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Urbanet

Research Discussion Paper

Benchmarking Perth's public transport accessibility in an Australasian context

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1. Introduction: Accessibility planning, public transport performance and benchmarking

Project approach

The purpose of this project is to provide a discussion paper for the Committee for Perth which investigates the performance of Perth's public transport system from a spatial accessibility perspective by making use of the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool. The intent is that this paper provides an input into the Committee for Perth's *Get a Move On!* project. The objective is to provide a benchmark on the performance of Perth's public transport system by employing a research evidence-based understanding of the accessibility provided by the existing public transport network in Perth and also relative to other Australasian cities.

By comparing Perth to Australasian cities, we can critically analyse the existing public transport system, and advise how the system might be expanded to alleviate traffic congestion as Perth continues to grow. By international standards, Australian cities are not well served by public transport, so reference to a selection of international cities (i.e. Vancouver, Helsinki, and Copenhagen) provides further analytical insight. This also enables an understanding of key principles necessary in public transport network design if Perth is to improve accessibility by public transport. These cities were selected because they also have expansive low-density suburbs, yet they maintain high public transport accessibility alongside high levels of car use.

This discussion paper contains the following:

- An investigation of the performance of metropolitan Perth's public transport system from a spatial accessibility perspective by making use of the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool.
- A comparison of Perth to the other large Australasian cities (Adelaide, Auckland, Brisbane, Melbourne and Sydney) and to three selected international cities. This allows for the positioning of Perth's public transport performance, identifying comparative strengths and weaknesses against each SNAMUTS indicator, and enables a discussion of policy opportunities and constraints.
- An analysis of post 2007 trends in public transport performance in Perth, highlighting the strengths and weaknesses of the current approach to integrated transport and land use planning in Perth.

Background

Australasian cities have long experienced rising traffic congestion and there have been ever increasing demands for large-scale infrastructure financing to build new roads and increase the existing roadway capacity (Low and Astle, 2009). Investment in public transport, however, offers a significant alternative to gain further market share from the car thereby reducing traffic congestion and also addressing the social and environmental impacts associated with car dependence.

Strong growth rates in public transport usage during the past five years are setting a new trend (BITRE, 2013). Australasia's public transport sector is facing a fundamental transformation, from its early start as a social welfare option for people who could not afford, or were unable to drive a car, towards a service for commuting to the central business district, and now towards a service capable of catering for all urban passenger transport needs across metropolitan areas (Mees, 2010). Public transport is now critical to people's sustainable mobility.

Since the mid-1990s policy goals formulated by Federal and State Governments have begun to emphasise the desirability and importance of increasing public transport mode share (DoI VIC, 2002; DoT WA, 1995). A National Charter for Land Use Transport Integration was adopted identifying the need to integrate public transport systems directly with land use development (DTRS, 2003). The Commonwealth Government's infrastructure agency, formed in 2008, provided federal funding contributions to state urban transport infrastructure that were conditional on the integration of strategic land use and transport planning, and initiated a reform agenda on major cities and infrastructure planning through the Council of Australian Governments (IA, 2009). In 2013, however, the incoming federal government terminated Federal action in urban public transport policy and funding, pointing to a significant partisan divide over transport policy in the political arena.

Public transport's role in influencing the land development investment and the functional patterns of cities is now well documented (Cao et al, 2009, Cervero et al, 2014). Areas with excellent public transport connectivity tend to attract residents who are most likely to utilise transit, increasing patronage (Cao et al, 2009). Long-term coordinated investment in structuring public transport networks to provide competitive access to a broad range of destinations creates a major opportunity to capture transport demand, transforming the mode share patterns in cities (Mees, 2000; Nielsen et al, 2005). The interplay between land use and public transport is multi-faceted, and improving the quality of public transport systems has several direct and indirect benefits beyond merely providing additional transport options for commuters in metropolitan regions.

Urban transport in Perth is a topic of ongoing public discourse. Unfortunately, political debates about public transport projects in Australia often lack reference to evidence or comparable interstate and international examples. This can result in arguments that do not match with the principles of how public transport can deliver genuine mobility to commuters, drive urban investment, create great places, and mitigate against the problems created by excessive car travel.

The Spatial Network Accessibility for Multimodal Urban Transport Systems (SNAMUTS) tool enables rigorous, methodical comparisons of public transport accessibility between cities. The lessons learned from these comparisons can inform improvements to urban transit in any city, including Perth. This maximises the benefits of infrastructure investments by maximizing the degree to which projects improve individual sustainable mobility, addressing traffic congestion, reducing pollution, identifying development opportunities where high levels of accessibility by public transport can be achieved, and improving the sustainability of the transport systems.

Benchmarking Public Transport

In this paper the SNAMUTS Accessibility tool is employed to benchmark public transport accessibility in Perth against other large Australasian cities and selected international cities. The benchmark is based on an objective where the public transport system provides residents a competitive alternative mode choice to the car. This benchmark is based on public transport accessibility for all; other researchers and practitioners have chosen different metrics. For example, it is common for governments to use 'public transport patronage' as a measure that reflects the expectation that investment in the public transport network 'paid off'. Others focus on the cost of operating the public transport network, or the costs of construction. After Walker (2008), we assert that the choice of metric is dependent on the policy objective 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, 2012) rather than based on the need to implement policy imperatives such as those identified above.

2. Accessibility planning and accessibility tools

Introduction

Accessibility describes how well residents and employees are connected to jobs and other journey destinations. Accessibility analysis provides the means to bring land use planning and transport infrastructure planning together. These fields have often operated in separated 'silos'; accessibility analysis is an innovative and integrated approach that allows assessment of how well infrastructure plans align with the locations in a city where high levels of human activity take place or are planned. It allows assessment of how well land use plans for urban centres, neighbourhoods and growth areas function in terms of maximising the use of public transport for access to people moving about the city. Ultimately, maximising public transport accessibility throughout a metropolitan area is a critical goal of both sustainable transport and land use planning. Accessibility planning also demonstrates how the careful location of land uses can effectively address traffic congestion.

Applying the accessibility assessment approach is valuable in maximising the return on investment for transport infrastructures, ensuring the resulting services are as effective and efficient as possible. Accessibility planning enables an understanding of why Perth's existing urban system functions in the way it does and provides insights for how both the transport network and development locations could be improved to make public transport a viable alternative to car travel.

Measuring accessibility using SNAMUTS

The SNAMUTS tool focuses specifically on accessibility by public transport. Analysis has been completed for 25 developed cities on four continents to enable comparison and benchmarking of public transport accessibility measures for policy development (see www.snamuts.com). The SNAMUTS tool measures accessibility at a minimum service standard[1] for the inter-peak period[2] set to be competitive with the car.

Accessibility performance is assessed from the perspective of the individual traveller, acknowledging that different users value different aspects of accessibility according to their specific movement and spatial needs. Public transport access points have a prominent role in the land use-transport system both from the perspective of public transport users, and of policy makers seeking to enhance the significance of the mode. Public transport

[1] SNAMUTS minimum standard requires bus and tram routes to operate at least every 20 minutes during the weekday inter-peak period, and every 30 minutes during the day on Saturdays and Sundays, to be included in the analysis. For rail and ferry routes, the minimum standard for inclusion is a 7-days-a-week service with 30-minute or better intervals during the weekday inter-peak period.

[2] In most public transport systems the weekday peak hours is the period when service levels are optimised to facilitate specific trip purposes (work and school journeys). In contrast, the weekday inter-peak period (approximately between 10.00 and 15.00) offers the greatest diversity of travel purposes and so determines the potential of public transport to offer a viable alternative to the 'go anywhere, anytime' convenience of the car so allowing residents and businesses to meet their travel needs.

access points can be seen as both transport nodes and urban places. Bertolini's (1999) 'node-place model' notes that while railway stations provide access to the transport network, which he defines as the 'node' element in his model, they also offer a 'place' function. So the railway station precinct can also be a destination where land use activities are available to public transport users and others. The place function, or accessibility of opportunity, is an important aspect of accessibility that must be considered as well as travel within a specific time range to and from each destination. As well as posing the opportunity for urban development, railway stations should also be desirable places to accommodate and welcome public transport passengers waiting for, transferring between, or alighting from transit services.

SNAMUTS contains a set of measurements of the public transport network, service development and land use activity and these in turn feature as SNAMUTS key indicators, which each evaluate different aspects of the system:

- **Service intensity** counts the number of trains and buses public authorities are prepared to provide in order to achieve a good public transport service;
- **Closeness centrality** describes the ease with which users can move about the network, achieved by minimising travel times and maximising service frequencies;
- **Degree centrality** describes how much the network depends on making transfers between different vehicles;
- **Network coverage** indicates the proportion of residents and jobs in the city that have a regular, full-time public transport service within walking distance of their homes or workplaces;
- **Contour catchments** illustrate what proportion of the city can be reached within a public transport journey of 30 minutes or less (the average duration of a job commute);
- **Betweenness centrality** looks at how the network is organised: examining which places and routes are 'at the crossroads' of travel paths, and which ones are in quieter zones:
- **Network resilience** assesses whether the network, and individual routes, have potential spare capacity to attract more passengers, or whether they are vulnerable to congestion;
- **Nodal connectivity** assesses how flexibly users can move between different parts of the network, and which places in the city are most suitable to convenient public transport access;
- **Efficiency change** compares how the network evolves over time, as services are improved or deteriorate, and as the city grows (or shrinks) around it.

3. Benchmarking Perth's Public Transport System

Perth's history of post-war suburban development, planned to be served largely by the private car and large highway systems, has substantially altered the function of the public transport system. Perth's radial train system, originally developed during the 19th and early 20th century, saw little expansion until the early 1990s. These so called 'heritage lines' have frequent stops, and encouraged the formation of small, mixed-used local town centres. Bus services mostly served as radial feeders, connecting suburbs with the CBD, or to key train stations. The construction of the Joondalup and Mandurah lines during the 1990s and 2000s respectively prompted the reorientation of bus services as direct feeders to stations along those lines, which are mostly situated within large freeway interchanges. While these services can generally meet the transport needs of some city workers, the system is poorly equipped to accommodate other travel patterns. SNAMUTS illustrates these deficiencies, and provides evidence of past and future trends for network and development investment.

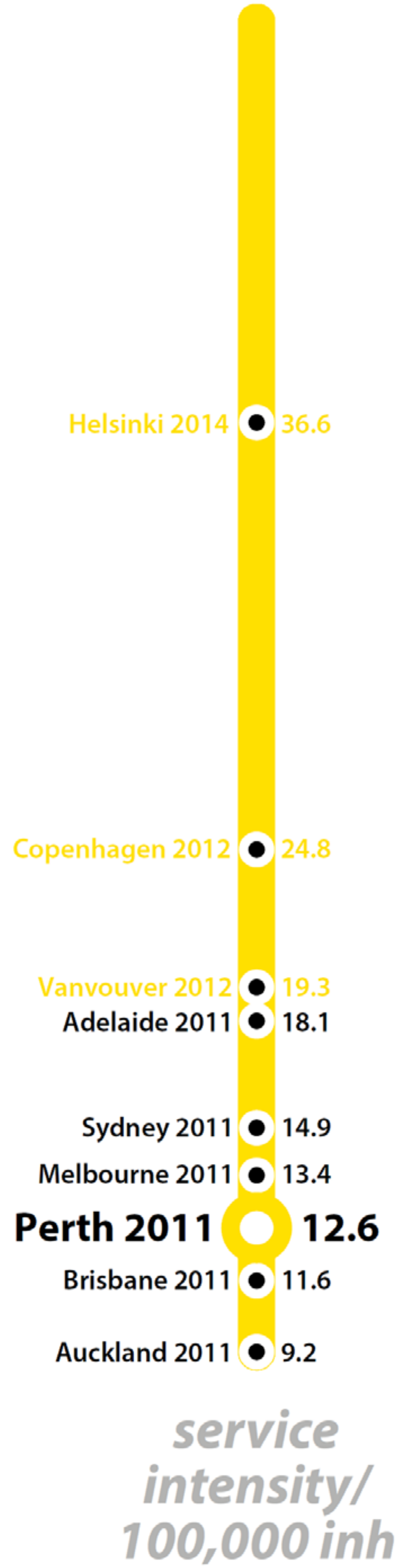
In this paper the analysis of the current public transport system for the different cities is based primarily on data collected between 2011 and 2014 comprising public transport timetables in the public domain and population and employment data.

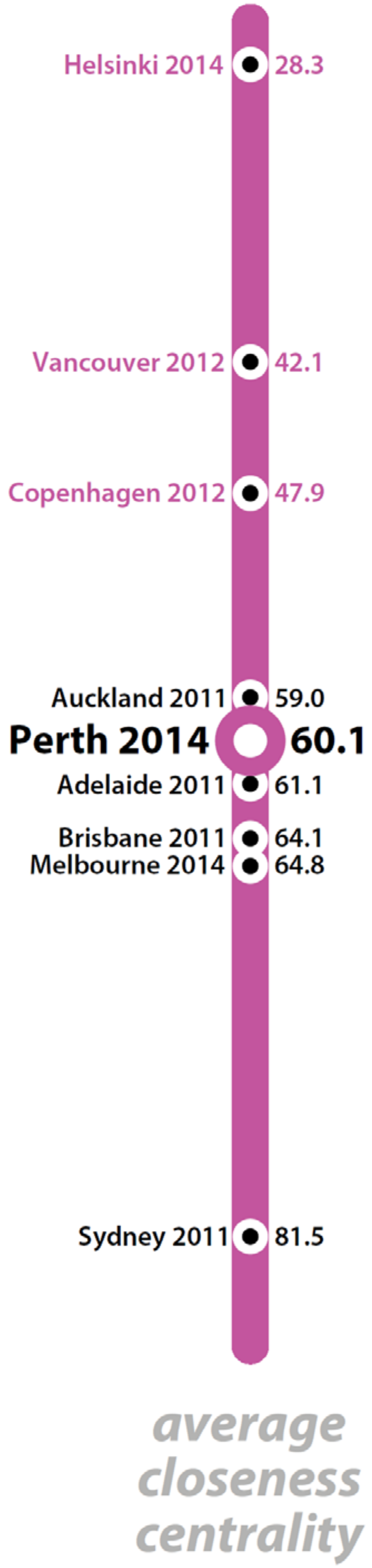
For Perth, the analysis also includes an assessment, based on past accessibility, drawing on earlier data from 2007 and an analysis for 2016 for the public transport components (but not the population and employment data since this is dependent on release of 2016 census data)..

Service intensity

The SNAMUTS **Service Intensity** index measures the operational input required to provide the minimum service standard. This is achieved by counting the number of vehicles for each mode that are in simultaneous passenger service during the weekday inter-peak period per 100,000 inhabitants. The index also expresses the efficiency of public transport operation – low travel speeds or circuitous routes can inflate the results. High service intensity scores are therefore not necessarily indicative of better service, but rather are indicative of the level of resources that agencies are prepared to allocate to operation.

The level of investment in operating services on Perth's network is quite low. However, Perth's sprawling suburban expanse makes building and operating lines expensive. Perth's multi-modal network is organised hierarchically. Buses act as feeders and distributors to commuter railways and service secondary inner suburban corridors; this maximises resource use effectively, partially compensating for the low level of investment. However, significant spatial gaps remain between corridors of good public transport service. High train speeds on the Joondalup and Mandurah lines, designed to compete with the car, results in a lower number of trains required to operate them at a reasonable frequency compared to the older suburban railway lines.





Perth's rail network is operated at minimum 15-minute service frequencies seven days a week during the inter-peak period. This standard represents the best consistent service level found in any Australasian urban rail system, though in global terms it is relatively modest. The service intensity figures for Vancouver, Copenhagen and particularly Helsinki demonstrate the accessibility benefits achieved in those cities that are absent from their Australasian counterparts.

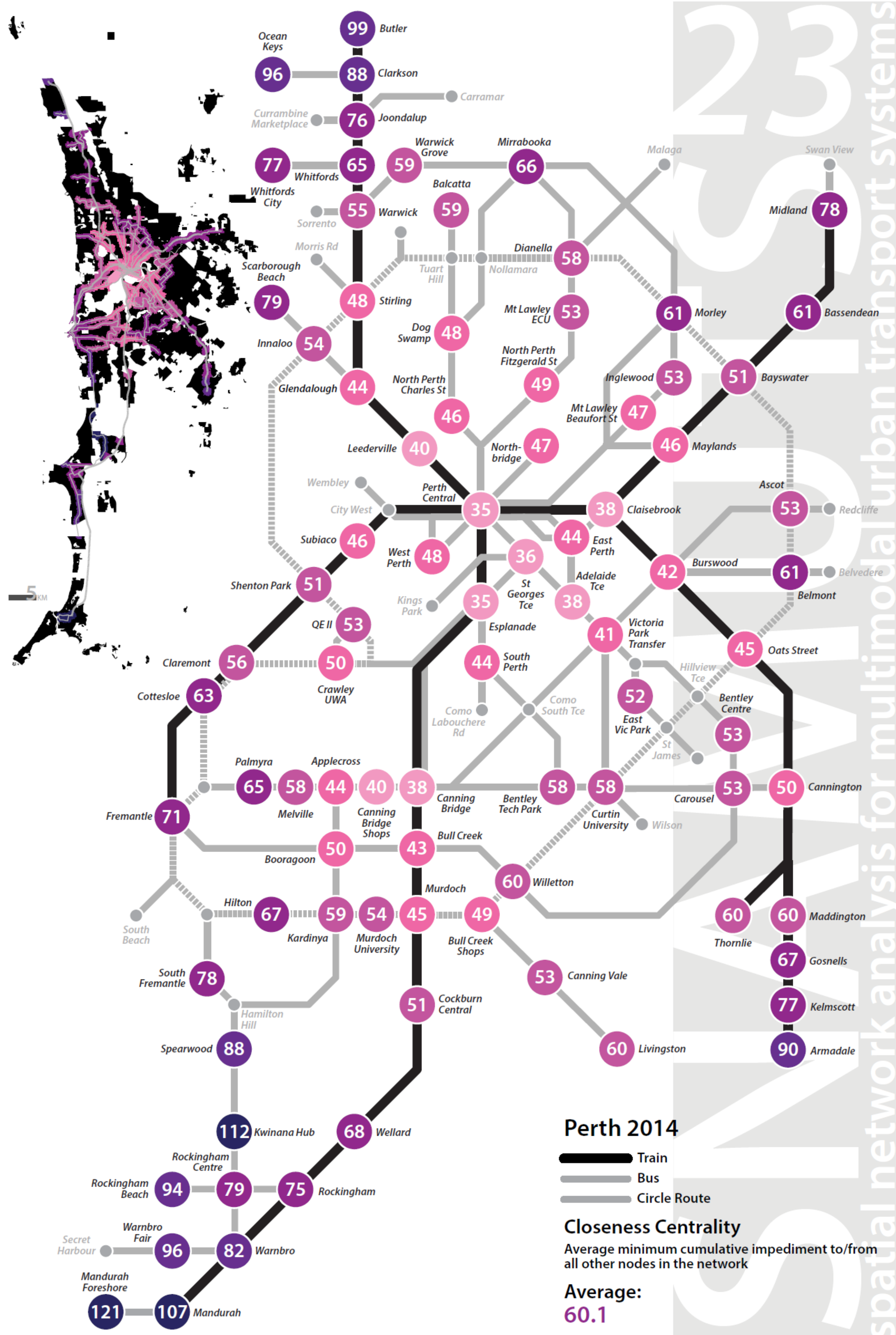
Service intensity levels in Perth have grown: from 9.8 vehicles per 100,000 inhabitants in the Perth and Peel metropolitan region in 2007 (prior to opening of the Mandurah line) to 12.6 in 2011 and to approximately 15 in 2016. The extent of the public transport network has thus grown significantly faster than population over the past decade, and also slightly faster than public transport patronage per capita. This is mostly due to frequency improvements on numerous inner urban and suburban feeder bus routes, including the gradual introduction of the 900-series routes with higher frequencies and longer operational spans.

Closeness centrality

This indicator quantifies the spatial separation, or travel impediment, users experience as they move about the system. It is composed of the travel time and the frequency of the service. Closeness centrality is shown as an average value across the network, and as an average for each activity node. Lower values indicate better performance or greater *ease of movement*. Good area-wide ease of movement is often achieved in lattice or web-shaped networks with many transfer points; conversely, in tree-shaped networks closeness values deteriorate rapidly from centre to periphery.

Among Australasian public transport networks, Perth's is relatively easy to move around in. This is due to the high speed and consistent 15-minute inter-peak and weekend daytime frequency of the train system, and the good integration between trains and buses. The key weakness is the relative lack of compact clusters of intense urban activity outside the centre of Perth. This leads to long journey distances that discourage discretionary public transport trips.

The network form is characterised by five radial rail lines interspersed by secondary radial bus corridors. The radial routes intersect in the middle suburbs with an orbital bus line (Circle Route 998/999). Rail stations usually have dedicated transfer facilities built to a high standard. A 'spider web' structure results, with a cluster of the lowest (best) closeness values in the CBD and then a wave-like spread of medium closeness values at the nodes along the Circle Route, better at intersections with rail lines and worse at intersections with bus lines.



The spacing and speed of the rail lines result in cross-suburban journeys from one rail corridor to another generally taking longer by the Circle Route than by a rail transfer trip through central Perth, but of less duration than by a transfer trip using radial bus lines. Outside the Circle Route, the network forms a tree-shape with outer suburban radial rail lines connecting to short bus feeders, with few orbital links between these corridors. In such conditions, closeness values increase quite rapidly with distance from the central city.

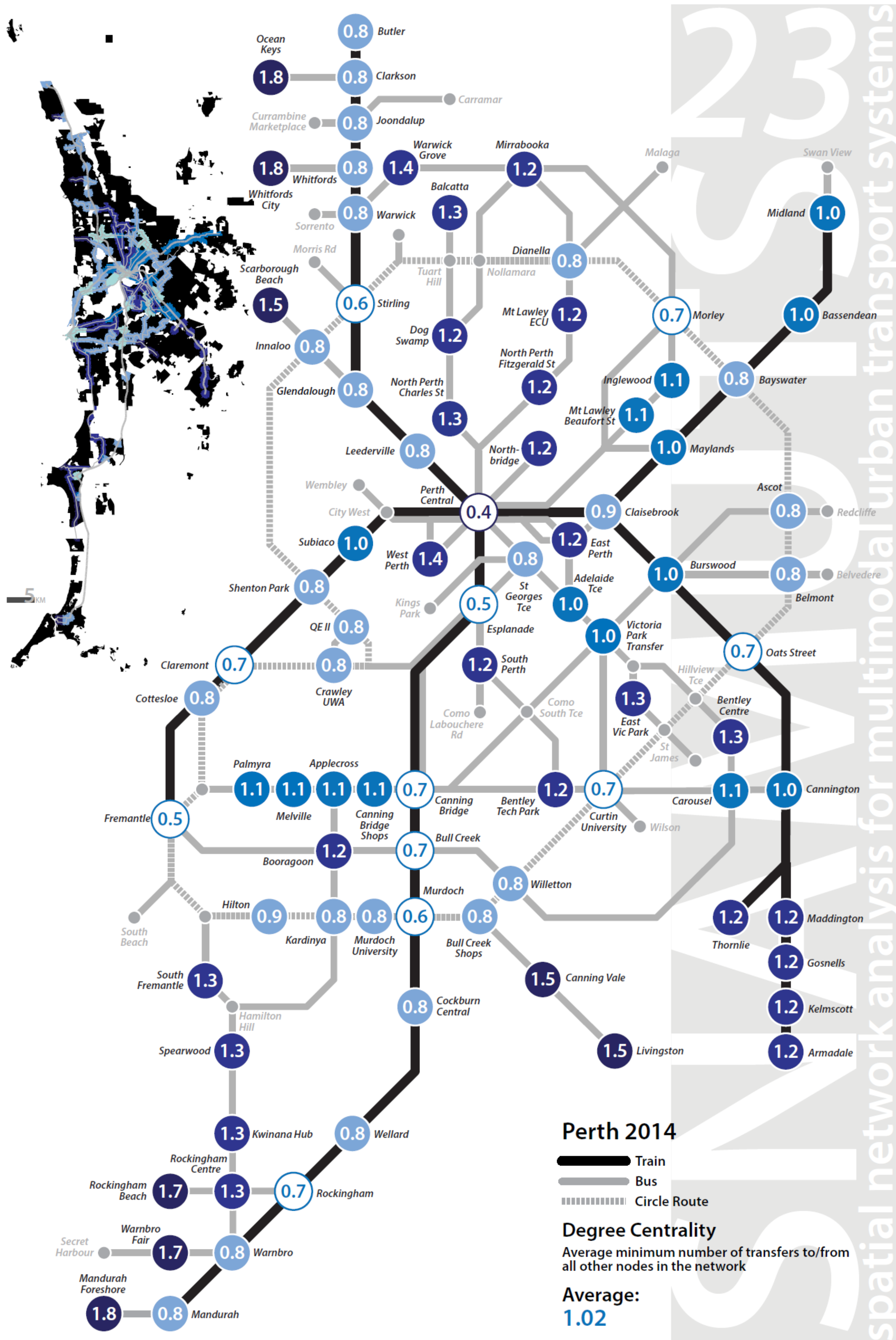
Closeness centrality values have fluctuated: first with the addition of the Mandurah line; later due to changes in the frequencies of rail and bus services. When the Mandurah Line opened in 2007, Perth's overall closeness centrality score improved, from 58.5 to 55.8. In 2009, daytime train frequencies on the north-south train line between Whitfords and Cockburn Central were cut, from a train every 7.5 minutes to one every 15 minutes resulting in the score deteriorating to 60.3. Since then, the measure has fluctuated between 59.3 (2011) and 60.9 (2016) with adjustments in bus routes and frequencies. In some cases, timetabled travel speeds along bus routes have been reduced to account for growing traffic congestions. This has had a negative effect on closeness centrality scores, and has reduced convenience for bus users.

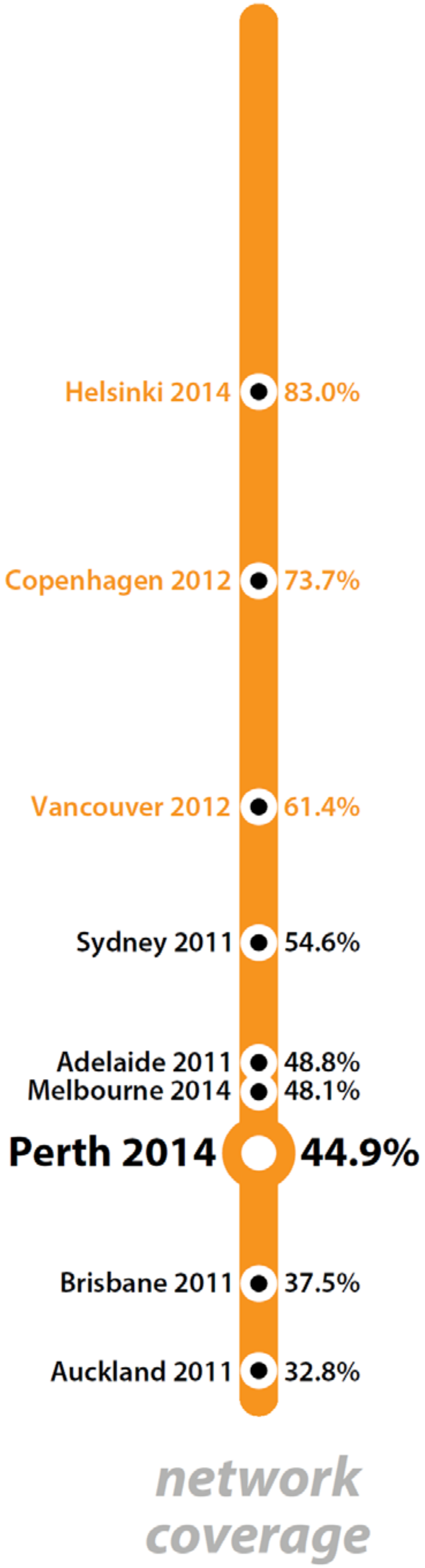
The public transport networks in Vancouver and the Scandinavian cities achieve a much better ease-of-movement standard than Perth through higher service frequencies and greater urban compactness. They also have a denser route network that allows users to move in a greater number of directions. Lattice or spider web-shaped elements dominate a larger proportion of the network, making it easy for users to reach their destinations without excessive geographical detours. Service frequencies also tend to be higher on average than in Perth.

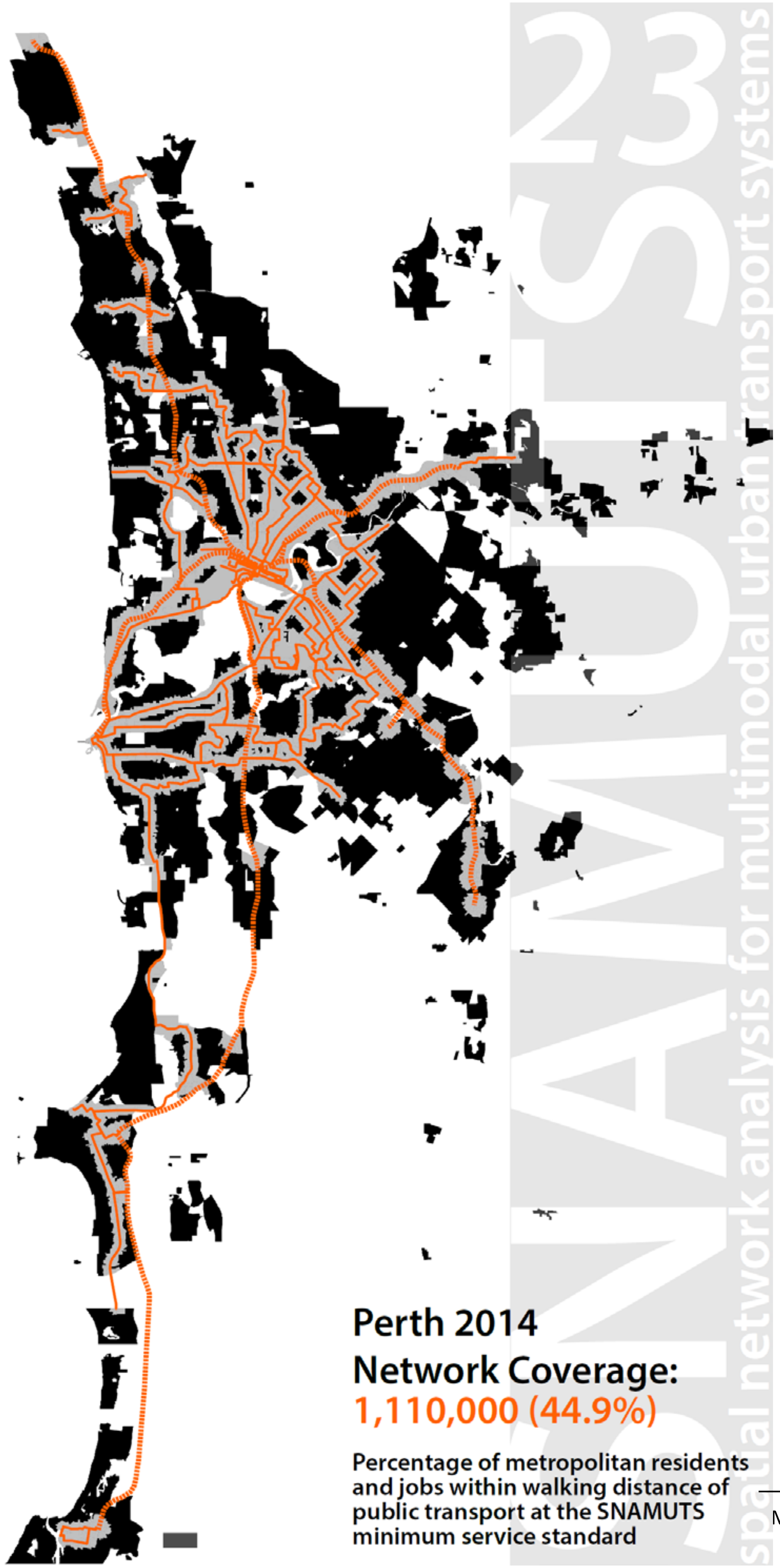
Degree centrality

This indicator measures the number of transfers users have to make on a public transport journey. Degree centrality is shown as an average value across the network and as an average for each activity node. Lower values indicate a system with lower reliance on transfers. In a network with high service frequencies a high number of transfer points can be seen as beneficial to flexibility of movement for travellers. Conversely where frequency of service is low this translates to higher overall travel times where transfers are involved, and where there are few transfer possibilities a reduction in flexibility of movement.

The indicator reveals hierarchical patterns in the network structure, including the roles allocated to different public transport modes, as well as the opportunities for multi-directional movement. The transfer intensity of Perth's public transport network is average among







Perth 2014
Network Coverage:
1,110,000 (44.9%)

Percentage of metropolitan residents and jobs within walking distance of public transport at the SNAMUTS minimum service standard

Australasian cities. Long train lines from one end of the city to the other and the Circle Route bus reduce the need for transfers, while the configuration of many bus lines as feeders to train stations increases it.

Perth's average performance on this index is similar to Sydney's but poorer than in Brisbane, Melbourne and Auckland. With few exceptions, the network has been designed to deliberately avoid operating parallel rail and bus lines along the same corridors, opting instead for a trunk-and-feeder system with clearly differentiated tasks between rail and bus. This configuration has the effect of driving up transfer values and generates a group of nodes with values significantly above the average (Warwick Grove, Scarborough Beach, Livingston, Rockingham Beach). However, the integration of the rail network with the Circle Route and other orbital bus connections, as well as the practice of operating a transfer-free rail service from one edge of the metropolitan area to the other (Butler to Mandurah and Fremantle to Midland) assists in reducing these numbers.

Before the opening of the Mandurah rail line, average degree centrality was at a level of 1.10 transfers per journey. From 2008 and 2016, it has fluctuated between 1.02 and 1.04. The Mandurah rail line, despite converting some previous radial bus routes into rail feeders that created new transfer needs, had a net effect of reducing the transfer dependency of Perth's public transport network. This is primarily due to the introduction of through services between Butler and Mandurah reducing the need for some city centre transfers, and the linking of train stations to both CBD bus terminals, creating easy connections between radial bus and train services.

The Copenhagen and Helsinki networks reduce transfer needs further by linking bus and tram lines to a greater number of train stations and activity centres than Perth. Vancouver's network increases transfer needs by following the rectangular street grid more rigidly.

Network coverage

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

Perth's Level of Service[3] by public transport accessibility is poor compared to other Australasian cities. Perth only provides higher-frequency and full-time public transport within walking distance to less than half its residents and jobs. Perth falls below Adelaide, Melbourne and Sydney, but outperforms Brisbane and Auckland, in terms of the percentage of metropolitan residents and jobs that are situated within walking distance from public transport stations or stops serviced at the minimum standard. This can be seen in the context of lower service intensity figures. In Sydney and Melbourne, the edge over Perth on this indicator is of a similar margin as for the network coverage indicator, though recent improvements to the bus network in Perth have begun to narrow the gap. Perth's lower rail station density than Melbourne's and Adelaide's, most of whose rail lines originate from the late nineteenth and early twentieth centuries and have much closer station spacing than Perth's more recent north-south line, also plays a role in limiting network coverage.

[3] Measured by SNAMUTS network coverage.

Vancouver, Helsinki and Copenhagen have a higher level of service by providing comparatively more resources into public transport operation, and by orienting more urban development around public transport nodes.

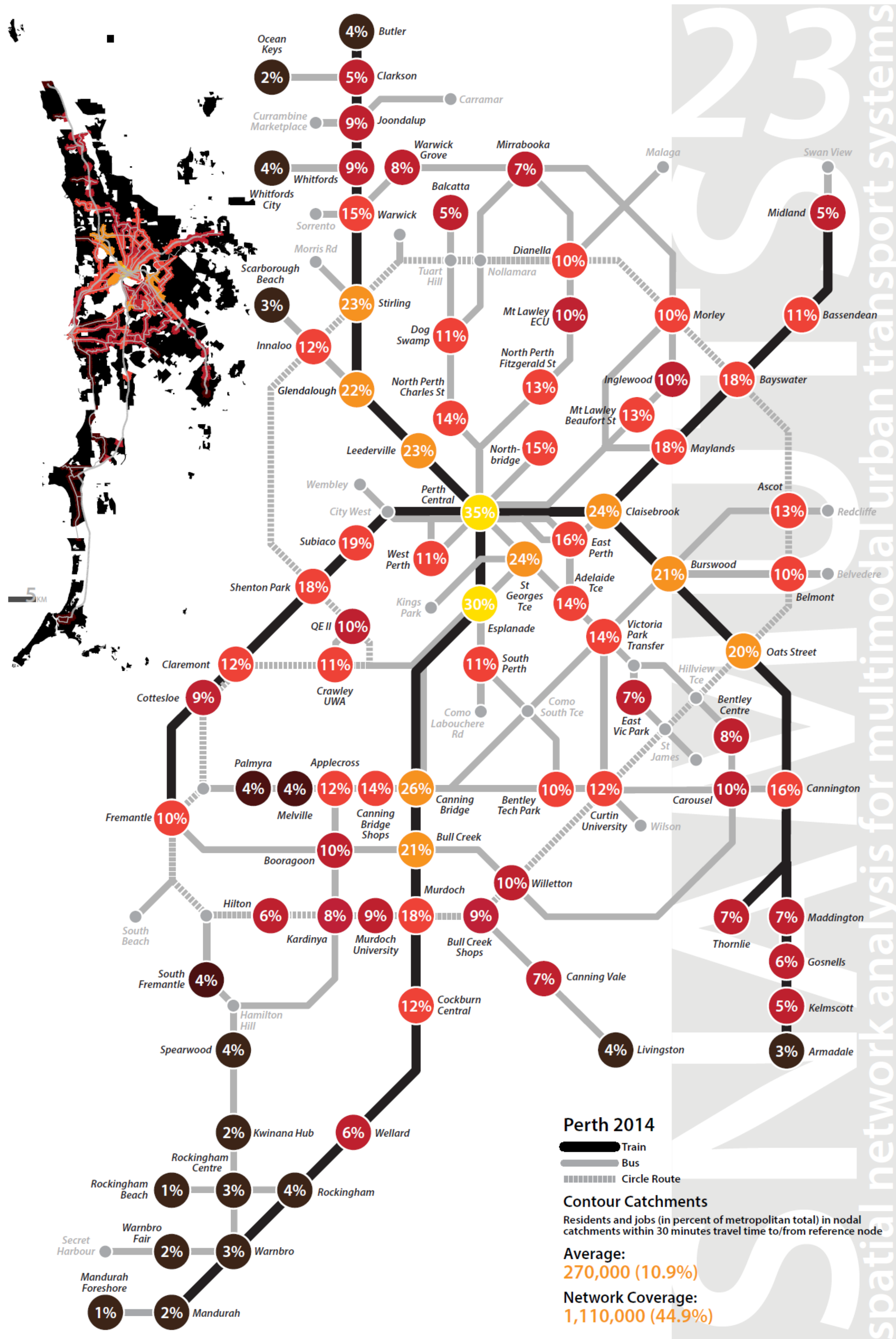
The opening of the Mandurah rail line increased network coverage modestly (from 36.7% to 39.9% of all residents and jobs); this is primarily associated to the location of the new stations either in the median of a freeway or in newly developing areas, without major pre-existing concentrations of land uses in the walkable station catchments. As the web of bus routes became denser during the following years, network coverage improved (to 41.4% in 2011) and further to an estimated 46.5% in 2016[4].

Contour catchments

The 30-minute contour catchment indicator counts the residents and jobs within all defined activity node catchments than can be reached from the reference point by kerb-to-kerb public transport journey of 30 minutes or less (a travel time contour around each activity node). The range of destinations accessible within travel time in Perth is similar to other second-tier Australasian cities, but low in international terms. This measure should be expected to fall with growing city size, giving Perth an edge over Adelaide, perhaps related to the greater speed on its train system. Larger Brisbane, however, draws almost even with Perth, suggesting that urban intensification in public transport-accessible locations in Perth has not yet occurred at the scale found in Brisbane.

On this indicator, activity nodes along fast modes (rail system, freeway bus routes) are at an advantage, indeed the Canning Bridge interchange has the third largest contour catchment network-wide. Conversely, the index drops off quite rapidly with growing distance from the CBD for all other radial bus corridors. In the middle suburbs, the figures for Stirling and to a smaller extent Shenton Park and Murdoch, show the effect of the Circle Route to expand travel contours by adding orbital directionality to the network. The network's single 'super-node' at Perth Central captures more than three quarters of the minimum-standard public transport network within a half-hour journey, representing (alongside Adelaide Central) the highest value across Australasia and illustrating the importance of the fast rail system in supporting this dispersed metropolis.

These contour catchment figures highlight the immense potential for Perth to become a more public transport-oriented city by the



4 Exact figures will only be available with the release of 2016 census data.

intensification of secondary city centres. Public transport connectivity (particularly closeness centrality of new nodes) will be central to the success of such activity centre land use strategies.

The network reforms after the opening of the Mandurah rail line increased the average contour catchment from 10.0% of all residents and jobs in 2007 to 11.4% in 2008; however, it dropped in 2009 as rail service frequencies were reduced (and accordingly, average transfer times lengthened) and has since fluctuated between 10.6% and an estimated 11.0% in 2016.

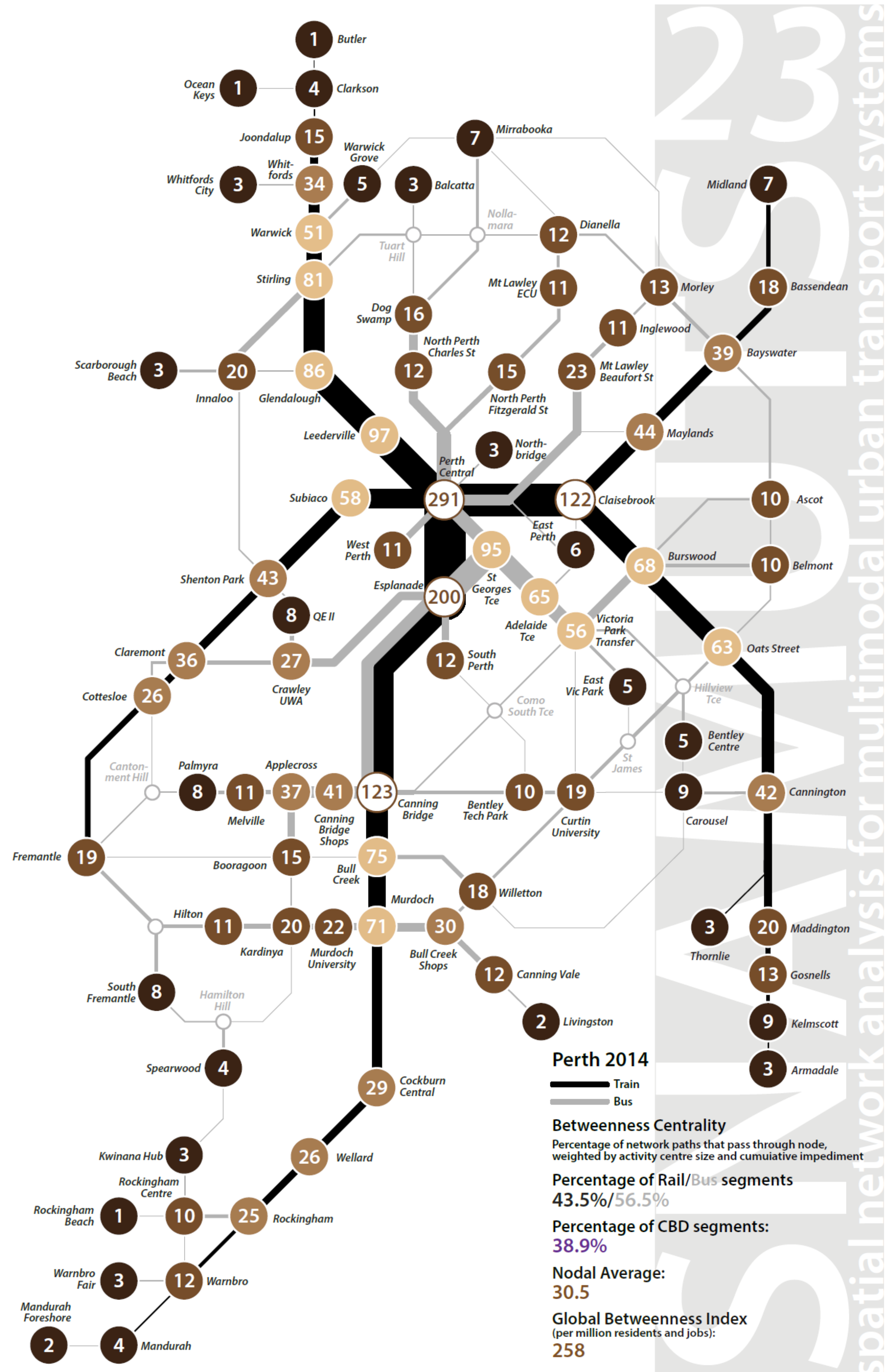
Vancouver, Helsinki and Copenhagen achieve much greater average contour catchment scores through a combination of greater urban compactness, more development around fast rail lines, higher service frequencies and a denser route network that allows users to avoid time-consuming detours.

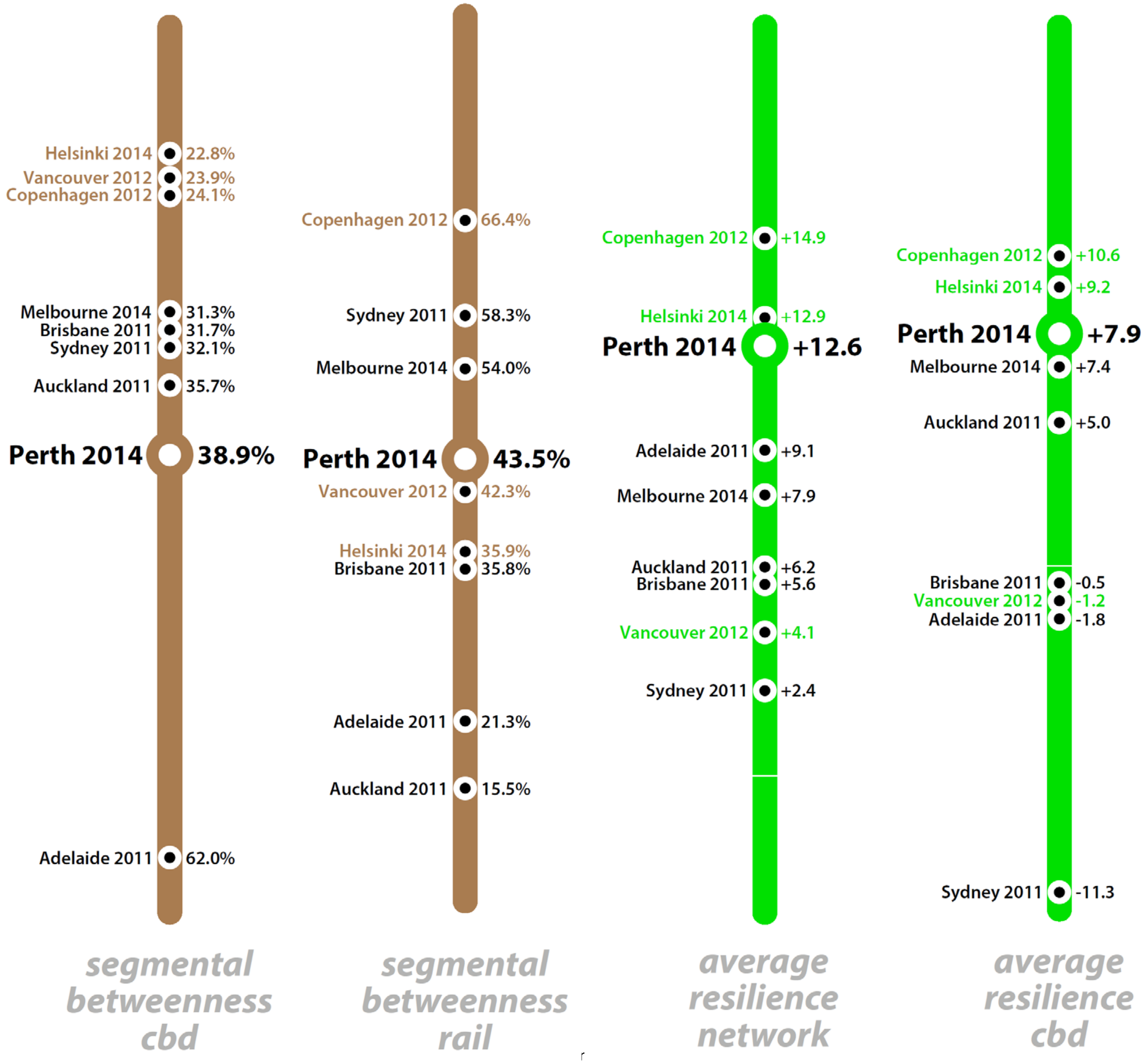
Betweenness centrality

This indicator visualises the *potential* for public transport to cater for urban movement. It shows where such 'movement energy' is concentrated and thus, to what extent an activity node or a transport corridor is located 'at the crossroads' of public transport supply.

Perth's public transport network is highly centralised: it primarily services the CBD area and channels many suburb-to-suburb journeys through the central city. In recent years, this constraint has been relieved marginally by service improvements to many suburban bus lines, making non-CBD journeys more attractive. Perth relies more on the rail system than other second-tier Australasian cities to facilitate public transport movement. However, since the Mandurah rail line opened, rail services have improved only marginally and buses have grown in relative importance.

In Perth, like in Sydney and Brisbane, the network stretches over a vast dispersed area compared to the number of inhabitants. As a result, the global betweenness indicator is more depressed than if the city were more compact. However, relative to population and jobs it represents the second highest result among the Australasian cities, outperformed only by Adelaide which has a vastly superior input of services. This illustrates the impact of the 15-minute rail frequencies and the high rail speeds on the generation of travel opportunities, compared to the 30-minute standard and slower services prevailing elsewhere. Perth appears to be more successful in channelling travel opportunities along the high-performance rail system, manifest in a rail share of the total betweenness score inferior only to much larger Sydney and Melbourne among its regional peers. Partly in consequence, however, the CBD share of the





orientation of the rail network and the scarcity of orbital links. In the Canadian and Scandinavian comparison cities, this constraint has been addressed by a network design that allows for far more convenient non-CBD journeys on public transport. This approach also drives up the global betweenness score in those cities.

Global betweenness in Perth rose from a level of 246 per million activities in 2007 to 259 in 2008 as a consequence of the Perth to Mandurah rail line opening; however, it dropped again to below the previous level in the following year following the reduction in daytime service frequency on the north-south trunk line. By 2016, global betweeness is estimated to have recovered roughly to the 2008 level thanks to the frequency improvements across the expanding bus network. Simultaneously, the Perth to Mandurah line shifted travel opportunities towards the rail network (from a share of 41.2% in 2007 to 51.7% in 2008). After the 2009 rail service cuts and subsequent bus improvements, this ratio shifted again in favour of buses, which captured 53.5% of travel opportunities in 2011 and an estimated 56% in 2016. The growth of the network and the improved accessibility of more non-CBD destinations has resulted in a decentralisation effect: while the CBD channelled 44.5% of travel opportunities prior to the Perth to Mandurah line in 2007 and only marginally less (43.0%) after its opening in 2008, this share dropped to 40.0% by 2011 and likely further to below 39% by 2016.

Vancouver, Copenhagen and Helsinki do not depend on their CBD interchanges as much as Perth to facilitate public transport journeys. They have stronger and more attractive orbital links and a network structure in the inner and middle suburbs that allows users to largely follow geographical desire lines between origin and destination.

Network resilience

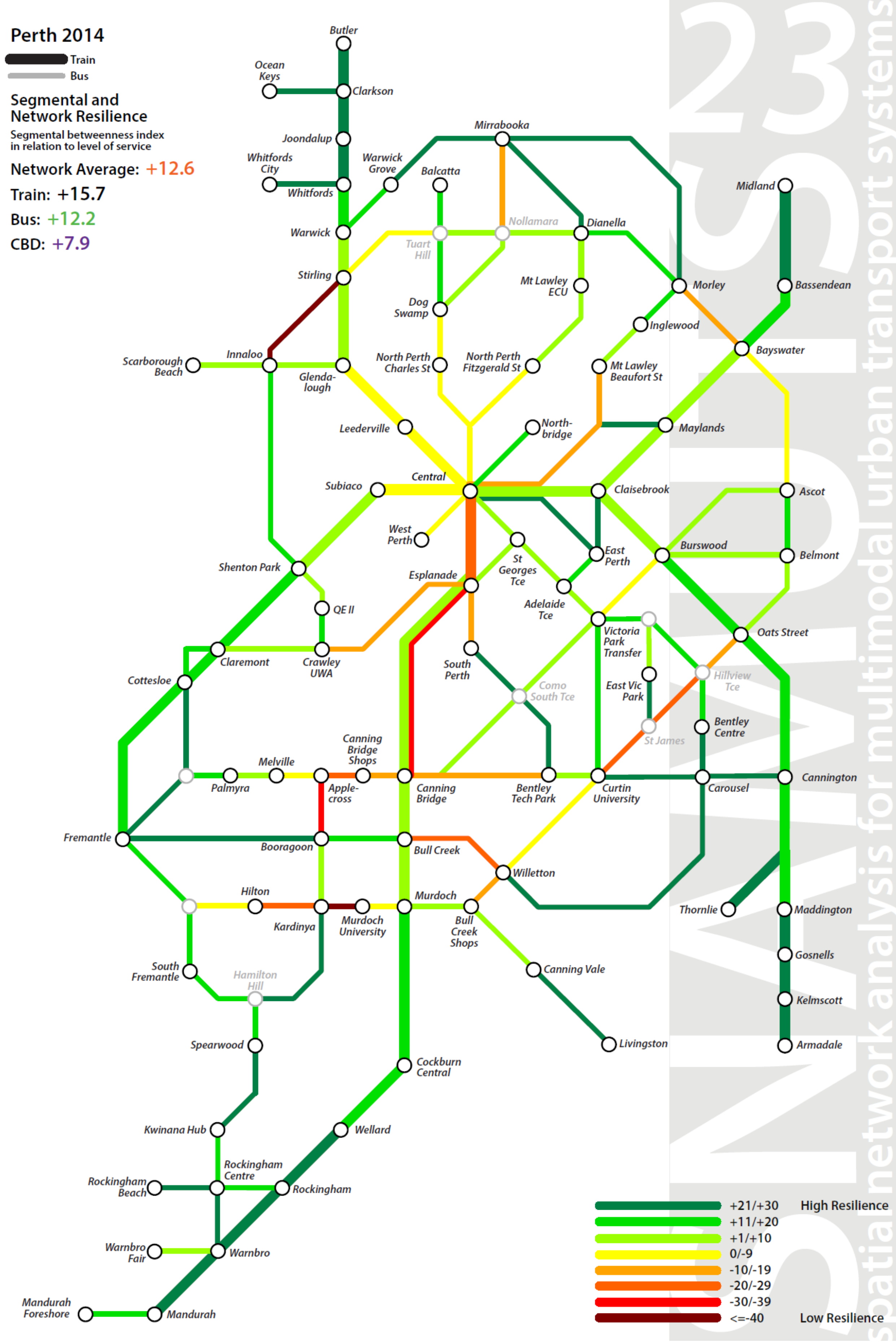
The resilience indicator provides a comparison between the significance of a route segment for the land use-transport system (betweenness) and the level of service provided (capacity).

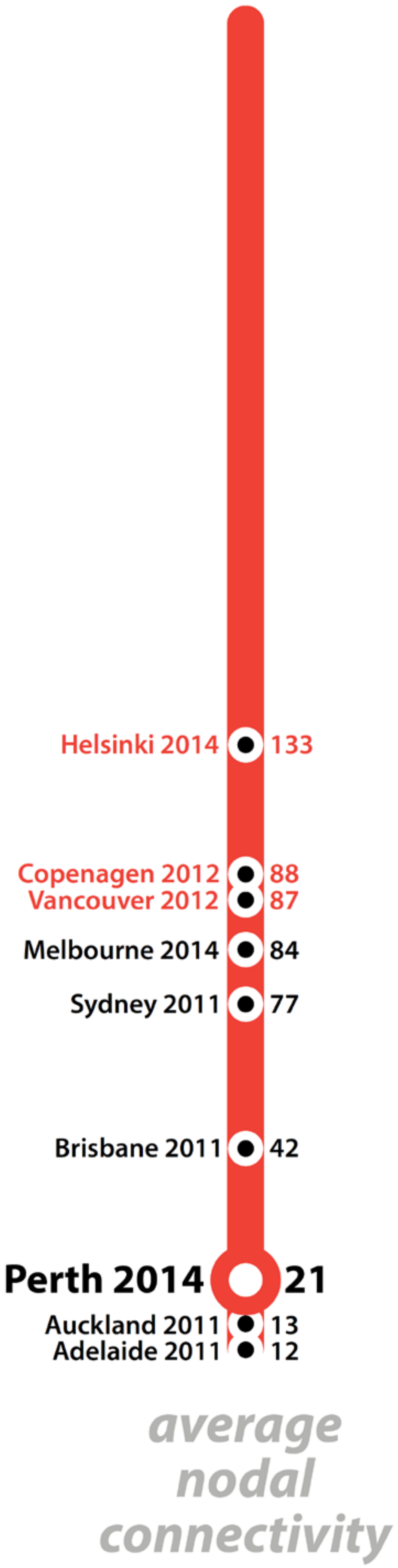
Perth's public transport network currently has the least resilience problems among the Australasian peers, due primarily to the pace of rail network expansion over the past 25 years. A continuing high rate of population growth, however, will erode this advantage in the future, unless further substantial investment is made to increase the capacity of public transport in both established and newly urbanised areas.

Perth has the best average segmental resilience results among the Australasian cities, indicating that the distribution of transport tasks to rail and bus along a hierarchical model offers a more robust network able to accommodate further growth. However, the network resilience indicator also suggests several problems. High stress values are frequently found on short bus feeder sections to rail lines (Innaloo to Stirling and Glendalough, Booragoon to Canning Bridge, Curtin University to Oats Street or Kardinya and Willetton to Murdoch). Here, the location of many rail stations away from concentrations of land use activity (much of Perth's north-south rail line is situated in a freeway median) is evident and highlights the need for land use strategies to focus on converting rail-bus transfer nodes to significant activity centres (as is the case at Murdoch, Stirling, Cockburn Central). Resilience figures also deteriorate on some radial bus corridors (Alexander Drive between central Perth and Dianella in the north-east; central Perth and Crawley-UWA in the west).

Copenhagen and Helsinki achieve a higher rate of network resilience than Perth by providing more resources to their public transport networks, and by offering a greater number of attractive route choices that help users avoid lines or areas where congestion occurs.

The opening of the Mandurah line brought significant relief averting a mounting capacity crisis on the public transport network. Since then there has been a gradual deterioration of resilience on the rail network, from a peak of +19.1 in 2008 to +16.4 in 2011 and a likely value below +15 in 2016 (daytime service levels were reduced in 2009 and have been stagnant compared to population and patronage growth since). Conversely, average resilience on the bus network improved following network and service improvements (from +7.4 in 2007 to +10.7 in 2011 and a likely stabilisation until 2016). Average network resilience in the CBD area, however, is expected to worsen, suggesting that service and network measures are required both to increase capacity in the CBD and to offer more journey options that enable users to bypass the CBD area.





Nodal connectivity

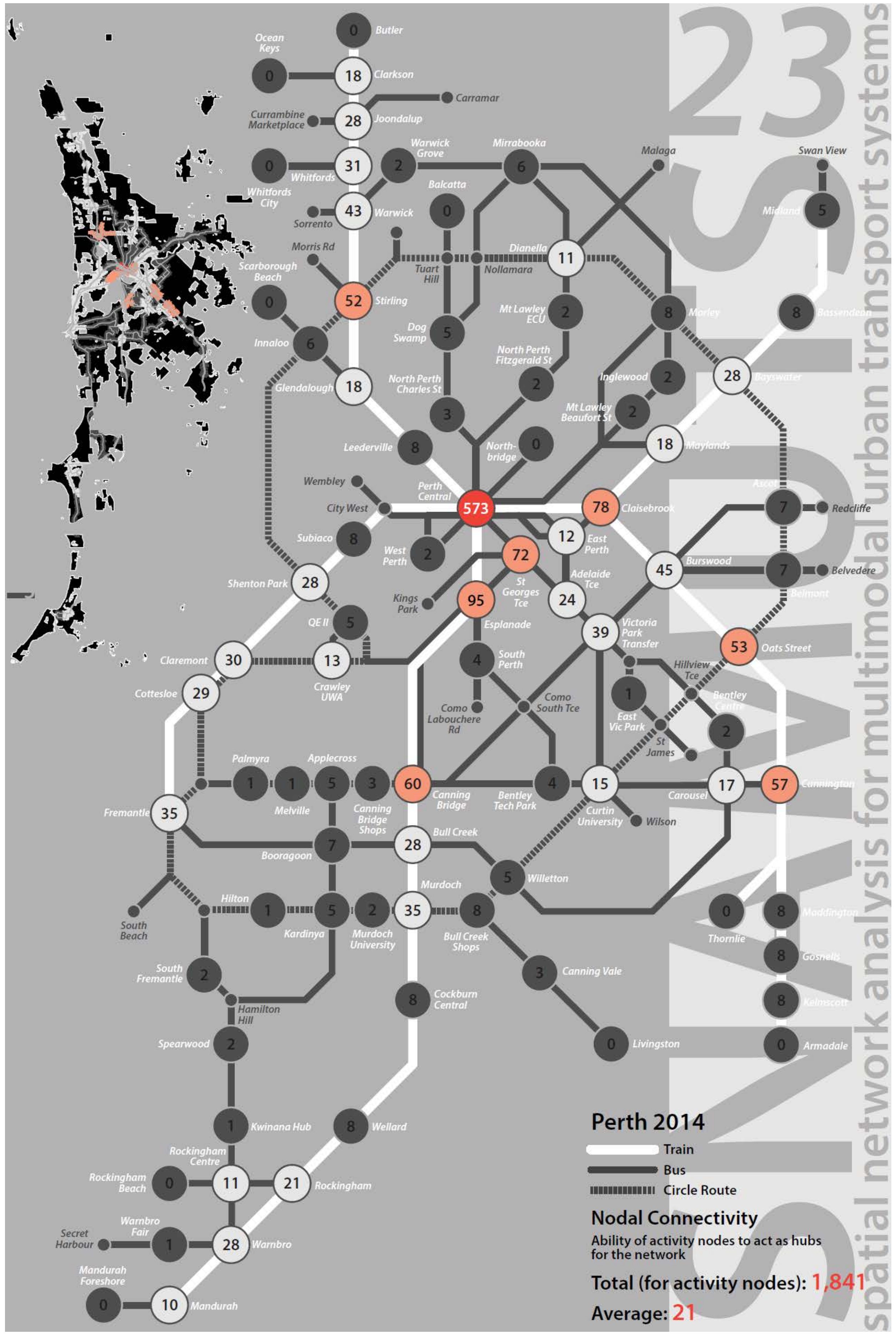
This indicator measures the strength of each activity node for integration of multi-modal public transport services, and by extension, the flexibility of users to move around the city on public transport. It captures the suitability of activity nodes for making transfers or breaks of journey with minimal disruption to the flow of movement. Nodal connectivity can thus be seen as a proxy for the confidence that can reasonably be exerted by residents to build their activities around public transport use, or by businesses around public transport access.

Perth's average nodal connectivity is third lowest in the global SNAMUTS sample before Adelaide and Auckland. There has been a small improvement in average nodal connectivity since the Mandurah rail line was opened: in 2007, the average nodal value was 14, and 19 at 2011. In 2016, it is estimated be in the low 20s, but is much lower than the average performance of cities with greater concentrations of land uses in inner areas (Brisbane), or with larger public transport networks with a greater number of transfer points overall (Sydney and Melbourne).

Only in the very centre of Perth does it appear reasonable for residents and businesses to rely primarily on public transport to travel around the city (shown by the red colour of the dot on this map). Suburban centres suffer from a low number of converging lines and limited service frequencies, which restricts the number of destinations that can be reached with ease, and increases waiting times. This suggests that many suburban centres as well as CBD fringe areas would require significant boosts in service levels as well as additional links in new directions if they were to become genuinely attractive locations for transit oriented development (TOD).

Larger cities like Melbourne and Sydney address this constraint by relying more on mid-capacity modes (trams and ferries) rather than buses, and by offering more suburban nodes from where users can travel in many directions.

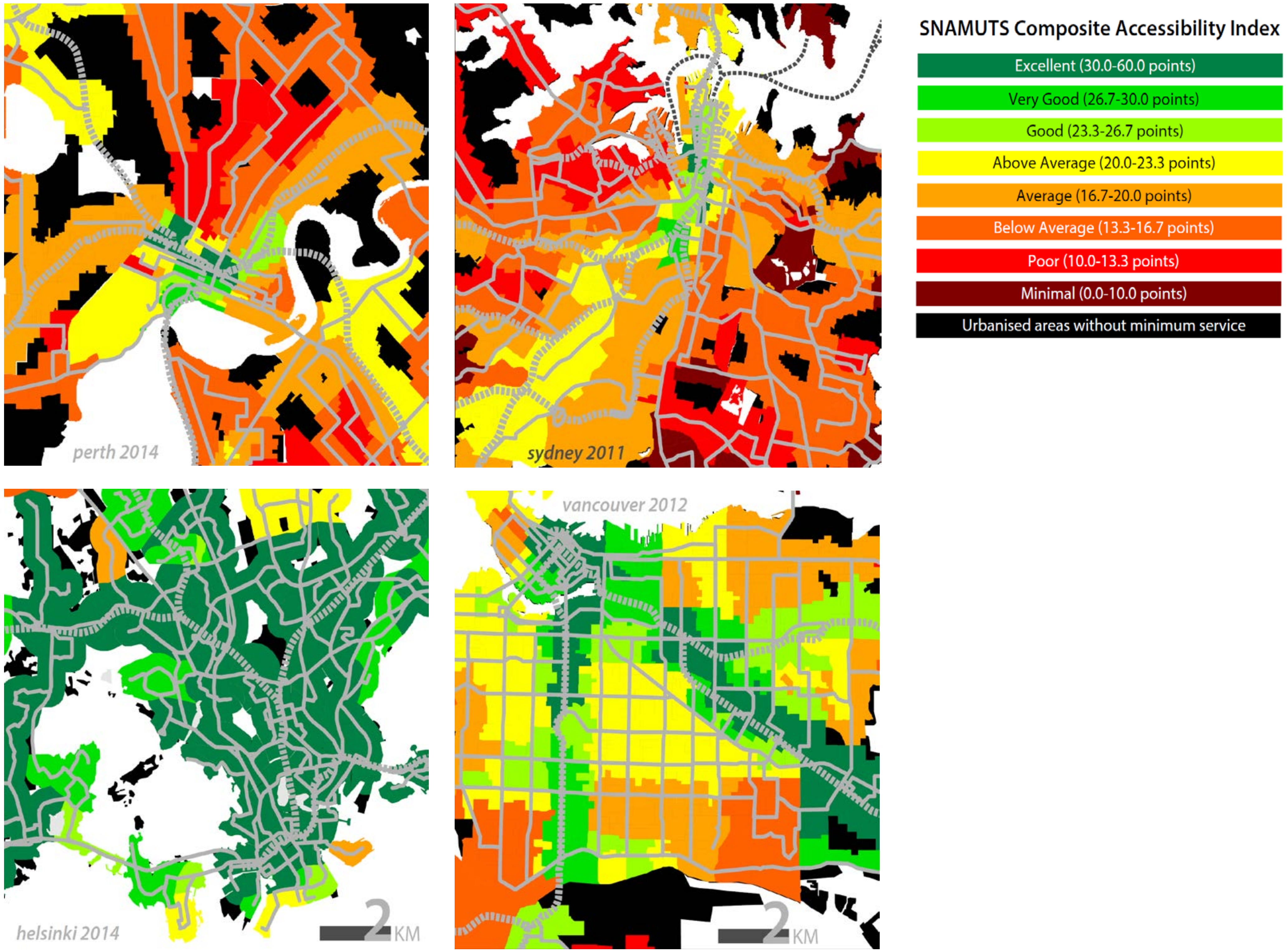
Vancouver and the Scandinavian cities have a more proactive policy to concentrate urban development around public transport interchanges with excellent service, and to maximise the number of such places. Considerable research over recent years has highlighted Park-and-Ride's negative effect of displacing urban actives away from railway stations, and reducing their effectiveness as a transfer point and as an urban destination (Mees 2014; Imran and Matthews 2015).



4. Summary and Conclusion

The characteristics and deficiencies of Perth's public transport are most strongly highlighted by composite accessibility maps, which integrate several of the SNAMUTS indicators to provide a broad overview of the accessibility of each district within a city. These maps, comparing only the central areas of each city, a 12 km square, serve to highlight Perth's central city focussed system, especially in comparison to Helsinki or Vancouver, which have lines structured to allow transport in almost any direction.

This analysis strongly demonstrates that Perth's public transport system has an excessive emphasis on servicing the central city area, driven largely by efficiency and cost-minimisation goals. While this assists in reducing peak-period congestion on Perth's freeway and highway network, improving the level of service provided by Perth's public transport system will require a shift to servicing a broader range of destinations. This includes the provision of orbital links and more high frequency direct connections between major activity nodes.



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