consolidation leading to higher frequencies on the trunk service.	18
Figure 14: Simplifying line structures to improve network integration based on transfers.	18
Figure 15: Consistent timetabling across days and weeks, Zurich.....	20

Introduction

The governance and management of public transport systems is an essential component of metropolitan planning and urban management. Most metropolitan strategies in Australia and in other jurisdictions presuppose the provision of public transport. Yet there is often a disconnection between transport plans and land-use schemes. Similarly, metropolitan land-use plans that do integrate with transport plans tend to focus on infrastructure rather than service quality and connectivity. A failure to adequately consider the quality of public transport networks in land-use planning analysis has the potential to produce poor planning outcomes in two key ways. First new land-uses may be inadequately served with public transport services, leading to dependence on alternative travel modes, such as cars. Second, the failure to recognise the significance of well-planned local public transport networks may result in the preclusion of some land-use options. This preclusion may relate to the location of land-uses or their design, such as over-provision of carparking. The continuing debate over whether to address suburban car-dependence via land-use change or via transport planning is a case in point. And while the arguments in favour of and against land-use change as a means to overcome car dependence are well known in the planning literature (Newman and Kenworthy 1999; Cervero 1998). There is a growing if not yet widely appreciated literature that advocates improvements to public transport network planning and coordination as a means of reducing car dependence. The recognition of improved public transport network planning as a means of reducing car dependence is immensely significant because it offers planners an additional or alternative tool for managing urban transport patterns beyond land-use variation or investment in heavy infrastructure.

Urban planning practitioners are not yet well served and informed by the broader public transport planning literature on the advantages of public transport network planning. While there is an extensive literature focusing on the economics and engineering of urban public transport systems the planning literature on the practices that contribute to success in public transport network design and operations is relatively poorly documented. There is also very little literature dedicated to public transport network design within Australian cities which are distinguished by highly centralised radial heavy rail networks with bus or tram networks that are well developed in inner urban zones but less so in the outer suburbs.

The remainder of this paper has four objectives for transport planning theory and practice. First the paper reviews the literature on public transport network planning *principles*; next the paper attempts to formulate these principles in practical terms such that they can be applied to line and network design; third the paper considers further dimensions of network planning, including institutional arrangements and transition points in network design. The paper is intended for three audiences. The first is planning scholars who are involved in debates about public transport. The second is strategic policy officials in planning agencies who are involved in the planning and design of public transport networks. The third audience comprises those involved in development processes and who seek insights into the technical components of public transport network planning.

Some caveats are appropriate however. The paper is not seeking to *justify* public transport network planning. The authors consider that the case for dedicated planning is implicit in the assumption that cities should provide good quality public transport to their residents. The wider case in favour of network planning has been successfully advanced elsewhere (see Thompson 1977; Mees 2000, 2010; Nielsen et al 2005). Conversely, the paper is not intended as a directly applicable manual of detailed transport planning practice. While it does offer some insights into the practical public transport network planning task such guidance is better provided by Nielsen et al (2005) and Vuchic (2005). Instead the paper highlights for urban planners the key strategies and tactics for that can be deployed to improve suburban public transport networks.

Understanding these principles should thus assist urban planners – and urban scholars – to better shape and evaluate urban development processes and patterns.

The policy significance of public transport

Cities across the globe face many pressing economic social and environmental challenges. Efficient public transport networks are integral features of modern urban transport systems. Public transport networks can contribute markedly to urban economic performance, social cohesion and sustainable environmental outcomes. Most major cities in the advanced nations, particularly those outside the USA, could not easily function without the public transport networks and the systems upon which many of their residents rely for urban travel. Mobility based on private motor vehicles is proving increasingly difficult to maintain and support as urban vehicle fleets expand and bring new costs measured in road congestion and increasingly expensive road capacity expansion that now often requires complex and costly engineering to avoid surface level displacement of urban communities. Public transport is increasingly recognised as a key contributor to improved social cohesion in cities (Lucas 2004; Currie et al. 2007). At a more mundane level public transport simply offers an alternative, and ideally preferable, mode of travel to the automobile.

The significance of public transport networks is growing further as new environmental and resource pressures bear upon cities providing the impetus for more sustainable forms of mobility. The global climate crisis, for example, implies an urgent need to drastically reduce global carbon emissions including those from private motor vehicles. Private motor vehicles contribute 44.5 per cent of transport sector emissions and approximately 23 per cent of global greenhouse gas emissions (IPCC 2007, p. 328). Recent assessments suggest that because of their chemical composition road transport emissions are the greatest sectoral contributor to global warming (Unger et al. 2010). Beyond the climate challenge there are mounting concerns about the sustainable use of global petroleum resources. Anxiety is growing over the recognition that within the next two decades the world may experience a decline in petroleum production as exhausted reserves and ageing production facilities place limits on extraction rates (Campbell 2005; Deffeyes 2005). If such a decline was to eventuate, it would threaten to disrupt the large suburban realms found in most major North American and Australian cities which rely heavily on private motor vehicles for travel. Public transport has been identified as an important mode of urban mobility in a constrained petroleum supply context (Newman and Kenworthy 1999; Mees 2000; Dodson and Sipe 2008).

Public Transport Network Planning

Public transport systems have operated in cities since the emergence of the horse-drawn omnibus in Paris in the 1820s. Services have evolved to incorporate a range of modes operating along across a mix of surface, elevated and underground routes and rights-of-way. The engineering achievements of public transport networks are considerable – many cities are defined by their public transport systems as the New York Subway, Paris Metro or London Underground attest. Yet the broader organisational frameworks which enable public transport services to be planned so as to operate as a coherent network, especially in dispersed cities, have been less well understood.

The past two decades have seen an increasing recognition that public transport operates most successfully when it is planned as a unified network to support seamless multi-destination travel rather than as individual lines catering to single trips. A range of authors (Thompson 1977; Mees 2000; Nielsen et al. 2005; Vuchic 2005; Mees 2010) have argued that public transport systems designed around widely distributed networks which connect to support multiple transfers can

offer a much a wider choice of trip making based on individual destination and journey preferences than public transport systems that attempt to cater for every potential origin-destination combination by supplying routes to satisfy these travel opportunities. Mees (2000; 2010) has demonstrated that the conception of public transport systems as networks rather than individual routes can generate higher levels of patronage than the planning of individual routes because of the unexpected trip making behaviour that the network can support and which planners might not have predicted. The ‘network effect’ that Mees describes can lead to patronage gains beyond those expected by conventional single-route cost-benefit analyses of public transport systems predicated on single-seat journeys because of the high demand elasticities that are unleashed by seamless ubiquitous interconnected networks offering a much wider array of transfer based trips. There is some evidence that public transport network planning is more important in dispersed urban environments where demand is similarly dispersed. The term ‘public transport network planning’ is used specifically in this paper to describe the intensive coordination of public transport services to achieve the ‘network effect’ and not in a general or broad sense of just offering some undefined level of public transport service.

Planning public transport systems as seamless integrated networks rather than as a series of individual routes serving a specified set of origin-destination pairs is therefore a critical task for metropolitan transport planning agencies. Yet there is relatively little information available to planning agencies on the strategies and tactics that can be applied to their public transport networks to improve route structures to achieve the ‘network effect’. In addition public transport planners often face ‘legacy’ route structures which have often persisted over many decades with little adjustment to contemporary customer demand or urban patterns. In some cases, such routes may follow the path of previous infrastructure such as tramway lines which have since been replaced with buses.

The problem of public transport network planning is accentuated in dispersed urban settings where the density of land-uses such as homes and workplaces is relatively low. For some decades planning practitioners have held the view that the density of land-uses is a key factor in determining the viability of public transport (Breheny 1995). A more recent body of research suggests that density is less critical to public transport demand (Mindali et al. 2004; Newman 2006; Mees 2009) compared to, for example, the quality of public transport operations and that suburban public transport can offer a viable alternative to private motor cars even in highly dispersed cities (Mees 2000; Mees 2010). The crucial challenge in supplying high quality suburban transport relates to the overall strategic and tactical planning of networks to ensure a fast seamless interconnected trip that is optimised to provide a competitive travel experience to the main suburban mode, the private motor car (Mees 2000; Newman 2006; Mees 2010). This challenge is arguably greater in the most dispersed car dependent suburban contexts, such as those found in North American and Australasian cities.

While the transport literature offers some broad conceptual assistance to public transport planners seeking to reconstruct their existing systems to provide a better networked structure of routes and lines the practical dimensions of this task are less well described. A considerable proportion of the technical literature focuses on *scheduling* problems in public transport systems rather than network strategy, structure and connectivity questions. Scheduling analysis is often highly mathematically driven and oriented to ideal-type operational capacity or safety analysis rather than being directed by the practical considerations surrounding the construction of route networks. This literature is exemplified in the review of network design and scheduling provided by Guihare and Hao (2008). Their comprehensive review of this topic emphasises mathematical optimisation and maximisation equations or algorithms rather than practical planning principles that planners can follow to achieve seamless ‘network effect’ public transport operations.

In contrast to the mathematical approach Nielsen et al's (2005) suggested methods for public transport network planning are comparably effective and readily applied in practical contexts while also methodologically simple and easy for non-technicians to adopt. Instead of building a mathematical computer model to better plan public transport networks Nielsen et al (2005, p. 36) suggest:

Create a simple sketch map on the principle of 'every bus line a separate pencil line' by the use of old fashioned colour pencils to combine the information from the network map and the timetables... Soon you have an important basic tool for network planning.

The advantage of this approach to network design and operation is that specialist mathematical skills are less important than a capacity to apply basic network planning principles systematically. Certainly scheduling tasks on some parts of a network will require calculations of operational parameters such as line capacity or safe stopping distances but these are different concerns to the problem of designing a fast efficient overall network structure. Indeed the design of a fast efficient network structure should be the primary consideration as this is the service 'offer' that is made to the public. While operational factors remain important network structure and timetables design can then drive the engineering agenda accompanied by related measures to improve the service 'offer' such as rights of way via on-road priority or dedicated infrastructure. This approach also offers cost savings; planners can thus look first to network design to overcome problems or network weaknesses rather than reaching immediately for an infrastructure solution.

The question of practical operational planning is of considerable importance in public transport network design. In contemporary cities, particularly those in developed nations, the task of producing a public transport network *de novo* is rarely presented. Most cities have some form of public transport system with many operating sophisticated and complex networks. Scheduling of services on individual lines is certainly of importance when capacity maximisation on fixed infrastructure is a critical question, as in a high-frequency metro system like those of Tokyo or London. But wider questions of network connectivity are less universally dependent on mathematical solution especially in dispersed metropolitan regions with fewer high capacity trunk links, as Nielsen et al (2005) demonstrate. Ideally technical scheduling should thus serve wider network planning rather than determine it. The challenge for public transport managers of network optimisation in such contexts hinges less on mathematics and more on practical connectivity planning based around public transport network planning principles.

To assist the conceptualisation of the public transport network planning challenge it is possible to draw a conceptual distinction between the public transport *network* and the public transport *system*. A public transport *system* may be described as the overall physical complex of infrastructure, technology and information that provides opportunities for passenger movement within urban space. A public transport *network* by comparison describes the spatial and temporal relationship between the lines of connection provided by the system. A renowned example of this conceptual separation of *network* and *system* is the London underground diagram which displays the connectivity between tube lines in abstract form (Figure 1). The map provides almost no indication of the operational character of the system such as vehicle mode or speed, line length or width or any signalling or scheduling information. Instead the user sees the network lines and their nodes of intersection.

The significance of this *network* vs *system* distinction is that individual passengers do not need to know the direct technical relationship between the system and their travel destination. Nor do the technical aspects of system operation need to be apparent to users; indeed it may be preferable that these are entirely opaque to customers. Knowing the spatial and temporal connectivity of the network should be all that passengers need. The factors that facilitate passenger use of public transport therefore are the simplicity and legibility of network structures, their connectivity and the time for travel along and transfers between network links. Network planning is thus akin to

the ‘software’ of a public transport system while the physical and technical infrastructure is the ‘hardware’. The planning and organisational task in managing public transport *networks* must therefore focus on making that software as easily and quickly navigable for passengers as possible in order to compete with other major urban mobility systems such as roads, in which the integration of network and system is unified. This planning task includes network and line structures as well as timetables, tickets and overall ‘branding’.



Figure 1: Diagram of the London underground tube network

Source: Transport for London (2010)

Strategies of public transport network planning

The overriding challenge for public transport planners in any given city is to deploy a finite system of spatially fixed lines¹ and nodes to satisfy the near infinite travel demands of the residents of that city, within the prevailing institutional and operational constraints on finance and management. The empirical evidence suggests that attainment of a high level of public transport patronage is most likely to be achieved if public transport networks are designed to serve multiple passenger cohorts and diverse travel demand patterns (Thompson 1977; Thompson and Madoff 2003; Mees 2009; Mees 2010). A focus on one passenger subset, such as, for example, inbound radial peak hour commuters, may fail to cater for other groups such as non-radial commuters, contra-peak or off-peak travellers. Residential and employment suburbanization has made this problem of serving dispersed non-radial trips difficult but not impossible. Indeed Mees (2010) demonstrates convincingly that planning can overcome the apparent physical constraints imposed on public transport systems by suburban form. Mees (2010) argues that network design and institutional factors play a much greater role than previously recognised in the transport literature, in comparison to the influence of urban form. Indeed, such factors are often recognised but not elaborated in key transport and land-use planning texts (Newman and Kenworthy 1999; Cervero 1998). Planning effort applied to public transport networks, it seems, can assist to overcome the deficits of dispersion and fragmentation

¹ In this paper we follow Nielsen et al (2005) in distinguishing between ‘lines’ which are the idealized paths followed by public transport services within networks and ‘routes’ which are the physical paths through urban space.

of suburban space. Coordination and inter-connection of public transport can thus ameliorate the disadvantages of dispersion and fragmentation.

Thompson (1977) estimated that radially organised public transport systems in dispersed suburbanized cities can cater only to around 10 per cent of regional trips. The greater the extent to which planners design services to serve single origin-destination pairs with individual lines the more likely the result will be a collection of routes rather than an interconnected network. Similarly such a collection of individual routes is less likely to cater to the diverse needs of all passengers. In contrast the more ubiquitous the network is and the more it is designed to be seamlessly interconnected the more likely it is to serve a multiplicity of passenger trip making desires. Similarly, the more specific the cohort of passengers a route is designed to serve the less likely it is that patronage will cover operational costs for that route. This is especially the case with off-peak non-trunk bus routes serving 'captive' cohorts. Limiting diverse cohorts' travel options to specific routes means fewer opportunities to expand the range of trips undertaken by public transport. This focus on individual routes in public transport provision thus risks trapping system planners into debates about the relative costs and benefits of serving a particular cohort-origin-destination combination and often leads to minimised service levels because the estimated demand per individual cohort is likely to be low. These problems can be exacerbated when 'gravity' demand models of trip generation are deployed as these assume that the activity mass of a destination is a determining characteristic. Effectively such models reproduce the assumption about urban density and public transport viability by incorporating their assumptions into demand models. A better strategy is to plan the networks to satisfy the demand of all cohorts. This means abandoning boutique cohort-specific routes in favour of a multi-cohort network. The principle of the 'network effect' assumes that the marginal gain in the elasticity of demand increase due to improved interconnection and integration exceeds the marginal cost of service improvement.

The public transport network planning problem has been identified and explicated in detail by Thompson (1977) Mees (2000; 2010) and Nielsen et al (2005). While Thompson (1977) provided some early insights into this issue Mees (2000; 2010) work has provided perhaps the clearest theoretical demonstration of the problem. Mees shows that public transport services are able to attract the highest level of patronage if they provide an interlinked web of services that support *transfers* so that the passenger selects from the entire network the combination of route segments required to undertake their journey. This network planning approach means that public transport managers no longer have to provide dedicated routes to meet specific passenger cohort demands – instead they should provide a network of services that enables a wide array of potential trips. This network system strategy for public transport system planning aims to create a ubiquitous network that is able to offer a multiplicity of origin-route-destination combinations from which different passenger groups, or individual travellers, can identify and select their optimal route for a given journey at a given time. Individual lines that generate substantial point-to-point patronage on their own should nonetheless be stitched into a wider integrated network because the connectivity they offer will support greater trip-making on that network.

Well designed public transport networks do not simply emerge from a web of uncoordinated superpositioned overlapping routes. Such networks require the further application of a coherent and consistent set of planning techniques and strategy. The design and structure of public transport services at the metropolitan scale can be described as the overarching 'network strategy'. Alternative network strategies have advantages and disadvantages that can be represented diagrammatically. The conventional network strategy followed in dispersed metropolitan regions, especially those which have undergone car based suburbanisation, is a *radial* system strategy (Figure 1) (Thompson 1977; Thompson and Madoff 2003). This strategy however only caters to a small proportion of intra-regional trips typically focused on peak hour

commuter travel. Patrons wishing to travel from point A to point B in Figure 2, for example, are forced to circuit through the city centre.

Radial network strategies

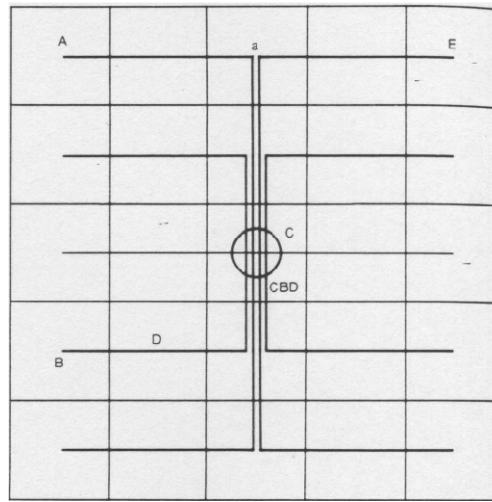


Figure 2: Conceptual radial network strategy

Source: Thompson 1977



Figure 3: Radial strategy in practice, Melbourne (rail only)

Source: Metlink (2010)

A typical version of a radial network strategy is represented in Figure 3. This network strategy links a set of sub-regional nodes via trunk transport networks served by radial links. Rail diagrams such as Figure 3 do not indicate whether bus services link between the rail lines – often a signal that such services aren't well integrated.

An expanded version of a radial network strategy is presented in Figure 4. This approach is emblematic of the 'transit oriented development' model that has been pursued in some jurisdictions, although it adds additional radial clusters. The Copenhagen and Stockholm S-Tog rail networks exemplify this 'beads on a string' model of activity and corridor provision (Cervero 1998). While this network strategy has potential to offer greater connectivity between some key nodes, there is a risk of generating only limited connectivity between the services within each radial cluster. While the network offers travel to multiple destinations the route structure

provides only a limited number of journey paths and in turn limits travel opportunities.

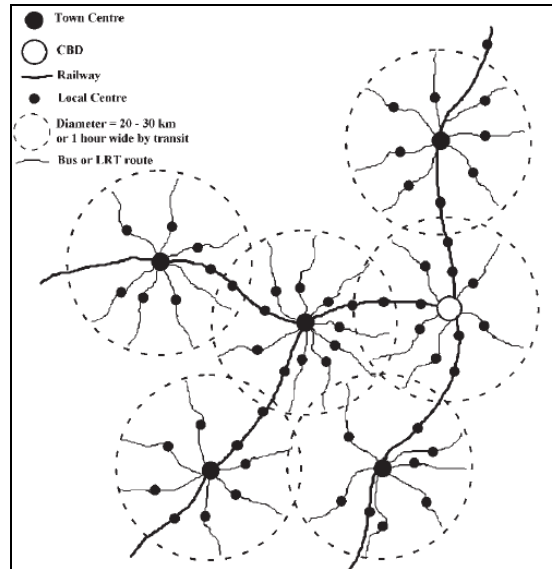


Figure 4: Radial network strategy in a poly-centric city.

Source: Newman and Kenworthy 2006

Dispersed network strategies

An alternative strategy to the radial approach is the multi-directional network design approach which seeks to provide a seamless web or grid of mobility across as wide a proportion of the urban area as possible. Wickham (2006, p.79) suggests a simple visual test of an integrated, networked public transport system:

Where there is an integrated transport system, the route map will resemble a grid rather than the spokes of a wheel: the system allows people to move around the city for many different reasons.

The dispersed network structure is depicted in Figure 5 which shows a widely distributed array of routes across a region. While many routes pass through the central zone the high proportion of non-radial routes supports multi-directional travel. A similar approach is Figure 6 highlighting the multiple transfer opportunities offered by the intersection of public transport lines. Such depictions are highly idealised – public transport networks must operate in real space with uneven geographies and distributions of land uses, unlike the geometrical elegance and complete spatial dispersion of Figure 5.

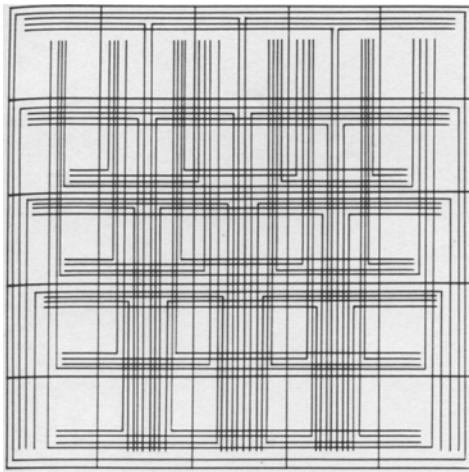


Figure 5: Conceptual dispersed network strategy

Source: Thompson (1977)

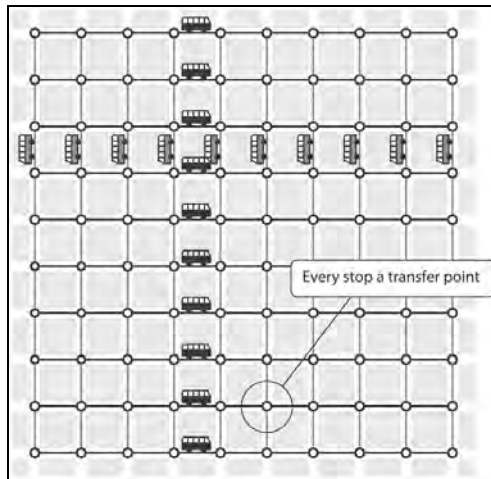


Figure 6: Conceptual dispersed network strategy indicating transfer opportunities.

Source: Nielsen et al (2005)

This network strategy is deployed in many of the successful public transport systems operating in Europe and in some North American cities such as Toronto and Vancouver. Brown and Thompson (Brown and Thompson 2008, p. 252) note that:

...transit managers who restructure their systems from a largely radial to a largely multideestination service orientation, in order to serve decentralized travel destinations, can sustain or increase their service productivity.

Advanced public transport networks are planned so as to support and enable transfer opportunities. An actually existing example of a highly successful dispersed network – Zurich – is presented in Figure 7. Zurich has one of the highest per capita rates of public transport use in the developed world and has achieved this without resort to strategic manipulation of urban form. The Zurich network is structured around a set of radial rail and tram lines intersected by multiple generally circumferential bus routes. Each rail, tram or bus line is intersected by multiple other lines enabling a web of multi-directional transfers. Services on most of the suburban bus

and tram lines operate at frequencies of 7.5 minutes². The result is short waiting times for transfers between most services on the network with regular and easily remembered service times that largely eliminate the need for timetables on most lines, although these are provided nonetheless.

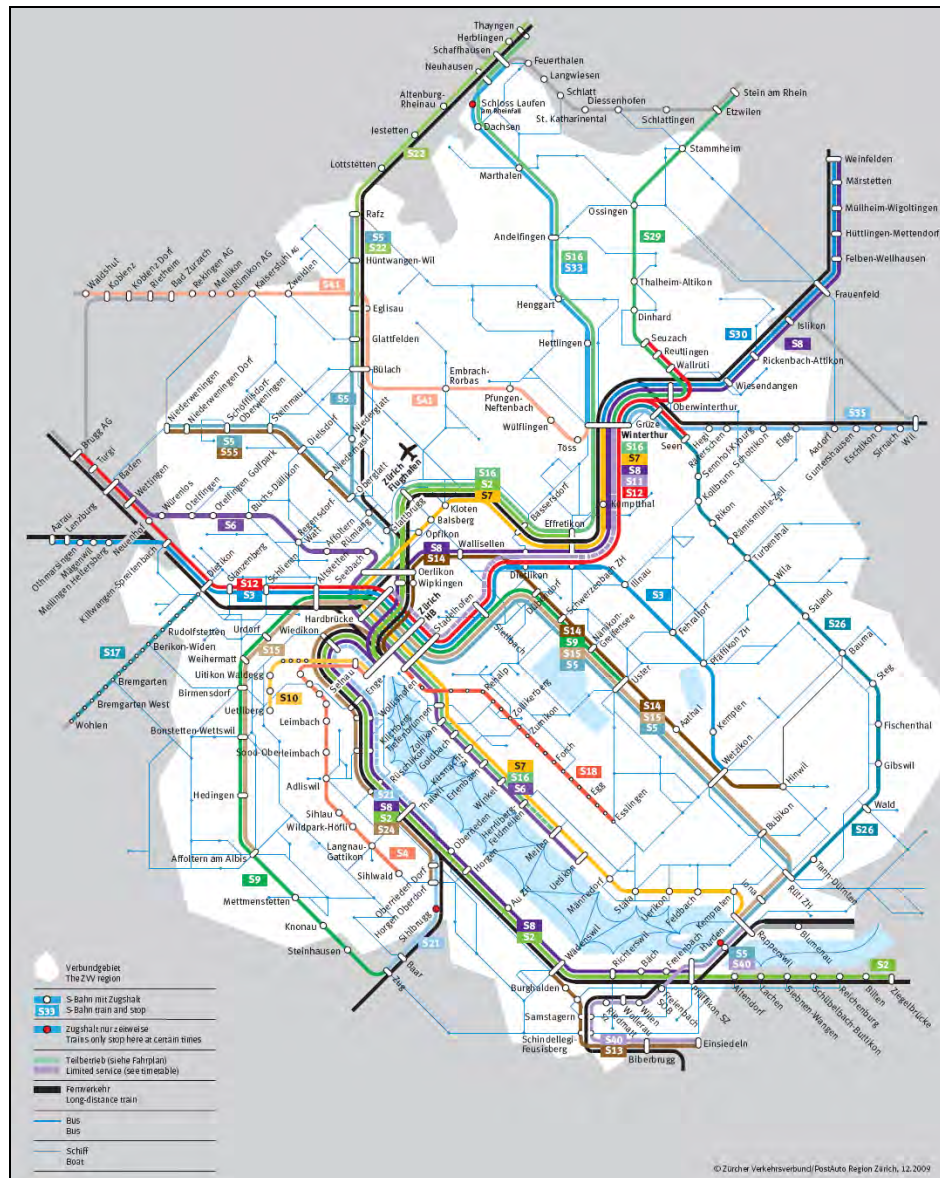


Figure 7: The Zurich regional public transport network.

Source: ZVV (2010)

Successful dispersed network strategies such as those found in many European cities are unlikely to be organically developed through either incremental planning of individual routes. There is growing evidence that modes of public transport management which conceive of public transport services as a set of separate commodities from which consumers select their preferred basket to match their intended travel are incapable of achieving high patronage levels (Kain 2007; Mees 2000). Rather the use of public transport is optimised when the aggregate network of services is treated as a unified commodity and travellers pay for access to the aggregate network (Nielsen et

² The use of 7.5 minute frequencies in Zurich enables four simple, stable and easily integrated frequency patterns across a sixty-minute cycle. Zurich services thus operate at 7.5, 15, 30 and 60 minute frequencies and thus greatly simplifying the service integration task especially on the metropolitan rail network.

al 2005, Mees 2010). The literature on the management of public transport networks is converging around the conclusion that a dedicated centralised public transport planning authority is required to provide the level of route, mode, timetable, ticketing and informational integration necessary to support a wide array of trips (Mees 2000, 2010, Wickham 2006). It is an irony of network planning that detailed and dedicated planning is required to generate a service that can support an array of infinite unplannable individual journeys.

Passengers must therefore also be able to easily understand information about route and stop patterns and timetables and any zone or transfer information that may influence the convenience or cost of travel. This requirement further places the onus on network planners to produce easily comprehensible networks. Such approach to public transport planning practice is common in European jurisdictions but is not well understood elsewhere. But some key principles of network planning can be applied to urban systems to assist with the reconfiguration of current arrangements into a more ubiquitous network arrangement.

Design principles for the public transport network effect

Two basic principles underpin the network effect. The first principle is to provide a simple and stable inter-connected network of public transport lines throughout the day with a structure and timetable that is easy for users to learn and understand (Nielsen et al 2005). Simplicity in this context means that lines follow direct routes that can support fast operating speeds with clear nodal points at intersections with other lines. Straighter, in most circumstances, also implies faster. Stability implies a regularity of service frequency during the day so that users can easily learn the service timetables for key periods (Nielsen et al 2005, Mees 2010).

The second key principle of network planning is to accept and support the proposition that many, potentially even a majority, of travellers will need to transfer between services to access their selected destination. This need is heightened in dispersed cities with only moderate or limited degree of activity concentration. As Thompson et al (1976, p. 9) observed, “it is very unlikely for a traveler to find their trip both beginning and ending on the same route. Therefore, tremendous emphasis must be placed on the task of making the transfer easy”. Transfers are made easy by coordinating timetables between services to reduce waiting times. This is perhaps the most crucial feature of successful network planning but it is often given little attention in wider discussions of public transport planning within cities.

The two principles of well designed network routes with coordinated timetables can be applied as key operational practices. The remainder of this section expands on and assesses some of the key operational practices that underpin public transport operations planning to achieve the ‘network effect’.

Key practice 1: Simple and direct network structures:

Public transport networks should be organised on the principle of ‘one section – one line’. Network planning should distinguish conceptually between a public transport *line* which comprises the *network* path travelled by a service and the *route* which is the physical path followed through the city (Nielsen 2005, p. 94-5). The fundamental principle is to provide simple direct lines whose physical routes can be easily remembered whether individually or within the wider network. Simplicity aids legibility. Physical factors inevitably influence route alignments but are less important for line design at the network scale.

Direct routes are typically quicker and shorter than circuitous ‘wandering minstrel’ routes and thus offer both faster travel and a better use of operational resources (Mees 2000). Direct line routing is important with bus lines that lack fixed physical infrastructure and thus offer little

permanent indication as to their route. Accordingly network planning should also limit deviations in the physical routes for bus lines on the principle that direct routes will attract patronage by offering faster operating frequencies than by offering wide spatial accessibility.

Line network structure design should thus seek to consolidate and concentrate multiple similar adjacent lines into unified simpler lines which can offer higher frequencies and direct routes. Where feasible lines should operate as diametral (cross town) ‘pendulums’ to support some through-passage at key activity centres and interchanges (Nielsen et al 2005). Reductions in coverage can be made up for through the use of feeder lines.

In addition to simplicity, Nielsen et al (2005, p. 104) also advocate network ‘parsimony’ such that “...the number of lines should be as few as possible in order to create an efficient, high quality main line system for the majority of public transport users”.

Key practice 2: Plan a hierarchy of lines into a network

Public transport networks require a hierarchy of interconnected lines that differ in capacity and speed with scale of operation. The range of lines in a typical hierarchy can be broadly categorised as: high-speed high-capacity cross-town links; inter-suburban connecting links; and local feeder services:

High speed cross city lines typically require fast dedicated rights-of ways with high volume passenger loads. Heavy or light rail is commonly used for this line function but some bus routes – such as high frequency busways -- can also serve such a role if deployed appropriately. High speed cross city links in low density contexts are unlikely to be able to attract sufficient patronage to justify investment unless they are connected into a highly integrated web of inter-suburban or local lines (see below). Unlike ‘mass’ transit in high density cities, Martinovich (2008, p. 20) has noted “in low densities the ‘masses’ must be brought or come to the railways” via connecting lines.

Inter-suburban lines typically operate at grade and can be used to link high speed lines with distant activity nodes such as shopping centres. Thompson and Matoff (2003, p. 298) describe such lines as “general purpose routes that interlock with each other to make intra-suburban mobility possible while feeding passengers to trunk route or dispersing passengers from trunk routes”. Inter-suburban lines may achieve frequencies and speeds approaching trunk levels and can be operated by bus and light rail modes. The planning focus for such lines should be on the consistency of timetables, the reliability of travel speeds and coordination with trunk line transfer points.

Local lines link suburbs with trunk or inter-suburban lines and nodes. Local lines are often used to provide links to regional or metropolitan trunk and inter-suburban lines or to provide low volume alternative connections to and between nodes. Because local lines often operate at low frequencies they thus must substitute consistency, reliability and speed of transfers for frequency. While they are often treated as residual components of metropolitan transport systems low frequency or feeder routes nonetheless require a high degree of planning to ensure that consistency, reliability and connectivity can assist to overcome low frequency. The additional planning investment in ensuring connectivity can thus produce higher patronage.

There is generally an inverse relationship between the frequency of services on a line and the degree of integration and planning required for that line. High frequency or trunk lines offer ‘forget-the-timetable’ frequencies and thus demand little service coordination with connecting services. Underground metro systems such as the Paris or London systems typically function on this principle. This category of lines still requires operational planning effort to ensure

consistency and reliability of service speed. On such lines the network planning challenge centres on preservation of right of way, scheduling and capacity rather than frequency and timetabling.

Key practice 3: Plan for speed, consistency and reliability:

Public transport planning should aim for travel speeds comparable to or faster than door-to-door travel times that can be achieved by car (Nielsen et al 2005; Mees 2000, 2010). This involves vehicles being able to travel fast along routes with minimal impedence from other traffic or intersections to ensure reliability. This in turn requires interventions to support priority for public transport vehicles, through right-of-ways, dedicated lanes and priority at intersections.

Lines should operate consistent timetables and stopping patterns that apply across wider periods. Lines operating consistent timetables enable service times to be more easily memorised than inconsistent patterns and can thus avoid the need to consult timetables. For example, passengers on Copenhagen's suburban rail network need only remember three figures corresponding to the minutes past the hour at which trains depart from their local station (eg :12, :32, :52) while most of Zurich's services operate on 7.5, 15 and 30 minute frequencies. This consistency of timetabling is sometimes described as a 'clock face' approach with times spread evenly across the hour to ease memorisation.

Key practice 4: Coordinate convenient transfers

The need to transfer for most trips means that journey speeds also depend on quick transfers. At the network scale the key task is to provide a basic structure of lines operating at high frequency so that waiting times at stops on these lines are minimal and timetables are not required. The literature suggests that frequencies of six services per hour (every 10 minutes) are the minimum necessary to avoid timetabled connections, with 12 services per hour (every five minutes) preferred (Thompson et al 1976; Nielsen et al 2005; Mees 2000, 2010). Zurich achieves 7.5 minute frequencies (8 services per hour) on most urban bus routes while Vancouver's Skytrain operates every 2-3 minutes throughout the day.

Fast and easy transfers support fast journeys to dispersed destinations within a public transport network. High-speed high frequency trunk routes provide the spine of a public transport network and in themselves require minimal coordination with other routes. Inter-suburban and local lines require greater coordination beyond the high-frequency trunk lines to offer a fast, consistent and reliable service.

Where trunk line frequencies are lower coordination should be applied between fast trunk and inter-suburban services in the first instance and then between inter-suburban and local services. For example where services depart a rail station at 10, 25 and 40 and 55 minutes past the hour services on connecting inter-suburban and feeder lines should be organised to deliver passengers to the station before trunk service departure and departing connecting services leaving shortly after the trunk service, to support transfers. Inter-suburban pendulum services feeding across trunk lines require further coordination to ensure waiting times for passengers either side of the pick-up/drop-off cycle are kept low; such services will likely also require route priority.

Coordination is equally important where suburban feeder lines link to inter-suburban lines. Depending on transfer distance factors feeder services should arrive at the relevant stop a few minutes prior to the departure. The literature varies on the transfer time period; Vuchic (2005, p. 224-225) suggests highly reliable services should offer 2 to 4 minute transfer periods and less reliable services 4 to 6 minutes. Cervero (1998, p. 10) notes Edmonton's successful timed transfer uses transfer times of 3 to 5 minutes. Such benchmarks should be adjusted in circumstances where connecting services are separated by some physical distance to allow for walking times between them.

Coordination can be relaxed where the service frequencies of interconnecting lines are high (8 minute headways or better). The higher the frequencies on two connecting lines the lower the transfer times and in turn the lesser the degree of coordination required to minimise transfer delays. The *minimum* frequency for such ‘forget-the-timetable’ services is around 10-8 minutes (Nielsen et al 2005) with higher frequencies preferable. Where frequencies of this order have been achieved planning effort should be expended on ensuring a high level of consistency and reliability along the network lines beyond the intersection.

Almost without exception public transport collects and distributes pedestrians. Pedestrian access networks are in effect extensions of the public transport network and must be planned on analogous principles of speed, connectivity and legibility as the overall public network. Coordination of public transport lines and networks should therefore include planning for the location and design quality of stops and the ease of access to stops, focusing on convenience for pedestrians. Stops should be carefully planned to minimise stop numbers and ensure optimal positioning relative to key trip destinations such as activity nodes, intersecting lines and pedestrian routes. Stops should be located as closely to activity nodes as possible and pedestrians should have access precedence over car modes. Interchanges, when needed, should be designed to minimise vehicle bays and movements and facilitate easy pedestrian passage. Park-and-ride facilities should be progressively reduced in favour of feeder services.

Stop and interchange design is an important factor to ensure passenger safety, comfort and ease of use. At interchanges walking distances between services should be very short - preferably no more than 10 metres (Nielsen et al 2005). The quality of stop design becomes more critical where long waiting times are required – passengers will tolerate poorer stop amenity where waiting times are very low. An example of basic interchange design on the Vancouver network is the connection at Joyce-Collingwood station (Figure 9). Buses wait immediately adjacent to the station for passengers alighting from the Skytrain; as service coordination is organised to minimise transfer times stop amenity is modest.



Figure 8: Intersecting rail and bus services in a Vancouver sub-region.

Source: Translink (2005)



Figure 9: Connecting buses at Joyce-Collingwood Skytrain station, Vancouver.

Source: Dodson

Key practice 5: Provide clear, ubiquitous and consistent information and marking

Clear accessible information for passengers is a key element of public transport networks. Stops should provide sufficient information for passengers to locate the stop within and navigate across the public transport network. Information about timetable frequencies for services on that line should be included as well as information about zones and fares. Major trunk stations should provide ticket purchase opportunities. Where possible stops should provide opportunities for the pre-purchase of tickets as is the case the Curitiba busways or in Zurich (Figure 8). Stops on nearly every line of the Zurich bus network offer ticket purchase and comprehensive fare, ticket and network information; costs are minimised by installing ticket machines in just one of an opposing stop pair.

Detailed information is less necessary for high frequency lines which can be marketed as ‘forget-the-timetable’ services. Information becomes harder to provide for lines with infrequent and inconsistent timetables.



Figure 10: Standard stop design, featuring information and full ticketing pre-purchase, Zurich.

Source: Dodson

Planning line structures for improved network function

The first principle of public transport network line structure planning is one of the key tasks in public transport network planning. Turning principles into operational actions is not always straightforward, particularly where multiple further factors enter consideration. For example many public transport systems face legacy network structures that have been designed with other objectives than those underpinning the approach to network planning described in this paper. Yet consistent, continuous and determined application of these principles can improve public transport network functioning. Such planning involves two key features, specifying the full network and simplifying line structures.

Specify the full network

For a public transport network to be operationally legible and understandable it needs to be described as a complete network. Passengers on public transport networks are motivated by their desire to travel across urban space. Although planners often engage in debates over the optimal transport modes for particular system tasks the critical factors from a passenger perspective are service speed, frequency, connectivity and legibility. Connectivity and legibility depend on the ability to understand the range of journey path options which in turn requires a full system map. It is difficult to visually represent all the variables that apply to a network. Nielsen et al (2005, p. 36) imply that after network line and node structure the most important distinction in a public transport network map is the difference in the hierarchy between high frequency ‘forget-the-timetable’ lines – whether cross-town or inter-suburban – and less frequent lines, as this clearly delineates for passengers the areas of fast and easy compared to slower less easy travel.

Displaying the public transport networks such as those found in extensive metropolitan regions such as Australia’s major cities is a challenge for graphic design. But a number of techniques can be employed to increase the richness of information conveyed in network maps while retaining simplicity. For example differentiating between modes is a common visual method. But identifying named stops and route street names on lines offers a simple proxy for local spatial information that would be otherwise difficult to represent. The Zurich public transport network map provides an example of such a graphic design solution (Figure 1). The map indicates all the lines within the city network in a clear simple way with actual route information implicit in the stop and street names. This in turn requires a high degree of consideration about the naming of stops in relation to local features such as shopping strips or landmarks. What the map foregoes in geographic accuracy it gains in the depiction of network connectivity. While it is difficult to also include timetable information within such network maps this can be partly overcome through the use of consistent service frequencies across the network, as achieved in Zurich.

Simplifying line structures

The literature identifies the creation of simple line structures as the basic element of a public transport network. Public transport networks and systems are the artefacts of human action and in the absence of dedicated institutional capacity to plan networks according the key principles identified in the above discussion networks will inevitably evolve in response to a range of operational factors. In the absence of continued dedicated public transport network planning effort the result of incremental change can be an accretion of individual network additions that may not necessarily conform to the principles of simplicity set out above.

Two features that add complexity to line and network structure in poorly planned public transport networks are indirect lines (Figure 9) and duplicate lines (Figure 10). Indirect lines are often found on sectors of a public transport network that have historically experienced low patronage or where limited service investment has been required to achieve greater spatial route

coverage. Indirect line structures, especially on bus routes, maximise spatial coverage but at the expense of speed due to frequent stopping and turning. Since travel time is a crucial factor on public transport networks indirect routes provide a disincentive to travel and are thus only attractive to ‘captive’ customer cohorts (Mees 2000). Such routes can occur where a minimum service obligation has been applied without much consideration of the needs of the users. The direct line example presented below (Figure 11) offers broadly similar spatial coverage overall but requires 18 fewer right-angle turns and is 60 per cent shorter in length than the indirect line. Rationalisation of indirect lines into direct lines has a number of advantages. Reduced route distance permits faster running times which compensates for reduced spatial coverage while also reducing operational costs which enable more frequent services to be offered. Put simply, straighter lines offer potentially higher journey times and are thus more attractive to passengers.

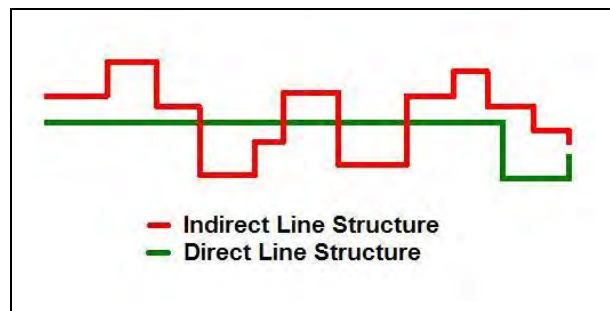


Figure 11: Direct and indirect line structures

Source: Adapted from Mees (2000).

Simplify network structures

Line structures should aim to reduce complexity for passengers. As Mees (2010, p. 169) observes:

[w]hile in theory, 20 bus routes running hourly down a joint corridor means a service every three minutes, in practice it means bewildered passengers. A single line running every five minutes would use less resources but provide a better service. This approach will often mean employing the ‘trunk and feeder’ model... ..This enables the trunk section to be served economically, avoiding vehicle congestion and saving resources which can be redeployed to provide higher service levels on the feeder routes.

Simplification of line structures can be achieved through a number of methods, many of which are described in detail by Nielsen et al (2005, pp. 95-110). The premise underpinning Nielsen et al’s (2005) discussion is that services should be concentrated into simple lines that can then offer fast high frequency travel which can then be connected into a metropolitan network of fast links. An implicit assumption of this conclusion is that the network advantages of line structure simplicity are greater than the benefits of transfer avoidance. The disadvantage to passengers of transfers between lines can be overcome by timetable coordination but the weakened network connectivity and increased complexity generated by the attempt to improve convenience through indirect line structures can often only be overcome with additional services. Consolidation of line structures also facilitates simpler timetables. Thus the seven separate timetables in Figure 13 can be replaced by a single trunk timetable with timed feeder services.

After common individual line routes are unified into a single trunk line the next design task is to simplify the remaining sections of the connecting lines to speed their operations as well. Line consolidation through straightening and ‘trunking’ should improve operational efficiencies by reducing route length and service duplication, while offering a more coherent legible service to

network users (Figure 12). Service efficiencies gained this way can then enable spare resources to be redeployed elsewhere on the network.

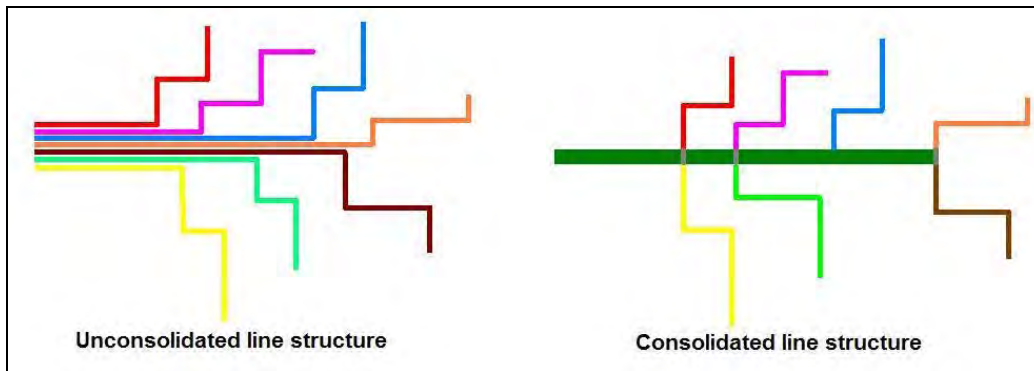


Figure 12: Line consolidation leading to higher frequencies on the trunk service.

Source: Adapted from Vuchic (2005, p. 209)

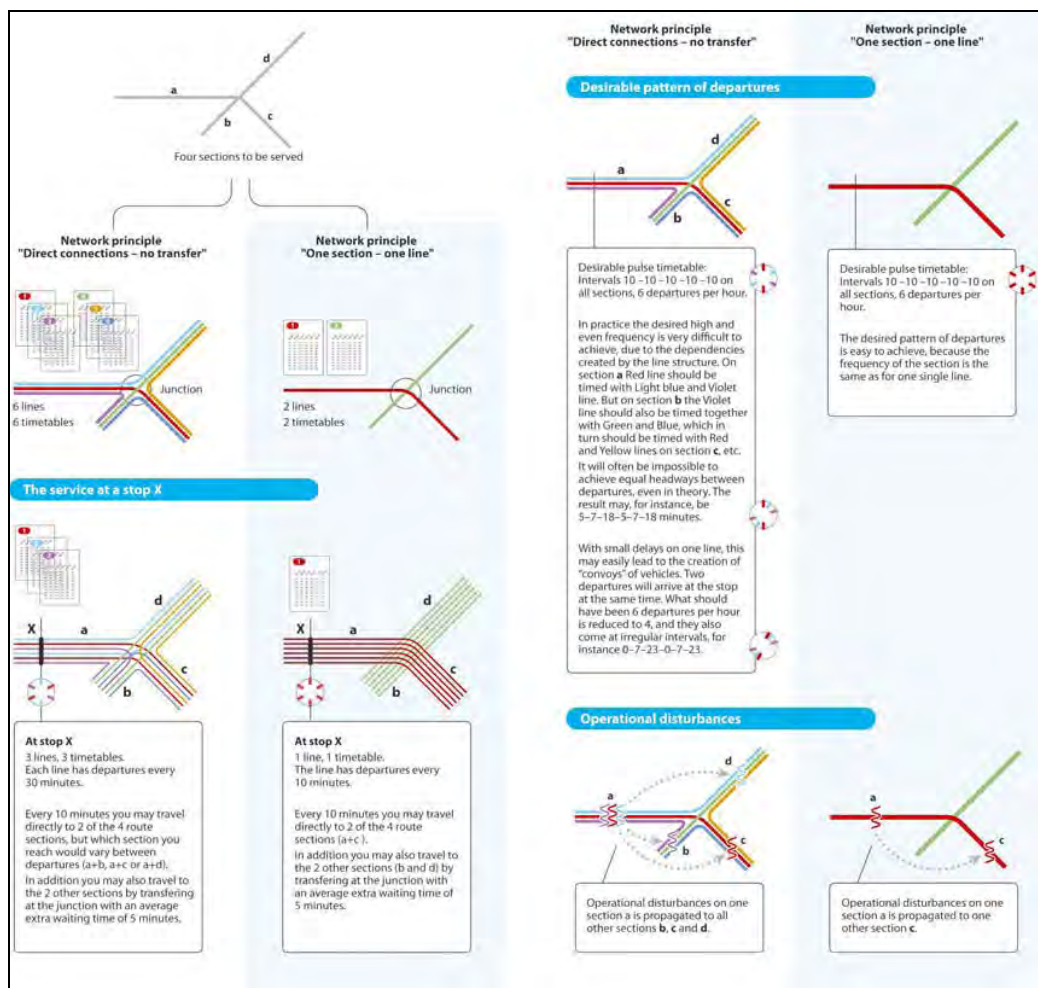


Figure 13: Simplifying line structures to improve network integration based on transfers.

Source: Nielsen et al (2005)

Coordinating timetables

Fast travel times can partly substitute for high frequency in situations where underlying demand is highly dispersed, such as outer suburban sites. After ensuring simple line structures a further means of supporting fast travel times is to minimise transfer times between services across the network. Vuchic (2005) suggests network planning and timetable planning are interdependent. The network of lines provides a simple grid of spatially interconnected pathways while timetable planning ensures these are also temporally connected.

Timetabling can appear a complex exercise – Vuchic’s (2005) discussion of the topic includes many complex mathematical equations. Nielsen et al (2005) are less mathematically focused but nonetheless see timetable coordination as inseparable from network planning — good network planning seeks faster and more concentrated services that generate more frequent timetables. It is important however to make the distinction between the simpler principles of network planning coordination of timetables and the more complex questions of scheduling which Vuchic addresses.

The literature distinguishes between two main timetabling techniques – ‘pulse’ or ‘timed’ transfers versus ‘forget-the-timetable’ lines (Nielsen et al 2005). The latter function most effectively on trunk lines operating services at better than ten minute headways while timed transfers are typically deployed on inter-suburban or feeder services operating at lower frequencies. The basic principle of ‘timed’ transfers is to ensure minimal transfer times by coordinating arrivals and departures of interconnecting lines. In a timed transfer multiple lines arrive at a network node simultaneously, rest to allow passengers to transfer between lines and then depart simultaneously. The concept of a ‘clock-face’ with arrivals and departures at set regular intervals can be used in this context – for example services arrive at a transfer node at 10, 25, 40 and 55 minutes past the hour allowing time for transfer and then depart at 0, 15, 30 and 45 minutes past (Mees 2010, p. 169). Such timed transfers require planning of two key features of the service: the coordinated arrival times provide the basic point of integration but require up-line planning of services on routes, especially for road-based modes such as buses and trams, to ensure reliably timed convergence at the transfer nodes. Timed transfers are commonly used to extend the passenger-shed of cross-town or regional rail services using feeder buses in dispersed urban contexts (Vuchic 2005). But well designed timed services can operate as more than feeders. Coordination of an overall public transport network which lacks extensive high frequency links through timed transfers can compensate for low service density. The case of Sternenbergr in Switzerland demonstrates this point clearly offering a small mountain hamlet twenty minute connections to the Zurich regional system via a regular timed feeder service to the regional rail and wider public transport network (Mees 2010).

High frequency services should still operate to regular and consistent timetables. This is demonstrated in the case of Zurich which operates many cross-town, inter-suburban and feeder services at high frequencies with consistent service patterns (Figure 14) typically at 7.5 minute frequencies.

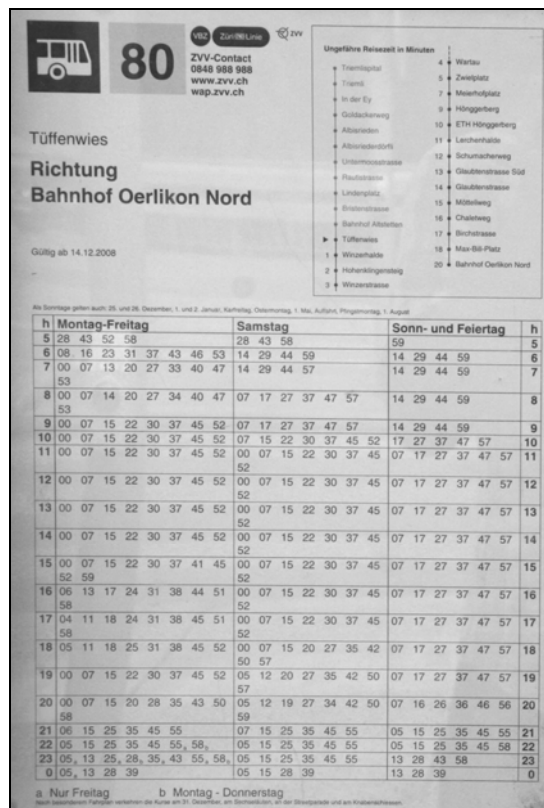


Figure 14: Consistent timetabling across days and weeks, Zurich.

Source: Dodson

Fare systems

Public transport fare systems are a further important component of the network planning effort. Public transport fare systems can support network planning by ensuring transfers between services do not incur further cost or purchase for passengers. Integrated fares in which transfers between lines on a network may be made without penalty support improved network planning by supporting a seamless user experience. The motto of the Zurich Verkehrsverbund “one ticket for all” alludes to the centrality of the fare as a critical component of that city’s successful seamless public transport network. Pucher and Kurth (1995, p. 286) describe the effect thus:

Even if passengers transfer from one line to another, from one type of public transport to another, or even from one public transport firm to another, only one ticket is needed for the entire trip from point of origin to destination. That innovation has improved the attractiveness of public transport in every Verbund...

Mees (2010, p. 175) sums this task up succinctly: “[t]ransfer-based networks require transfer-friendly fares”. Despite their importance to the public transport user experience the literature on the relationship between fare structures and public transport network design is surprisingly sparse. Most discussions of the role of fares focus on questions of price setting based on the demand elasticities for travel at various service qualities or for various subsidy levels (Balcome et al. 2004) rather than the operational effect of various fares and their effect on network useability. Mees (2010) argues that fare structures are less significant than service quality though because passengers will gladly use a higher priced good quality service than a poor quality cheap service.

Integrated fares are however essential to the operations of well-planned public transport networks. Integrated fares typically operate in conjunction with a zone structure which applies set

fares for travel within a geographical area, usually over a set time period. In most public transport systems fare systems are integrated with a collection system which includes the use of zone structures, fare structures and ticket modes in the operational decision mix. Zone structures, are not addressed in the present discussion beyond the observation these should be designed to be legible to passengers and to cohere with the broad structure of the overall public transport network. Likewise the complexity of fare structures and ticket modes places them largely beyond the scope of the present discussion except where they affect the user experience.

Other than cost the key ticketing concern from a public transport network planning perspective should be operational speed and convenience to the user. To support improved network operations ticketing should not interfere with the speed of services on a line through increased dwell times due to the effect of ticket issuance. This requirement will typically require fares to be purchased independently of the boarding component of the trip, thus requiring pre-boarding or on-board purchase while travelling. Pre-purchase of fares from a station counter or self-service vending machine is the most commonly used method.

Electronic smart cards becoming more common on public transport systems to store and redeem value for travel using electronic sensors. As with conventional paper tickets smartcards should also be designed with close consideration of the user experience: smart cards should be widely available for purchase at a range of outlets including at and beyond public transport nodes; they should be easy to operate and manage both for storing funds and travelling. Smart cards are not inherently supportive of improved network planning. From a network perspective such cards are primarily valuable where they improve the operation of service on public transport lines through improved boarding and travel times or improve the user experience through reduced transfer penalties or avoidance of cash-handling. A smart-card which reduces convenience by placing the burden of ticket acquisition on passengers whether through high search or transaction costs should be avoided.

Institutional Design for Public Transport Network Planning

Metropolitan public transport network planning implies a planning authority. This section reviews the literature on public transport network planning to identify the characteristics of a successful public transport network planning agency. The paper does not intend to rehearse arguments about the relative merits of planned public transport networks against unplanned or market driven arrangements. Such questions were debated extensively over the past two decades and the empirical failures of the market-based model – along multiple assessment criteria -- are now widely known. Buchanan and Partners (2003), Wickham et al (1999) and Atkins (2001), for example, as well as the Australian Senate (2009) found that a regional public transport planning authority was a key feature of good practice in urban public transport policy implementation. For the purposes of this discussion therefore the considerable evidence in favour of the proposition that well planned successful public transport networks require centralised coordinating agencies is accepted (see Mees 2000; 2010). This section thus assesses some of the key characteristics of such agencies; these include planning a fast efficient network, specifying all service characteristics for operators and managing subsidies, designing fare structures to support the network, undertaking marketing of the overall system, and managing the network financing.

The clearest general model of a public transport network planning authority is offered by Pucher and Kurth (1995) in their study of the Verkehrsverbund agencies established in many European cities following the initial example of the Hamburg Verkehrsverbund (HVV) in 1965. The HVV motto of ‘One network, one fare, and one ticket’ has been widely adopted (for example in Zurich). Pucher and Kurth argue that this general Verkehrsverbund model is successful because these agencies have been able to achieve levels of patronage growth that are higher than

comparable cities without a Verkehrsverbund model. In this paper we refer to this phenomenon as the European Verkehrsverbund (EVV) model.

The key network planning features of the EVV examples studied by Pucher and Kurth (1995) included service expansion, better quality services, more attractive fare structures, and better marketing. Service expansion comprised two forms – expansions of fast trunk ‘S-bahn’ rapid rail and ‘U-bahn’ underground networks supplemented by extensive express feeder links, combined with the ‘taktverkehr’ system of simple and consistent timetabling to make schedules easy for travellers to remember. The EVVs improved services by enabling faster travel and ensuring on-time performance through reserved right-of-ways with traffic-light priority for transit lines on surface roads combined with improved timetable coordination to facilitate easy transfers. The EVVs have also focused on creating simple uniform and integrated fare structures that encourage customers to make more trips, including fare rewards for monthly and yearly tickets. Service improvements and the wider social, economic and environmental advantages of public transport are intensively communicated to passengers through marketing campaigns that highlight the advantage of this mode, attract new customers from the private motorist travel market segment and reinforce the loyalty of existing customers.

The EVV model encompasses more than public transport network planning however. The model also incorporates institutional design measures that enable the agency to undertake the coordinating tasks upon which improved network design depends. An EVV doesn’t necessarily operate the public transport services that it plans. Typically an EVV is an overarching planning agency which integrates the services of the separate component service provider companies. These firms are responsible for providing services at agreed levels and take responsibility for the management and maintenance of all fleet factors, including vehicles, staffing, work schedules and maintenance. This separation leaves the EVV to concentrate on planning and marketing rather than operational matters.

A further critical underpinning of the EVVs is the continuing expansion of service subsidies (Pucher and Kurth 1995). The EVVs have consistently increased the subsidies they have provided to public transport services in part due to the extensive services they have offered, especially in dispersed outer suburban zones. Fare revenue has not always covered the full cost of provision. This cost recovery problem may however be in part due to the problem that positive externalities from improved public transport services and greater public transport use are not captured by the network planning agency; instead such improvements may rather flow to other groups such as motorists who benefit from reduced road or the community more widely from improved accessibility and reduced vehicle emissions. Nielsen et al (2005) argue that irrespective of the institutional formation used to plan public transport networks well crafted service contracts can assist to limit service costs.

An EVV model is not solely sufficient to support improved public transport network planning. Even if a fast efficient integrated network can be *planned* the planning agency must also have the capacity to *implement* it. This means the agency must have the legal power and necessary funding to procure services according to the raft of necessary specifications required to ensure good network performance with the ability to alter and adapt services to meet changing customer demands and if necessary to change service providers to improve quality. Without such abilities public transport authorities may not be able to improve their networks at a sufficient rate to generate anticipated patronage growth for a given level of expenditure.

Transition points in network reconfiguration

Many public transport networks, especially those not operated by EVV agencies are not optimally configured from a fast seamless network planning perspective as set out in this paper. This

problem is especially the case in public transport systems which have historically experienced large declines in public transport use and where vestigial networks have been retained without adequate investment available to re-configure services to improve efficiency. Yet with greater interest in the economic and environmental benefits of public transport and growing evidence of increasing patronage on many public transport networks globally there is a new imperative to re-evaluate whether existing network configurations are optimised to deliver higher service qualities.

At what point should a public transport network be re-configured to improve network planning and design? Good network planning – based on the key practices set out above – should be a normal component of the governance and management of public transport in cities. In many European cities the Verkehrsverbund model has institutionalised this approach to public transport management; the planning agency itself takes on the role of continuous innovator in service and network quality. The significance of this managerial role should not be underestimated. Vuchic (2005, p. 317) argues that sprightly management and periodic rejuvenation may be critical in the improvement of public transport network planning:

With time organisations have a tendency to develop a pattern of operation that is convenient for personnel, rather than for passengers and long-term operating efficiency. This pattern of operations is not easy to change, because in an organization a resistance to change develops that may be designated as “self-defense of incompetence”... The less competent employees are, the more they resist any changes ... Management must undertake energetic steps to break the pattern of service deterioration, decreasing economic efficiency, and resistance to innovations....

European Verkehrsverbund public transport authorities have led to a rolling set of improvements to public transport network planning in the cities where they were established from the 1960s onwards (Pucher and Kurth 1995) with some evidence that similar arrangements have been effective in North American cities (Vuchic 2005). While the establishment of a public transport authority on an EVV model is not essential to good public transport network planning the evidence suggests that it can facilitate achievement of improved network quality.

In cities where an EVV model public transport authority has been recently been established a greater network planning effort will likely need to be undertaken especially in jurisdictions that have seen little recent service innovation. The establishment of such an authority provides an ideal moment for improved public transport network planning as the capacity and powers of the authority, suitably constituted, offer considerable potential for the rationalisation and integration of lines into a comprehensive metropolitan network. Inevitably a new authority will take some time to adjust to its operating environment and the task of building institutional capacity. Beyond a few years of operations though the task of a comprehensive audit of line and network structure relative to the principles of network planning set out in this paper and similar texts if not undertaken should be considered well overdue.

The network efficiency imperative is enhanced where new investment is planned. Ideally networks should be comprehensively audited and re-configured to offer optimal service quality prior to the resort to new infrastructure investment as a service enhancement tool. Likewise, where new infrastructure investment is planned networks should be audited to test whether they are configured to extract maximum service advantage from the additional value of the new investment. Public transport network planning thus has an important role to play in leveraging patronage gains from existing networks or, where it has been determined necessary, from new infrastructure investment. As Mees (2010) has shown good network planning can increase the elasticities of demand for travel by public transport which in turn leverages better performance from existing infrastructure. In addition to institutional innovations such as an EVV, major new investments in public transport infrastructure, or plans for rolling investment in such infrastructure should be viewed as moments for network audits and rationalisation. It is not

inconceivable that improved network planning could offer sufficient service quality gains that infrastructure investment is not needed or can be postponed.

Network efficiency is likely to be crucial where fare structures are altered to recover a greater proportion of the cost of service operation from passengers. The elasticity of demand for a set level of public transport service relative to ticket price is relatively low (Pucher and Kurth 1995), especially for discretionary users (Litman 2007). This means that fare discounting for a given level of service is unlikely to attract a commensurate level of additional patronage. In contrast the elasticity of demand for fast efficient travel is relatively high; Litman (2007) places headway elasticity at approximately 0.5. Mees (2010) has argued that elasticities of demand for single lines can be multiplied many times greater than 1.0 by good network planning. Service improvements for a given price are thus likely to have a higher elasticity of demand. Hence instances where ticket prices increase without commensurate gains in service quality may act as a disincentive to customer loyalty. Efficiency gains through improved network planning may thus both improve service quality and act as a counter to disadvantages from rising fare costs. This places a particular onus on public transport planners to ensure that their own organisation contributes to efficiency gains in public transport provision through improved network operational efficiency rather than externalising the cost of sub-optimal network management onto customers.

Conclusions

Public transport is widely regarded as a critical infrastructure for cities and a key tool for mitigating the urban effects and impacts of climate change and higher oil prices. There is increasing realisation that public transport should operate as more than a collection of uncoordinated routes and modes. Rather public transport should be planned as an overall network which provides convenient, multi-directional and seamless travel to a wide range of passenger cohorts. The literature on the key practices that contribute to such public transport network planning remains under developed. Much of the focus in public transport planning is on engineering and operational considerations often linked to scheduling algorithms rather than on designing an overall network that is coherent to users. A clear task was apparent to draw this emerging literature together to improve understanding of the significance of public transport network planning.

This paper had three objectives. First the paper draws upon the urban public transport governance and management literature to assess the strategic significance of public transport network planning within wider urban strategy. This discussion recognised that public transport planning is a key factor in supporting improvements in urban sustainability. This role is especially important in dispersed suburban contexts where other sustainable alternatives to the motor vehicle such as walking and cycling are less viable. Well planned public transport supported by rigorous design and planning of the network of lines and their interconnections is essential to achieving the task of making car dependent cities more sustainable.

A second objective of the paper was to assess some of the key strategies and tactics used to improve and expand the planning of public transport networks within cities. The paper reviewed two broad network strategies which were described as 'radial' and 'dispersed' network strategies. The literature has demonstrated that dispersed strategies are better suited to contemporary suburban travel patterns as these offer the opportunity for a wider range of multi-destination journeys than conventional radial network schemes which are often limited to serving centrally oriented commuter trips. The paper then reviewed the key practices identified in the literature that contribute to improved public transport network planning. The two overriding principles guiding this practice were to establish a clear and consistent interconnected network of fast frequent lines throughout the day, and to plan and provide for easy, seamless and convenient

transfers by passengers within the network. Together these principles were shown to drive a raft of further network design practices that improve network function and the 'offer' to customers. Timetabling was also a key area of design for public transport network planning with 'forget-the-timetable', 'clock-face' and 'timed transfer' line and timetable coordination being especially significant.

The paper finished with a discussion of institutional frameworks and transition points in public transport network planning. The literature has identified a single public transport authority with the power to design and manage public transport networks as being the optimal institutional means of achieving improved public transport network planning. From the literature a 'European Verkehrsverbund' (EVV) institutional model was viewed as being especially successful. The most successful version of this model is found in Zurich, however many cities in Germany, Switzerland and Austria operate such authorities with considerable success. The instigation of such a model within a city was viewed as providing an opportunity for improved public transport network planning. There remains a task though for public transport authorities to deploy public transport network planning techniques effectively to shift beyond existing or 'legacy' line and service patterns to achieve the 'go anywhere anytime' seamless service achieved in most EVV jurisdictions.

Australian cities still have a long way to travel before they match world exemplars such as Zurich in the quality of their public transport network planning. The authors anticipate that subsequent work will test current public transport planning practices in Australian cities against the emerging public transport network planning literature to evaluate whether current spatial and temporal service patterns are achieving their potential optimal performance relative the resources expended in their delivery. We suspect that considerable deficits are present within multiple aspects of Australian transport planning practice including the application of network planning principles, line design, timetable coordination, and the institutional vehicles used to plan and provide public transport.

We hope this paper will contribute to better recognition of such deficits by public transport planners, policy officials, politicians and the wider public who comprise the majority of public transport users. The capacity to recognise such deficits should assist public transport planners to adopt the new knowledge emerging in the literature about the planning of public transport networks and the critical practices that contribute to improved network design. Through such methods our cities may better respond to the various challenges of urbanisation, climate change and resource insecurity.

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