PLANNING FOR PUBLIC TRANSPORT ACCESSIBILITY

AN INTERNATIONAL SOURCEBOOK

CAREY CURTIS AND JAN SCHEURER

ROUTLEDGE

Public transit is an essential component of a sustainable future, but how to design a system that meets accessibility needs given finite budgets? Curtis and Scheurer offer help in the form of a sophisticated yet practical tool for analyzing transit accessibility. They demonstrate its use with a fascinating comparison across four continents that yields insightful lessons for planners.

Susan Handy, University of California, Davis, USA

This is a unique and comprehensive sourcebook in the field of transport and urban planning. If you want to understand how cities and metropolitan areas around the globe are performing in terms of public transport accessibility, and what opportunities there are to improve it, read this book.

Karst Geurs, University of Twente, the Netherlands

PLANNING FOR PUBLIC TRANSPORT ACCESSIBILITY

Bringing together a comparative analysis of the accessibility by public transport of 23 cities spanning four continents, this book provides a "hands-on" introduction to the evolution, rationale and effectiveness of a new generation of accessibility planning tools that have emerged since the mid-2000s. The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool is used as a practical example to demonstrate how city planners can find answers as they seek to improve public transport accessibility. Uniquely among the new generation of accessibility tools, SNAMUTS has been designed for multi-city comparisons. A range of indicators are employed in each city including: the effectiveness of the public transport network; the relationship between the transport network and land use activity; who gets access within the city; and how resilient the city will be. The cities selected enable a comparison between cities by old world–new world; public transport modes; governance approach; urban development constraints. The book is arranged along six themes that address the different planning challenges cities confront. Richly illustrated with maps and diagrams, this volume acts as a comprehensive sourcebook of accessibility indicators and a snapshot of current policy making around the world in the realm of strategic planning for land use–transport integration and the growth of public transport. It provides a deeper understanding of the complexity, opportunities and challenges of twenty-first-century accessibility planning.

Carey Curtis is Professor in City Planning and Transport at Curtin University, Australia. She is Visiting Professor at University of Amsterdam. Her research interests cover land use planning and transport planning, including a focus on city form and structure, transit oriented development, personal travel behaviour, accessibility planning, institutional barriers to sustainable transport, governance and transport policy. She has published over 90 papers, book chapters and books including *Institutional Barriers for Sustainable Transport* (2012) with Nicholas Low, and *Transit Oriented Development: Making it Happen* (2009) with John Renne and Luca Bertolini.

Jan Scheurer is a Senior Research Associate at Curtin University, Australia and RMIT University, Australia/Spain. Trained in architecture and sustainability policy, his research straddles the gaps between urban design and spatial planning, transport policy, user behaviour and mobility culture. He has been an activist for sustainable transport in several parts of the world since 1989 and lives nomadically, but regularly sets anchor in Amsterdam, Barcelona, Melbourne and Perth.

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To Professor Paul Mees OAM (1961–2013)

Paul started this research project with us and his insights into urban public transport networks not only launched our appetite to understand cities further, but to follow in his footsteps in trying to improve cities with this knowledge. We miss him immensely.

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CAREY CURTIS AND JAN SCHEURER

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Preface

How can cities improve public transport accessibility so that all residents and employees can have an alternative choice of transport to the car? What are the most effective infrastructure interventions to make? This book is the culmination of an international research project seeking an answer to these questions in the field of transport and urban planning. The purpose is to provide a comprehensive sourcebook of richly illustrated spatial accessibility indicators, visualised by maps and diagrams, together with a snapshot of current policy making around the world in the realm of strategic planning for land use–transport integration and the growth of public transport.

A sample of 23 cities spanning four continents provides the source for our analysis. The cities selected present a mix of New World, European and wealthy Asian cities to enable a comparison between cities which embraced public transport accessibility as a real transport mode choice many decades ago, and recent newcomers. The cities have also been selected in order to provide a mix of different public transport modes, a range of different governance approaches, a range of different geographical or policy-induced urban development constraints. In this way it is possible to interrogate a rich set of variables. The narrative of the book is arranged along six key themes which address the different planning challenges cities confront and cities are grouped according to these themes.

This is a new approach to understanding public transport accessibility in urban transport and planning where there has been an absence of such knowledge. The book is addressed to researchers, practitioners and policy shapers interested in gaining a deeper understanding of the complexity, opportunities and challenges of twenty-first-century accessibility planning.

Carey Curtis and Jan Scheurer

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Carey Curtis and Jan Scheurer

In addition to our joint acknowledgements we each have personal things we want to acknowledge.

I would like to thank my fellow author Jan. We have worked together now for many years – meeting first as members of the Fremantle Bicycle User Group and then taking turns to 'own' Babbaganoush, the cat. Our friendship cemented as we both got interested in accessibility – for me with what I thought would be a relatively easy question to answer – 'how can you compare three station precincts by their accessibility to the region?' Well it turned out the answer was more complex and the questions grew and grew! From here SNAMUTS developed with planning practice work in Perth and Melbourne and eventually the inspiration for the global study of cities. As with any good partnership we offer different and complementary skills – Jan's ability with fine detail and modelling complemented my contribution of strategic overview and application and as narrator to practitioners. That we both analyse in colour also helps! The research grant succeeded, but with serious budget cuts, and without Jan's bohemian lifestyle the fieldwork would not have been possible.

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On a more personal note I acknowledge my partner David for his support. To my son Janni – well you were always telling me I should catch the bus to work – now here's the evidence as to just how challenging that task is! You and your generation have a mission – other cities in this book show that cities can offer great public transport accessibility.

Carey Curtis

I have little to add to Carey's wonderful description of the refreshingly non-linear evolution of our collaboration, which now spans a good decade and a half and is certain to embark on many more academic adventures in the future. Thanks! My gratitude also goes to my colleagues at RMIT University's Centre for Urban Research (CUR), who have provided me with an academic base since 2005 across a plethora of research grants, consultancy and short-term teaching contracts as well as periods of transition between funding sources. Thanks particularly to Serena Lim and Yani Iskandar for holding the administrative side of things together. At the other end of the continent, I was privileged to maintain a similar base at the Curtin University Sustainability Policy Institute (CUSP) – thank you to everyone and especially to Prof Peter Newman and Prof Jeff Kenworthy, whose inspiring work on global cities played no small part in encouraging me to embark on a mission of international fieldwork and comparative analysis of my own. More recently, RMIT Europe in Barcelona has become a welcoming host, and community, for the completion of this book.

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Jan Scheurer

1 Introduction

What Is Accessibility Planning and Why Does It Matter?

Cities of the developed and developing world are facing major problems with ever increasing car congestion, rising fuel prices and the need to stem carbon emissions. In response many city planners and politicians are confronting the challenge of how to provide public transport to a standard which offers a viable alternative to the car. This challenge has several dimensions: establishing the most effective infrastructure interventions to make – both spatially and temporally – that enhance accessibility; considering how to link public transport infrastructure with urban development as a means of improving spatial accessibility; finding cost-effective solutions.

A major stumbling block in improving public transport accessibility is the lack of strategic overview. In our work to date (see, for example, Curtis and Scheurer, 2010; Curtis et al, 2013) we have noted that while city planners are prepared to embrace the challenge, they lack the technical planning support tools capable of supporting their endeavours. Accessibility tools provide one solution. Designed well, these tools can offer a means of measuring, visualising, and facilitating a stakeholder dialogue about efforts to better integrate transport and land use planning in contemporary cities. Such efforts have led to a variety of narratives on how such integration goals can be achieved in the specific local context of each city or city-region, and assist in the challenges set by the sustainability agenda and the transition to a low-carbon future. A critical overarching theme in this process is the reassessment of the role of public transport systems in the mobility mix of cities, and the imperative to increase the role of public transport modes for urban movement and accessibility particularly where current patterns of car use appear wasteful or excessive.

Historically, planning for urban public transport has seen a number of phases (Schaeffer and Sclar, 1975). Each phase has been the result, on the one hand, of the transport modes available at that time and the urban development needs of the city, and on the other hand, the result of transport policy choices made by bureaucrats and elected officials. Early cities relied on walking as the means of transport and city form was dictated accordingly. With the introduction of horse-powered buses and tramways in the early industrial age cities were able to expand, but for the most part remained compact with resultant health and sanitation problems. The development of suburban railways in the late nineteenth century facilitated greater spatial expansion of settlements, a favoured policy response to the ills of the industrial city, where railway owners were also land developers. The rise of the private motor car in the 1950s saw a significant further expansion of urban boundaries and investment in public transport was all too often abandoned as cities pursued the 'modern age'. Public transport was often relegated to a 'welfare option', deemed only necessary to supply a skeleton service to serve those not able to afford a car or unable to drive.

Since the 1980s there has been a paradigm shift towards sustainable mobility – a response to environmental and later social concerns of urban development, namely the carbon intensity, pollution effects, spatial and socio-economic inequities associated with individual motorised transport (Whitelegg, 1997). A result of these concerns has been a renewed interest in the role of urban public transport. Cities throughout the world are at different stages in the development of their urban public transport systems for the twenty-first century. Some have made astounding progress as they embrace the environmental and economic imperative to keep cities functioning with less reliance on private cars. Others remain tardy, unwilling to recognise that a transport system based on the car as the primary mode is on a collision course with the future resilience of cities. In either case, resource availability dictates that decisions about improving public transport accessibility must be carefully considered beyond simply choosing to keep investing in the car at the expense of public transport, particularly where the total transport budget is finite.

New accessibility tools can assist decision making. Their use can help answer critical planning questions. How should the city develop in future – what is the most suitable urban form to optimise public transport accessibility – polycentric/monocentric, contiguous/ dispersed, concentrated and/or decentralised? How should we invest in public transport infrastructure – what are the public transport modes, and their interplay, that deliver the best accessibility outcomes under what physical conditions? What should the focus of operational resources be on – the top-performing routes (by patronage) or a spread to increase network coverage (Walker, 2012)?

This book provides a 'hands-on' introduction to the evolution, rationale and effectiveness of a new generation of accessibility planning tools that have emerged since the mid-2000s. The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool, one such tool developed by the authors, is used as a practical example to demonstrate how city planners can find answers to the questions that arise as they seek to improve the accessibility of their city by public transport.

Uniquely among the new generation of accessibility tools, SNAMUTS has been designed for multi-city comparisons. A range of indicators are employed in each city. Each indicator is designed to measure key aspects of the system, including the effectiveness of the public transport network itself; the relationship between the transport network and land use activity; who gets access within the city; and how resilient the city is. The latter indicator addresses where future opportunities for growth and potential bottlenecks may be located. For each city, these indicators are set against the background of their differing historical development, urban geography and settlement form, spatial configuration of public transport networks and their institutional governance, and strategic plans for the future.

RESEARCH APPROACH

This book draws on a major research project which set out to provide a national benchmark for public transport accessibility in Australian cities by analysing the experience of a range of international cities. For us, integral to our concept of public transport accessibility is the need to consider the accessibility of the transport network and the accessibility of place (the opportunities different places provide to those using the network). This approach lies at the heart of new ideas of land use–transport integration, whereby cities are developed so that public transport can support people's daily activities as an alternative to the car, and also that land use (activity) can support public transport (by optimising patterns of patronage).

Our interest was in whether an accessibility tool could be employed to deliver comparable outputs for cities and regions with different cultures and histories concerning the evolution and state of the built environment as well as planning and transport policies and institutions. If this could be achieved, then the knowledge could inform Australian policy shapers, and ideally benchmarks could be set for improvements to urban public transport aimed at offering a quality service to all (where currently only between 5 and 10 per cent of trips are made by public transport in Australian metropolitan areas). The challenge was how to design an accessibility tool to address the performance of all relevant transport modes and land use trends within a specific urban or regional environment – bearing in mind the considerable differences in public transport service. We were also interested in how an accessibility tool could be communicated and utilised effectively among a broad range of stakeholders with varying degrees of influence and articulation in the political process and public arena. This book demonstrates the ability of accessibility tools to do just that. Further, we dream that citizens will take up an interest in the question of just how accessible their city is by public transport, especially compared to the car, and use this book as a resource to seek improvements.

STRUCTURE OF THE BOOK

While accessibility analysis is not new, there is an emerging range of new tools. These have been designed to address contemporary urban planning and transport issues. Many tools remain in the ivory towers of researchers, a limited few have been taken up in planning practice (te Brömmelstroet et al, 2014), and of those, some have been successfully utilised to inform future development and infrastructure investment (Curtis et al, 2013; Curtis and Scheurer, 2010). In Chapter 2 we take the reader through the key network theory and best practice concepts informing the design of the SNAMUTS tool. The eight component indicators are explained alongside practical questions emerging from the introductory discussion. Our aim is to provide the explanations in layman's terms, thus making the language of transport accessibility accessible to both professionals and interested citizens in terms that align with everyday experience of getting around their city.

Chapters 3 to 8 are organised around six themes consistent with the key questions about planning for public transport in different situations across the globe. Each chapter also features an accessibility profile of each city, illustrated with SNAMUTS maps of each core indicator.

Chapter 3 explores the theme of continuity and change in the Australasian cities of Perth, Melbourne, Sydney, Adelaide, Brisbane and Auckland. These cities are by and large characterised by a low-density, horizontally dispersed urban form, strong central cities and high rates of urban growth. Public transport networks are anchored by long-standing radial suburban rail systems and a post-war policy history of prioritising the needs of car-based transport over those of public transport. In recent years, pressures from rising petrol prices, increasing road congestion, a resurgence of public transport usage and a shifting preference particularly of younger generations towards inner urban living have begun to influence the policy focus on the potential of public transport to capture a much greater share of the urban travel market.

Chapter 4 continues with the analysis of New World cities. The theme of stagnation and aspiration paints the picture for a sample of North American cities which share some similarities with their Australian counterparts in terms of their generally high growth rates and the prevalence of post-war, low-density suburban form. There are also some differences in public transport supply, particularly the absence of historically grown suburban rail networks that make a significant contribution to urban mobility in much of the US and Canada. Hence, most contemporary North American public transport networks are the outcome of recent retrofits with high-capacity infrastructure elements. The selection of the four cities – Seattle, Portland, Montreal and Vancouver – reflects the breadth of approaches found across the continent, where city planners seek to establish a new role for public transport in cities that had embraced automobility like no others during a now fading phase of their evolution.

From the New World cities we move to the Old World established cities. In Chapter 5 the theme is 'more with less' exploring the relationship between fostering efficiency in a public transport system and achieving accessibility outcomes. European cities follow a range of approaches to designing and managing the public transport–land use context, owing to their varying cultural and historical characteristics as well as varying governance arrangements and planning traditions. The four cities selected – Hamburg, Munich, Porto and Edinburgh – provide an overview of these different approaches. Munich, in less than 50 years, has transitioned from a public transport system based primarily on radial suburban rail and urban trams to one where an expansive metro system designed for the needs of the post-war city forms the backbone of movement, supplemented by trams and buses in a lean, integrated multimodal network. Hamburg's approach has a greater complexity, characterised by the need to adapt pre-existing rapid transit systems during post-war reconstruction and the inability to complete the post-war metro expansion program that had served as the rationale for closing the tram system. Edinburgh represents another extreme. The city openly encouraged different public transport operators to compete for passengers in the same network segments, creating a heavily serviced bus system designed to minimise transfers between services. Porto's bus network is similarly structured to Edinburgh's, but has seen a gradual transformation towards greater multimodal integration when a new light rail system was introduced at the beginning of this century.

Staying with Europe, Chapter 6 follows the theme 'eclipsing the car'. Drawing on the cities of Copenhagen, Zurich, Vienna and Barcelona, it becomes evident that there have been dedicated efforts to rein in the role of the car for urban mobility and that this has been underpinned by redirection of resources. Copenhagen has a well-performing, though in a European comparison somewhat underutilised, public transport system whose main competitor in inner urban areas is the bicycle rather than the car – bicycle use is higher than in any other major city except Amsterdam. In Zurich, a metropolitan region with a pronounced dispersed–concentrated settlement structure, departure from a program of urban freeway and metro building in the 1970s led to a strategy to optimise and upgrade existing suburban rail, tram and trolleybus networks into a superbly organised multimodal system. In Vienna, public transport developed as a majority mode through well-targeted infrastructure investments aimed at optimising transport tasks and transport modes. In Barcelona, there has been a strategy to gradually reduce the role of the car in the very dense inner area in favour of improved public transport, expanded pedestrianisation and the reintroduction of the bicycle.

Chapter 9 brings Asian cities into the analysis with a theme of 'transit-dominance' in an examination of Singapore and Hong Kong. The extraordinarily rapid growth of high-capacity urban rail systems, now mirrored in many cities across mainland China and other developing Asian countries, has generated a significant land use–transport integration trend and generated accessibility outcomes that will profoundly shape the future form of cities on this most populated continent.

Up to this point the accessibility analysis has focussed mainly on cities developed at the metropolitan scale. In Chapter 8 we examine a settlement trend that has emerged in many urban agglomerations as they grow and begin to merge and overlap geographically. Clusters of self-contained, monocentric cities evolve into multi-centred wider urban regions with growing degrees of regional interdependency and cross-commuting, a process aided by the establishment of high-speed rail or other fast public transport links. We use the example of the Dutch Randstad, a polycentric region comprised of the major centres of Amsterdam, Den Haag, Rotterdam, Utrecht and many smaller cities.

Finally Chapter 9 brings together the analysis to enable a reflection on policy questions of importance to planners including the public transport mix and infrastructure that can deliver the best accessibility outcomes; the type of urban form and structure that can optimise accessibility by public transport; the operational input and efficiency.

2 Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS)

Understanding the Indicators

INTRODUCTION

In order to understand the accessibility analysis of cities presented in the following chapters it is important to explain the construct and rationale behind each indicator used. The starting point for developing an accessibility tool is to take the perspective of an everyday user of a city's land use–transport system. Everyday users make, and are often constrained by, long-term decisions about where their everyday activities take place, for example, the location of home, workplace, schools and the homes of regular social contacts such as family members or close friends. These locations generally change infrequently, and for many people, the spatial arrangement of these anchor activities will influence any changes they are in a position to make. Individuals also make many short-term, discretionary decisions about activities: where to go shopping, where to socialise away from home, where to engage in recreational pursuits, and how often any of these things occur. A critical premise of accessibility research is to recognise the impact that urban structure and the available transport networks have on the location and distribution of these activities. Everyday users are more likely to frequent activities and places that they perceive as convenient to access. To the extent that such destinations form clusters where a significant number or variety of activities are contained within relatively small areas, we can begin to understand a city as a composition of 'activity hotspots' or sub-centres, forming the hubs or nodes of a network in which transport infrastructures act as the links or edges.

People, especially in wealthy and relatively compact cities or parts of cities, are also likely to have a choice of transport modes to get around. They can draw on the services of overlapping, sometimes complimentary and sometimes competing networks for private motorised transport, public transport, walking and cycling. For public transport to assume a significant role in the mobility mix of a city it must offer a viable alternative for as many travel purposes as possible. It must be well aligned with the land uses it serves. The most significant factor in attracting choice travellers to a public transport network is its ability to offer an equivalent to the 'go anywhere, anytime' convenience usually associated with the private car, or at a smaller spatial range with non-motorised modes. In large cities, the best way to achieve this is usually to configure public transport as a multimodal network that allows travel along geographical desire lines, at service frequencies high enough to not require timetable consultation, and with seamless transfers between vehicles both in terms of physical co-location and in terms of integrated ticketing and timetable coordination. The interplay of these characteristics is what is known as the 'network effect' of public transport services, where the ability of the network as a whole to provide accessibility is superior to that of the sum of its individual components (Mees, 2010a; Nielsen et al, 2005; Walker, 2012).

In understanding accessibility we need to find out the extent to which such network-based synergy has been optimised for the land use–transport context in a given city, and to pinpoint areas with room for further improvement. On this basis we have established a set of tasks and measurements that highlight the challenge of land use–transport integration from a range of perspectives:

- What is the number of public transport services required to achieve an optimal level of accessibility across the network, noting that resources may be limited?
- What is the ease of movement offered on public transport across the city and for each route? Fast and/or frequent services reduce 'spatial resistance' to the user compared to slow and/or infrequent services.
- What is the transfer intensity of the network? While transfers are a necessary component of an integrated public transport network, is there a way of measuring whether their occurrence may be excessive or underdeveloped?
- What is the percentage of residents and employees within walking-distance to public transport services at a standard that allows for both planned and spontaneous trip making across most hours of the day, seven days a week?

• What is the geographical range users can cover by way of a public transport journey within a particular time frame, and how many destinations are located within this range?

• How does the public transport network channel concentrate and disperse the travel opportunities generated by the interplay of land uses and the transport system? Where on the network do these effects result in a potential mismatch between public transport supply and potential demand?

• How well is each activity centre connected in order to attract stopovers on public transport chain journeys and encourage land use intensification to capitalise on such flows of people?

• Can the results of these indicators be calibrated to arrive at a comparative scale for public transport accessibility between different cities and within one city over a time line?

KEY ASSUMPTIONS AND DEFINITIONS OF SNAMUTS

To analyse and quantify these different aspects of accessibility performance, Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) has been developed as a GIS tool operating on a database that captures the configuration and service levels of the public transport network in question. It can be used for the networks of entire metropolitan regions as well as for specifically defined subregions or corridors.

The core methodology of SNAMUTS has primarily been inspired by the Space Syntax theory (Hillier and Hanson, 1984) and by the Multiple Centrality Analysis tool (Porta et al, 2006a, 2006b). Space Syntax investigates the organising principles within built environments or movement networks and their inherent patterns of relationships. Among the resulting categories is the distinction of convex (topological) and metric shapes, a dichotomy that also constitutes the Multiple Centrality Analysis methodology as primal and dual graphs of spatial representation. In brief, the topological perspective examines the degrees of separation between a pair of objects in a spatial context or network, measured in changes of direction, passages through doors or gateways, or (in public transport networks) number of transfers. In contrast, the metric perspective examines the objects' distance from each other, expressed either in common measurements of distance (kilometres, miles) and/or by a proxy measure (travel time, travel cost, ease of movement). Operationalised for analytic output, these categories inform the concepts of *degree centrality* and *closeness centrality*, a terminology used frequently in the analysis of networks (Neal, 2013) and adopted for the SNAMUTS indicator set with some important variations (discussed below). Space syntax merges degree centrality and closeness centrality by developing concepts of integration and connectivity (Hillier, 1996). This understanding allows us to query whether a location that is functionally *well-connected* to others (spatially or visually overlapping) is also *well-integrated* with others (easy to get to and from) – or whether there are prominent mismatches between these properties, which can have a detrimental impact on a network's legibility and resilience.

This insight provides a potent vantage point for the development of an accessibility tool, particularly in a complex urban system where overlapping movement networks (such as for pedestrians, motor vehicles and off-street public transport) act partially in concert with and partially in competition to each other. Put simply, are those locations within an urban system that have the largest number and concentration of activities also the locations that can be accessed most easily? How does their accessibility by public transport differ from that by other modes? Since public transport distributes patrons through a limited number of access points (rail stations or bus stops), patrons cannot frequent intermediate land uses in the same way that pedestrians, cyclists or motorists can (albeit with some constraints regarding the availability of parking for the latter). Underground railway passengers are also visually removed from what occurs above ground in land use terms. The relationship between movement and urban form is thus a different one in public transport networks than in those for individualised modes of transport. A useful way to understand this is to see public transport access points in terms of both nodes and places (Bertolini, 1999).

Bertolini's 'node-place model' notes that while railway stations provide access to the transport network, which he defines as the 'node' element in his model, they also offer a 'place' function. So the railway station precinct can also be a destination where land use activities are available to public transport users and others. The place function, or accessibility of opportunity, is an important aspect of our inquiry and urges us to see accessibility not only in terms of 'ease of movement' or 'degrees of separation'. The extent of concentration of activities around public transport facilities, as well as within a specific travel time range to and from each destination, emerge as equally critical factors in understanding accessibility. These concepts inform the SNAMUTS measures of *network coverage* and *contour catchments*.

In the node-place model the observation that there can be 'balanced' or 'unbalanced' node-places is also important. A *balanced node-place* benefits from a good match between the level of transport network accessibility and the mix of activities (opportunities) to access within the precinct. In this way both the transport network and the place are efficiently used. An *unbalanced node* suffers from good transport network access but a limited number and range of activities, while an *unbalanced place* will be characterised by a vibrant mix and concentration of activities but poor transport network access. Further, node-places can experience stress where both node and place functions are exceptionally high, generating pressures such as transport network and interchange congestion, strong market demand for further land use intensification and increasing property values (Bertolini, 2005). To examine and quantify these dynamics, SNAMUTS returns to a concept from the Multiple Centrality Analysis toolbox known as *betweenness centrality* (Porta et al, 2006a, 2006b). This set of measures aims to assess and visualise how the distribution of land uses in a settlement area and their interdependence generate travel opportunities in accordance with the spatial configuration and service levels of the public transport network. We have also focussed specifically on the phenomena of stress and resilience in the land use–transport system by deriving a dedicated *network resilience* measure from the betweenness results.

A MATRIX OF ACTIVITY NODES

To produce a set of accessibility indicators for a land use–transport system, SNAMUTS assesses the hierarchy of central places in an urban area. Strategic planning documents can assist with the identification of district, regional or neighbourhood centres (where there are clusters of employment, retail, education or health facilities, recreational uses and/or large concentrations of residences). Extensive on-site observation and, where available, station or stop-specific public transport boarding data is used to pinpoint activity centres. A matrix of central places and nodes is compiled as each potential origin-destination pair is subjected to a GIS-based way-finding procedure. An activity centre is included if it is spatially associated with a particular public transport access point or interchange and if its walkable catchment (an 800-metre radius for rail stations and ferry ports or a 400-metre corridor around surface routes) contains an average minimum of 10,000 residents and jobs. In some cases, however, network nodes with no or weak associated land use clusters (the 'unbalanced node' archetype) are prominent within an urban area, such as where major public transport corridors follow freeways or freight rail lines without historic activity centres in their vicinity, and with limited amenity to attract the emergence of new ones. Multimodal public transport interchanges of this type are generally included in the matrix despite their often limited residential and employment catchments.

MINIMUM SERVICE STANDARD

Public transport network elements are included in the analysis where they meet a minimum level of service. The rationale relates to user amenity. To be perceived as a regular service where transport users can organise both planned and spontaneous activities, public transport must allow for a degree of flexibility in personal schedule (i.e. run at a minimum frequency) and maintain a presence throughout the day and week (i.e. have operation hours that cover most or all potential travel purposes). The minimum standard also defines an outer geographical limit to the network (as the minimum service standard is usually not upheld for intra-urban and long-distance public transport links) and so shapes the city form SNAMUTS actually analyses.

The minimum service standard SNAMUTS uses is flexible in theory. In this book, however, a uniform minimum standard is applied (SNAMUTS 23) in order to maintain the comparability of results across case study cities. This requires a service frequency of 20 minutes (or better) during the weekday inter-peak period (about 10.00 to 15.00 hours) and 30 minutes (or better) during weekend days for surface modes (bus and tram), and a 30-minute frequency on weekdays combined with service seven days a week for segregated rail and ferry modes. The differentiation in service standard between modes with or without dedicated right-of-way reflects the ability of rail stations or ferry terminals to act as anchors for urban activities and attractors for land use development in their own right, an effect that tends to be significantly weaker with surface routes, particularly on-street buses.

Many conventional models of public transport performance focus on the weekday peak hours, since this is usually the period when the capacity constraints of a network are most apparent. But in most public transport systems, this is also the period when service levels are optimised to facilitate specific trip purposes (work and school journeys). In contrast, the weekday inter-peak period offers the greatest diversity of travel purposes and, we assert, determines most critically the potential of public transport to offer a viable alternative to the 'go anywhere, anytime' convenience of the car.

STRUCTURAL INDICATORS

For each city in the database we present a set of three indicators that serve to position their size, structure and role of public transport in a broader context: the total residential population within the metropolitan area; the average settlement density of the urbanised area in residents and jobs per hectare; and the number of public transport trips per capita per year. Each of these indicators requires detailed definitions (see Appendix 1) and there is a potential for incongruity among the data as they are sourced from a large number of different agencies in different cities. These local records may utilise varying definitions for the component data sets that make up these indicators.

SERVICE INTENSITY

This indicator, derived from the network analysis, measures the operational input required to provide the service levels across the system (at the minimum service standard). The number of vehicles for each mode that are in simultaneous revenue service during the weekday inter-peak period is counted. The index is expressed relative to metropolitan population (vehicles or train sets per 100,000 residents). Note that the figures for the actual numbers of vehicles required by the operators are higher as no provision is made for service breaks at the termini, contingencies for delays or disruptions, non-revenue journeys, and for vehicles undergoing scheduled or unscheduled maintenance. Greater numbers of vehicles are also generally required to operate peak hour services.

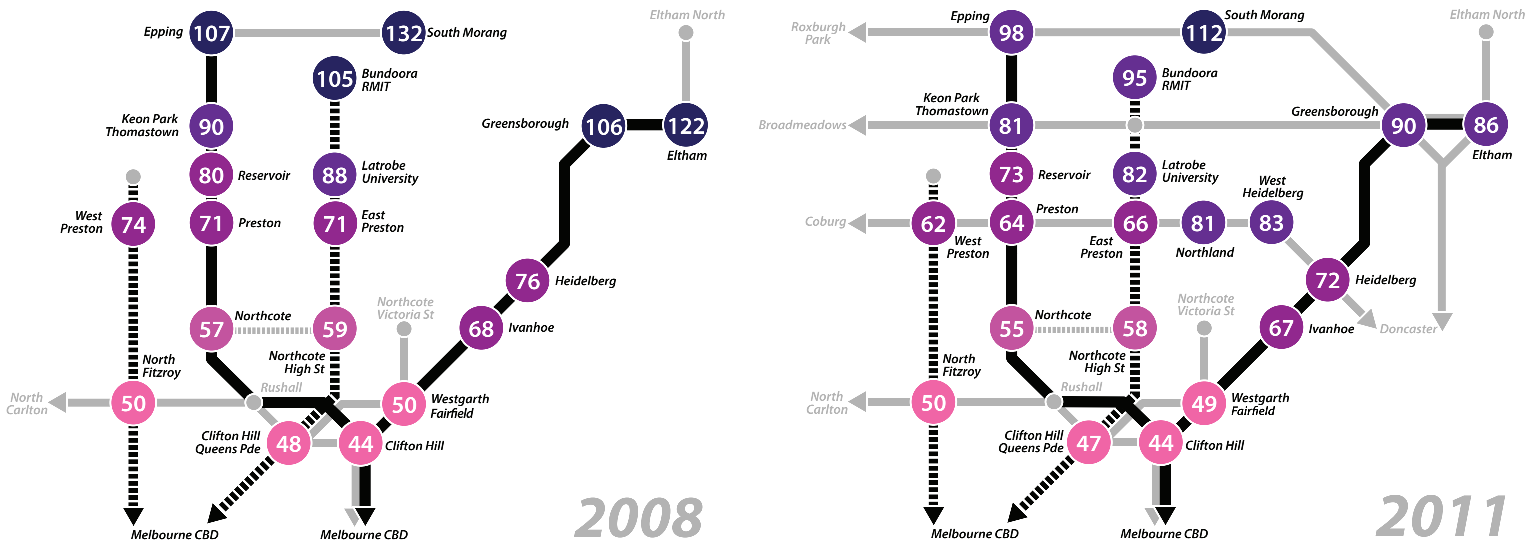
No differentiation is made between vehicles of varying capacity or performance, since the interest is in counting travel opportunities available for the transport user. Providing passengers are not turned away for overcrowding, and discounting for the effect of different travel times, a 40-seater bus every 10 minutes offers the same number of opportunities for passengers to get from A to B as a 600-person metro train every 10 minutes along the same route. Moreover, we are interested in the operational effort required to run the service, and particularly the staff cost which in developed cities forms a significant part of the total cost of operations. Each train, tram or bus in operation generally requires one on-board staff member (the driver); exceptions include some automated rail systems and the presence of conductors on some services.

Service intensity can be interpreted in two ways. Firstly, it illustrates the generosity of an operator to provide resources, and secondly, the efficiency of their deployment. For example, higher frequencies will increase the figures while shorter travel times will reduce them, yet both approaches will result in improvements on most other SNAMUTS accessibility indicators. Thus the ratio between service intensity changes and shifts on the accessibility measures (below) can help to determine the efficacy of initiatives to expand/reduce public transport services. This duality of service largesse and service efficiency can also be observed where a dominant role for fast high-capacity modes, particularly heavy rail, will tend to depress relative service intensity figures, while a large number of high-frequency, slow-moving surface routes inflates them. The intensity figure also increases, all other factors being equal, where settlement areas are dispersed or separated by geographical barriers, thus lengthening journey distances and times between places of activity. High service intensity scores are therefore not necessarily indicative of better service, but rather are indicative of the level of resources agencies are prepared to allocate to operation.

CLOSENESS CENTRALITY

This indicator describes the spatial properties of a public transport system and relates to the metric function of networks (discussed above). It is based on a proxy index for spatial separation, or *travel impediment*. Rather than accounting for metric distance between origin and destination, this travel impediment measure takes in travel time and service frequency, since both measures are key concerns of public transport users. These inputs are derived from published timetables that form part of the regular user information provided by public transport agencies. Travel time can vary greatly in relation to metric distance, depending on the speed of the service: in many cities, a metro train on a fully segregated alignment can cover a distance of several kilometres in the same time it takes a bus to cover only one kilometre along the streets of a congested central area. Service frequency adds a travel opportunity factor to the equation: the more travel opportunities per unit of time and the shorter the duration of the journey, the lower the travel impediment. From ample experimentation with different formulas we have concluded that the most meaningful way to express the ratio of these two factors in an impediment measure is to divide the travel time in minutes by the square root of frequency in departures per hour (multiplied by four to arrive at more readable numbers).

This travel impediment measure is calculated separately for each route segment (link between two adjacent nodes) across the network. A GIS wayfinding tool then automatically determines, out of all possible paths between each pair of nodes, the path with the lowest cumulative impediment while allowing up to three transfers between different lines. Closeness centrality is shown as an average value across the network, and as an average for each activity node. Lower values indicate better performance or greater *ease of movement*. Good area-wide ease of movement is achieved in lattice-shaped networks with a multitude of transfer points; conversely, in tree-shaped networks closeness values deteriorate rapidly from centre to periphery. The two network sections of Melbourne's northeast (shown below) demonstrate how closeness centrality improved after orbital bus links were added to the radial public transport in the area and how these benefits become progressively more apparent with increasing distance from the city centre. However, this circumstance is

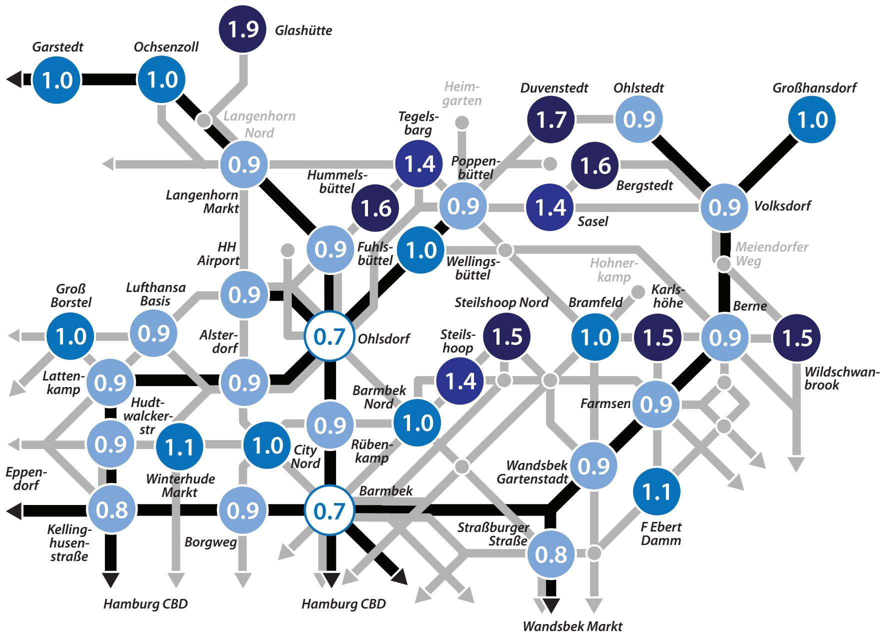


sometimes determined by urban geography or settlement patterns rather than purely by network design. Cities with more dispersed settlement patterns and more convoluted links between places of activity are at a disadvantage for public transport accessibility compared to more compact ones or ones with faster public transport systems.

DEGREE CENTRALITY

The second indicator describing the structural network properties takes a topological perspective: measuring the *degrees of separation* between each pair of nodes. Traditionally, degree centrality is used to measure the number of network paths converging in a node, for example, the number of separate streets radiating from an intersection (Neal, 2013). In a public transport network, the most meaningful way to capture this measure is by counting the number of transfers required to make the journey in question, suggesting that a node has the same degree of connection to all other nodes that are located along the same public transport lines as itself. Degree centrality, in the SNAMUTS tool, thus describes the *transfer intensity* or the *directness of journeys* along the public transport network. Use of the same GIS wayfinding tool as the closeness centrality index, the tool determines the path with the minimum number of transfers, even if this leads to a greater cumulative travel impediment value (as slower and/or lower-frequency routes are being used). Degree centrality is shown as an average value across the network and as an average for each activity node. Lower values indicate lower transfer intensity.

The index reveals hierarchical patterns in the network structure: it can pinpoint the roles that are allocated to different public transport modes, as well as the opportunities for multi-directional movement fostered by the network. In the example of Hamburg's northern suburbs (below) there are consistently low (less transfer-intensive) results at activity nodes along the radial rail lines, with the lowest scores at stations where several rail lines intersect (Barmbek and Ohlsdorf). Conversely, degree centrality values spike in activity nodes that depend on relatively short bus feeders to nearby rail stations and allow for movement in only one or two directions (Hummelsbüttel, Bergstedt,



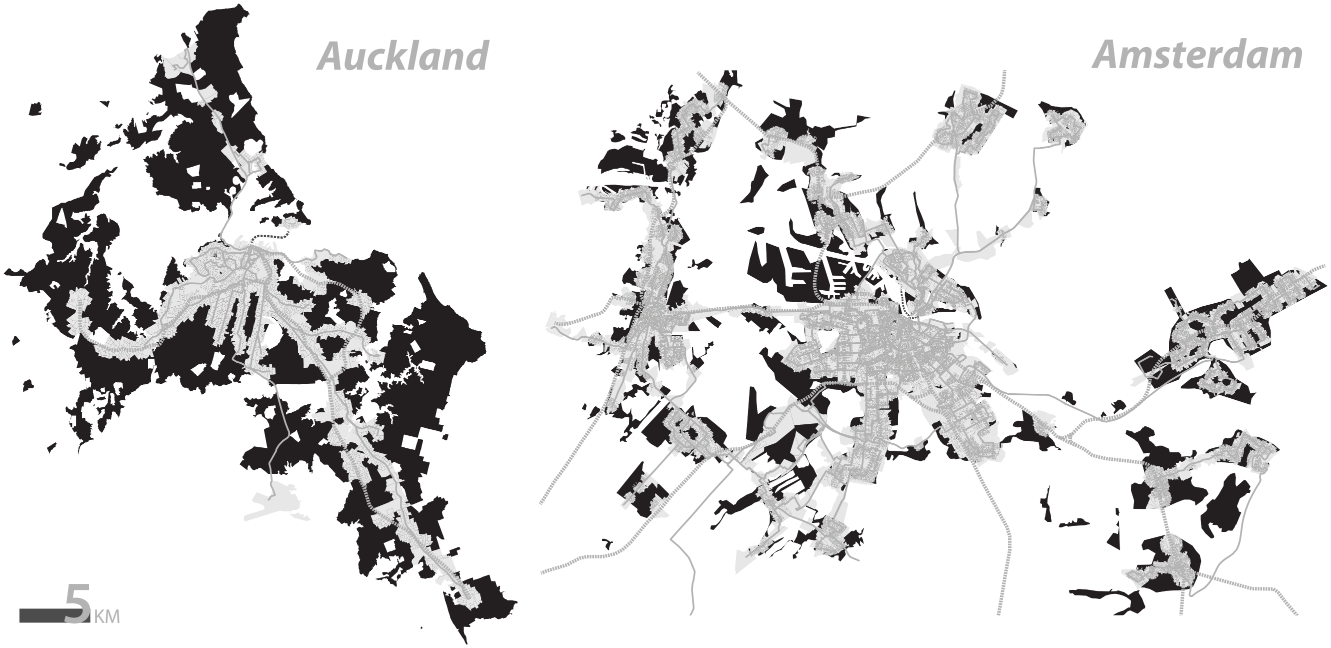
Duvenstedt and Glashütte). In other bus-only nodes, there are greater opportunities to travel in a broader range of directions, and for longer distances as the bus lines link into a number of activity nodes elsewhere in the city. Accordingly, the degree centrality results are much closer to the level found along the rail lines (Groß Borstel, Lufthansa Basis, Winterhude Markt, City Nord, Barmbek Nord and Bramfeld). A further group of nodes (Steilshoop, Karlshöhe, Tegelsbarg, Sasel) occupies an intermediate position between these extremes.

Low average degree centrality is indicative of a well-connected metropolitan network, but it can also be indicative of another type of network design encountered in several of our case study cities (the bus networks of Edinburgh, Hong Kong and Singapore). This network design aims at transfer-free connections between as many nodes and corridors as possible by offering many separate, low to mid-frequency lines. It is characterised by a flat hierarchy of modes and different types of services. In contrast, networks where most corridors are only serviced by a single, mid- to high-frequency line are configured around a greater reliance on transfers in the interest of operational efficiency, reliability and system legibility. In these networks (see Vienna and Zurich), the convenience of transfers is usually enhanced by supportive measures such as through-ticketing, timetable coordination between connecting services and their physical integration into purpose-designed transfer facilities (Nielsen et al, 2005). Average degree centrality results across the network, however, tend to climb accordingly.

NETWORK COVERAGE

This index illustrates who receives walkable access to public transport and who does not. Walkable catchments around stations and stops[1] are superimposed on a land use map and the number of residents and jobs contained within are counted. The proportion of this figure of the metropolitan total provides the network coverage result. It can be read as a proxy for the inclination of city decision-makers to supply public transport services of a certain standard to as large a pool of potential users as reasonably possible.

High network coverage can be characterised as a policy goal competing with the quest to simply maximise ridership, given that a limited pool of operational resources can be allocated to enlarge the geographical reach of the network rather than concentrate only on those routes or network segments that offer the greatest potential for patronage or mode share growth (Walker, 2012). Given that SNAMUTS measures network coverage only for services that meet or exceed the minimum standard and thus already pass a certain productivity level, network coverage should



be expected to grow with increasing service intensity. However, where the goal of network coverage overrides the goal of addressing the capacity needs of the most popular services in the allocation of resources, we should expect this index to be correlated in inverse proportion with the network resilience index (discussed below).

The maps above show the metropolitan areas of Auckland, which has the lowest network coverage (33 per cent) of the case study cities, and Amsterdam, which has one of the highest (80 per cent). In Auckland, public transport at the SNAMUTS minimum standard is only provided along the most important radial corridors, leaving adjacent land serviced at a poorer standard, if at all. In Amsterdam (whose population is about 50 per cent higher than Auckland's), it extends across most of the settlement area.

THIRTY-MINUTE CONTOUR CATCHMENTS

The contour catchments index adds detail and qualification to the network coverage measure. A proportion of the total figure of metropolitan residents and jobs within walking distance to public transport is allocated by drawing a walkable catchment area specific to each activity node, consisting of the rail station radius (including, where applicable, those of neighbouring smaller stations that do not carry SNAMUTS activity node status in their own right) and/or the linear corridors of surface modes converging in the activity node. Boundaries with neighbouring activity node catchments along these corridors are determined by geographical barriers such as watercourses, or administrative borders, or simply set at the geometrical halfway point. Wherever two or more activity nodes are in such close proximity that their immediate 400/800-metre radii overlap more than marginally, the residents and jobs contained within the overlap zone are allocated in equal proportions to each activity node catchment. Importantly, the sum of residents and jobs within all activity node catchments in a metropolitan area is equal to the total network coverage figure.

The 30-minute contour catchment index counts the residents and jobs within all defined activity node catchments than can be reached from the reference point by way of a kerb-to-kerb public transport journey of 30 minutes or less (a travel time contour around each activity node). The calculation is done for the inbound and the outbound travel direction and, should the contour lines differ (travel times can vary between directions), the average of the two is used. The assessment allows for a maximum of one transfer during the 30-minute window while accounting for the average network-wide duration of a transfer (from arrival of the first vehicle to departure of the second vehicle) and requiring that both legs of the transfer journey are operated at least every 15 minutes during the reference period (weekday daytime). The contour catchment index is expressed as a percentage of the total number of metropolitan residents and jobs and is shown for each node as well as an average for all nodes. By definition, no individual nodal contour catchment score can exceed the aggregate value for network coverage.

The contour catchment is a composite indicator using parameters from several fields of inquiry and so is sensitive to manipulation of each component. Contour catchments are influenced by land use factors such as the density and concentration of urban settlement, changes to which will alter the results on this index even if the geographical extent of the contour line remains constant. They are also influenced by the speed of public transport, the configuration and density of the network and, as per our transfer definition elaborated above, the prevalence of service frequencies of 15 minutes or better. As these aspects are subject to change, the size of the contour can be expected to expand or shrink. At a broader scale, contour catchments are further influenced by the spacing of activity centres within the metropolitan area. Hence, they can also be read as a proxy measure for an agglomeration's degree of compactness or dispersal.