

# **Planning Public Transport Networks—The Neglected Influence of Topography**

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## **Abstract**

*The principles of public transport network planning include coverage, frequency, legibility and directness. But trade-offs are made in implementing these principles, reflecting the economic, institutional, temporal, and natural environments in which public transport is planned, funded, and operated. Analysis of the case study of Sydney, Australia, shows how implementing network planning principles is influenced by the natural environment. The neglected influence of topography on public transport network planning can be improved through understanding of the impact of topography on planning, expansion, operations, and public transport use; measuring the nature of the walk access in providing coverage; ensuring planning guidelines recognize topography in measuring walking access; and choosing the most efficient mode topographically while ensuring other policies support multimodal networks.*

## **Introduction**

The impact of the physical environment on urban form is well-known, as is the relationship between urban form and transport use. But the role of the physical environment in influencing the provision of public transport has been neglected, with the principles of public transport network planning often overturned by topography. The paper concentrates on the role of topography in the spatial aspects of network planning decisions including coverage, frequency, legibility, and

directness. The paper identifies and discusses how topography is a factor in many aspects of public transport, from network planning, network growth, operations, and use. Sydney, with its physical geography of coastal location, harbors, bays, rivers, and deeply dissected plateaus, is used as a case study to analyze how topography influences rail, bus, and ferry and the elements of public transport planning, growth, operations and use.

The paper is structured as follows: First, network planning principles are discussed. Then the impact of topography on public transport planning, network expansion, operations and use are identified, followed by a case study of Sydney that discusses the impact of topography on public transport in Sydney. The last section discusses and identifies how to better recognize the impact of topography in public transport network planning.

## **Network Planning Principles**

Public transport networks reflect interactions among the economic, institutional, temporal, and physical environments in which they have developed and currently exist. The economic environment includes the budget available for public transport and cost constraints for capital investment, operations and maintenance (Colin Buchanan and Partners 2003). Institutional environments determine the governance and regulatory environment of who plans, funds, provides, and regulates public transport (Van de Velde 1999). The temporal environment includes historical factors and the legacy of previous decisions on transport and land use and the modes of public transport available, which is why the network design at any one point in time is a function of its historical evolution (Barker and Robbins 1963). The physical environment includes elements of the natural environment such as climate and topographical features, including water features of harbors, bays and rivers and land features of peninsulas, ridges, slopes, and elevations.

Theoretical guidance on planning spatial networks, from a customer-oriented perspective as opposed to the operational determination of network design, is scarce. *HiTrans Best Practice Guide* for medium-size European cities is a recent guide for practitioners that fills the gap, noting that “by tradition, public transport operations have been a practical, non-academic business” (Nielsen et al. 2005, p. 14). Nielsen et al. (2005, p. 168) also note that a literature review did not reveal sources of comprehensive network planning advice. In the U.S., a single chapter (Pratt and Evans 2004) provides guidance on bus routing and coverage in the U.S. While there is no commonly-cited set of principles for planning public transport networks,

from observation, common objectives include coverage, frequency, legibility, and directness as described in Table 1.

**Table 1. Principles of Network Planning from a Customer Perspective**

<b>Coverage</b>	The spatial coverage of the origins and destinations covered by the network.
<b>Frequency</b>	Frequency of service, often achieved by building services into corridors. Frequent services reduce the wait time, which is heavily weighted in total journey time (Abrantes and Wardman 2011).
<b>Legibility</b>	The ability of the network to be understood by users and potential users to maximize “many to many” trip opportunities. Interchange creates a penalty estimated as equivalent to 17 minutes in-vehicle time (Wardman 2001), although this maybe smaller when transfer is between high-frequency services (Paulley et al. 2006).
<b>Directness</b>	Direct services can reduce travel time. Directness can also impinge on network legibility. Straightening out routes offers savings of the order of 30% (Jansson 2003), although the costs and benefits of straightening out routes can impact different demographic groups (Ljungberg 2005).

The principles carry different importance according to the aims for the network under consideration and need to be balanced by operator- or supply-oriented requirements. These include efficiency and optimization of resources such as vehicles and crew and can determine the minimum and maximum lengths of routes, and location of termini and interchanges. For instance, Ceder (2007) identifies the importance of vehicle scheduling, timetabling, and crew rostering and the interactions between these elements. These requirements also have an influence on patronage through their impacts on service reliability and customer-oriented timetables such as memory headways.

Implementation of customer-oriented principles, together with operator-oriented requirements, is subject to constraints that vary by city. In practice, trade-offs are made that influence network strategies such as developing a hierarchy of routes, developing corridors of services, and the extent of interchanges and transfers. Planning guidelines for individual cities such as Sydney (NSW Ministry of Transport 2006), Vancouver (Greater Vancouver Transportation Authority 2004), and Helsinki (HKL 2008) identify the trade-offs that policy makers, operators, and the community are prepared to make.

These trade-offs often focus on corridors. The theoretical basis to focusing on corridors is demonstrated by Mees (2000) through a “Squaresville example,” consisting of a grid-iron street pattern with streets 800m apart, which shows how frequency

can be enhanced with a given set of resources. However, this assumes services are planned on a featureless, flat plain and does not recognize land use and urban form. High-frequency corridors create a network effect that, with interchange, can expand the number of different destinations that passengers can access at good levels of frequency. While this is a good planning principle, *HiTrans* (Nielsen et al. 2005, p. 89) recognizes that in practice, two different types of restrictions for the exploitation of the network effect are common: low demand insufficient to support high-frequency services, and infrastructure capacity restrictions both for rail and road-based modes of public transport.

The economic environment is becoming more important, with today's public transport provision increasingly facing budget constraints. Trade-offs that concentrate services in corridors, thus enhancing frequency, are seen as good strategies to increase patronage (Currie and Wallis 2008). Pratt and Evans (2004) suggest for the U.S. that planning should simplify and straighten routes so as to provide for new travel demand patterns and remove interchange. In contrast, *HiTrans* (Nielsen et al. 2005) promotes the focus on simple, high-frequency networks based on high-frequency corridors that provide the network effect for an urban area by relying on transfers and interchanges between routes and modes. This latter approach could be seen as the "European" approach, in which integrated ticketing with no penalty for transfer has been a longstanding feature, well before the introduction of electronic ticketing.

This section on network planning principles has concentrated on the bus mode. In planning multimodal networks, rail-based routes are regarded as fixed in location, with flexibility achieved by the addition of bus-based services to develop a network. The fixity of rail services means that their contribution to spatial changes in network design is limited, and network planning and design for rail corridors considers only elements such as timing, frequency, and interchange opportunities.

## **Influence of Topography on Public Transport Planning Principles**

The network planning principles of coverage, frequency, legibility, and directness assume a featureless plain. In practice, network planning principles are heavily constrained by the natural environment and topography in both the initial development and growth of a network. Topography has affected both the historical development of modes and public transport networks as well as the restructuring of current networks and expansion and growth of networks. Moreover, the

influence of topography on public transport operations and public transport use is often underestimated in development of public transport networks. Topography can influence all modes of public transport through its impacts on planning, network expansion, operations, and public transport use. These factors are clearly inter-related and can have a cumulative influence.

**Topography and Public Transport Network Planning and Expansion**

Table 2 shows the effect of topography, by mode, on the network planning principles from the customer perspective. The presence of topographical constraints explains many of the network designs observed in urban areas today. For example, many rail lines today reflect the technical constraints on curves and gradients that existed when the line was first built, leaving many modern cities with a rail network that was spatially determined by the passenger needs of the mid-19th century (Bedarida 1968). For bus services, while grid patterns make for easy network design, few cities and suburbs outside the U.S. have been planned on a grid pattern, and even where a grid has been planned, this can easily be disrupted by creeks, valleys, and rocky outcrops, creating discontinuous streets, one-way streets, and cul-de-sacs. Moreover, street patterns, evolving historically (Marshall 2005), have followed topography.

**Table 2. Effect of Topography on Network Planning Principles, by Mode**

Mode	Planning Principle	Effect
Rail	Directness	Location of rail infrastructure is constrained by technical factors or gradient or curvature constraints or cost issues. Alignment often follows the path of least resistance, which may be along valleys or along ridges, and avoiding routes requiring expensive bridges or tunneling
Bus	Directness, Legibility	Routes need to avoid steep streets, narrow streets, circuitous streets, and one-way streets arising out of topographical features. Improved vehicle technology has reduced some constraints, but new ones are created by the introduction of low-floor buses, meeting physical accessibility standards, but with lower vehicle clearance.
Ferry	Coverage	Location of wharves is constrained by waterside factors, and potential patronage varies according to whether the ferry wharf is located at the head of a bay or at the tip of a peninsula. Wharves in bays have a much higher proportion of land (relative to water) in their catchments and are likely to have higher patronage.

Topography affects network growth through its impact on the cost of network expansion, particularly for rail, which requires its own right-of-way. Water crossings

of rivers or harbors, whether by bridge or tunnel, can be expensive, as can tunneling to provide suitable gradients. Topography affects the nature of tunneling material, whether sandstone, silts, or sands, and therefore choice of alignments for new links and location of stations. This is clearly illustrated in the case study of Sydney below.

**Topography and Public Transport Operations**

As identified in the previous section, network planning principles are tempered by the needs of operators to achieve efficient operation. Table 3 shows how topography creates operational constraints, by mode.

**Table 3. Effect of Topography on Public Transport Operations, by Mode**

Mode	Operational Effect
<b>Rail</b>	Curves and gradients to overcome topographical features reduce operating speed, increasing travel time, affect passenger comfort, and reduce patronage. Topographically-difficult terrain usually results in increased maintenance and operations costs.
<b>Bus</b>	Spacing and location of bus stops with bus stops required at closer spacings in steeper areas or with areas with topographical barriers to prevent severance impacts and to ensure coverage. Closer stops increase dwell time and reduce overall operating speed, increase total travel time and reduce patronage (Zografos and Levinson 1986; Bertini and Li 2008).
<b>Ferry</b>	Location of wharves has impact on journey time and operational costs. Ferry services that need to divert into a bay have a longer journey time and higher cost through traveling greater distances. Different marine environments within the network (open harbor crossings and shallow rivers) increase vehicle mix, with consequential increases in maintenance costs and a potential to reduce reliability through vessel availability. Tidal flows affect timetabling and the ability to create legible networks.

*HiTrans* (Neilsen et al. 2005, p. 14) recognizes that “the road system, topography, and other barriers also affect the location and spacing of public transport stopping places.” The spacing of stops as shown in Table 3, is one factor in the development of a mix of services with all stops, slower feeder services, and express or limited stop services serving fewer stops that are more widely spaced. As for rail curves and gradients, winding bus routes on narrow streets can affect passenger comfort and safety, especially for older adults and less mobile passengers.

**Topography and Public Transport Use**

Topography affects public transport use through its influence on land use, urban form, and structure, which affects travel behaviour and potential public transport use, and on patronage through its impact on the ease of access and egress.

Understanding of urban form and land use, including the size of centers, hierarchy of centers, and center location, is underpinned by the theory of land rent-gradients in a homogeneous physical environment, as summarized in Evans (1985). But topography disturbs these theoretical outcomes. Aspects of land use and urban form affected by topography include concentration of development along corridors such as waterways or ridges, the location of centers, and the catchments for centers, including severance impacts of topographical barriers. Topography can influence the density of development through creating locations perceived to be attractive or unattractive. In the early days of urban development, steep slopes may initially have been considered unattractive due to construction difficulties and higher cost. Over time, land and steep slopes that offer water views have become more attractive and are now likely to have higher densities of development.

Related to this, the urban form and the built environment, influenced by the physical environment of topography, in turn influence travel behaviour including choice of mode (Cervero and Kockelman 1997; Cervero 2002; Handy et al. 2005). Quantifying the direct impact of the physical environment on public transport use is less well understood as it is limited by data and measurement complexities. For instance, Taylor et al. (2009) proposed a conceptual model of the factors influencing aggregate transit demand, including regional geography, which includes population, density, and area as well as regional topography/climate. However, there were no data source for regional topography/climate.

For access and egress to public transport, there are data and measurement difficulties, including self-selection, where reported studies capture those people who have made the decision to walk given the environment. Taking a different approach, Wibowo and Olszewski (2005) investigated the effort of walking to access public transport in Singapore and found the effort to climb one ascending step is equal to 2.8m of level walking, so the effort to climb one pedestrian bridge with 32 ascending steps is equal to 90m of walking.

Overall, the discussion on public transport planning, operations, and use suggests that the network planning principles identified previously may be seriously constrained by topography. Networks that are developed in cities with diverse topographical elements may well end up with a public transport network that looks very different from that suggested by the planning principles. The next section considers Sydney, the capital of New South Wales, Australia, as a case study to illustrate the constraints imposed by topography on public transport as well as some of the solutions that are transferable elsewhere in the world.

## **Case Study: Sydney**

### ***Sydney's Topography***

While all the state capital cities in Australia are founded on rivers and share some aspects of Sydney's topography such as bays, harbors, and a coastal location, the combination of diverse topographical features in Sydney's physical environment is unique. Sydney, the capital of New South Wales and Australia's largest city, is a global city centered on a spectacular harbor and surrounded by national parks and ocean beaches (NSW Government 2005).

Sydney's distinctive topography includes its coastal location, dominated by the drowned river valley forming Sydney Harbour based on the Parramatta and Lane Cove rivers. Other rivers flowing generally from the west east to the coast include the Georges River, Cooks River, and Hacking River to the south of the harbor, creating Botany Bay and Port Hacking. The Hawkesbury–Nepean River is the western and northern boundary to Sydney, flowing at the base of the Blue Mountains to the west and entering the ocean to the north of the city. The rivers and their many creeks and tributaries dissect Sydney, creating ridges, plateaus and valleys. The many rivers also create peninsulas of development along the harbor, which are highly valued for their water views and amenity but can be difficult to serve efficiently by public transport. North of Sydney Harbour, Middle Harbour divides the Lower North Shore from the northern beaches. The northern beaches area has many coastal lagoons, and the long, narrow Pittwater peninsula is a distinctive landform in the far north.

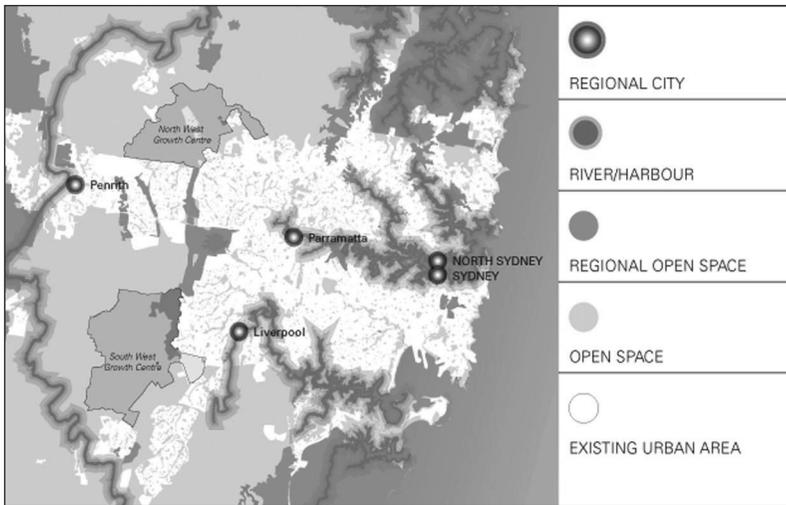
Sydney's colonial development was affected by this topography, with the first European settlement in 1788 at Sydney Cove on the eastern edge of the Sydney basin, on the southern side of the large harbor. Sydney's land use strategy notes the impact of topography on development:

If the first fleet had settled at Parramatta rather than Circular Quay, Sydney would be a more typical global city, such as London and Paris, with the CBD in the middle of the urban area on relatively flat ground next to a river that could be bridged easily. Sydney, however, grew from a town perched on the harbor at the eastern edge of the Sydney basin, then spread quickly to the more fertile areas south and west along the rivers, across the flatter lands to the west, and eventually north across the harbor (NSW Government 2005, p. 32).

In the growth of Sydney, land that was initially considered more difficult to build on or less suitable for agriculture, such as rocky outcrops or steep slopes, was left

undeveloped and often preserved as parks and reserves. Indeed, “almost half of Sydney [comprises] national parks, State Forests, regional and local space, water catchments, and wetlands that are protected from inappropriate development” (NSW Government 2005, p. 204).

Land use planners in Sydney have demonstrated their understanding of Sydney’s topography and its impact, perhaps moreso than transport planners, through Sydney’s strategic plans, including the 25-year strategic plan (NSW Government 2005) that identifies a hierarchy of strategic centers, recognizing the importance of rivers in Sydney’s urban form and structure. The Global City of Sydney and North Sydney is based on the harbor, while the three Regional Cities are located on rivers—Parramatta on the Parramatta River, Penrith on the Nepean River, and Liverpool on the Georges River (see Figure 1).



Source: NSW Government (2005)

**Figure 1. Sydney's physical environment**

It is clear that Sydney’s urban form and structure have been influenced by its physical environment. The next sub-sections use the case study of Sydney to illustrate the points made in the previous section before discussing how network planning principles might be improved to take account of topographical constraints.

### ***Topography and Network Planning***

Sydney’s public transport has a suburban rail network as its backbone, with buses providing flexibility and spatial coverage. One short section of light rail exists, cre-

ated from the conversion of a previous freight corridor. An extensive ferry network provides connections across the harbor and mitigates, to a certain extent, the lack of water crossings. This section first considers the topographical constraints on the rail network, as this in itself provides knock-on issues for the other modes.

Sydney's rail network reflects the technical constraints on curves and gradients that existed when lines were first built and that still affect network expansion. For instance, Sydney's North Shore follows a tortuous route north of the harbor, reflecting technical constraints on grade and curvature when being built in the 1890s. As with many "river" cities, Sydney is constrained by limited water crossings, with only three in total over a river distance of 30km, the first being the iconic Harbour Bridge, completed in 1932.

Topography also has an influence on the network and route planning of Sydney bus services. Very few, if any, parts of Sydney have extensive suburbs with a grid street pattern. Even where subdivisions may have been planned on a traditional grid pattern, the implementation of the grid pattern on the ground is disrupted by creeks, valleys, and cliffs, leading to discontinuous streets, one-way streets, and cul-de-sacs. Few major bus corridors in Sydney are straight, direct routes and are predominantly routes first established many years ago. Many roads in early colonial Sydney were based on walking tracks along ridges used by Aboriginal people. These walking tracks developed into roads and, later, tram lines. When bus services replaced trams in the 1950s, they continued to serve the development that had built up around the tram lines. Major bus corridors with a concentration of services forming a radial network into the CBD twist and turn, following ridges. Even where land is flatter, such as the Cumberland Plain in western Sydney, the location of residential and commercial development has been constrained by floodplains. In turn, this has affected the demand for public transport and, consequently, the design of bus routes as part of the network.

Ferries provide important links and, often, much faster access. The ferries not only provide cross-harbor links, providing extra capacity for the water crossing, but are also successful where journeys by bus would be very circuitous because of topography. For example, in southern Sydney, Bundeena is a small community on the southern shore of Port Hacking surrounded by national park. The privately-operated ferry service, which takes approximately 30 minutes between Bundeena and Cronulla, provides an important public transport link as an alternative to the 30-km, 45-min drive from Bundeena through the national park to the nearest station.

### ***Topography and Network Growth and Expansion***

Topographical constraints had several related impacts on the most recent rail network expansion—the Epping-Chatswood Rail Line, which opened in 2009. There were two options for the proposed rail line to cross the Lane Cove River in the Lane Cove National Park: either a tunnel under the river to minimize visual amenity and vegetation impacts, or a high-level bridge across the river. The decision to cross the river in a tunnel meant that a proposed station at an isolated university campus (UTS Ku-ring-gai) to the east of the river was deleted because the station would be too deep. The gradients involved in rising from the tunnel under the river also meant a longer length of track was required to connect into the existing surface North Shore line. The longer track increased construction cost and increased travel time. In addition, some existing rolling stock could not use the new line due to the impact of steepness on power requirements.

Rail construction costs affected by topography affected decisions made over 2008–2010 on the cancellation of the heavy rail North West Rail Link and its replacement metro rail projects, the North West Metro and CBD Metro. The original concept for the North West Rail Link in flatter western Sydney included an elevated section of track to avoid floodplains. One of the attractions of metro rail as a replacement for the heavy rail North West Rail Link was the smaller tunnel size required and cheaper tunneling costs. Sydney is built on sandstone, which has a high cost for tunneling at up to \$400 million per km (NSW Government 2009). While the properties of Sydney sandstone are generally considered good for tunneling, unpredictable fault lines can be encountered. As a replacement for the North West Rail Link, the North West Metro project was announced in March 2008, with 32 of 37 km in tunnel and 4 harbor crossings (Darling Harbour, White Bay at the Anzac Bridge, Iron Cove at the Iron Cove Bridge, and under the Parramatta River at the Gladesville Bridge) at a total cost of \$12 billion (escalated cost for completion in 2017). Due to the cost of the project and the state's declining fiscal position, the North West Metro project was canceled in October 2008 and replaced by the shorter CBD Metro project. At 9 km and requiring only 2 harbor crossings, it cost \$4.8 billion when announced, but increased to \$5.3 billion 6 months later due to uncertainty. The CBD Metro itself was canceled in early 2010. This history illustrates the way in which extending or creating new links in an old and established network that is subject to topographical constraints can be very costly and difficult to justify on normal evaluation procedures.

### ***Topography and Operations***

In Sydney, topography affects public transport operating speeds, travel time and costs, and, thus, patronage. On the Sydney rail network, the four main corridors to access the metropolitan network are shared by passenger and freight services. Passenger services have priority on the metropolitan network, with freight services usually restricted from operating on lines in peak times. But due to the topography, it is difficult to provide separate space for dedicated lines for freight and passengers. Widening corridors requires blasting through sandstone cliffs and widening water crossings, which can be done, but at a cost.

On the Sydney Light Rail in inner Sydney, the route alignment and station locations were affected by the topography of the sandstone headland. The route uses the existing circuitous freight alignment that was originally carved through sandstone, with the result being slow travel times as well as very deep stations with low visibility and poor access.

With bus services, topography affects operational issues such as the speed of buses and the location of bus stops. The major northern corridor of the Spit Bridge across Middle Harbour illustrates operational impacts, where the steep approaches on both sides of the bridge—with elevation of 95m on the south, 6m at the bridge and 70m on the north—and the winding access on the southern approach slows down buses. In addition, traffic stops while the bridge opens and shuts six times each weekday (in the off-peak) to allow boats in and out of Middle Harbour and eight times each weekend day.

In Sydney, ferries operate in three environments with different characteristics: across the heads of Sydney Harbour to Manly, in the inner harbor, and up the Parramatta River. The variety of operating environments requires a mix of vessels from ocean-rated vessels to vessels with low draught and low wash for upper river operations. Walker (2007) discussed the negative impact of fleet diversity on reliability and cost and recommended reducing the number of vessel classes. In contrast to Sydney, Brisbane ferry services operate on the Brisbane River with a single class of vessel. In addition, because of local topography, some Sydney Harbour ferry wharves are accessible to passengers only by steep stairs.

### ***Topography and Public Transport Use***

In Sydney, both land use and urban structure as well as access to public transport are affected by topography. This section gives an example from each mode.

Sutherland Shire in the south of the Sydney is bounded by water on three sides, with the ocean to the east, Georges River and Botany Bay to the north, and Port Hacking to the south. A tributary flowing into the Georges River further divides the Shire into east and west portions. There are limited river crossings connecting the area to the rest of the city to the north, with only one rail crossing across the Georges River.

Sutherland Shire is also characterized by a series of narrow peninsulas of residential development to the north and to the south, which are difficult to serve efficiently by bus. Sutherland Shire Council has created an accessibility index for individual parcels of land that includes topography through gradient (Koernicke 2007), showing how residents of these peninsulas, which are often very steep, have more limited public transport and less provision of services than the ridge areas of the shire, showing a lower level of accessibility.

North of the harbor, the northern beaches region of is similarly isolated, with limited access points across Middle Harbour and limited rail access. Ferries provide an important link between Manly on the north shore and the CBD.

## **Discussion**

### ***Network Planning in Sydney***

While topography has clearly influenced Sydney's public transport, it is more difficult to determine whether topographical constraints have helped or hindered Sydney's public transport development and use. Sydney has developed into Australia's largest city, with the highest public transport mode share of any Australian city both for the journey to work and for all trip purposes (BITRE 2009). With a CBD-focused rail network, more than 70 percent of work trips to the Sydney CBD are by public transport (Transport Data Centre 2008). In addition to its CBD, Sydney has a strong set of suburban centers, identified in the Metropolitan Strategy as Regional Cities and Major Centres. But have these suburban centers developed in response to poor or good public transport? The 3 Regional Cities and 9 of the 11 Major Centres are served by rail and connected by a network of Strategic Bus Corridors, but less well so than the CBD. Public transport use for work trips to the non-CBD centres varies from 10 percent to just over 40 percent (TDC 2008). Parking is still readily available at most non-CBD centres.

The topographical constraints identified previously have been posited as being all "bad" for public transport network planning, operations, and use. However, these same topographical barriers can serve to channel demand into more concentrated

services. As such, the constraints may make some services viable where this might not have otherwise been the case. But concentrating services into constrained corridors can also lead to bottlenecks that create adverse congested conditions, particularly if there is competition between public transport and the private car. To effectively concentrate patronage using the topographical constraints positively requires government to identify public transport as the key or only user of the corridor.

Network planning in Sydney is guided by the *Service Planning Guidelines: Sydney Contract Regions* (NSW Ministry of Transport 2006). While network planning focuses on connecting centers, guidelines are unhelpful in not using the same language to identify the hierarchy of centers as the strategic land use plan. In Sydney, bus networks are planned as a hierarchy of routes: Regional Routes, District Routes, and Local Routes. Criteria in the guidelines include:

- Coverage: Ninety percent of households to be within 400m of a rail line and/or a Regional or District bus route during commuter peaks, interpeak and weekend day time; and 90 percent of households to be within 800m of a rail line and/or a Regional or District bus route at other times.
- Network legibility: Peak and off-peak services should use the same route wherever possible.
- Route design (directness): Maximum diversion from the fastest or shortest route (between termini) to be no more than 20 percent.

The network area coverage criterion is the key benchmark, calculated “as the crow flies.” As this paper has demonstrated, 400m of steep access is very different from access of 400m along flat land. It is clear that the guidelines treat Sydney as uniform, with no allowance for different physical environments. In addition, by aiming to provide the same spatial coverage to everyone, it does not take account of the way in which topographically-difficult areas may require a disproportionate allocation of the public transport budget for both capital and operating costs. In turn, this raises equity issues since in Sydney, as with other waterside cities, people with higher incomes live in the more attractive and expensive locations, such as waterfronts, which are the more challenging and expensive to serve by public transport.

### ***Implications for Public Transport Network Planning***

While any city has a unique combination of features, and Sydney is no exception, there are more general lessons that can be learned from the case study for implementing and understanding trade-offs among the four planning principles of

coverage, frequency, legibility, and directness in the presence of topographical constraints. The implementation of these lessons will vary depending on the institutional and regulatory environment for public transport planning. The most important message is for a centralized regulatory environment in which the government provides planning guidelines; here, the planning guidelines should recognize the influence of topography in terms of coverage and the way this is related to access and egress from public transport stops and stations. In deregulated environments where operators plan services to maximize revenue or profit, they may give more primacy to corridor strategies at the expense of coverage.

For consumers, the case study shows topography has the most influence on strategies to achieve coverage of origins and destinations. Coverage of origins is often expressed as a walk distance to a bus stop, such as 400 m. Guidelines for Vancouver, Canada, for example, reduce the expected walking distance for steep grades (GVTA 2004). Perth guidelines (Public Transport Authority 2003) have a goal of a bus stop within 500m of 95 percent of Perth's population but recognize the pedshed concept for walkable catchments, defined as actual area within a 400m (5-minute) walking distance, expressed as a percentage of the theoretical area within a 400m walking distance, where a good target is 60 percent. In network planning principles, coverage should be calculated by reference to walking accessibility in terms of the equivalent walk effort required, not just distance, as shown by Wibowo and Olszewski (2005).

While GIS can be used to take topography including gradients into account, further research is needed to better understand which elements of topography affect people's walking decisions—Can footpaths overcome steep gradients? How much does gradient influence walking distance? Are more stops required in steeper areas?

As topography influences location of land uses and the transport that accesses land uses, transport and land use planners must encourage and support integrated transport and land use planning through strategic and local planning to ensure that major land uses and centers are located where they can be served efficiently by public transport.

## **Conclusion**

The case study of Sydney, with its combination of topographical features, highlights the two-way process of the relevance of taking topography into account in the planning and provision of public transport and the way in which the development of public transport is influenced by topography. A failure to recognize the impact of

topography in, for example, planning guidelines, can give regressive equity impacts from trade-offs among network planning principles of coverage, frequency, legibility and directness. Moreover, the presence of topographical constraints means that extending the public transport system is expensive in both capital and operational terms, with trade-offs between the areas to serve becoming necessary in a budgetary and evaluation constrained environment.

Topography would be better taken into account in public transport network planning in several ways: better understanding its impact on planning, expansion, operations, and public transport use; better measuring the nature of the walk access in providing coverage; ensuring that planning guidelines measure walking access realistically, recognizing topography; and choosing the most efficient mode topographically while ensuring that other policies support multimodal networks. Integrated transport and land use planning can also ensure that public transport is provided most efficiently in topographically-constrained environments.

## References

- Abrantes, P. A. L., and M. R. Wardman. 2011. Meta-analysis of UK values of travel time: An update. *Transportation Research Part A* 45(1): 1–17.
- Barker, T. C., and M. Robbins. 1963. *A History of London Transport, Vol. 1: The Nineteenth Century*. George Allen and Unwin.
- Bedarida, F. 1968. The growth of urban history in France: Some methodological trends. In Dyos, H. J. (ed.), *The Study of Urban History*. London: Edward Arnold.
- Bertini, R. L., and H. Li. 2008. Toward optimal transit stop spacing. Sixth International Conference on Traffic & Transportation Studies (ICTTS), Nanning, China, August 5–8. [http://web.pdx.edu/~bertini/papers/spacing ICTTS2008\\_final.pdf](http://web.pdx.edu/~bertini/papers/spacing ICTTS2008_final.pdf).
- BITRE. 2009. Information Sheet 31—Urban passenger transport: How people move about in Australian cities. Bureau of Infrastructure, Transport and Regional Economics, Canberra.
- Ceder, A. 2007. *Public Transit Planning and Operation*. Oxford, UK: Butterworth Heinemann.

- Cervero, R. 2002. Built environments and mode choice: Toward a normative framework. *Transportation Research Part D: Transport and Environment* 7(4): 265–284.
- Cervero, R., and K. Kockelman. 1997. Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment* 2(3): 199–219.
- Colin Buchanan and Partners. 2003. *Transferability of Best Practice in Transport Policy Delivery: Final Report*. <http://www.scotland.gov.uk/Publications/2003/08/17895/23881>.
- Currie, G., and I. Wallis. 2008. Effective ways to grow urban bus markets: A synthesis of evidence. *Journal of Transport Geography* 16(6): 419–429.
- Evans, A. W. (1985) *Urban Economics, An Introduction*. Oxford, UK: Basil Blackwell.
- Greater Vancouver Transportation Authority. 2004. *Transit Service Guidelines Public Summary Report*, GVTA.
- Handy, S., X. Cao, and P. Mokhtarian. 2005. Correlation or causality between the built environment and travel behaviour? Evidence from Northern California. *Transportation Research Part D: Transport and Environment* 10(6): 427–444.
- HKL. 2008. *Public Transport Planning Guidelines in Helsinki*. HKL Publication Series A: 1/2008, HKL Planning Unit, Helsinki.
- Jansson, J. O. 2003. Key factors for boosting the bus transport market in medium-size towns. *Competition and Ownership in Land Passenger Transport Thredbo* 8.
- Koernicke, I. 2007. Accessibility constraints mapping for walking and public transport in the Sutherland Shire. *Papers of the 30th Australasian Transport Research Forum*, Melbourne. [www.patrec.org/atrf.aspx](http://www.patrec.org/atrf.aspx)
- Ljungberg, A. 2005. Using Geographic Information System (GIS) doing CBA on new bus route systems—An empirical example of the city of Linköping. 9th Conference on Competition and Ownership in Land Transport, Lisbon, Portugal.
- Marshall, S. 2005. *Streets and Patterns*. London: Spon Press.
- Mees, P. 2000. *A Very Public Solution*. Melbourne.
- Neilsen, G., J. D. Nelson, C. Mulley, G. Tegner, G. Lind, and T. Lange. 2005. *HiTrans Best Practice Guide 2: Public Transport—Planning the Networks*. HiTrans, [www.hitrans.org](http://www.hitrans.org).

- NSW Government. 2005. Metropolitan Strategy *City of Cities: A Plan for Sydney's Future*. December, [www.metrostrategy.nsw.gov.au](http://www.metrostrategy.nsw.gov.au).
- NSW Government. 2009. Public Notice: Grants Distribution. *The Sydney Morning Herald*, 30 September.
- NSW Ministry of Transport. 2006. *Service Planning Guidelines: Sydney Contract Regions*. June. [www.transport.nsw.gov.au/busreform/service-planning-guidelines.pdf](http://www.transport.nsw.gov.au/busreform/service-planning-guidelines.pdf).
- Paulley, N., R. Balcombe, R. Mackett, H. Titheridge, J. Preston, M. Wardman, J. Shires, and P. White. 2006. The demand for public transport: The effects of fares, quality of service, income and car ownership. *Transport Policy* 13(4): 295–306.
- Pratt, R., and R. Evans. 2004. Bus routing and coverage. Chapter 10, *Traveler Response to Transportation System Changes*, TCRP 95. Transportation Research Board, Washington DC.
- Public Transport Authority. 2003. *Design and Planning Guidelines for Public Transport Infrastructure: Bus Route Planning and Transit Streets*. Western Australia.
- Taylor, B., D. Miller, H. Iseki, and C. Fink. 2009. Nature and/or nurture? Analyzing the determinants of transit ridership across U.S. urbanized areas. *Transportation Research A: Policy and Practice* 43A(1): 60–77.
- Transport Infrastructure Development Corporation. 2008. *North West Rail Link Supplementary Submissions Report*. March, Sydney, <http://majorprojects.planning.nsw.gov.au/files/21028/Submissions%20Report%20Part%20001.pdf>.
- Transport Data Centre. 2008. Transfigures employment and commuting in Sydney's centres, 1996–2006. Transport Data Centre, NSW Ministry of Transport, Sydney.
- van de Velde, D. M. 1999. Organizational forms and entrepreneurship in public transport, Part 1: Classifying organizational forms. *Transport Policy* 6: 147–157.
- Walker, B. 2007. Report of the special commission of inquiry into Sydney Ferries Corporation. October, [www.transport.nsw.gov.au/inquiries/walker-ferry-report.pdf](http://www.transport.nsw.gov.au/inquiries/walker-ferry-report.pdf).
- Wardman, M. 2001. A review of British evidence on time and service quality valuations. *Transportation Research Part E* 37: 107–128.

Wibowo, S. S., and P. Olszewski. 2005. Modeling walking accessibility to public transport terminals. Case study of Singapore Mass Rapid Transit. *Journal of the Eastern Asia Society for Transportation Studies* 6: 147–156.

Zografos, K. G., and H. S. Levinson. 1986. Passenger service times for a non-fare bus system. *Transportation Research Record* 1051: 42–48.

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