Improving accessibility in growing Australian cities

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Abstract: The resurgence of public transport usage in many Australian cities over recent years has renewed the focus of policy makers on how public transport could play a greater role in the urban mobility mix of the future. It has also coincided with an increased occurrence of stress on existing public transport infrastructure to cope with growing passenger numbers as well as residential and job growth in established, transit-accessible areas. These trends suggest that a fundamental rethink is needed about the way in which public transport networks and service patterns can be reorganised and re-equipped to effectively service Australian cities of the future.

This paper will provide an overview of the performance of public transport networks in Australia's five largest cities using the findings from the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS), with particular emphasis on the constraints experienced from insufficient service levels and incoherent network development in the context of increasing urban intensification. It will then turn its attention to the SNAMUTS work in European cities in order to find examples of public transport supply that appear to cater for a greater geographical expansion of good public transport accessibility in a metropolitan region, as well as provide relief to network stress. How do cities facilitate a land use-transport interplay that embraces a higher public transport mode share in activity-rich urban areas without bringing the system to its knees?

Introduction

Since the middle of the last decade, public transport usage has grown by around 50% in Perth and Melbourne in terms of absolute numbers of trips (PTA, 2012; DOT, 2012). Passenger numbers in Sydney, Adelaide and Brisbane were also subject to increases greater than the rate of population growth. This resurgence has renewed the focus of policy makers on how public transport could play a greater role in the urban mobility mix of the future. In reviewing the trends in journey to work mode share for Australian cities, Mees and Groenhart (2013) highlight the opportunity to use this change for a radical reversal of transport priorities to deliver European-style public transport service quality in Australia.

The increase in public transport use has also coincided with observations of increased occurrence of stress on existing public transport infrastructure to cope with growing passenger numbers as well as residential and job growth in established, transit-accessible areas. These trends suggest that a fundamental rethink is needed about the way in which public transport networks and service patterns can be reorganised and re-equipped to effectively service Australian cities of the future.

This paper will provide an overview of the performance of public transport networks in Australia's five largest cities using the findings from the Spatial Network Analysis for Multimodal Urban Transport Systems tool (SNAMUTS), particularly focussing on service levels, network coverage and network stress in the context of increasing urban intensification. It will then turn its attention to the SNAMUTS work in European cities in order to find examples of public transport supply that cater for passenger volumes comparable to those likely to be experienced in Australian cities in the future if current growth trends continue. Do European cities use a disproportionate extent of additional operational resources and do they achieve better outcomes in terms of public transport accessibility and congestion relief? Or in other words, how do cities facilitate a land use-transport interplay that embraces a higher public transport mode share in activity-rich urban areas without bringing the system to its knees?

Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS)

The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool is a GIS application designed to assess the interplay between public transport network configuration, performance and service standards on the one hand, and the geographical distribution or clustering of land use activities across a metropolitan area on the other hand. 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.

SNAMUTS was originally developed through consideration of how Space Syntax theory could best be applied to public transport networks. Space Syntax theory examines the effect that the spatial configuration of streets has on the distribution of movement throughout an urban area (Hillier, 2004). Porta, Scheurer and others (Porta et al, 2006; Scheurer and Porta, 2006) adapted the concepts commonly used in Space Syntax theory to develop the SNAMUTS measures, together with adding measures that had been presented within the literature as being important to accessibility, such as the amount of places that can be reached within a given travel time (Baradaran, 2001; Bertolini, 2005). SNAMUTS has subsequently been applied to over 25 cities worldwide and refined through this process, with several additional indicators developed.

SNAMUTS produces multiple measures of accessibility, together with a composite accessibility score for each city. Detailed descriptions of the SNAMUTS indicators, including the formulas used to calculate the measures, have been presented at previous SOAC conferences (Scheurer, 2009; Scheurer and Woodcock, 2011), and can also be found in Curtis and Scheurer (2010). This paper will primarily focus on the SNAMUTS measures of service intensity, network coverage and network stress.

Figure 1 (left): Service intensity in number of vehicles in simultaneous revenue service at the SNAMUTS *23R* standard during the weekday inter-peak period per 100,000 metropolitan residents in Australian and European cities

| City	Value
Edinburgh	38.2
Amsterdam	28.7
Zürich	25.9
Wien	25.5
Porto	24.9
København	24.8
Barcelona	22.5
Adelaide	18.1
Zuid Holland	16.8
Hamburg	16.5
Utrecht	16.2
Sydney	14.9
München	14.2
Melbourne	13.4
Perth	12.6
Brisbane	11.6

Service intensity

From the SNAMUTS database for each city-region, we can extract the number of public transport vehicles that are required to be in simultaneous revenue service in order to deliver the extent of the public transport network that is operated above a specified minimum standard, and express them in proportion to metropolitan population (Figure 1). Note that the figures for the actual numbers of vehicles required by the operators are somewhat higher than shown, 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. These figures also do not reflect the usually greater numbers of vehicles required to operate peak hour services.

The minimum service standard used by SNAMUTS imposes a restriction on what proportion of each city's public transport network actually enters the analysis. For the standard used in this paper (referred to in other publications as SNAMUTS *23R*), rail and ferry routes (off-street, fixed infrastructure) are required to offer at least a half-hourly service frequency during the weekday inter-peak period, in combination with a 7-days-a-week operation, in order to be included in the database. For bus and tram routes (on-street), the minimum standard is 20 minutes during the weekday inter-peak period and 30 minutes during the day on Saturdays and Sundays. This minimum service standard level 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 practice, this cut-off level leads to the inclusion to the overwhelming majority of suburban rail and tram/light rail services in Australian cities, but only of selected bus and ferry services.

The service intensity 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, but they may well be indicative of the level of resources stakeholders within a city-region are politically and economically prepared to mobilise and allocate to public transport operation.

Figure 2 (left): Network coverage as a percentage of all metropolitan residents and jobs within walking distance of public transport services at the SNAMUTS *23R* standard in Australian and European cities
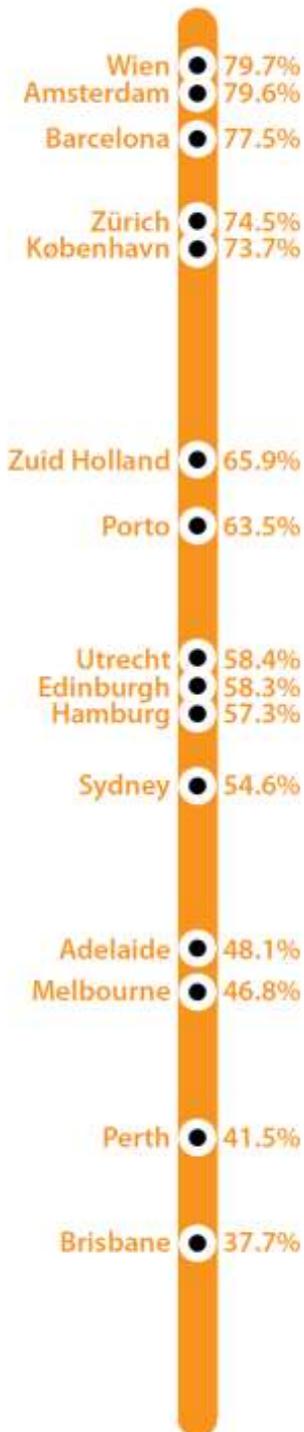
Network coverage

The network coverage indicator is designed to query the land use patterns of the metropolitan area in question, and in particular identify those parts of it that are serviced by public transport at the minimum service standard. The indicator measures the percentage of residents and jobs that are located within walking distance (800 metres around rail stations and ferry terminals, 400 metres along tram and bus corridors) of at least one public transport service that meets this standard, and expresses them as a percentage of the total metropolitan number of residents and jobs (Figure 2).

The network coverage index is another way of measuring the dedication of public transport authorities and their political masters to supply a good standard of accessibility to as many of their constituents as possible. As such, it should behave roughly proportionately to service intensity, the indicator presented previously. Figure 3 shows how these two measures are indeed closely correlated: discounting for the 'outlier' Edinburgh, the R^2 value of the regression rises to 0.83. Australian cities, on the whole, tend to fare lower on the scale in terms of both service intensity and network coverage than European cities. Within the Australian sample, Adelaide has the highest service intensity value but achieves less network coverage than Sydney does with a lower input of operational resources.

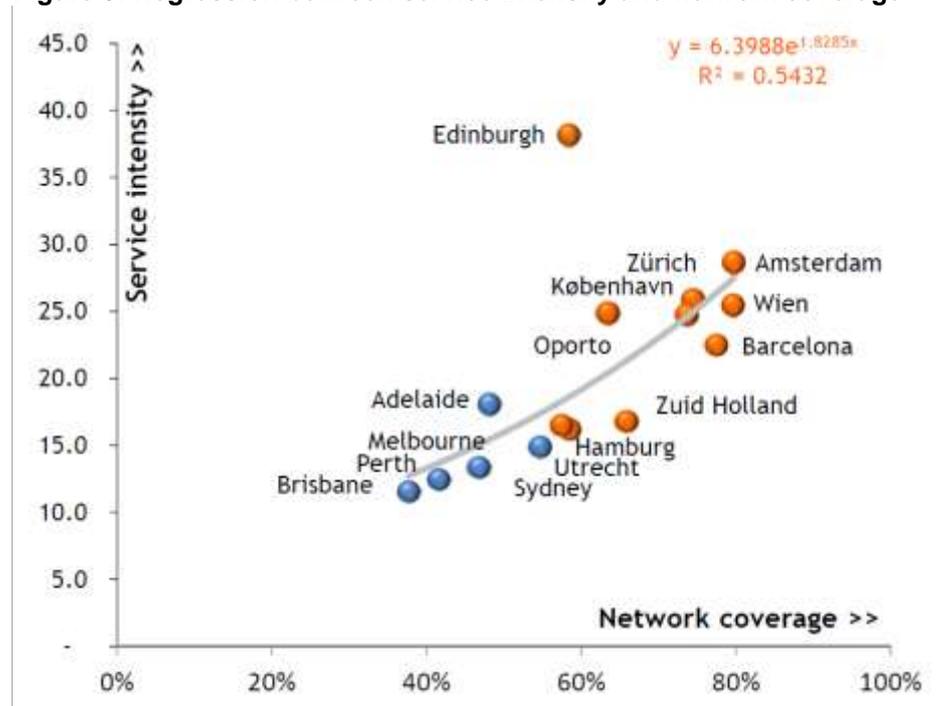**Figure 3: Regression between service intensity and network coverage**

4

Zürich ● 10.6
Wien ● 11.5
Edinburgh ● 13.6
København ● 15.1
Amsterdam ● 16.9
Barcelona ● 17.8
Perth ● 18.6
Utrecht ● 19.0
Adelaide ● 20.9
Hamburg ● 21.3
Melbourne ● 22.4
Porto ● 22.5
Zuid Holland ● 23.7
Brisbane ● 24.4
Sydney ● 27.6

Figure 4 (left): Segmental congestion (network stress) index at the SNAMUTS *23R* standard in Australian and European cities

Network stress

The network stress or segmental congestion index is based on the segmental betweenness index, a measure that determines the spatial distribution of travel opportunities across the network generated by the location and concentration of land use activities, the configuration of the network and the levels of service offered. In colloquial terms, the betweenness index attempts to trace and capture the amount of 'movement energy' derived from the land use-transport system found along each network element. The network stress index then draws a ratio of the segmental betweenness index with the actual quantitative ability of the public transport service to move passengers along each segment, determined by the service frequency and the size of the vehicles used. This index is designed to highlight where in the network the concentration of travel opportunities appears to outstrip, match or remain below the carrying capacity offered by the transport mode(s) and service levels on each route segment assessed (Scheurer and Woodcock, 2011). The network stress index uses an arbitrary scale designed to allow for comparison between cities as a whole, as well as between specific activity nodes or network elements within each city (Figure 4).

By determining the ratio of the betweenness index score and the actual passenger capacity offered on each route segment, the network stress index follows the logic that a bus-operated route segment will hit a congestion ceiling at a much lower number of passengers than a rail-operated route segment, given that a train is usually capable of moving at least than ten times as many people as a bus. High levels of network stress as expressed in this index, however, do not necessarily correlate with an actual experience of overcrowding, and conversely, low stress levels need not always indicate ample spare capacity on the route segments in question. Beyond land use concentration and ease of movement on the public transport system (the variables that make up the betweenness index), actual usage of public transport is further influenced by factors such as the competitiveness of other transport modes (in terms of speed, availability, comfort, safety and/or user cost) and the legibility of the network (and thus the ability of passengers to easily pick the most effective journey path as suggested by the SNAMUTS analysis). To avoid a potentially congested public transport service, passengers may also employ strategies such as deciding to travel to less convenient destinations, travel via less convenient routes or forego travel altogether as long as they can absorb the subsequent reduction in amenity.

It is to be expected that network stress levels show a negative correlation with service intensity, given that a greater rollout of services, all other things being equal, should result in some form of congestion relief. Figure 5 explores this context and shows that Australian cities do indeed have greater average network stress values as well as lower service intensity than most of their European counterparts. But the R^2 value of the regression suggests that only half of the variation between the cities in the European and Australian sample can be explained from the assumption that a greater outlay of services will bring congestion down.

Figure 5: Regression between service intensity and network stress

$$y = 50.504e^{-0.05x}$$
$$R^2 = 0.4974$$
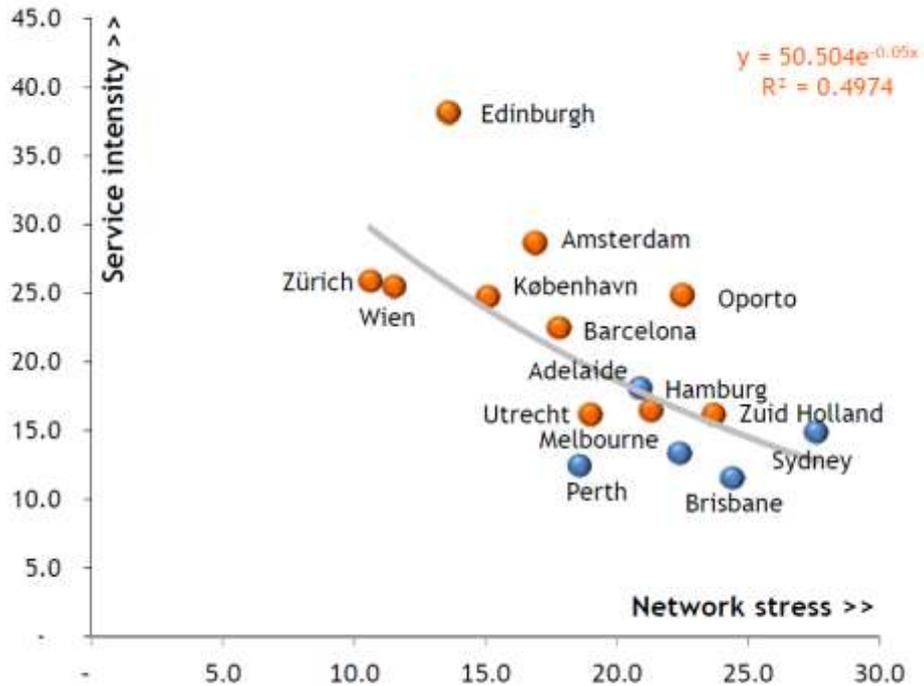
An even lower level of correlation (though still relevant) becomes apparent when examining the relationship between network coverage and network stress (Figure 6). Moreover, among themselves Australian cities tend to behave contrary to the European-Australian trend in this correlation: with the exception of Brisbane, lower network coverage tends to be associated with lower network stress.

Figure 6: Regression between network coverage and network stress

$$y = 1.0167e^{-0.028x}$$
$$R^2 = 0.3286$$

6
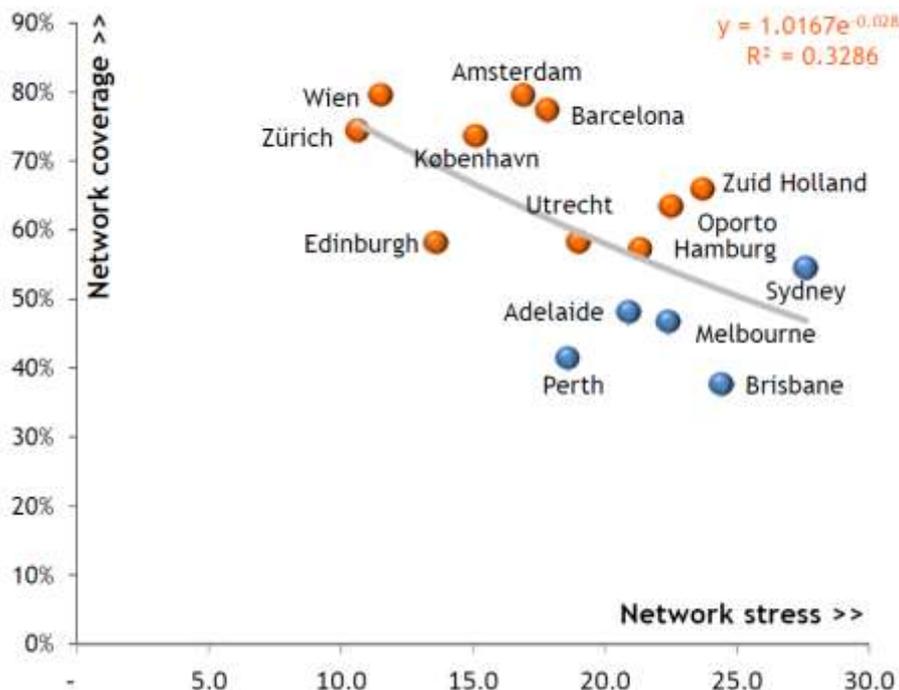
Australian cities: Detailed results

SNAMUTS was applied to the five largest Australian cities in 2011 and is based on land use data (geographical distribution of residents and jobs) derived from the 2011 census (ABS, 2013). In this section, we will focus on the measures of service intensity, network coverage, contour catchments and network stress. Further detail, including the results of the other indicators, can be found on the project website at urbanet.curtin.edu.au.

Service intensity

Table 1 shows the public transport service intensity counts for Australia's five largest cities in numbers of vehicles in simultaneous revenue service during the weekday inter-peak period, differentiated by mode and in relation to total metropolitan population.

Table 1: Service intensity in numbers of vehicles or train sets in Australian cities at the SNAMUTS *23R* standard

SNAMUTS *23R* (2011)	Melbourne	Sydney	Brisbane	Perth	Adelaide
Number of trains	70	83	28	26	18
Number of trams	269	4	-	-	10
Number of buses	198	562	188	191	195
Number of ferries	-	6	17	1	-
Number of services (total)	**536**	**654**	**233**	**218**	**223**
Metropolitan population	4.00m	4.39m	2.01m	1.73m	1.23m
Services per 100,000 inh	**13.4**	**14.9**	**11.6**	**12.6**	**18.1**

As mentioned previously, service intensity figures tend to not only reflect the determination (or largesse) of public authorities to supply public transport services, but also the efficiency of their deployment: relatively large numbers of small vehicles moving slowly (such as buses in congested conditions) will inflate the figures without necessarily providing additional accessibility benefits to passengers. Similarly, a greater share of large vehicles moving fast (such as trains on segregated alignments) will depress the figures without a concomitant loss in accessibility. From this perspective, it is not surprising that Adelaide, the most bus-dominated major Australian capital city, comes out with the highest service intensity figure in the Australian sample and that Melbourne, where (higher-capacity) trams prevail over (lower-capacity) buses in making up the surface network, has a lower overall service intensity than Sydney which has only a single tram line.

A more poignant angle of analysis would be whether greater service intensity is actually correlated with greater usage of public transport, given that in theory, more operational input should enhance a city's capability to lift the presence or competitiveness of public transport among the travel choices of its citizens. Figure 7 highlights this context by drawing a correlation between service intensity and the average annual number of public transport journeys per capita. Note that reporting standards for public transport journeys may vary between cities and lead to some irregularities in the counts: the numbers shown should be taken as a guide only.

Figure 7: Regression between service intensity and public transport usage
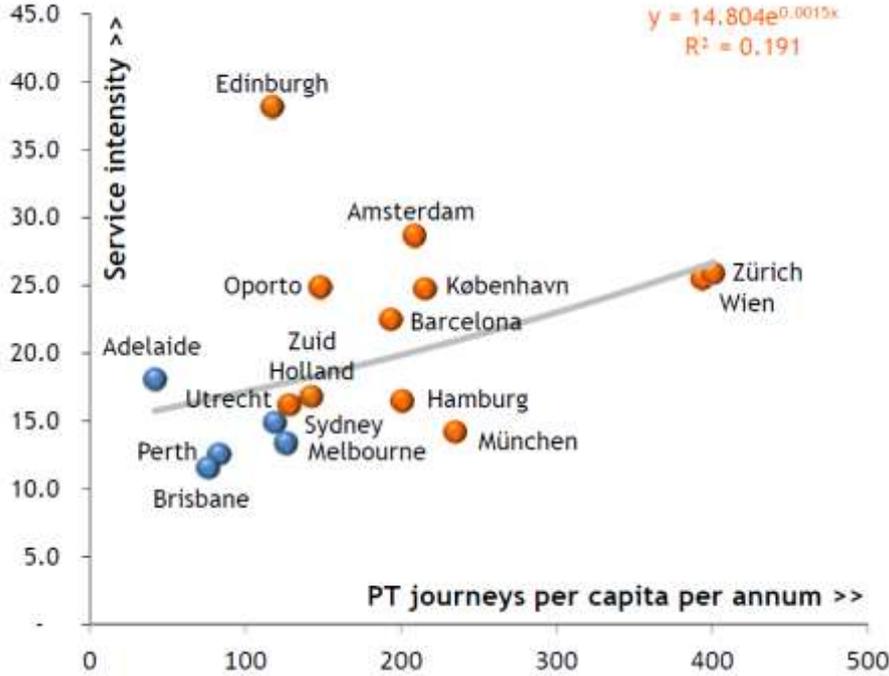
The two Australian cities with the highest level of public transport usage in terms of annual trips per capita, Melbourne and Sydney, only reach approximately the level of the two European cities with the lowest level of public transport usage (Edinburgh and Utrecht). Overall, public transport trip making in Australian cities seems to correlate with city size, though Melbourne now has a slight edge over (marginally larger) Sydney and Brisbane slightly trails (marginally smaller) Perth. Among European cities, there is no discernible correlation between size and number public transport journeys. The best performer – Zürich at 401 journeys per capita per year – is one of the smaller cities in the sample (1.44m inhabitants), whereas the largest city – Barcelona at 4.85m inhabitants – is only a mid-fielder in terms of public transport usage (193 trips per capita per year). Among the German-speaking trio of Hamburg, München and Wien, public transport journeys per capita are in inverse proportion to city size. Across the bi-continental regression, the correlation between service intensity and public transport usage is quite weak, even when discounting for Edinburgh whose service intensity figures are somewhat anomalous ($R^2 = 0.39$).

Network coverage

Table 2 shows the network coverage figures for the five largest Australian cities in terms of absolute numbers of residents and jobs within walking distance of public transport at the SNAMUTS minimum service standard, and as a proportion of all metropolitan residents and jobs. The table further shows the average 30-minute contour catchment from each activity node by way of a public transport journey, using the same measurements.

Table 2: 30-minute contour catchments and network coverage (in absolute numbers and percentage of all metropolitan residents and jobs) in the Australian case study cities at the SNAMUTS 23R standard

SNAMUTS *23R* (2011)	Melbourne	Sydney	Brisbane	Perth	Adelaide
Network Coverage	2,663,000 (46.8%)	3,398,000 (54.6%)	1,091,000 (37.7%)	1,027,000 (41.5%)	837,000 (48.1%)
Average 30-min contour catchment	526,000 (9.2%)	519,000 (8.3%)	307,000 (10.6%)	263,000 (10.7%)	188,000 (10.8%)

In 2011, only Sydney serviced the majority of its residents and jobs by public transport at the SNAMUTS *23R* standard within walking distance from their homes or workplaces. Aggregate network coverage ranged between 54.6% in Sydney and just 37.7% in Brisbane, a range that sits fully outside

8

the spectrum of the ten European cities studied, which vary between Hamburg at 57.3%, and Wien at 79.7% (Figure 2).

The contour catchment index adds a further dimension to the network coverage assessment, in that average 30-minute contour catchments are also influenced by the density and concentration of urban settlement, the speed of public transport and the spacing of activity nodes within the metropolitan area, which can be read as a proxy measure to its degree of compactness or dispersal.

Average 30-minute contour catchments can be expected to grow with city size in absolute figures, but decline with increasing city size in proportional figures. Among the similarly sized cities, Melbourne thus seems to have an edge over Sydney on this index, with Perth, Brisbane and Adelaide all quite similar. Once more, all Australian cities are outperformed on this index by their European counterparts, whose average 30-minute contour catchments range between 10.8% in Zuid Holland (the highly polycentric agglomeration around Rotterdam and Den Haag in the Netherlands) and a staggering 31.2% in Vienna. There appears to be a link between this measure and the spatial coherence of the network as a whole, as determined by network design and urban geography, and the choices of cities as to which corridors and locations they concentrate their resources for higher-frequency public transport services into.

Network coverage, in bringing public transport services of a particular standard to a certain proportion of residents and jobs, should be expected to show some form of correlation with public transport usage. And indeed, as shown in Figure 8, this relationship is one of the strongest between the indicators presented in this paper when subjected to a regression. Melbourne comes out with a slightly higher level of public transport usage than the European-Australian trend line would suggest for its level of network coverage, whereas Adelaide comes out with a lower one. The remaining Australian cities seem to be behaving roughly according to the trend in this correlation.

Figure 8: Regression between public transport usage and network coverage
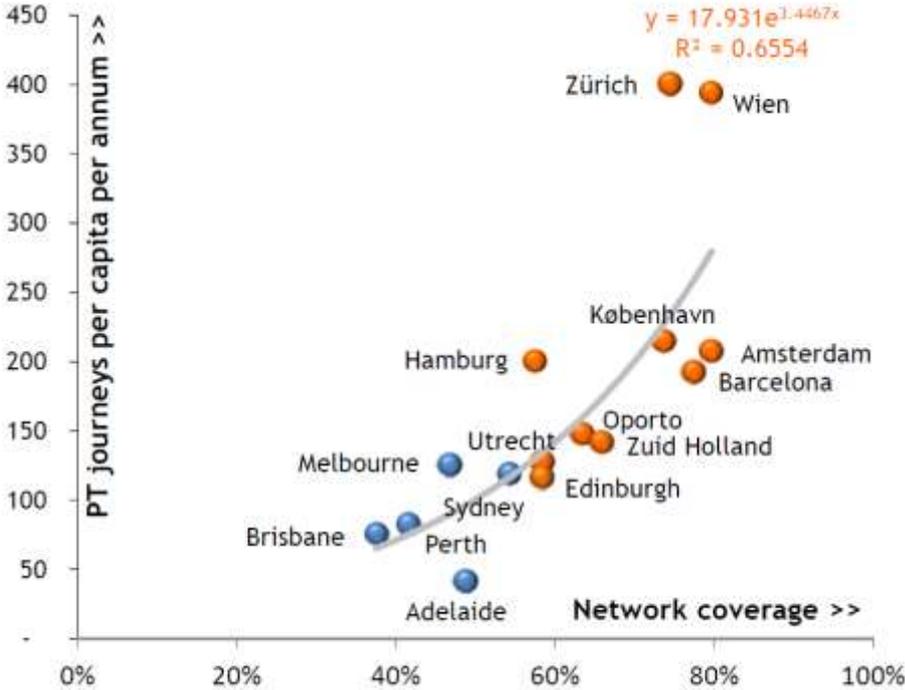
Network stress

Table 3 below shows the results of the network stress or segmental congestion indicator for Australian cities, on a scale where higher figures indicate greater levels of network stress, and differentiated by mode as well as collated specifically for route segments located in the CBD areas of the respective cities.

Table 3: Network stress index in the Australian case study cities

SNAMUTS *23R* (2011)	Melbourne	Sydney	Brisbane	Perth	Adelaide
Average segmental congestion index	**22.4**	**27.6**	**24.4**	**18.6**	**20.9**
Segmental congestion – rail	20.3	16.1	9.2	13.6	10.2
Segmental congestion - tram	19.6	28.8	-	-	19.4
Segmental congestion - bus	27.7	29.5	28.0	19.3	22.3
Segmental congestion - ferry	-	2.8	9.5	0.0	-
Segmental congestion – CBD area	23.3	41.3	30.5	21.6	31.8

Sydney shows the highest levels of average network stress (27.6), and Perth the lowest (18.6). There are some interesting results in between, with Brisbane and Adelaide both scoring higher than Melbourne on this measure. Sydney, Adelaide and Brisbane's stress shows up highly on the tram/light rail and bus systems, is less evident on train lines and is almost non-existent on the ferry routes. Perth and Melbourne show more balanced stress across modes, with bus routes still being the most stressed in both cities. Both Melbourne and Perth also have notably less congested routes in their CBD areas (23.3 and 21.6) than the other cities, with Sydney having the highest segmental congestion in its CBD area (41.3).

It would seem intuitive to assume that higher levels of network stress are at least partly the result of high levels of public transport patronage, even though SNAMUTS does not analyse transport demand but rather the generation of travel opportunities through the interplay of the public transport supply and the land use system – opportunities that may or may not be taken up by passengers in real life. However, as Figure 9 illustrates, the opposite is the case across our Australian-European sample of case study cities, in a regression that explains 37% of the variation between cities on this correlation. On the whole, there is a weak trend that appears to associate lower levels of network stress with higher levels of patronage.

From a methodological perspective, this finding makes a lot of sense: the segmental betweenness measure which forms the numerator of the network stress equation depicts an absolute proxy value for the number of travel opportunities generated by the intensity of land use, and by the ease of movement provided by the public transport links in question. If a network with high rates of trip making was to actually enable the resulting amount of public transport movement, it would either need to maximise the capacity of its public transport service – the denominator of the network stress equation – or configure the network in such a way as to moderate segmental betweenness values at least in critical, congestion-prone areas (or a combination of the two). Both strategies bring down average network stress scores, and both strategies can be observed in real-life cities, if not as deliberately targeted policy measures then certainly as underlying themes that inform the way in which public transport network and service planning have been and continue to be handled as part of the co-evolution of urban form and transport supply.

Figure 9: Regression between public transport usage and network stress
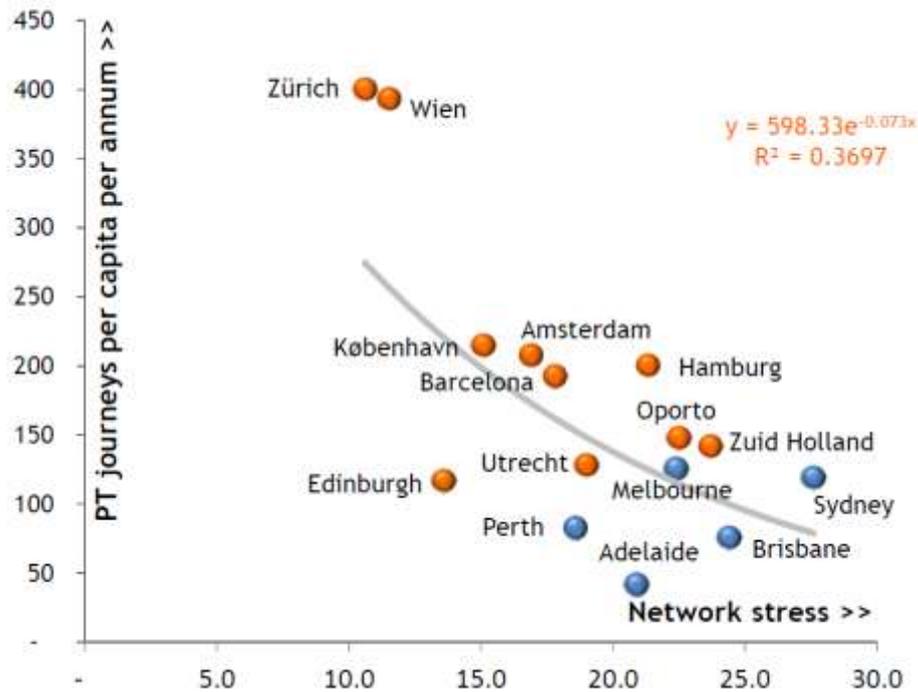
Summary and discussion: The future of public transport accessibility in Australian cities

The comparative data on Australian and European cities collected by the SNAMUTS analysis has shown that Australian cities trail their European counterparts on the measures of public transport service intensity, public transport network coverage, average 30-minute contour catchments of public transport journeys, relative network stress and the critical resulting measure of public transport journeys per capita per year. Moreover, with few individual-city exceptions, the entire spectrum of performance of Australian cities is situated below the entire spectrum of performance of European cities on each measure.

The service intensity measure depicts the operational input each city is determined to make available in order to provide a network at a standard that reasonably allows for both planned and spontaneous public transport journeys for a broad variety of journey purposes. On this measure, Adelaide stands out as the one Australian city that exceeds the operational input of the 'frugal' group of European cities (Hamburg, München, Utrecht and Zuid Holland) and in turn, achieves a degree of geographical network coverage that is second only to Sydney among the cohort of Australian cities. This is despite Adelaide being the smallest and slowest-growing major Australian capital city, and its consequent relative absence of significant spatially concentrated clusters of land uses outside the central area. It is true that Adelaide has more buses, relative to both population and network size, crawling through its CBD at low speeds than its counterparts elsewhere in Australia, marking a degree of operational inefficiency that contributes to the service intensity measure. However, it is also true that the South Australian capital has successfully introduced a minimum service standard (GO Zones) that includes 15-minute frequencies or better on weekdays and 30-minute frequencies weekends and evenings, and that applies to all major bus and tram corridors in the inner suburbs without leaving significant coverage gaps outside walking distance from such corridors. This is a standard that can be found across the contiguously urbanised areas of practically every European city, at least within their core jurisdiction, and the remaining Australian cities would do well to work towards a similar extent of network density (and relative operational input) in the future.

On the network coverage measure, the best Australian performance is on record for Sydney, which appears to primarily be a result of Australia's largest city's long-standing policy of land use intensification around rail-based activity nodes across the metropolitan area that has generally been stronger than among its neighbours (Newman, 2009). In combination with the city's formidable topographical constraints to outer suburban expansion, this strategy has helped to place a larger proportion of metropolitan residents and jobs into walkable catchments of public transport than in its

peer cities elsewhere in Australia. This pursuit of urban compactness and transit orientation, while rarely taken to perfection, is also a prevailing theme in the co-evolution of transport and land use systems in European cities. Some cities, such as Barcelona and København, have comparable or greater topographical constraints to fringe area expansion as Sydney. In other countries, notably the (western) Netherlands and (northern) Switzerland, regional population densities are such that maximising spatial efficiency in urban development has been imperative for many decades in order to protect scarce productive agricultural and forestry areas, as well as nature reserves. In these cases, a proactive land policy at a regional scale appears to result in urban growth to cluster around public transport infrastructure (Gallez et al, 2013; Van Wee & Maat, 2003) and thus facilitate the rollout of public transport services to a large proportion of the population without excessive use of operational resources.

On the network stress measure, Perth and Melbourne have an edge over their Queensland, New South Wales and South Australian peers. Perth arguably is the Australian city with the most ambitious strategy for public transport network development and investment during the past 25 years (Curtis, 2008) and despite maintaining a long list of further worthwhile infrastructure projects yet to be realised, has achieved a relative balance where rail and bus modes are characterised by complementary task-sharing that seeks to maximise the efficiency of both. Most (but not all) European cities follow a similar path and over decades of co-evolution, have optimised their networks to enable a fine-tuned interplay of public transport modes with varying performance and capacity, in many cases using a greater range of transport modes than Perth which currently only has heavy rail and (mostly) street-running buses.

In Melbourne, the relatively low network stress measures are clearly associated with the widespread presence of such an intermediate capacity mode in the form of the Victorian capital's extensive tram system. Despite Melbourne's trams being relatively short compared to those in most European first-generation operations, their comfortable passenger load is still about twice that of a bus (most of which are also relatively short in Melbourne). This circumstance limits operational input particularly for the CBD surface network compared to Melbourne's peer cities. For instance, according the SNAMUTS database, 22.1% of metro-wide public transport vehicles plying the minimum service standard network can be found in Sydney's CBD at any one time during the weekday inter-peak period, while in Melbourne, this share is only 19.6%. In Sydney, more than 70 buses per hour per direction attempt to travel along George Street and several other CBD corridors even outside peak hours, while in Melbourne, the maximum number of trams along any single route (Swanston Street) is 45. In such circumstances, it is no coincidence that Sydney, Australia's city with the highest SNAMUTS average network stress results on several measures (network-wide, in the CBD and, jointly with Brisbane, on the bus system) is now pursuing a substantial expansion program for its light rail network to improve operational efficiency, build passenger capacity and free up operational resources currently tied up in CBD bus congestion.

In Europe, the role of intermediate modes, mostly trams and light rail, is not consistent across our 11-city sample, but the majority of cities either look back on long-standing strategies to modernise, prioritise and expand a first-generation tram system (Wien, Zürich, München, Amsterdam, Rotterdam, Den Haag) beside heavy rail/metro and bus operations, or to reintroduce the mode after a long period of absence or relegation to a heritage niche (Utrecht, Barcelona, Oporto, and Edinburgh in 2014). These cities have realised the efficiency dividend that accompanies the differentiation of the mode mix into a greater number of performance categories and, with the exception of Zuid Holland whose heavy rail system is under considerable stress (or would be if residents travelled between Rotterdam and Den Haag to the same extent as they do between urban districts of comparable size in more contiguous cities), have reduced their segmental congestion figures to levels not seen in Australian cities.

Concluding remarks

This analysis of comparative accessibility performance in Australian and European cities has shown that the public transport networks of Australian cities generally have lower operational input, lower geographical coverage and lower levels of resilience against the pressures from increasing patronage than their European counterparts. To resolve these shortfalls in the manner of the European cities that generally cater for much higher patronage levels than Australian cities – in some cases three or four times as high – would require the mobilisation of additional resources, over and beyond the rate of population growth, to allow for public transport operations to be allocated to the geographical expansion of the networks. Such geographical expansion would increase the proportion of metropolitan residents and employees that have the opportunity to rely on, and build their daily activities around public transport accessibility. In order to keep the networks functional as passenger

numbers grow, however, it will also be necessary to optimise their configuration and to develop them towards a more efficient form of task-sharing between transport modes of different capacities, and to increase the range of transport modes by stepping up investment in the expansion and introduction of higher-capacity modes such as heavy rail, light rail, trams and bus rapid transit.

Acknowledgements

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