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Benchmarking public transport accessibility in Australasian cities

Carey Curtis (Curtin University)
Jan Scheurer (RMIT University/Curtin University)

Abstract

There is growing recognition by all tiers of government that transformation of the public transport system is necessary if it is to offer a real alternative to car-based travel in Australasian cities. City planning framed around public transport accessibility raises the question of what quality of public transport system can deliver this objective. This paper explores the use of benchmarks, both to assess the extent to which Australasian cities currently meet the policy objective of public transport accessibility, and as a potential metric for future planning and investment.

We draw on the first comparative results from an application of the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool to eight Australasian cities (Adelaide, Brisbane, Melbourne, Perth, Sydney, Auckland, Christchurch and Wellington). We highlight some of the early challenges that accompany the collection of public transport supply and land use data that is robustly compatible between different cities. This in itself makes any assessment difficult. We present the results from the application of three SNAMUTS indicators and debate how we might use these as a benchmark for public transport accessibility as a means to inform future investment decisions.

Keywords: Transport, Accessibility, Land use transport integration

Introduction

Australasian cities are experiencing rising road congestion which has led to ever increasing demands for large scale infrastructure financing in order to build new road space and to increase the capacity of existing road space. Investment in public transport offers a significant alternative to this insoluble approach to car-based mobility. It is recognised that there are opportunities for public transport to gain further market share from the car, thus reducing road congestion as well as addressing the social and environmental impacts associated with excessive car dependence.

Strong growth rates in public transport usage, already apparent in several cities during the past five years, are set to continue. Australasia's public transport sector is facing a fundamental transformation following its growing recognition by all tiers of government as a critical and desirable contribution to people's mobility within our largest cities. This raises a significant challenge for both public transport planners and the public transport system itself as it evolves from a dual orientation, focussed on central city job commuting and the provision of a social safety net, towards a service that is capable of catering for all urban passenger transport needs across metropolitan areas (Mees, 2010).

Policy goals formulated by Federal and State Governments have begun to emphasise the desirability and importance of increasing public transport mode share since the mid-1990s (DOT, 1995; DOI, 2002). These are set within a new understanding of the need for transport planning to deliver accessibility rather than simply mobility. Policy aspirations for city planning framed around accessibility rather than mobility have long been promoted by the academic community (Cervero, 1998; Vigar, 2002) and are now being embraced in planning practice. Mobility planning assumes that city dwellers will gain access to services required to support their daily needs through a transport system based on high levels of mobility by car, regardless of the relative location of land uses. In contrast, by planning for accessibility the approach considers proximity of land use as well as the transport network itself. This shift in perspective is slowly emerging in Australia. A National Charter for Land Use Transport Integration has been adopted (DOTARS, 2003) which links the need to integrate public transport systems directly with land use development. The Commonwealth Government's infrastructure agency, formed in 2008, requires federal funding contributions to state urban transport infrastructure conditional on the integration of strategic land use and transport planning, and has initiated a reform agenda on major cities and infrastructure planning through the Council of Australian Governments (IA, 2009). Translating these goals into practical action, however, presents a formidable technical, as well as political challenge.

City planning framed around public transport accessibility raises the question of what quality of public transport system can deliver this objective. Public transport for urban mobility in developed cities varies greatly, from just over 2% of all trips in Atlanta and Los Angeles to between 26-31% of all trips in Barcelona, Vienna and Singapore (Kenworthy & Laube, 2001). Australian cities range between 4-10% of all trips. This variation is influenced by historic and current policy priorities for infrastructure and service development as well as settlement form, and the competitiveness of different transport modes (Newman & Kenworthy, 1999; Mees, 2000; Gleeson, Curtis & Low, 2003; Mees, 2010).

To meet such an objective where public transport can offer a real alternative transport mode choice to the car requires a new approach for planning and evaluating public transport accessibility. It requires a method that can also serve stakeholders and decision makers as they deliberate on the best public transport network configuration, service levels and capacity upgrades. It is evident that there has been an absence of such an approach designed to usefully inform key policy objectives about the future public transport network in relation to accessibility improvements (Curtis et al, 2010). Instead strategic planning for public transport has often been unambitious, with most proposals offering incremental improvements to the existing radial, mono-centric network based on demand forecasting rather than future planning in the context of meeting policy objectives (Curtis et al, 2010).

The development and establishment in practice of methodologically robust and user-friendly accessibility tools for integrated land use-transport planning in Australasian cities and regions is therefore a timely, urgent endeavour in the context of recent changes to policy priorities at Federal and State level (SSCRRAT, 2009). The Commonwealth Government has identified the significance of public transport investment in cities and stated its intention to greatly increase its contributions for funding these pivotal items of infrastructure, while clearly tying such contributions to a satisfactory integration of strategic planning in land use and infrastructure at state level (IA, 2009). In this way it is apparent that the Commonwealth Government requires a layer of assessment for future State Government proposals towards the co-funding of infrastructure that has land use transport integration and accessibility performance at its heart. Given the multi-billion dollar scope of infrastructure proposals, the substantial costs to the Australian economy and the environment implied in making sub-optimal or poorly informed decisions for infrastructure investment (where it fails to deliver alternative accessibility to the car and therefore fails to reduce car-based transport emissions), this quest for greater rigour of assessment is vital to allow for the most efficient allocation of government resources and the greatest benefit to the Australian public. Our ongoing work in the development of a new accessibility tool provides one way of evaluating the extent to which cities offer the potential for residents and employees to have accessibility by public transport (Curtis and Scheurer, 2010). The application of our tool in planning practice in Perth and Melbourne has demonstrated its useful role in forging constructive collaborations between transport and land use planning agendas. Considering this work within the context of the above national policy agenda for evidence-based public transport investment has brought to the foreground the need to establish appropriate benchmarks for public transport accessibility for Australian cities.

As we explore the notion of benchmarking we expose many different ways of considering it. To go back to basics, benchmarking can be defined as, “a standard or point of reference against which things may be compared” (Oxford Dictionary). At this level of definition we might be asking simply – how do the public transport systems of Australasian cities compare? To take the idea a step further, in the context of the policy imperative ‘future public transport planning’, the definition, “a standard of excellence, achievement etc., against which similar things must be measured or judged” (Online Reference Dictionary) adds the dimension of excellence or best practice. So in the context of this paper this suggests the need to establish a benchmark, or metric, for an excellent public transport system. This is a question rarely posed by policy makers, yet it is a critical question if national policy aspirations are to be met.

The idea of benchmarking in this paper is conceived in two dimensions: current and future. In the first, our interest is in how current public transport systems in Australasian cities compare. Exploring this dimension enables us to assess the merits of the SNAMUTS indicators in different contexts and with differing data availability. In this way we can consider whether it is even possible to apply a universal benchmark. In the second dimension, our interest is in what the benchmark, or standard of excellence, for a public transport system in Australasian cities should be. Our overarching metric is derived from the national policy and our interest in sustainable accessibility, in this case a public transport system that provides an alternative mode choice to the car for the city’s metropolitan residents. As our research progresses we have started to extend the SNAMUTS tool to other international cities, in part to test the methodology but also to enable us to consider an Australian benchmark in the context of other ‘best practice’ public transport cities. So far we have tested SNAMUTS in the European cities of Hamburg, Copenhagen, Amsterdam and Den Haag/Rotterdam, and in places in this paper we compare the

Australasian position with these as a preliminary exploration to assist the debate about benchmarks.

While our benchmark is based on public transport accessibility for all, others have chosen different metrics. For example, it is common for governments to use ‘public transport patronage’ as a measure that reflects the concern that investment in the public transport network ‘paid off’, or that demand forecasts were met. Others might focus on the cost of operating the public transport network, or the costs of construction. We assert that the choice of metric is dependent on what policy objective is being considered. All too often the choice has been based on the cost of public transport framed around the storyline of ‘public transport subsidy’ (Curtis and Low, forthcoming) rather than being based on the need to implement policy imperatives.

The context: Public transport usage and mode share patterns

An important consideration in understanding any application of a benchmark must be to consider the SNAMUTS outputs for different cities in their broader context (Table 1). Before presenting our SNAMUTS outputs, therefore, we compare population, employment, the geographic size of the city, the intensity of residential and employment uses. All of these factors have an impact on the public transport task and are important considerations in the context of our later accessibility findings. In addition we report mode share and public transport use; both factors may well be the product of the extent to which public transport accessibility is achieved.

Table 1: Metropolitan population and jobs, urban density and public transport boarding and mode share data from seven Australasian cities in 2006 and 2010.

Contextual Data	Sydney	Melbourne	Brisbane	Perth	Adelaide	Auckland	Wellington
Metropolitan population (2006)	4.12m	3.59m	1.80m	1.48m[1]	1.23m	1.46m[5]	
Metropolitan employment (2006)	1.74m	1.51m	0.80m	0.66m	0.51m	-	
Urbanised land in sq km (2006)	1,681	1,784	1,092	954	725	-	
Residential density per urbanised* hectare (2006)	24.5	20.1	16.5	15.5	17.0	-	22.0[6]
Employment density per urbanised hectare (2006)	10.3	8.5	7.3	7.0	7.0	-	8.1[6]
Annual PT boardings# (2006)	505.5m	397.2m	198.0m[2]	100.9m	49.4m	-	
Annual PT boardings (2010) (proportion of all Australian boardings)	522.6m (40%)	504.3m (37%)	152.6m[2] (11%)	136.0m (9%)	51.3m (3%)	63.6m[5]	

Contextual Data	Sydney	Melbourne	Brisbane	Perth	Adelaide	Auckland	Wellington
Annual PT boardings per capita (2006)[3]	118	106	107[2]	63	39	-	57[6]
Annual PT boardings per capita (2010)[3]	114	124	75[2]	77	38	44[5]	
Private motorised transport mode share by journey-to-work trips (2006)[4]	69.6%	78.1%	76.9%	82.0%	82.1%	-	76.9[6]
Public transport mode share by journey-to-work trips (2006)[4]	21.2%	13.9%	13.8%	10.4%	9.9%	-	3.8[6]
Non-motorised transport mode share by journey-to-work trips (2006)[4]	5.6%	4.9%	4.8%	3.9%	4.7%	-	19.4[6]

* Urbanised land is derived where a census collection district (CCD) had an average dwelling density of 2 or more per hectare at the 2006 census. Land outside this definition is considered urbanised if it is within a mesh block (the smallest spatial unit of the 2011 census, for which numerical results were not yet available at the time of writing) with a defined land use category of either Industrial, Commercial, Educational, Health/Medical or Transport. All large regional parkland, water surfaces as well as semi-rural settlement areas from the urbanised area are excluded from the definition. A stricter standard is applied to the inclusion of residential areas that are still under development – these must be at least partially inhabited at the time of the census.

Public transport boarding figures are reported by public transport operators and agencies. They do not use a uniform standard. In some cases boardings by transferring passengers are counted separately, in others (such as Adelaide) they are disregarded, or they are only counted if the transfer is between different modes. In some cities, notably Brisbane, the algorithms used to arrive at patronage estimates were modified as public transport's institutional structures changed and as electronic ticketing systems were introduced, rendering boarding numbers all but incomparable over a timeline.

1 Metropolitan area from ABS Census - in Perth includes SSD Mandurah.

2 Survey methodology changed with the establishment of Translink in 2008 (fare integration and electronic ticketing), hence 2006 and 2010 figures are not immediately comparable.

3 Population figures for this item are taken from the annualised data in the ABS National Regional Profile, which differ from the 2006 census figures used in the density calculations and the SNAMUTS land use data.

4 ABS Census 2006, as compiled in Mees, Sorupia and Stone (2007)

5 Transit Australia, April 2012, Vol 67, No 4

6 Source: Kenworthy and Laube (2001) from Millenium Cities Database 1996.

On a global scale, Australasian cities are characterised by low average urban densities, at par with US cities but significantly below those typically found in European or Asian cities. However, there is variation the cities. Australia's second-tier cities (Brisbane and Perth) have the lowest figures and New Zealand's cities mirror these o some extent (notwithstanding data availability issues), while densities are higher in the first-tier cities (Sydney and Melbourne), especially Sydney which has greater geographical constraints on urban expansion than Melbourne. Other than Sydney, intensity of employment use is similar in the other Australian cities.

In terms of public transport usage and the scale of the public transport task, Sydney and Melbourne display significantly higher levels of public transport boardings compared to the other cities. While Sydney's annual boardings have seen only a small growth between 2006 and 2010, Melbourne and next Perth have seen a substantial increase in annual boardings. The extent to which annual boardings is a product of sheer population numbers is addressed by reference to the boardings per capita figure. Here Melbourne takes the lead over Sydney in boardings per capita despite having a lower proportion of annual boardings. Perth also shows a strong upward trend, while in Sydney and Adelaide, the rate of public transport growth was much closer to the population trend during the same period.

In global terms for mode share, all five cities can be positioned towards the high-car use, marginal-public transport end of the spectrum; only US cities tend to deliver even more extreme results.

SNAMUTS: An overview of the accessibility tool

This section is intended to provide the reader with a broad overview of the tool prior to the discussion on 'current benchmarks'. A full explanation of the tool can be found in Curtis and Scheurer (2010). The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) is a GIS-based tool designed to assess centrality and connectivity (primarily) of urban public transport networks in their land use context, and in their market position among multimodal travel options. In particular, SNAMUTS endeavours to identify and visualise a land use-public transport system's strengths and weaknesses of geographical coverage; the ability and efficiency to connect places of activity; the strategic significance of routes and network nodes; and the speed competitiveness between public transport and car travel in a coherent mapping exercise. The tool is intended to aid discussion and to lend weight to decision making within the fields of land use planning and transport planning, particularly where outcomes leading to more sustainable transport options are needed.

The development of the tool has been closely linked to needs arising from the recent metropolitan planning strategies, including Melbourne @ 5 million (DPCD, 2008) and Perth's Directions 2031 (DOP, 2010), where there are movement and activity centre networks promoted as redevelopment corridors and nodes. While such strategies articulate key sustainable transport concepts such as the desire to 'promote public over private transport' and land use transport integration, to date the basis for critical decisions as to which centres should be promoted or where to improve the public transport network have been made in a vacuum. SNAMUTS aimed to fill that vacuum and could to serve as a communicative tool for transport and land use planners, urban designers and community advocates.

The tool is designed to reflect a vision of world best practice in public transport that has consolidated from the contributions of numerous scholars and practitioners over the years and is most comprehensively documented in the European Union HiTrans project (Nielsen et al, 2005). In geographical and operational terms, the success factors most frequently discussed in the literature are:

- A configuration of the system in terms of network coverage and service frequencies that offers a viable alternative to the car for most, if not all, travel purposes across the urban area (Laube, 1998; Nielsen et al, 2005; Mees and Dodson, 2011);

- A legible network structure that is efficient to operate, easy to navigate and offers a choice of routes wherever possible (Mees, 2000; Mees, 2010; Mees and Dodson, 2011; Vuchic, 2005);

- A speed advantage of urban rail over road traffic along a city's main corridors (Newman, 2009; Newman, Beatley and Boyer, 2009);

- The integration of public transport facilities with supportive urban development, in particular high-density, mixed-use, walkable nodes around rail stations and major interchanges (Bernick and Cervero, 1997; Cervero, 1998; Dittmar and Ohland, 2004; Curtis, Renne and Bertolini, 2009);

- An institutional framework that allows for integrated, publicly accountable capital investment and service planning (Mees, 2005; Mees, 2010; Nielsen et al, 2005).

To examine these geographical and configurative success factors more closely, a range of measures and indicators were developed in order to explain the common observation, intuitively quite obvious, that public transport tends to perform better and attract a greater share of trips in parts of the city with greater centrality. A high level of centrality in a geographical sense can be understood as spatial proximity to a high number and range of urban activities. In a network sense, it can be measured in several different ways, according to the configuration of a movement system around nodes and edges and their distribution over, and their relationship to the activities within, the urban space.

SNAMUTS breaks down the land use-transport system into a set of activity nodes and route segments derived from the hierarchy of activity centres identified in strategic planning documents, and the location and service standard of public transport routes. In particular, SNAMUTS makes the following definitions:

Minimum service standard: SNAMUTS defines a minimum standard for inclusion of a public transport route into the analysed network, normally requiring a service frequency of 20 minutes (or better) during the weekday interpeak period (about 10.00 to 15.00) and 30 minutes (or better) during the day on Saturdays and Sundays. This level, referred to in this paper as SNAMUTS 20, has been chosen as it reflects the minimum for public transport to be perceived as having a full-time presence and attracting usage for a variety of both planned and spontaneous journey purposes. In some SNAMUTS applications, we debate this standard by applying a less stringent standard of a 30 minute frequency during the weekday interpeak period in combination with a seven-days-per-week operation of the route in question has been chosen. This standard is referred to as SNAMUTS 30.

Activity nodes: these refer to a list of higher-order activity centres across a metropolitan area that appear in strategic planning documents or have been identified by on-site observation, with some adaptations to the configuration of the public transport network in order to also capture major transfer points and some linear corridors along high-frequency surface lines. Each activity node is assigned an exclusive catchment of residents and jobs located within walking distance from the associated rail station(s) (800 m) or tram/bus corridors (400 m). Wherever two or more of these catchments overlap geographically, the residents and jobs are distributed in equal parts among the associated activity nodes. In effect, every resident and job within walking distance from a minimum-standard public transport service has been assigned to one, and only one, activity node catchment.

Travel impediment: SNAMUTS measures spatial separation, or spatial resistance (a proxy value for distance) by relying on the units that are closest to the user experience, namely travel time and service frequency. Each route segment is labelled with an impediment value consisting of the average travel time divided by the number of services per hour, separately for each direction, and multiplied by a factor of 8 to arrive at more readable numbers. The travel impediment (proxy distance) between any two activity nodes on the network is thus made up of the sum of the impediment values on each route segment traversed along the path.

Weekday interpeak: SNAMUTS' network performance measures refer to the service levels offered during the weekday interpeak period (roughly between 10.00 and 15.00 on Mondays to Fridays). This is considered to be the time when the greatest diversity of travel purposes over a daily and weekly cycle coincide, and when the potential of public transport to offer a viable alternative (or not) to the 'go anywhere, anytime' convenience of the car is most critically determined.

Benchmarking: How do current public transport systems compare

Our early work has been based in Perth and Melbourne and enabled us to develop the SNAMUTS tool. The outputs from each city have drawn the question – which public transport system is best, and in which dimensions, and from this to questions about where future investment might be best directed. These questions clearly articulate the desire to set benchmarks. In this respect we set about constructing the data bases to report the current position for public transport in the remaining Australasian cities.

What we uncovered were a series of problems that not only demonstrate the difficulty of constructing a comparable data base for each city, but more importantly demonstrate a finding that if Australasian cities are to be able to deliver public transport accessibility for all, comparable to the car, there is a need for collection of fairly basic data at a uniform standard. Without this it is not easy to evaluate a city's public transport system against the objective.

Data items and challenges

Timetables and maps: SNAMUTS timetable databases are compiled from public-domain material. This is a deliberate choice as the intention is to evaluate public transport accessibility from a user perspective. It is therefore important to rely on the passenger information that all users can access. In every Australasian city, such material is available both as printed timetable brochures as well as an online format.

The standard of mapping material for public transport differs between Australasian cities. Some cities make detailed scale maps containing the routing of every public transport service available in both online and paper formats (Melbourne, Sydney and Auckland). In other cities such information only exists in the form of diagrams and sometimes only on a line-by-line basis (Brisbane). One aspect of our work has been to trace accessibility over time. The procurement of timetables for past or historic levels of service, however, is problematic since Australasian cities generally do not publish their timetables as a system-wide compilation that could be extracted from an archive like some European cities.

Definition of activity nodes: SNAMUTS indicators are derived from an origin-destination matrix based on activity nodes, ie. places with geographical concentrations of trip origins and destinations (urban activities) that are linked through the public transport system. The number and location of relevant activity nodes requires careful definition and needs to contend with the differing urban structure and public transport network configuration in each case study city.

The ideal for our work is that activity nodes are determined by reference to a city-wide travel survey. This was the case in Perth where the initial activity node definition used origin and destination data from the Perth Area Regional Travel Survey (PARTS). All journeys for non-home trip destinations (for all travel modes) were plotted on a map, thus producing a preliminary list of activity nodes. Superimposing the public transport network at the SNAMUTS 30 standard to this map, it was found that not all of these centres were actually on the public transport system, and that conversely, some significant public transport nodes were not identified as major concentrations of origins and destinations. The task of accurately allocating residents and jobs to a SNAMUTS activity node, however, practically requires the inclusion of every major transfer point on the network in the matrix of activity nodes, regardless of whether or not it is a focus of significant land uses. This is particularly relevant along Perth’s north-south train line, much of which is located in the median of a freeway. Another issue that emerged was how to differentiate public transport access at several locations in large activity centres, particularly in the CBD which in Perth’s case, contains eight separate activity nodes.

Not all cities conduct a metropolitan travel survey. In these cases the starting point for activity node definition was the metropolitan strategy current at the time. For example in Sydney, Melbourne, Adelaide and Brisbane, the planning strategies specified an activity centre hierarchy. As with Perth, some activity centres were not on the public transport network at the SNAMUTS 20 standard. In other cases where the strategy produced very few activity centres further activity nodes were identified by reference to specific high frequency bus routes (for example Adelaide’s “GO Zones’).

Making detailed decisions about specific activity nodes was also required in certain circumstances. For example, some centres were located on the public transport network but had multiple, functionally unconnected access points (such as where spatially separate rail stations and tram or bus corridors service the same activity centre within walking distance) Another issue arose with activity centres that contained several connected transfer points, each with a different network function (such as in Melbourne’s CBD where every intersection is served by a different combination of tram and/or bus routes). In these cases a separate activity node was assigned to each of these access points, resulting in the division of some suburban activity centres into two or three SNAMUTS activity nodes. In the Melbourne CBD, for example, this produced a total of 24 activity nodes (Hoddle grid). An issue also arose in places that contained linear activity corridors (for example in Melbourne along tram lines). Such tram corridors are characterised by a string of relatively closely spaced smaller neighbourhood centres. These may not form contiguous corridors of non-residential uses, or appear in the list of higher-order activity centres in the planning strategy, but they clearly constitute places of interest for the public transport network. In these cases the activity centre was defined as the relevant tram line's terminus, or intermediate intersection of lines.

For cities which did not have a metropolitan planning strategy (Wellington and Christchurch) identification of activity nodes occurred primarily through site observation during the field visits. Apart from public transport interchange hubs, activity nodes include linear (street-based) and free-standing clusters of commercial activity, major university campuses and hospitals.

Geographical distribution of residents and employment: A SNAMUTS land use database ideally consists of residential and job figures at as fine-grained a geographical level as possible, to allow for a best-fit allocation of their locations to the 400/800-metre catchment areas of public transport access points.

In all Australian and New Zealand cities, residential data that meets this requirement is available from the ABS/Statistics NZ census usually conducted every five years and published in the public domain at a level of detail sufficient for SNAMUTS purposes (ABS, 2008, 2011; Statistics NZ, 2011). For the 2006 Australian census used in this paper, the basic geographical units are Census Collection Districts (CCD) and each CCD is defined as either fully within or fully outside the walkable catchment of public transport at the relevant minimum service standard.

For employment data, however, such geographical detail is generally not available publicly or for free. We therefore relied on several different approaches:

- In Perth, we relied on a state-based survey where number of employees per business at the property-level were aggregated to CCD level using GIS. This database did not contain all employment in metropolitan Perth. To avoid the risk of underestimating the actual concentrations of jobs in activity nodes, extrapolating the job numbers from the survey with regional aggregates derived from census data available for larger geographical units (such as Statistical Local Areas or SLA) provided a means of adjustment.

- In cities where no such survey existed (Melbourne, Sydney), the 2006 Census journey-to-work destination database (based on respondents' answers to the 'where did you go to work on census day?' question) was referred to. The data omits all those employees who did not go to work on census day, but was generally considered a good match to the residential data. One issue is that the geographical unit used (journey-to-work destination zones) is not identical to the CCD. The allocation of jobs to walkable activity node catchments thus had to be performed separately, using the same procedure as for residents. In Brisbane and Adelaide the geographical unit was the Statistical Local Areas (SLA), which were too large to make allocations of the total number of jobs in an SLA to activity node catchments if a gross overestimation of the number of jobs within walking distance from public transport access is to be avoided. A viable solution consisted in determining the total area of urbanised land for each SLA and for each CCD in order to extract an average job density figure (per hectare of urbanised land) at the SLA level. The average job density per SLA is then applied uniformly to each CCD within that SLA to deliver an approximate figure for the number of jobs per CCD. While this procedure obviously disregards possible job density gradients within the urbanised area of each SLA and is thus unsuited to pick up specific concentrations of employment, for example, in the immediate vicinity of public transport terminals, in practice the effect of this shortfall may be relatively minor.

- In Sydney, a source available for free download from the NSW Bureau of Transport Statistics website (BTS, 2012) allowed us to follow a similar methodology as previously utilised for Melbourne. In this case the relevant geographical unit was a travel zone. Travel zones differ from CCD; there are a total of 2,275 of them in the Sydney metropolitan area (compared to 6,788 CCD). In areas with a high concentration of jobs (such as Sydney's CBD) travel zones tend to be smaller than CCD, thus providing greater geographical detail, while in residentially dominated or partially urbanised areas, the opposite is the case. Travel zones were individually allocated to SNAMUTS activity nodes using the same methodology as for CCD, meaning that travel zones fully or predominantly within the 800-metre circular catchment area around rail stations or ferry terminals, or within the 400-metre linear catchment area along bus routes, are assigned to one or several SNAMUTS activity nodes, among which the total employment count within the travel zone is then distributed.

- In New Zealand, there appears to be an absence of robust and geographically specific employment data. This has impeded the elaboration of a full set of SNAMUTS indicators that take into account the land use dimension of public transport accessibility. The New Zealand census does not include a question on the commuting destination on census day. We have not been able to ascertain whether a consistent alternative database exists that could deliver location-specific numbers of workplaces, or whether such an endeavour is intended in the future at the national level. Until such time, it is unlikely that a land use-transport integration assessment of a similar quality as in Australian and some overseas cities can be developed for New Zealand cities.

Current Benchmarks – Comparing Australasian Cities

This section presents the results for four SNAMUTS indicators: service intensity, closeness centrality, degree centrality and network catchment. In so doing we highlight important differences and similarities between the eight case study cities, allowing for a new understanding of public transport accessibility and for the identification of specific trends and patterns in land use and transport integration.

Service intensity: The SNAMUTS timetable database, compiled for each case study city at the SNAMUTS 20 minimum service standard during the weekday inter-peak period, provides us with an estimate of the numbers of public transport vehicles that are required to be in simultaneous revenue service in order to deliver the public transport network that is operated at this standard (Table 2). Note that the figures for the actual numbers of vehicles required by the operators are somewhat higher than that, as the SNAMUTS calculation does not make provision for service breaks at the termini, contingencies for delays or disruptions, non-revenue journeys, and for vehicles undergoing scheduled or unscheduled maintenance. Nor do these figures reflect the usually greater numbers of vehicles required to operate peak hour services.

Table 2: Service intensity in the Australasian case study cities

SNAMUTS *20* 2011	Sydney	Melbourne	Brisbane	Perth	Adelaide	Auckland	Wellington	Christchurch
Number of trains	72	64	16	26	11	7	1	-
Number of trams/LRT	4	269	-	-	10	-	1*	-
Number of buses	561	198	188	191	195	119	74	111
Number of ferries	-	-	14	-	-	-	-	-
Number of services (total)	**637**	**531**	**219**	**217**	**216**	**126**	**76**	**111**
Metropolitan population (2010)	4.58m	4.08m	2.04m	1.77m	1.34m	1.46m	0.48m	0.57m
Services per 100,000 inh	**13.9**	**13.0**	**10.7**	**12.0**	**16.1**	**8.6**	**15.8**	**19.6**

* Cable car
Sources for population figures: ABS (2011), Statistics NZ (2011)

The SNAMUTS 20 standard imposes a restriction on what proportion of each city's public transport network actually enters the analysis. For instance, only in Perth is the entire rail system included (since the standard daytime frequency on all rail lines in the WA capital is 15 minutes). In Melbourne and Sydney, several rail lines do not meet the standard and are disregarded; in Brisbane, Adelaide, Auckland and Wellington, this is true for the majority of the networks as the standard daytime rail frequency in those cities is usually 30 minutes. Among the ferry-operating cities, only Brisbane's meet the SNAMUTS 20 standard.

Relative service intensity (ie. 'services per 100,000 population') reveals some variation across the sample. Among the Australasian cities, Adelaide, Christchurch and Wellington display the highest service intensity results per capita, while Auckland and Brisbane have the lowest. The two largest cities occupy the middle ground, with Sydney slightly ahead of Melbourne on this index.

The indicator is influenced by the propensity of public transport agencies and operators to provide resources to run the system as well as by its efficiency: a dominant role for fast high-capacity modes, particularly heavy rail, will depress relative service intensity figures, while a large number of high-frequency, slow-moving surface routes tends to inflate them. The intensity figure also increases 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. It is, however, reasonable to suggest this indicator as a benchmark, hereby using it as a focus to examine the public transport effort in cities with low service intensity scores. The examination could be conducted by cross-reference to other SNAMUTS indicators (see later) to ascertain whether accessibility benefits in relation to operational inputs into the public transport system could be lifted to a level commensurate with peer cities.

Closeness and Degree Centrality: These two indicators are designed to capture the structural properties of the public transport networks; they do not incorporate a land use dimension beyond defining the number and location of activity centres. Closeness centrality considers accessibility in a way most closely described as 'ease of movement'. An average score for travel impediment (travel time divided by service frequency), or ease of movement, is calculated between any two activity nodes on the network. The final figure for each activity node represents the average impediment score for all journey possibilities between this node and all others on the SNAMUTS 20 public transport network. Degree Centrality considers accessibility by public transport from the perspective of number of transfers required to make a journey between any two centres. The figure given for each node thus describes the average transfer intensity for journeys to or from all other nodes on the network.

Table 3: Closeness and degree centrality in the Australasian case study cities

SNAMUTS *20* 2011	Sydney	Melbourne	Brisbane	Perth	Adelaide	Auckland	Wellington	Christchurch
Number of activity nodes served (number of activity nodes in total)	168 (187)	183 (208)	78 (112)	79 (100)	76 (97)	58 (84)	27 (39)	34 (40)
Average Closeness Centrality	**62.7**	**45.4**	**31.7**	**52.6**	**41.9**	**44.2**	**43.3**	**27.7**
Closeness (lowest value)	34.4	24.7	16.9	30.4	23.0	24.9	26.3	15.7
Closeness (highest value)	173.3	103.4	99.2	125.3	109.3	117.0	99.9	71.2

SNAMUTS *20* 2011	Sydney	Melbourne	Brisbane	Perth	Adelaide	Auckland	Wellington	Christchurch
Degree Centrality	**1.15**	**0.91**	**0.94**	**1.03**	**0.98**	**0.97**	**0.84**	**0.59**
Clustering Coefficient	11.9%	15.9%	17.6%	16.4%	16.5%	19.1%	31.9%	38.6%

For both indicators, lower figures indicate greater metropolitan public transport accessibility in principle. Comparisons, however, need to be seen in a broader context to allow for valid conclusions across the sample. Firstly, on both closeness and degree centrality we should expect average results to increase with city size (measured here by the size of the public transport network and its number of activity nodes within the 20 minute service frequency zone) and the resulting complexity of the public transport network. On this basis, all other things being equal, smaller networks will invariably return better average, lowest and highest closeness values than larger networks, as well as lower counts of degree centrality (ie. transfer intensity). From this perspective, it is unsurprising that Christchurch, the second smallest city in the sample, comes out as the best performer on both indexes, while Sydney, the largest city, has the poorest average results.

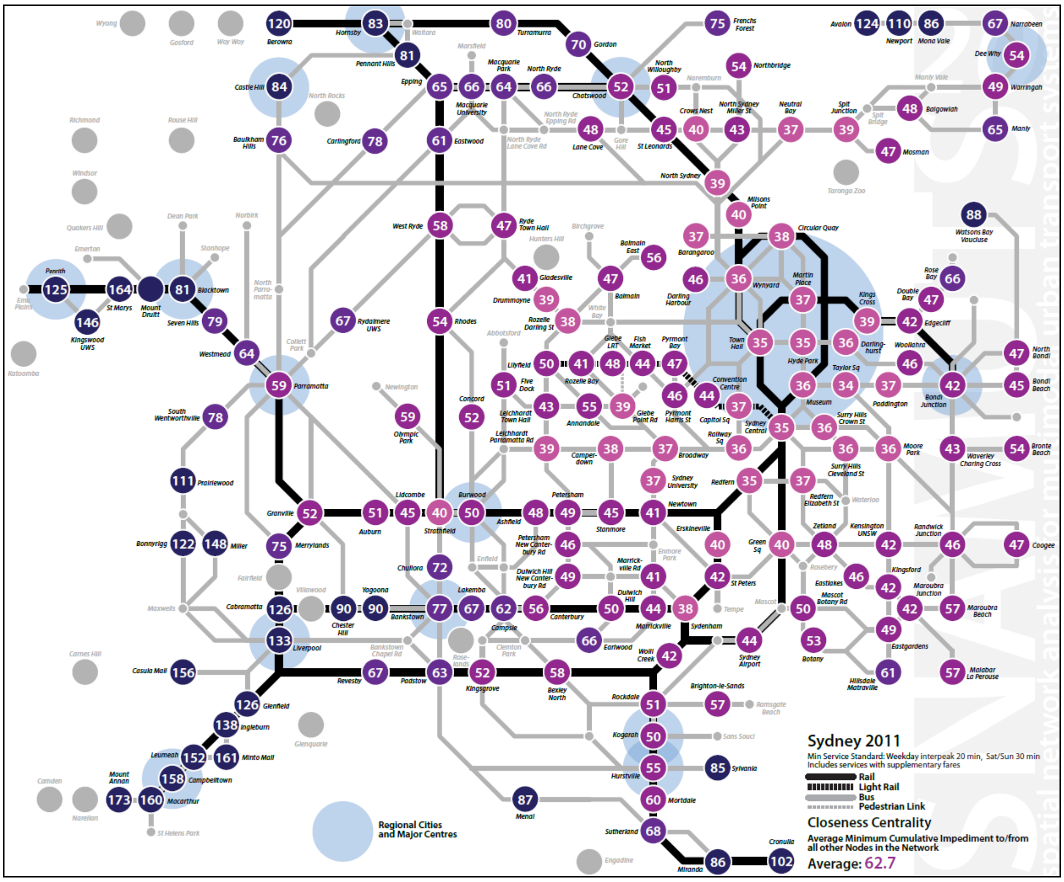
Other factors influence the closeness centrality score and can provide a useful insight into where improvements to accessibility can be made. Closeness centrality is measured by travel impediment, which in turn is composed of travel time and service frequency. Cities where activity centres are spaced further apart (in terms of public transport travel time, not necessarily metric distance) or in other words, 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. Where a city is geographically spread out the choice of a higher speed system will ensure a greater level of accessibility is provided to its residents and employees. So it is the choice of public transport network that is critical if accessibility is the key objective. This can be seen in Figure 1. Comparing Brisbane and Perth (at the 20 minute inter-peak service frequency) illustrates this point. Perth's network, using a fast but medium-frequency (15 minutes) rail service sees accessibility provided across a large geographical area that extends all the way to the urban fringe. This is in contrast with a relative scarcity of high-frequency surface routes in inner suburbs. Very few of Perth's activity centres, however, are not served by public transport at the minimum standard (shown grey on the respective map). In Brisbane, slower high-frequency surface routes and dedicated busways are the dominant network elements, but their focus is on servicing a greater proportion of the inner suburbs with nearly no public transport at the SNAMUTS 20 standard to the outer suburbs (since the standard daytime rail frequency in Brisbane is 30 minutes). A far greater number of Brisbane's activity centres are thus not served by public transport at this standard.

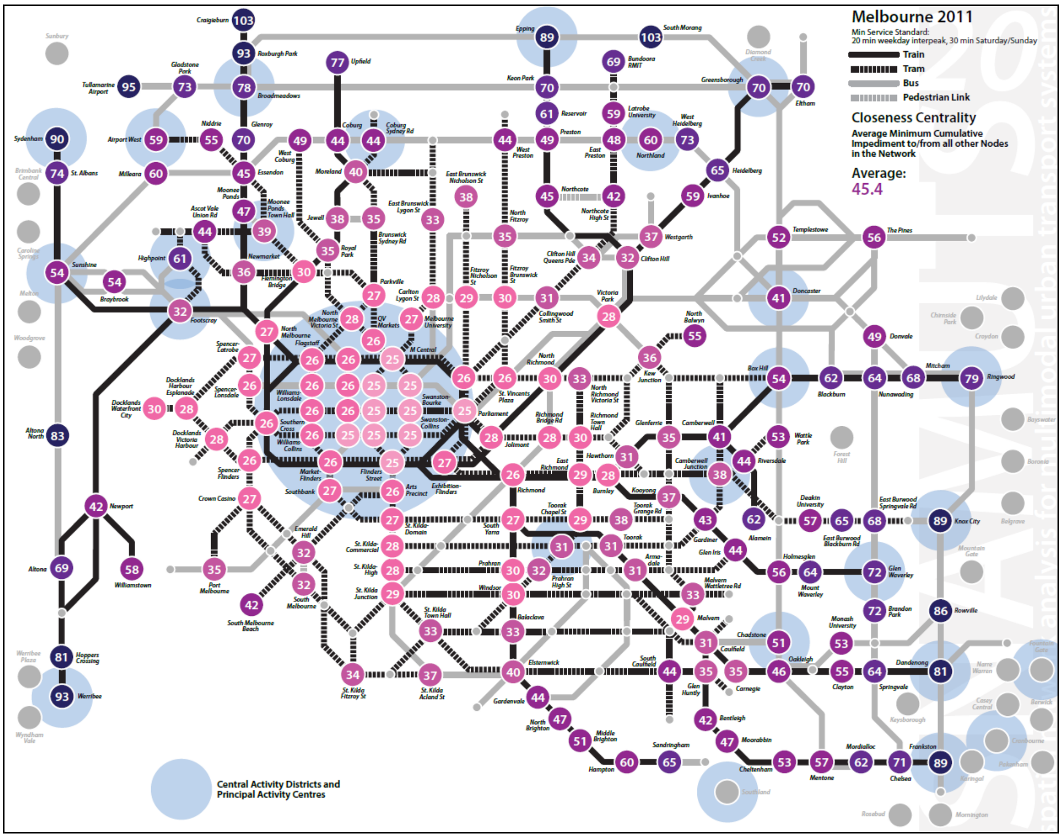
Some might disagree with our measure of accessibility (that is, that access by public transport should be commensurate with the car, which as a consequence causes us to consider access from each activity centre to all others as the ultimate in choice) arguing that it is only necessary to ensure the central CBD and designated strategic activity centres should serve a metropolitan wide function. Again in comparing Perth and Brisbane, the choice of network and service shows Perth's strategic activity centres (as classified in DOP, 2010) are all served by public transport at service frequencies of 20 minutes or better, whereas only six of Brisbane's eleven principal regional centres are (see DLGP, 2009). It is these circumstances that account for Brisbane's lower Closeness Centrality score in Table 2 and thus bring to the fore the need to consider any benchmark by taking both the Closeness Centrality score and its relationship to the total number of activity centres it is possible to serve in each city.

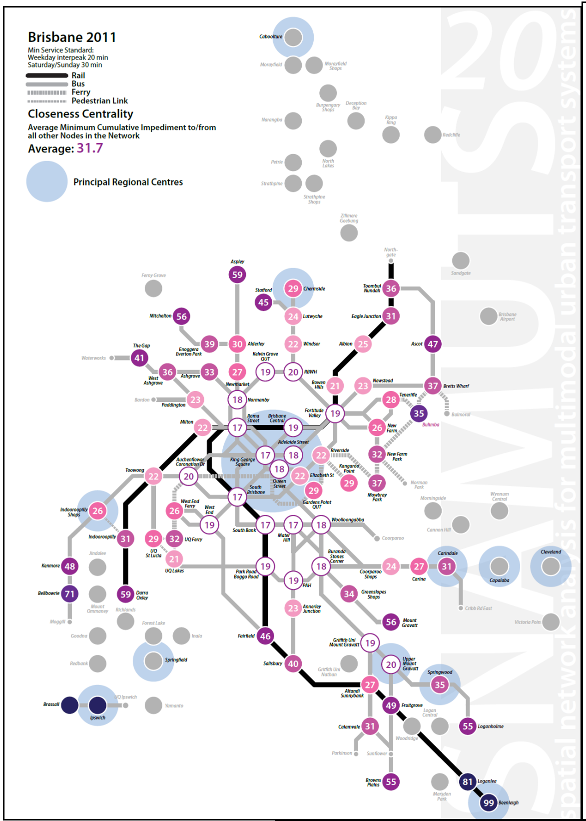
Melbourne's metropolitan strategy (DPCD, 2008) designates 25 central activity districts or principal activity centres outside the CBD, 22 of which are accessible by public transport at the SNAMUTS 20 standard. Sydney's 14 regional cities or major centres (DPI, 2010) are all located on SNAMUTS 20 public transport routes. In Adelaide, this is true for nine out of thirteen designated regional and major district centres (DPLG, 2010).

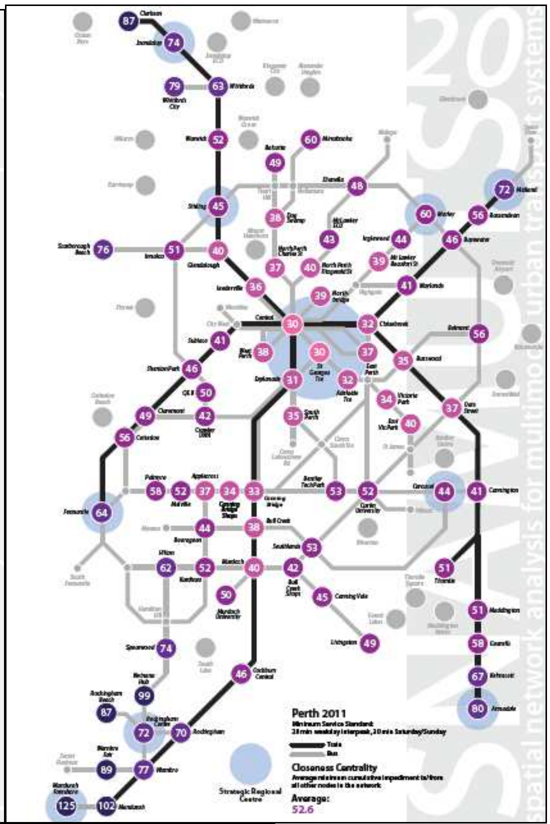
In Perth, six out of eight higher-order suburban centres return closeness centrality scores that are poorer than the metropolitan average. In Sydney, this is only the case for seven of the fourteen most important strategic centres. Of the 22 higher-order centres accessible by public transport at the SNAMUTS 20 standard in Melbourne, 16 perform poorer than average on the closeness centrality index; of the nine centres in Adelaide this is true for five and of Brisbane's six centres, two. From this cursory assessment, it appears as though Sydney's interplay of designated centre hierarchy and ease of movement on public transport is most effective, whereas both Perth and Melbourne suffer from an excessive strategic focus on centres in peripheral locations, and Adelaide and Brisbane face a challenge to boost their public transport service levels on critical parts of the network that connect these centres.

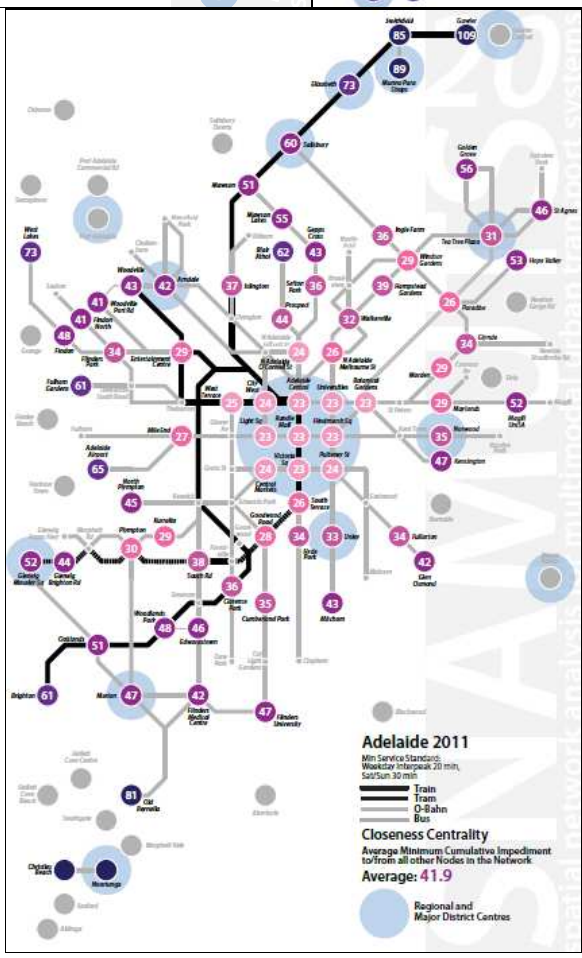
Figure 1: Closeness Centrality Maps for Eight Australasian Cities






Brisbane 2011
Min Service Standard:
Weekday interpeak 20 min
Saturday/Sunday 30 min
Rail
Bus
Ferry
Pedestrian Link
Closeness Centrality
Average Minimum Cumulative Impediment to/from all other Nodes in the Network
Average: 31.7
Principal Regional Centres


Perth 2011
Closeness Centrality
Average: 52.6
Strategic Regional Centre


Adelaide 2011
Min Service Standard:
Weekday interpeak 20 min,
Sat/Sun 30 min
Train
Tram
O-Bahn
Bus
Closeness Centrality
Average Minimum Cumulative Impediment to/from all other Nodes in the Network
Average: 41.9
Regional and Major District Centres

As we examined this SNAMUTS indicator we compared the effect of our choice of 20 minutes service frequency. Once the SNAMUTS 20 standard is relaxed to SNAMUTS 30, the public transport networks are significantly enlarged by way of inclusion of more lower-frequency routes and the performance gap between Perth and Brisbane on the closeness centrality index reverses: at the more lenient standard, Perth achieves an average Closeness Centrality value of 68.2 compared to Brisbane at 93.8 (Figure 2). Of interest here are some context specific variables that may account for the differences in public transport network choice. Perth metropolitan average residential density, at 15.5 persons per hectare, is only slightly lower than Brisbane's at 16.5, but it does not appear to be low residential densities that have driven the choice but rather the different governance arrangements. Brisbane's metropolitan area consists of only five local government areas, with the largest, the City of Brisbane, accounting for just over half of the total metropolitan population. The City of Brisbane also operates its own bus system, as well as ferry service, and it is these services, besides a small number of trunk rail routes where two or more half-hourly train lines overlap, that make up the network at the SNAMUTS 20 standard. As a result, only seven out of 78 SNAMUTS activity nodes at this standard are located outside the City of Brisbane, and none at all in the council areas of Moreton Bay and Redland.

On the degree centrality index, the key influencing factor beside network size and route density is the extent to which a public transport system has been organised around a hierarchy of modes. That is, whether there are lower-capacity modes used as feeders and distributors to and from higher-capacity modes servicing trunk corridors, or whether modes of different capacity and speed fulfil comparable movement tasks without much functional integration. In Perth, for example, bus routes along the northern and southern rail corridors have been configured to connect to rail at designated transfer hubs, from where only rail caters for the trunk service into and out of the central city. Conversely, in Brisbane's inner south a rail trunk line and a dedicated busway run parallel along a common corridor. All Australasian cities embody some elements of both approaches, though it is arguable that the hierarchical integration of modes is most evolved in Perth and Sydney. Both of these cities have the highest average degree centrality results. The average figures for the remaining cities are relatively similar, except for Christchurch which excels on this measure, most likely because its (pre-earthquake) network consisted of a highly developed interplay of pendular and orbital lines intersecting in a multitude of activity nodes (pendular lines are those that connect two suburban termini diametrically via the CBD, see Nielsen (2005)). This configuration creates extra connectivity and operational efficiency and thus enables an unusually large proportion of transfer-free trips between activity centres.

The last measure in Table 3, the clustering coefficient, describes this exact property: the average percentage of activity nodes that can be reached from the reference node without a transfer. It has been included here because it can serve as a proxy for the extent to which the system can be characterised as a 'small-world network' (Latora and Marchietti, 2002), or in other words, to describe how well the parts of the network 'hang together' as a coherent entity, offering a choice of routes between a greater number of origins and destinations. For this reason that the clustering coefficient can serve as an explanatory variable for variations in the average closeness centrality results, at least for cities that are roughly in the same population size bracket. The figures show that an inverse relationship between overall transfer intensity and clustering coefficient is present in the comparison of the largest (Sydney and Melbourne) as well as the smallest cities (Wellington and Christchurch), but not among the four mid-sized cities. In both Sydney and Wellington, a lower clustering coefficient than in its comparison city is a function of network design as well as urban geography, which contains a greater number of natural barriers (water bodies, mountain ranges) than in Melbourne or Christchurch.

Network Coverage

The Network Coverage indicator is designed to query the land use patterns of the metropolitan area in question, and in particular of those parts of it that are serviced by public transport at the minimum service standard. No Australian city currently services a majority of its residents and jobs by public transport at the SNAMUTS 20 standard within walking distance from their homes or workplaces (Table 4).

Aggregate network coverage ranges between just under 50% in Sydney and just over 40% in Adelaide; however, it drops to a low of only 26% in Brisbane. Network coverage counts the residents and jobs within statistical units that are fully or predominantly located within the 800 metre radius of a rail station or ferry terminal, or the 400-metre linear corridor along bus or tram lines that meet the SNAMUTS 20 standard. The reason for Brisbane's low performance on this index is related to its superior performance on the closeness index, as elaborated above: the city focuses its higher-frequency services on a relatively compact and comparatively densely urbanised geographical area, while subjecting most of the more dispersed suburban areas to a lower standard of public transport services than its peer cities. On the basis of the overarching objective – to provide accessibility by public transport for all residents and employees across the metropolitan area – this SNAMUTS indicator provides a clearly accountable benchmark where one would assume the ideal would be 100%. The four European cities for which a SNAMUTS analysis has been completed – Hamburg, Copenhagen, Amsterdam and Den Haag/Rotterdam – achieve network coverage values between 55% and 78% at the SNAMUTS 20 standard) Our debate, however, has also revolved around whether the SNAMUTS 20 standard is sufficient to capture the properties that characterise public transport movement and the land-use transport interplay in Australasian cities, or whether this standard be lowered to include at least the structuring elements of public transport networks (rail stations, ferry terminals, tram and dedicated busway routes) at 30-minute inter-peak frequencies.

Table 4: Network coverage in the Australian case study cities

SNAMUTS *20* 2011	Sydney	Melbourne	Brisbane	Perth	Adelaide
Network Coverage in absolute numbers of residents and jobs sited within walking distance of the 20 minute frequency network, and percentage of metropolitan total	2,911,000 **(49.8%)**	2,419,000 **(47.4%)**	680,000 **(26.2%)**	970,000 **(44.5%)**	701,000 **(40.3%)**

NB. Lack of job data for New Zealand cities.

Discussion and Conclusions

On the outcomes of the SNAMUTS analysis, it appears as though the current best-practice accessibility benchmarks for public transport in Australasian cities are:

- a 15-minute or better daytime frequency on at least one trunk route servicing every suburban activity centre that is categorised at the highest level of the centre hierarchy outside the CBD (Sydney);

- the deployment of around 14 public transport vehicles per 100,000 population in simultaneous revenue service on routes operating at least every 20 minutes during the day on weekdays in cities with strong rail systems (Sydney and Melbourne), and of around 20 vehicles per 100,000 population in bus-dominated cities (Christchurch);

- half the designated activity centres in the highest category of the centre hierarchy deliver a closeness (ease of movement) score better than the metropolitan average at the SNAMUTS 20 standard (Sydney);

- different public transport modes are organised into a multimodal network with interchange facilities providing for easy transfers and avoiding parallel services along the same corridor by different modes; the slight increase in transfer intensity this layout produces is compensated for by additional operational efficiency and network legibility (Perth);

- half the metropolitan residents and jobs are located within walking distance of public transport services operating at least every 20 minutes during the day on weekdays (Sydney).

Other findings, in particular the actual level of average closeness centrality in each network, are more difficult to cast into a meaningful Australasian benchmark since such a benchmark would have to control for the vastly different network expansion and geographical configuration found across the Australasian sample, based on historical and current patterns of infrastructure investment and operational resources (represented in part in Table 1).

As for the SNAMUTS methodology, this comparative analysis has highlighted a need for refinement of the closeness centrality index, in that it currently appears to reflect the effects of service frequency more strongly than those of travel times and network configuration. Similarly, there is a case for a selective relaxation of the minimum service standard to include fixed public transport infrastructure at a lower level of frequency (every 30 minutes), particularly the heavy rail systems that have had a prominent role in structuring the growth of every Australasian city in the sample except Christchurch, and whose ensuing presence and legibility is likely to result in a lower threshold for users to consider them as a mobility option.

As a guide to the future of public transport in Australasian cities, we have shown elsewhere (Curtis and Scheurer, 2010; Scheurer, 2011) that significant progress can be made on average closeness centrality values as well overall network coverage (though much less so on degree centrality) in scenarios of future improvements to public transport services and infrastructure as well as greater intensification of land use patterns around public transport facilities. However, in a direct comparison of Perth future scenarios with the status quo in Copenhagen it has also been demonstrated that many structural features of both the activity centre and movement networks are sufficiently entrenched as to render a full ascension of an Australian city to a European standard of public accessibility unrealistic within a 25-year time frame even under the most favourable assumptions (Scheurer, 2010).

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