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Benchmarking Accessibility and Public Transport Network Performance in Copenhagen and Perth

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Abstract

As a result of rapid metropolitan growth, Perth is poised to overtake Denmark's capital Copenhagen in terms of population size within this decade. The city's 'coming of age' has also sparked a fundamental rethink about how urban transport is organised: during the past twenty years, Perth gradually shifted from a system of near-universal automobility towards the emergence of at least a core network of competitive public transport, including some of Australia's pioneering efforts at integrating land uses around multimodal accessibility.

Copenhagen is one of Europe's lowest-density cities and does not stand out among its neighbours for an extraordinarily successful public transport system. However, a benchmarking exercise using the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool reveals that in 2009, land use-transport integration as well as public transport network performance in Copenhagen were superior to Perth by orders of magnitude.

This paper will describe how the varying performance of both cities' land use-transport systems has evolved in the past and make a detailed comparison of accessibility performance from several angles. It will then move on to the more pertinent question whether Perth has any realistic chance to approach or match the levels of accessibility performance found in Copenhagen in years to come. For this purpose, we will draw on some future scenarios for land use and infrastructure priorities developed for the WA government in 2009 with the aid of the SNAMUTS tool. How radical a departure from current urban development and mobility trends would be required if Perth were to ascend to the ranks of an average-performing European city? How would Perth's growth need to be accommodated and what infrastructure and service measures would need to be pursued until 2030 if this goal was imperative to strategic planning?

1. Introduction: Perth and Copenhagen

The cities considered in this comparison, Perth and Copenhagen, both occupy a second-tier role in the urban hierarchy of their national/regional context. Perth is the capital of Australia's fourth largest (by population) and arguably most geographically isolated state, while Copenhagen is the capital of Denmark, one of Europe's smaller countries with a total population comparable to that of Victoria. In 2008-09, there were 1.68 million inhabitants in the Perth metropolitan region, stretching over a land area of 7,270 sq km (ABS, 2010) while in Copenhagen, 1.85 million inhabitants occupied a metropolitan area of 2,780 sq km (DST, 2010). Perth experienced its most rapid growth period after World War II, mostly on the late-

modernist paradigm of functional segregation, single-family detached homes as the dominant housing form, and an assumption of universal automobile access for practically all journey purposes. Consequently, overall urban density is among the lowest in the world at 13.6 residents and 6.3 jobs per urbanised hectare in 2008 (ABS, 2010). Growth continues at a fast pace, particularly along the Indian Ocean coastline that constrains Perth's expansion to the west, and the city is expected to more than double in size during the next 40 years.

Like Perth, Copenhagen was subject to substantial spatial expansion in the years after 1945, and while much of this growth also followed the modernist paradigm of the day, it did so along a pattern of growth corridors along radial rail lines, and green wedges in between (Svensson, 1981). This template is known as the Finger Plan, directing urban growth in the shape of a handprint, with the palm of the hand depicting the denser, pre-war parts of the city centred on the municipalities of Copenhagen and Frederiksberg. Metropolitan planning since the 1970s converted the radial Finger Plan into a more lattice-shaped pattern, aided by the construction of an orbital motorway system alongside the radial rail network. Today, Copenhagen is among the lowest-density metropolitan areas in Europe at 25.2 residents and 13.5 jobs per urbanised hectare (DST, 2010). Fixed bridge and tunnel connections to the Danish mainland and to Malmö in Sweden, opened in the late 1990s and early 2000s, have reduced the city's relative geographical isolation and increased functional interdependence particularly with the Swedish province of Skåne, which is now within convenient commuting distance to and from Copenhagen.

Perth's public transport system was all but abandoned between the 1950s and 1970s: the city closed down an expansive tram system during the 1950s and left a limited, diesel-operated suburban rail system to languish in neglect before embarking on its gradual closure as well, starting with the Fremantle line in 1979. Community opposition and a change of government in 1983, however, led to a reversal of this trend and subsequently, a modernisation and expansion agenda for the rail system. The Fremantle line was reopened in the same year, the existing system electrified and supplied with state-of-the-art rolling stock in 1991, before eventually doubling in size with the construction of new routes to the north (1993) and south (2007), in response to the increasing north-south orientation of the city parallel to the coastline (Newman and Kenworthy, 1999). Today, Perth arguably operates the most efficient urban rail system in the country, planned and coordinated by a government agency also in charge of buses, whose integration with rail is superior to that found in other Australian cities (Mees, 2010). In the context of Perth's growth projections, however, the pressure to significantly expand the public transport system continues, both to allow it to capture a greater share of the urban travel market and to prevent excessive congestion on the still-dominant urban road system: during the 2000s, Perth's public transport mode share by trips still hovered around the 5% mark (James and Brög, 2003).

Copenhagen, like Perth, abandoned its first-generation tram system in the 1960s but unlike Perth, maintained a dense, high-frequency, grid-shaped bus system in its place, particularly across the older, inner neighbourhoods. Simultaneously, the city expanded its suburban rail system to provide a backbone of mobility along all the suburban corridors of the original Finger Plan. In recent years, public transport infrastructure development has focussed on upgrading and extending an inner orbital rail line to take pressure off the central area, the introduction of a new driverless metro system to service a central corridor and to access inner urban growth areas, and the development of new and improved regional rail services, including across the new fixed link to Sweden. The bus system, functionally and institutionally integrated with rail like in Perth, has also been restructured to provide three colour-coded types of services: high-frequency inner urban routes (red), cross-city express routes (blue) and suburban feeder routes (yellow). Overall, however, public transport's market share in 1995 amounted to 16%, no better than average for a European city and significantly lower than, for example, Munich (27%) or Vienna (30%) (Kenworthy and Laube, 2001). Copenhagen does stands out among its European neighbours for its very high share

of bicycle travel though, supported by expansive infrastructure, and for long-standing restrictive policies on car parking in the CBD as well as comparatively high taxes on vehicle sales. Together, these result in comparatively low rates of car ownership and wide proliferation of carfree lifestyles particularly in inner urban areas, an effect that is all but absent from Perth (Scheurer, 2001).

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

As a multifaceted set of accessibility indices, SNAMUTS has been developed in the context of several research and consultancy projects funded by public agencies in Victoria, Western Australia and the Commonwealth since 2006 (Scheurer, Bergmaier and McPherson, 2006; Scheurer and Porta, 2006; Scheurer and Curtis, 2008; Curtis and Scheurer, 2009). It is a GIS-based tool designed to assess centrality and connectivity of urban public transport networks in their land use context. In particular, SNAMUTS endeavours to identify and visualise a land use-transport system's strengths and weaknesses of geographical coverage, ability and efficiency to connect places of activity, strategic significance of routes and network nodes, and speed competitiveness between public transport and car travel in a coherent mapping exercise. The tool is designed to reflect a vision of world best practice in public transport supply 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, 2005), as well as in Mees (2010).

In its initial stage of development (Scheurer and Porta, 2006), SNAMUTS was adopted from an analytical tool designed to assess the performance of individual movement networks (pedestrians and/or private vehicles) in specific urban settings, sometimes quite small in scale (Porta, Crucitti and Latora, 2006a, 2006b; Crucitti, Latora and Porta, 2006; Latora and Marchiori, 2002). The adaptation of this methodology to public transport networks expanded it to the size of entire metropolitan regions, or sub-regions, placing further emphasis on the distribution of land use activities to arrive at more accurate measures of network performance. Thus SNAMUTS evaluates regional-scale land use-transport integration and hence, accessibility (Bertolini, 2005). To make the application valid in the context of a real-world public transport system, careful consideration is needed of how the analysis of public transport networks diverges, and requires different assumptions and definitions, from the analysis of movement networks for individual transport (ie. pedestrians, cyclists and motorists). This issue has been discussed in detail in a previous ATRF paper by Scheurer, Curtis and Porta (2007) and led to the conceptualisation of an *impediment measure* that uses *average travel time along a route segment divided by the frequency of the service* (number of departures per hour per direction) as a proxy for spatial separation, or path distance. SNAMUTS further defines a number of *activity nodes* on the network as public transport stations or stops located in activity centres as identified in strategic planning documents such as Perth's Directions 2031 (WAPC, 2009), or as major multi-modal transfer points. Each transfer-free connection between any two activity nodes on the network is defined as a *network edge* in its own right, hence the number of transfers required along a given path is always equal to the number of edges traversed less one. By this method, paths across the network can be clearly measured both metrically (cumulative impediment value) as well as topologically (number of segments between transfers).

In an application funded as a component of an ARC Linkage Grant on transit-oriented development in a new rail corridor during 2007-08, the SNAMUTS tool was used and further refined to undertake a comprehensive before-and-after comparison of network performance across metropolitan Perth associated to the opening of the Perth to Mandurah rail line in December 2007 (Scheurer and Curtis, 2008; Scheurer, 2008). This work led to the commission of a further study funded by the WA Department of Planning and Infrastructure,

working with stakeholders to compile and investigate scenarios for future urban growth in metropolitan Perth until 2031, designed around various templates of transport-land use integration (Curtis and Scheurer, 2009). These sources also contain significant detail on the purpose and methodology of each SNAMUTS indicator used in this paper.

3. Applying SNAMUTS to Perth and Copenhagen

To arrive at a valid comparison between network performance in Perth and Copenhagen, a minimum service standard for inclusion of a route into the SNAMUTS database has been determined. As in previous benchmarking exercises (Scheurer, 2009), the minimum service standard is a 20-minute frequency during the interpeak period on Mondays to Fridays, and a 30-minute frequency during the day on both Saturdays and Sundays. This level has been set because it reflects a practical minimum at which users are likely to consider public transport a competitive mode for a variety of journey purposes, even if they have a car available. For Perth, the SNAMUTS results from the original study (Curtin and Scheurer, 2009), which used a more lenient standard, were adapted for this comparison.

In Copenhagen, 20 minutes is the standard pulse of the public transport system: while the suburban rail system is generally operated at 10-minute intervals along all routes during business hours, suburban (yellow) and express (blue) buses vary between 10-minute and 20-minute intervals. Most inner urban (red) bus routes and the metro have intervals of less than 10 minutes – 3 minutes in the case of the metro trunk route. In Perth, the standard frequency across the rail system is 15 minutes, matched by most connecting bus routes that are included in the SNAMUTS model. A large number of bus routes, however, are operated at 30-minute or 60-minute intervals, or have frequencies drop significantly outside business hours, particularly on Sundays, and were hence not included in the exercise described here. For this reason, the comparative figures for overall service provision for both cities obscure a greater proportion of lower-frequency services in Perth than they do in Copenhagen. To operate Perth's component of the weekday interpeak network at SNAMUTS minimum service standards, a total of 25 train sets and 143 buses are required to be in operation simultaneously. In Copenhagen, the comparable figures are 81 suburban train sets, 16 metro train sets, 329 buses and 2 ferries. Relative to population, Copenhagen's service intensity is more than twice as high as Perth's, with 24.2 vehicles/train sets per 100,000 inhabitants compared to Perth's 11.7. Thus to provide a public transport service at a standard critical to be competitive to car use, Perth would need to double its input to draw even with Copenhagen.

This chasm is also evident in the geographical coverage of the minimum-service networks. For this data item, the numbers of residents and jobs located within a maximum 800-metre walk from train stations or 400-metre walk from bus corridors included in the SNAMUTS database are expressed as a percentage of the metropolitan total. (For procedural purposes, they refer to statistical districts fully or mostly within such contours, rather than individual properties). In Copenhagen, 72% of metropolitan residents and jobs enjoy such walkable access to competitive public transport services, while in Perth, this proportion only amounts to 41%. Thus Perth would also need to nearly double its network's geographical coverage to provide a standard equivalent to Copenhagen.

To allow for the SNAMUTS indicators to be drawn, it was further necessary to settle on a list of activity nodes for each city. In Perth's status quo network, 71 activity nodes were derived from the activity centre hierarchy included in strategic planning documents such as Network City (WAPC, 2004) and Directions 2031 (WAPC, 2009). The equivalent figure for Copenhagen is 128. The difference is roughly proportional to the difference in metropolitan size and public transport network coverage, with the average number of residents and jobs per activity node in Perth at 12,180 and in Copenhagen at 15,075.

4. Comparative SNAMUTS indicators

4.1. Closeness Centrality

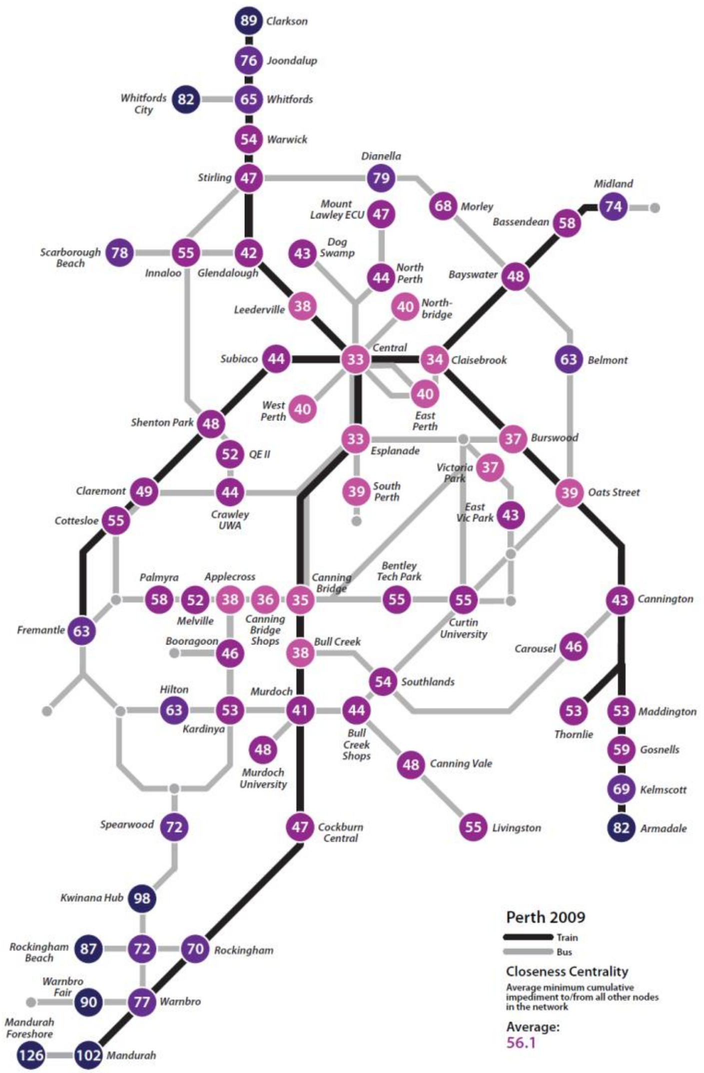
The first indicator, *closeness centrality*, uses a GIS-based pathfinding model to determine the journey with the lowest cumulative impediment value between every pair of nodes on the network. It attempts to capture *the proximity and ease of movement between origins and destinations* across the network, as measured in the travel impediment category explained above. This procedure preferences transfer journeys over direct journeys wherever this results in a reduction of cumulative impediment; however, a maximum of three transfers per trip applies. The closeness centrality index takes average cumulative impediment values for all paths that start or end at a particular node, as well as an average across the network. Lower figures indicate greater centrality. Maps 1 and 2 show the results for both cities.

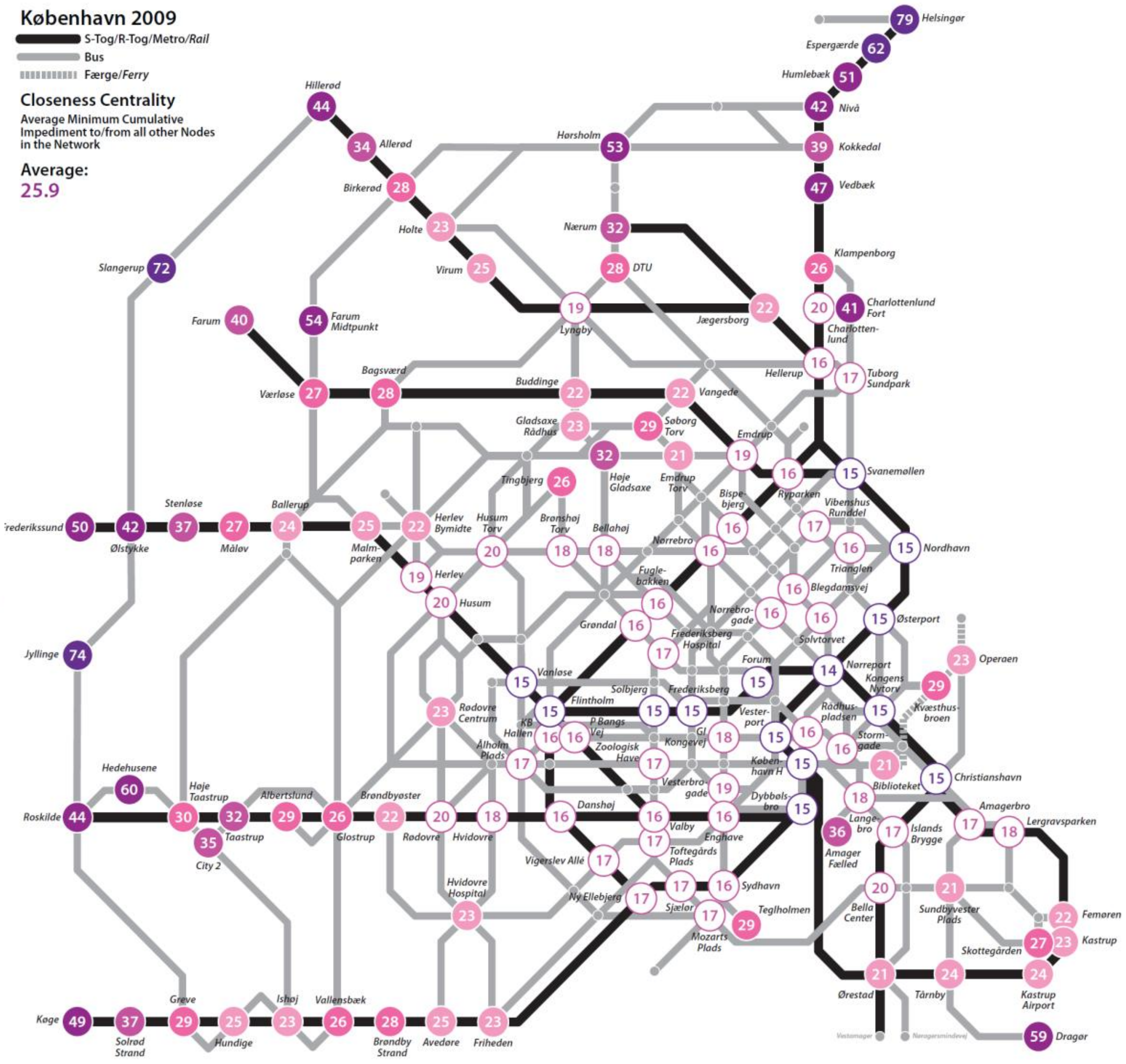
Average closeness centrality per activity node in Perth is 56.1, while in Copenhagen it is 25.9. The best score on this index for an activity node in Perth is 32.7 (Perth Central), a figure still significantly higher even than the Copenhagen average. In fact, only 24 out of 128 nodes in Copenhagen have closeness centrality scores that rise even to within the bandwidth of Perth's nodes, and most of these are located at considerable distance of from the central city.

The reasons for this substantial difference in performance between the two cities are primarily related to network density and service provision, particularly in the inner area. Perth's minimum-standard public transport network consists of a group of radial rail and bus routes with few interconnections, with the exception of a bus circle route orbiting the central area at a radius of between 6 and 15 km. In Copenhagen, the structure of the network, particularly within the area circumscribed by the inner orbital rail line (connecting Hellerup and Ny Ellebjerg via Nørrebro, Flintholm and Danshøj) is akin to a tightly-knit grid, offering a multitude of route choices for any node-to-node journey and a similar abundance of potential transfer points. Passengers in Copenhagen thus have the option to travel along geographical desire lines, including for chain journeys involving multiple destinations, whereas in Perth, movement is much more prescribed along a limited number of corridors with even fewer transfer points.

Service frequencies also have a strong impact on this indicator. In Perth, the only routes with weekday interpeak frequencies of less than 15 minutes are some bus trunk routes (such as along Adelaide Terrace, Mounts Bay Road or Alexander Drive) and the CAT bus services in the CBD and Fremantle. All rail lines except the section between Perth Central and Cannington (7.5 minutes) are operated every 15 minutes, following a service cut on the north-south route in 2009 in an untimely response to a period of rapid passenger growth. In Copenhagen, service intervals between 3 and 6 minutes during the weekday interpeak period are standard across the metro network as well as the busiest routes of the suburban rail network, including the inner orbital line. A similar standard applies to the high-frequency (red) bus routes in the inner area.

Less significant, though not entirely without impact on the two cities' performance for this indicator is the compactness of the urban structure. Where clusters of activity are located in closer proximity, one would expect that they offer greater ease of movement between each other, all other influences such as service speed and frequencies being equal. In Perth, 29 out of 71 nodes (41%) are located within the arc described by the circular bus route between Crawley/UWA and Curtin University via Stirling and Morley, and on to Canning Bridge, a radius of some 6-7 km from Perth Central station. In Copenhagen, there are 62 out of 128 nodes (48%) within a similar radius from Nørreport station.





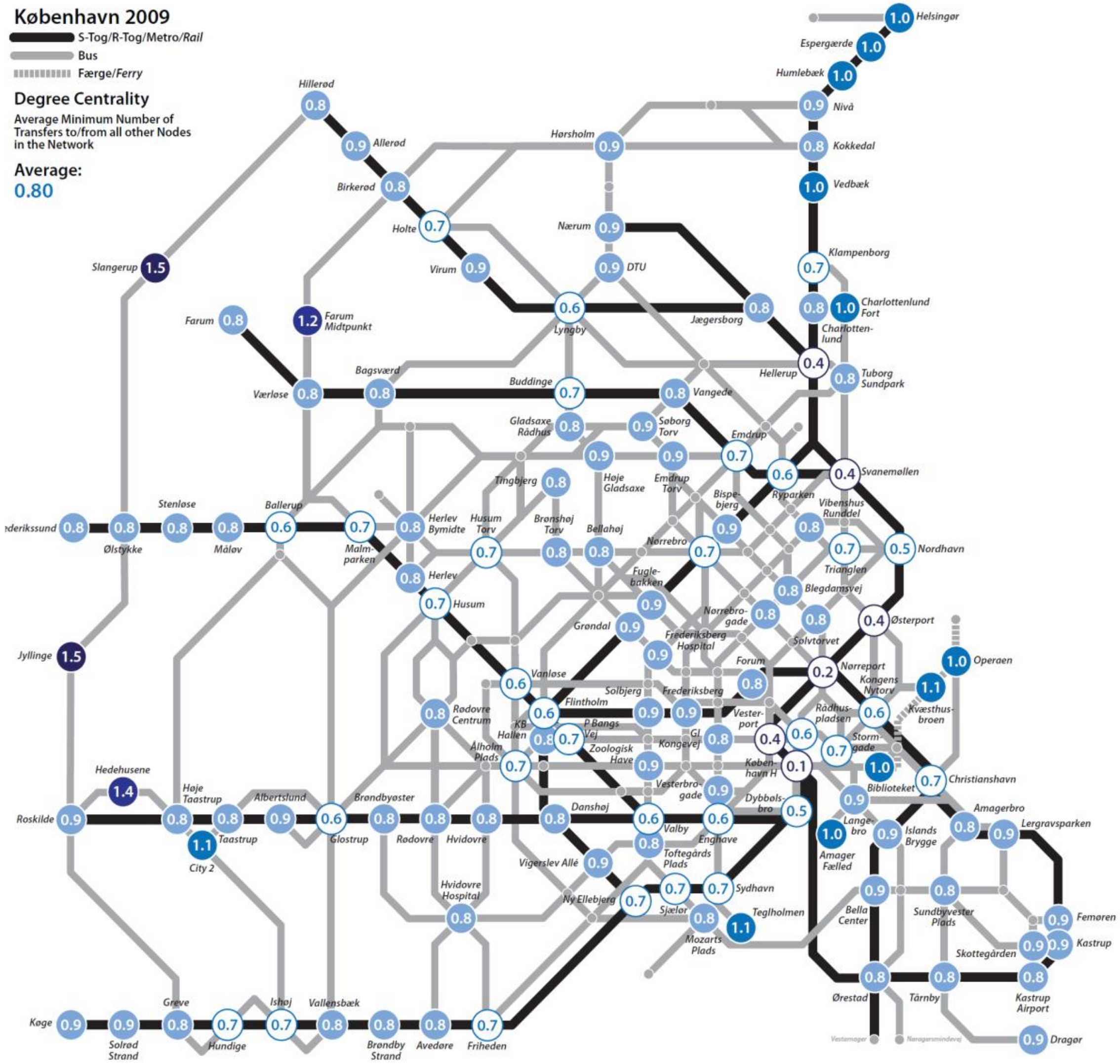
Maps 1 and 2: Closeness centrality indexes for activity nodes on Perth's and Copenhagen's public transport networks in 2009.

4.2. Degree Centrality

The second indicator, *degree centrality*, attempts to visualise *the need for making transfers between routes or modes* while moving across the network. It uses the same GIS pathfinding model as the closeness centrality index but selects preferred journeys using different parameters: here, the path with the lowest number of transfers is chosen, even where this incurs considerable detours associated with longer travel times or the use of lower-frequency services. Maps 3 and 4 depict the average figures per node and globally for the Perth and Copenhagen networks.

Average degree centrality in Perth is 1.06 transfers per journey, while in Copenhagen it is 0.80. The difference can again be largely attributed to the greater density and complexity of the network structure in Copenhagen, where a substantial number of orbital and diagonal routes offer transfer-free links between nodes that in Perth would require one or more transfers. In Copenhagen, values greater than 1.0 on this indicator can only be found on nodes away from the rail network in outer suburbs and in some waterfront locations in the inner area, as well as along the regional rail line to Helsingør. In Perth, values of 1.0 or higher prevail anywhere except on parts of the rail network and the circular bus route.

Both cities use a hierarchical network structure, meaning that rail and buses have different, complementary roles taking into account their variation in performance and capacity. Thus transfers are built into both networks and catered for by purpose-designed physical facilities as well as timetable coordination. In Copenhagen though, the bus network at minimum service standards provides a geographically congruent movement system in its own right, dedicated to frequent service along second-order urban corridors linking a multitude of transfer points with rail and with each other. In Perth, buses act primarily as radial feeders to rail over relatively short distances to and from selected nodes. Notable exceptions from this pattern include the circular bus route and the route connecting Canning Bridge and Curtin University, a major education and employment hub.



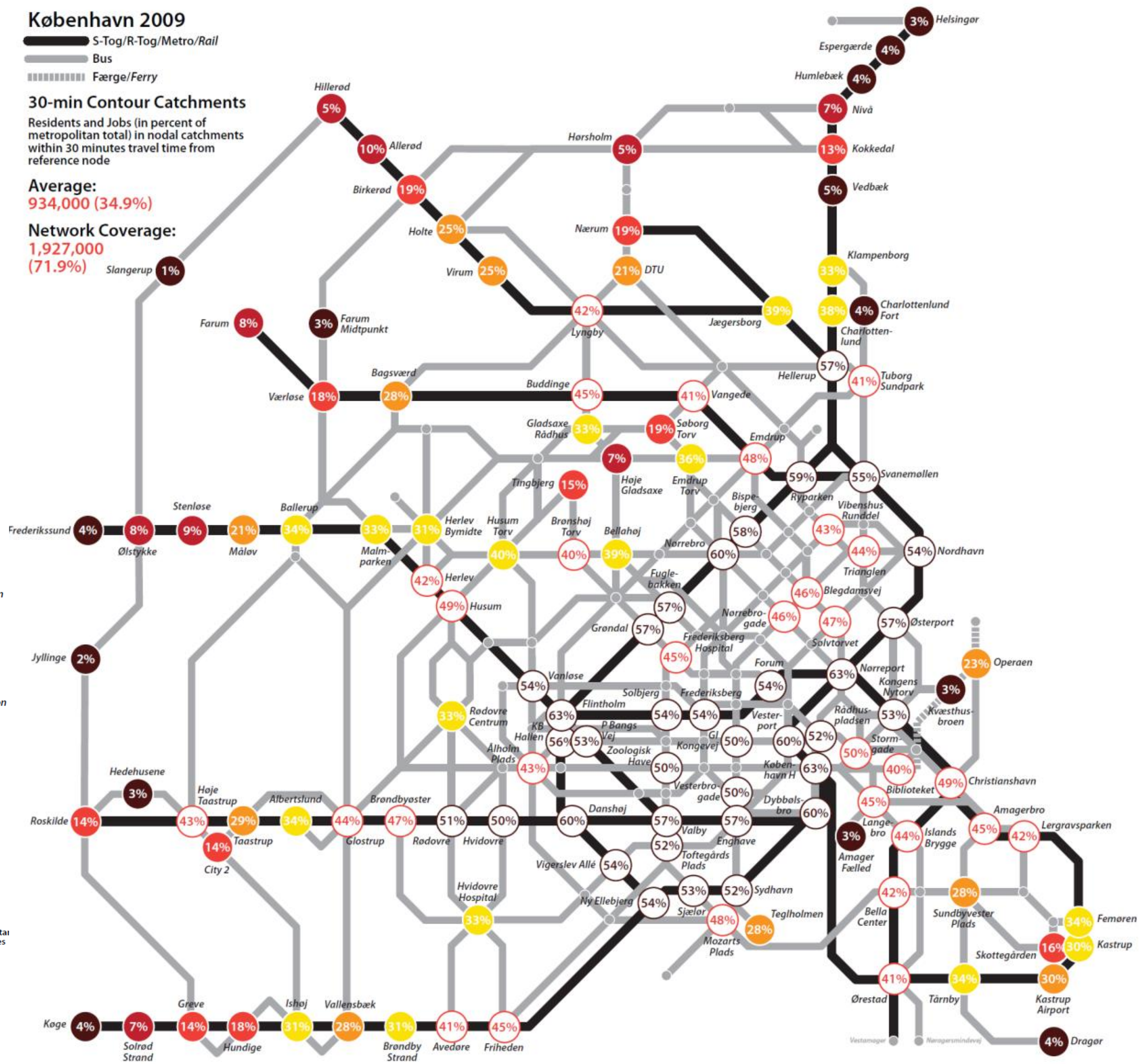
Maps 3 and 4: Degree centrality indexes for activity nodes on Perth's and Copenhagen's public transport networks in 2009.

4.3. Contour Catchments

The third indicator contains a land use measure derived from population and employment counts. It shows *how many residents and jobs can be accessed within a fixed travel time budget* to and from each point of reference. Each activity node was assigned an exclusive, walkable catchment based on drawing 800-metre circles around train or metro stations, and 400-metre linear corridors along tram or bus routes. By adding up travel times along route segments, we were able to determine the number of nodes located within the 30-minute travel time contour and then add up their catchments in terms of residents and jobs. The value of 30 minutes is significant, as it relates to the daily travel time constant discussed by Marchetti (1994), Prud'homme and Lee (1999) and Bertolini et al (2005) who suggest, with some variation on the theme, that the average longest personal one-way trip in cities around the world and throughout history tends to hover near the 30-minute mark per day.

A few covenants apply for the calculation: Only one transfer is allowed within the 30 minutes window, and only where both legs of the transfer trip are operated at least every 15 minutes. A flat penalty of 7.5 minutes in Perth and 5 minutes in Copenhagen is applied to the transfer, roughly equivalent to the time an average transfer takes between arrival of the first leg and departure of the second leg. The difference in penalty between the two cities is associated with the generally higher frequencies (10 minute standard across the network) in the Copenhagen system. Maps 5 and 6 show the 30-minute contour catchments for each node on the Perth and Copenhagen networks.

The average figure for Perth on this indicator is 11.7%, while in Copenhagen it is three times as high at 34.9%. Perth's highest-performing node (Perth Central) has a score of 33%, while Copenhagen's highest-performing node (København H) has a score of 63%. Note that the maximum achievable value on this index is the coverage of residents and jobs as provided by the minimum-standard network as a whole in proportion to the metropolitan total, which is 40.6% in Perth and 71.9% in Copenhagen. Since high service frequency cannot make up for low speed in this indicator or vice versa (unlike in the closeness centrality index), contour catchments are a descriptor of travel times between and concentration of residents and jobs at activity nodes. The comparative figures thus demonstrate both a greater degree of compactness of the urban structure in Copenhagen than in Perth, and a greater prevalence of direct connections (in terms of avoiding time-consuming detours) between activity nodes.



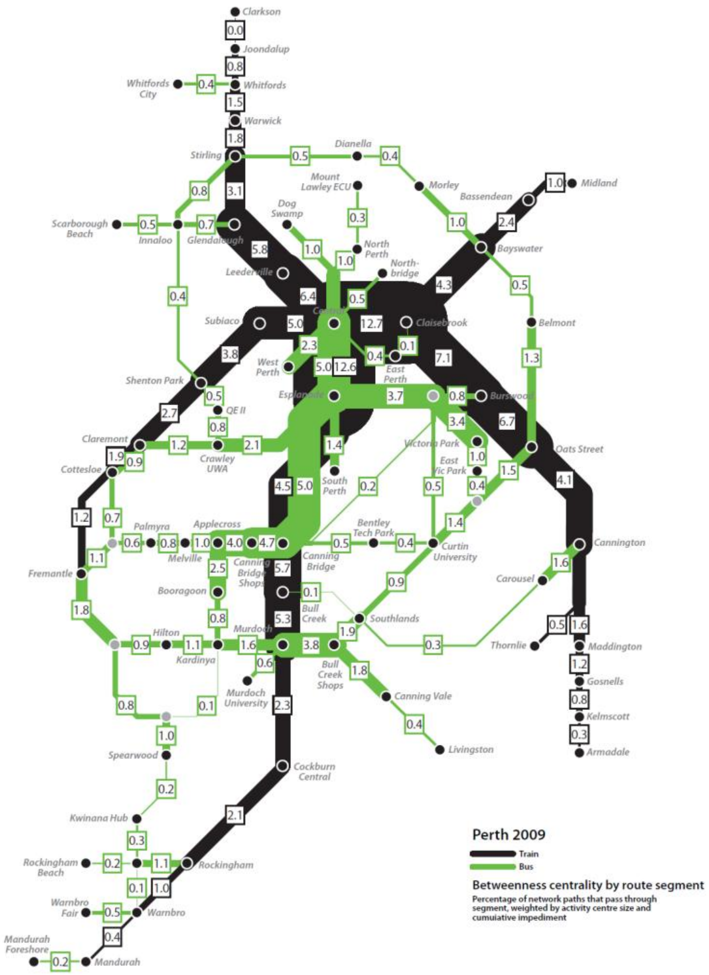
Maps 5 and 6: 30-minute contour catchments for activity nodes on Perth's and Copenhagen's public transport networks in 2009.

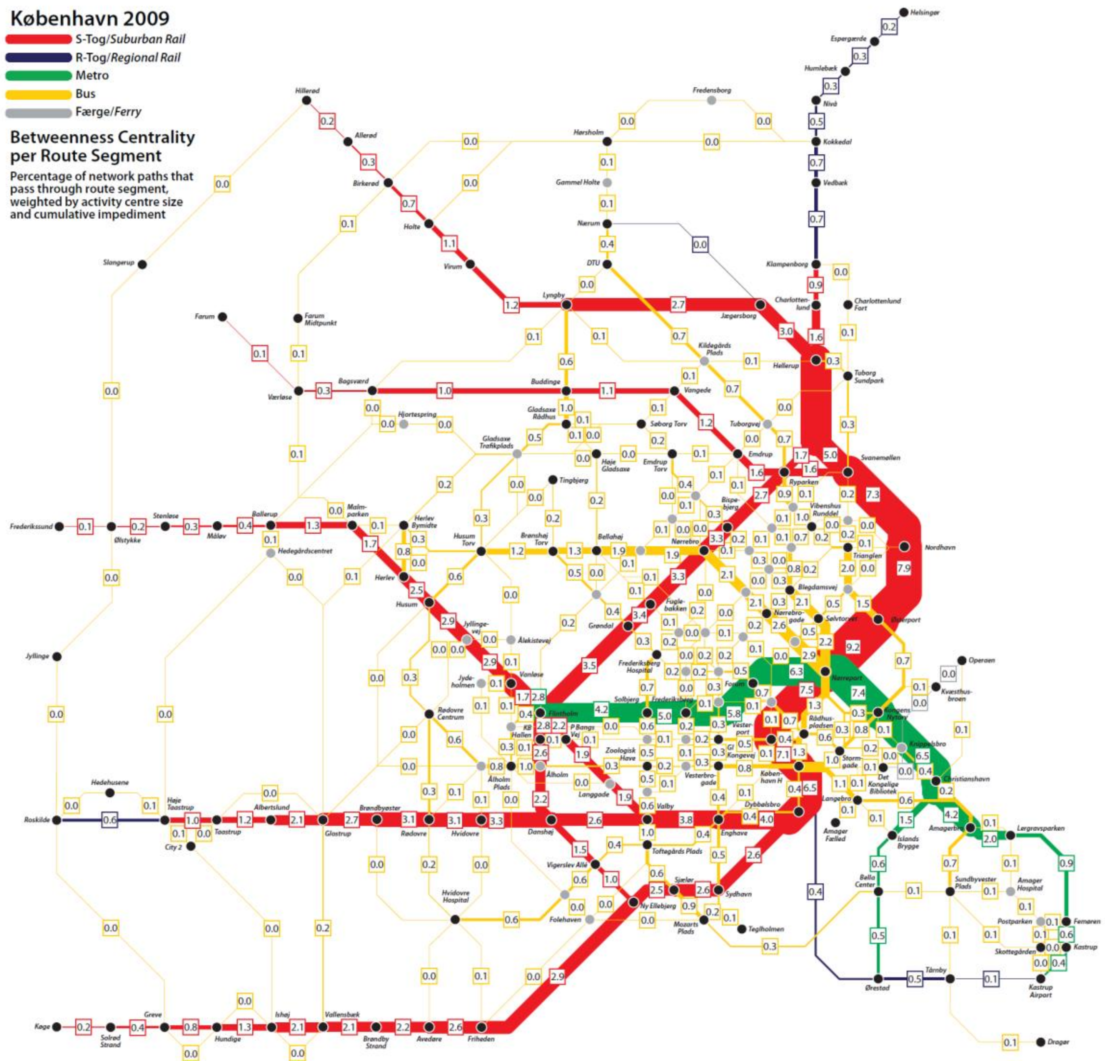
4.4. Betweenness Centrality

The last index discussed here is termed betweenness centrality and attempts to capture *the geographical distribution of travel opportunities across network elements*, as provided by the location and service level of routes and nodes. It counts the number of preferred network paths that pass through each route segment, weighted by the importance of the path as determined by the size of the activity node catchments at either end, as well as the proximity of the nodes to each other. This indicator, while expressed in percentage figures, is largely qualitative and does not lend itself to easy node-by-node or segment-by-segment comparison between the two cities. But since it depicts the strategic significance of each route segment and node for the functioning of the network as a whole, in proportion to the strength of land uses influencing each trip relation, this index can provide some insights about how the networks are structured and how well they respond to the movement tasks the urban structure generates. It also allows for some reflections on the most significant weak spots, underutilised potential and whether future plans to modify the network are suitable to address these. Maps 7 and 8 show the betweenness centrality indexes for both cities.

In Perth, the dominance of the innermost sections on both the rail and the bus system becomes apparent in this index. Cross-suburban routes capture a relatively low amount of network significance, though the performance of the circular bus route is broadly satisfactory. A mismatch between mode performance and network performance is demonstrated between Perth Esplanade and Canning Bridge and to smaller extent between Claremont and Fremantle, where travel times and service frequencies on parallel rail and bus routes are such that strategic significance is not effectively distributed towards the higher-performing mode (rail). In Copenhagen, a similar phenomenon only occurs, and only to a relatively marginal degree, on the bus route along Lyngbyvejen connecting DTU campus with Ryparken station and the central city. Otherwise, the betweenness index demonstrates the strong performance of the metro trunk route, opened in 2002, as well as the inner orbital suburban rail line. Only one bus corridor (between Husum and Nørreport along Nørrebrogade) has a network significance equivalent to that of rail lines. The significance of the regional rail line between København H and the airport is likely understated, since this route continues on to Malmö on the Swedish side, which was omitted from this network analysis exercise.

In Perth, service tasks according to the betweenness index are almost evenly distributed between rail (45.4%) and bus (54.6%) though as we have seen, rail could increase its share here if frequencies were boosted at the expense of parallel bus routes. In Copenhagen, rail modes clearly dominate this index with suburban and regional rail together making up 52.0%, metro 12.1% and buses 35.9%. Thus, Copenhagen's betweenness index performance is more in tune with the modal performance hierarchy, though there still remains room for improvement, which is being addressed by current projects to construct an additional, circular metro line around the inner area as well as a middle suburban orbital light rail corridor.





Maps 7 and 8: Betweenness centrality indexes for the public transport networks in Perth and Copenhagen in 2009, showing the percentage of all node-to-node paths within the network passing through the route segment in question, weighted by combined catchment size and cumulative impediment.

5. Can Perth's public transport network ascend to Copenhagen standards?

The previous section has shown that the performance of Perth's public transport-land use system trails that of Copenhagen on every SNAMUTS indicator considered: Perth's network is characterised by far lower service intensity and geographical coverage relative to population and the expansion of the metropolitan area than Copenhagen's. It offers lower ease of movement, fewer direct connections between activity nodes, shorter ranges of activity within a given travel time budget as well as greater inefficiencies in its reliance on a small number of key corridors. This section will investigate what prospect there is for Perth's public transport-land use system to evolve towards a level of performance more at par with Copenhagen, bearing in mind that Copenhagen is only an average performer itself in this respect among its European neighbours. This is also in reflection of a long-standing mode share target in Perth, first appearing in the 1990s (Department of Transport, 1995) stating a policy aspiration that public transport should capture 13% of all trips by the end of the 2020s (Scheurer, 2005), only three percentage points shy of Copenhagen's share in 1995.

For this purpose, two scenarios have been adapted from an original set of five examined in a collaborative exercise with stakeholders from various Western Australian government agencies in 2008-09. These scenarios were designed to determine the degree of improvements to network performance achievable in the short term through a package of service-based measures, as well as in the long term by including larger infrastructure projects such as new and extended rail lines, alongside different priorities where to accommodate Perth's projected growth in residents and employment (Curtis and Scheurer, 2009). This paper looks at the scenario Frequency Boost (FRB), containing a range of initiatives across the city to offer (restore in one case) weekday interpeak service intervals of 7.5 minutes on core rail and bus routes, and 15 minutes on most of the remainder of the network connecting Perth's key activity nodes and corridors. These measures can be implemented without or with only marginal adaptation to the infrastructure, and are based on the land use data from the Status Quo, ie. the scenario does not include any growth projections. Conversely, the scenario Composite Wishbone (CWB) contains a 25-year target network featuring a number of heavy and light rail extensions as well as reconfigurations and upgrades to the bus system, and makes geographically specific assumptions about the locations of residential and employment growth. These assumptions, alongside the key SNAMUTS results, are summarised in Table 1.

Table 1: Overview of SNAMUTS indicators for Perth (Status Quo, Scenario Frequency Boost, Scenario Composite Wishbone) and Copenhagen (Status Quo).

Indicator	Perth (2009)	Perth (FRB)	Perth (CWB)	Copenhagen (2009)
Residents in metropolitan area[1]	1,445,078	1,445,078	2,064,125	1,748,380
Jobs in metropolitan area	664,331	664,331	948,919	931,626
Activities in metropolitan area	2,109,409	2,109,409	3,013,044	2,680,189

[1] The population and employment data used for the SNAMUTS tool refers to the base years of 2006 (Perth) and 2001 (Copenhagen) since these were the latest years for which such figures were available at a sufficient level of geographical detail.
Perth's metropolitan area contains the statistical division of Perth and the statistical sub-division of Peel (Mandurah). Copenhagen's metropolitan area contains the capital region (Region Hovedstaden) except Bornholm, and the county (landsdel) of Østsjælland.

Indicator	Perth (2009)	Perth (FRB)	Perth (CWB)	Copenhagen (2009)
Percentage of activities within walkable access of minimum standard public transport service	41%	54%	59%	72%
Service intensity at minimum standard (vehicle revenue hours per hour, weekday interpeak)	169 Train 25 Bus 143	307 Train 35 Bus 272	374 Train 46 LRT 75 Bus 253	426 Train 81 Metro 16 Bus 329 Ferry 2
Service intensity per 100,000 inhabitants	11.7	21.2	18.1	24.4
Number of activity nodes	71	90	121	128
Degree centrality (average minimum number of transfers between each pair of nodes)	1.06	1.08	1.00	0.80
Closeness centrality (average minimum cumulative impediment between each pair of nodes)	56.1	45.8	40.9	25.9
Contour catchment (average number of residents and jobs within 30 minute public transport travel time from activity node)	246,000 (11.7%)	291,000 (13.8%)	545,000 (18.1%)	934,000 (34.9%)
Betweenness centrality per mode	Train 45.4% Bus 54.6%	Train 47.2% Bus 52.8%	Train 49.9% LRT 32.9% Bus 17.2%	Train 52.0% Metro 12.1% Bus 35.9%

The Composite Wishbone scenario, named after a wishbone-shaped light rail route linking Booragoon and Scarborough Beach via the eastern CBD fringe, assumes that all land use growth will take place in nodes and corridors around existing and new rail infrastructure and, with a Greenfield component of 20-25%, represents something like a maximum of what is realistically achievable in a 25-year time frame, both in terms of transit orientation and location in established areas of new development, as well as considering the amount of new public transport infrastructure delivered. Thus CWB is a ‘best-case’ scenario for land use-transport integration and has been deliberately designed for best performance. But does this vision stack up to Copenhagen’s performance in the present?

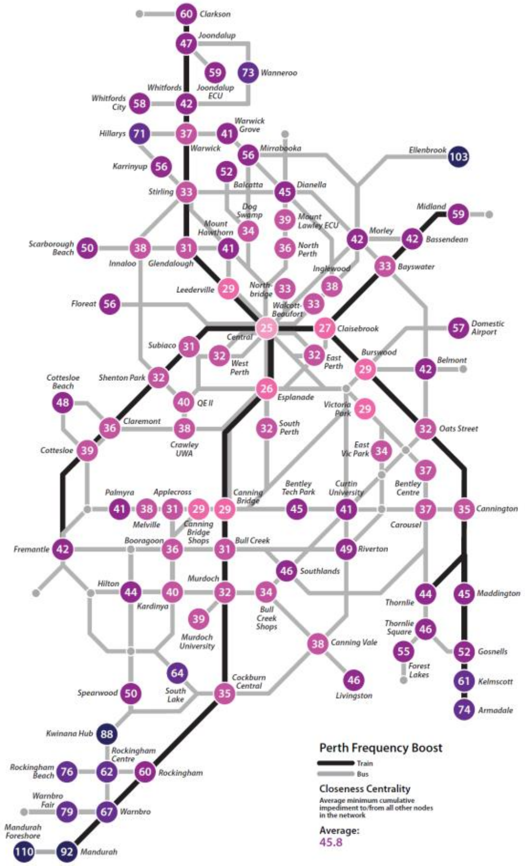
5.1. Scenario Frequency Boost (FRB)

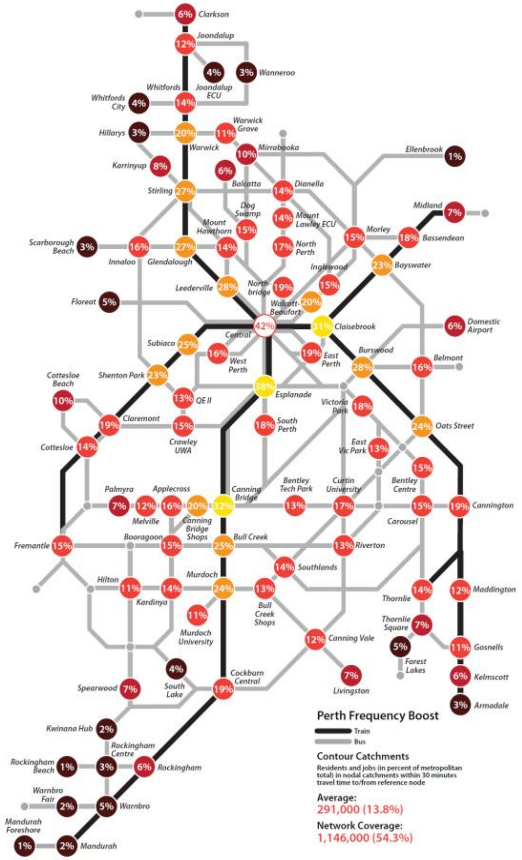
Key results of the Frequency Boost scenario are depicted in Maps 9-11. The number of activity nodes included in the network increases by 19 to 90, as the service improvements make more activity centres accessible by public transport at the minimum service standard. This is also reflected in the figure for network coverage (minimum-service public transport stops within walking distance), which increases significantly from 40.7% to 54.3% of all residents and jobs in the metropolitan area – narrowing but not nearly closing the gap to Copenhagen (71.9%). The number of trains required to operate the network during the weekday interpeak period increases from 25 to 35 (an unproblematic shift, since an even greater number of trains is already available for peak hour service), while the number of buses required grows by 129 to 272. This last figure, however, does not take into account that most bus routes upgraded for the FRB scenario are already in operation in the Status Quo, albeit at a service standard below the defined minimum, and thus overstates the extent of additional operational resources needed. Relative to population, there are 21.2 buses and

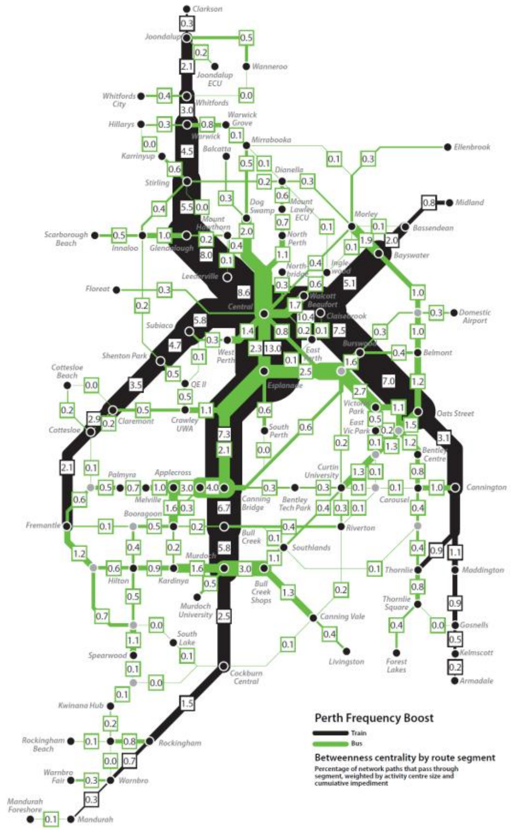
train sets per 100,000 inhabitants in simultaneous operation in the FRB scenario, a significant increase from 11.7 in the Status Quo, but still below the figure for Copenhagen (24.4).

Closeness Centrality, on average, drops from a value of 56.1 in the Status Quo (Map 1) to a value of 45.8 (Map 9) in the FRB scenario, a significant improvement though still with considerable distance to cover to reach Copenhagen's figure of 25.9 (Map 2). Similarly, the average 30-minute contour catchment in Perth grows from 11.7% (Map 5) to 13.8% of all metropolitan residents and jobs (Map 10), which indicates some progress, but it remains a mere fraction of Copenhagen's 34.9% (Map 6). In terms of degree centrality, the average score even deteriorates slightly from 1.06 to 1.08 transfers per journey, compared to Copenhagen's 0.80. In all three indicators, the inclusion of 19 additional activity nodes in Perth has the effect of moderating the change, as most of these new nodes are in relatively marginal locations and tend to drag down the average. Or in other words: the increase in network coverage achieved by the scenario incurs an expansion of the network into areas that are relatively more problematic for public transport to service effectively. If the Frequency Boost was limited to the routes and nodes already included in the Status Quo network, average performance of the (smaller) network might be superior to that in the FRB scenario, but the division between transit-poor and (relatively) transit-rich parts of Perth would deepen.

The Betweenness Index (Map 11) illustrates Perth's continued strong reliance on its five radial rail routes, while moderating the previously mentioned effect of parallel rail and bus routes competing for strategic significance to some extent (the overall division of tasks between both modes shifts very slightly towards rail, from 45.4% to 47.2%). Other than along several CBD approaches and short feeder links between rail-bus interchanges and nearby activity nodes, the only bus segments whose performance stands out on this index follow the eastern section of the circular bus route between Morley and Curtin University (upgraded to 7.5-minute service intervals in this scenario). For potential infrastructure investment such as the insertion of additional rail lines, this finding poses a challenge: in order for such projects to show a level of network significance in the Betweenness Index that appears worthy of rail (or rather, worthy of the investment cost associated with rail), they will either need to achieve substantial travel time improvements over buses, or be implemented in conjunction with urban intensification programs in their catchment areas, or a combination thereof. The Composite Wishbone scenario will attempt to address these issues.







Map 9: Closeness centrality index for activity nodes in Perth in the scenario Frequency Boost (left).
Map 10: 30-minute contour catchments for activity nodes in Perth in the scenario Frequency Boost (centre).
Map 11: Betweenness centrality index for the public transport network in Perth in the scenario Frequency Boost (right).

5.2. Scenario Composite Wishbone (CWB)

The Composite Wishbone scenario contains approximately 50 km of new heavy rail lines and 100 km of light rail lines, including a tunnel underneath the CBD and the Swan River. It further envisions a comprehensive reconfiguration of the bus network to create a multitude of upgraded and new orbital and diagonal links to integrate with the extended rail system and to provide a number of previously unserviced direct connections between activity nodes. As such, the network layout will come to resemble that of Copenhagen with its effective hierarchy of modes with different performance, and its multi-directional grid pattern. Greater land use intensity will be achieved by accommodating 70-80 percent of Perth's growth until 2030 in established areas, especially around new rail infrastructure. This amounts to about 650,000 to 700,000 additional residents and jobs, catered for by incremental densification around light rail corridors towards an average target density of 90 residents and jobs per hectare, and dedicated master planning around specific nodes and central areas towards an average target density of 180 residents and jobs per hectare.

Thus in theory, Perth in 2030 could look a lot more like Copenhagen today. But will its land use-transport system function like Copenhagen's?

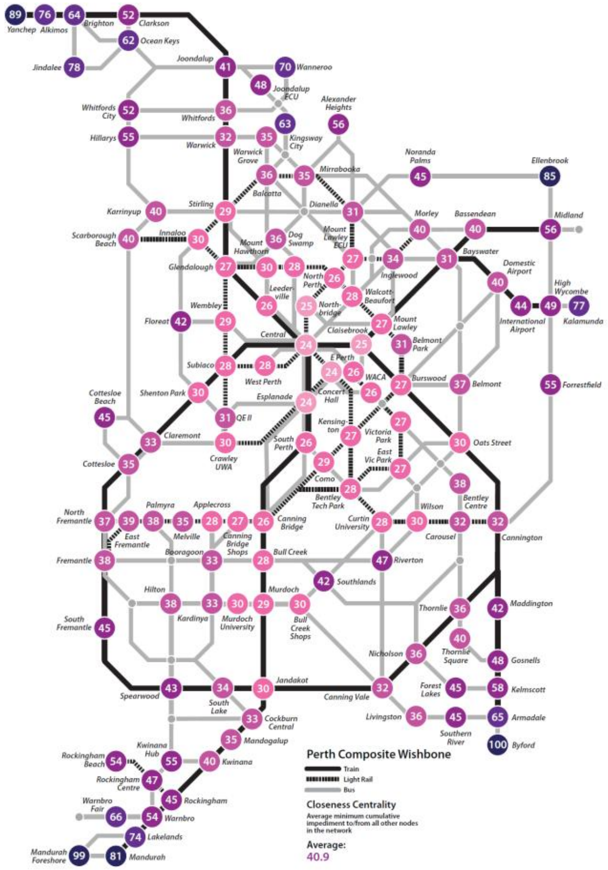
The combination of network expansion and land use intensification will lift the extent of geographical coverage of walkable access to minimum-standard public transport from 40.7% (Status Quo) to 58.8% in the CWB scenario, an impressive improvement though still below Copenhagen's level of 71.9%. The number of nodes increases by 50 over the Status Quo (31 over the FRB scenario) to 121, with the new nodes relatively evenly scattered over fringe locations, inner urban corridors and specific redevelopment sites in established areas. An additional 21 heavy rail train sets, 75 light rail train sets and 110 buses will be required to operate the minimum-service network in this scenario over the Status Quo; note, however, that the number of buses decreases slightly over the FRB scenario, owing to the conversion of several busy bus corridors to light rail. Service intensity relative to population also decreases from the FRB scenario from 21.2 to 18.1 vehicles/train sets per 100,000 inhabitants in simultaneous operation during the weekday interpeak period, compared to Copenhagen's 24.4. This trend does not necessarily equate to a deterioration in service quality though: substituting a higher-performance for a lower-performance mode, as is the case with the conversion of bus routes to light rail, may result in improved service for users with less input, due to travel time savings and the reduction of very high bus frequencies (30 or more per hour) in slow operating environments (Newman and Scheurer, 2010).

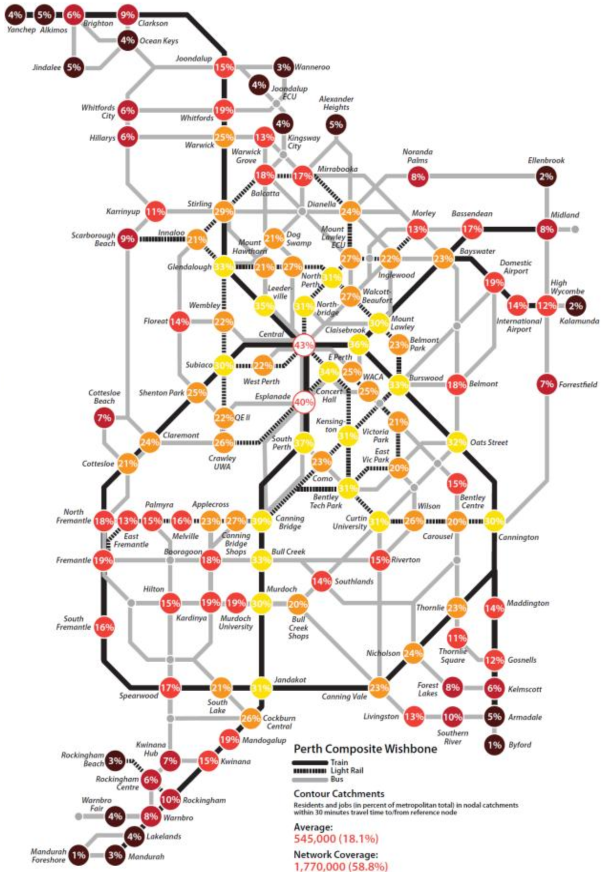
The Closeness Centrality index shows a further improvement of the average score per activity node from 56.1 in the Status Quo and 45.8 in the FRB scenario to 40.9 in the CWB scenario (Map 12). There are now 39 nodes with a closeness value of less than 30, equivalent to more than 30% of the total, when in the FRB scenario there were only eight such nodes (9%) and in the Status Quo there was none. In Copenhagen, 101 out of 128 nodes or nearly 80% fall within this category: their proliferation, or in other words a relatively smooth gradient in closeness centrality scores from centre to periphery of the network, appears to be a direct outcome of enhanced network connectivity. Degree Centrality improves in the CWB scenario from 1.06 in the Status Quo to 1.00, though Copenhagen remains significantly ahead on this count as well (0.80). The average 30-minute contour catchment extends to 18.1% of all metropolitan residents and jobs in the CWB scenario, up from 11.7% in the Status Quo and 13.8% in the FRB scenario – a quite impressive achievement facilitated by an assumed ambitious urban consolidation strategy around public transport, yet it still only represents just over half the performance level of Copenhagen at 34.9% (Map 13). In detail, the number of Perth nodes with a contour catchment value of 30% or greater grows from only 1 out of 71 in the Status Quo to 4 out of 90 in the FRB scenario, and 21 out of 121 in the CWB scenario (Copenhagen has 83 out of 128 nodes fulfilling this

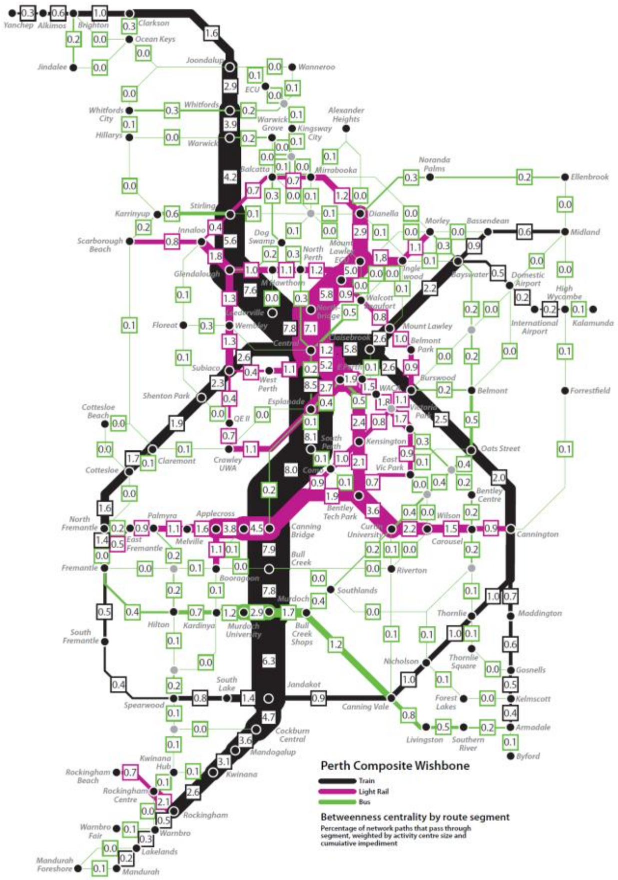
standard). Growing network complexity and an expanded role for faster modes (rail), both of which facilitate attractive connections with few transfers to a multitude of destinations, converge to increase the number of nodes above this threshold.

In the Betweenness Centrality index (Map 14), the CWB achieves a highly prominent role for the new light rail system, confirming that the rollout of this mode, now seriously being considered by local and state governments, in conjunction with a corresponding land use intensification strategy does indeed represent a viable pathway towards much improved public transport accessibility across Perth. Light Rail accounts for 32.9% of the total betweenness score of the network, while heavy rail also grows slightly to 49.9% (from 45.4% in the Status Quo) and buses drop quite drastically to 17.2% (from 54.6% in the Status Quo). Thus the distribution of network significance is much closer aligned with modal performance in the CWB scenario than in the Status Quo or in the FRB scenario.

Light Rail's ability to attract network significance is most impressive along the Alexander Drive–CBD–Curtin University trunk route, with figures otherwise only experienced on the north-south heavy rail trunk line. The southern orbital linking Fremantle and Cannington, the western orbital between Subiaco and Stirling and the Wishbone route between Scarborough and Booragoon also prove their potential as vital links in the network. Conversely, the existing rail network, with the exception of the north-south route between Yanchep and Mandurah (at whose extremities most Greenfield growth would take place in the CWB scenario), is weakened in relative terms over the FRB scenario (or put differently, relieved from a level of network significance that might translate into congestion as usage grows). The southern orbital rail link via Jandakot performs well, with entertainment and recreational traffic (which the resident and employment figures used in SNAMUTS cannot quantify) compensating for the relatively sluggish section along the ocean shore between Fremantle and Spearwood.







Map 12: Closeness centrality index for activity nodes in Perth in the scenario Composite Wishbone (left).
Map 13: 30-minute contour catchments for activity nodes in Perth in the scenario Composite Wishbone (centre).
Map 14: Betweenness centrality index for the public transport network in Perth in the scenario Composite Wishbone (right).

6. Conclusions and Reflections

This paper examined the performance of the public transport-land use systems in two similar-sized cities, Perth and Copenhagen, against the background of a policy aspiration to greatly increase the mode share of public transport in Perth, to a level (measured as a proportion of all trips) approaching that of Copenhagen in the 1990s within 20 years. Even following substantial investment in public transport infrastructure in recent years and a national best-practice approach to intermodal coordination, however, it was demonstrated that public transport accessibility and network performance in Perth face a transformative process of further drastic improvements if they were to approach the levels of service enjoyed by the Danish capital.

Two scenarios for Perth’s future land use-transport integration were tested to illustrate the magnitude of this task. These scenarios can be understood as subsequent stages of transformation: Scenario Frequency Boost (FRB) attempts to bring public transport supply in terms of service frequencies in Perth to a level comparable to Copenhagen, while Scenario Composite Wishbone (CWB) also includes a layer of additional public transport infrastructure with associated land use planning priorities to concentrate urban growth around rail. Both scenarios deliver tangible and worthwhile improvements to Perth. The FRB scenario primarily expands geographical coverage of car-competitive public transport services across the metropolitan area and enhances ease of movement by rail and bus, while the CWB scenario adds a significant expansion of activity ranges within fixed travel time budgets for users, as well as delivering the network and mode-specific efficiency gains required for public transport to continue to increase its market share in a fast-growing city. Neither scenario, however, comes even close to matching Copenhagen’s performance in the present as shown by drawing comparable figures for both cities on each indicator.

The implications of this conclusion are twofold. Firstly, while current levels of personal access, affordability and relative absence of major road congestion prevail for private motorised transport in Perth, it is unrealistic to expect that a city deliberately designed around the car for decades can achieve a full transition towards an urban mobility mix as found in a European city with a long-standing tradition for competitive public transport and non-motorised travel within a 20-year time frame. This is even more sobering when considering that the CWB scenario includes ‘best-case’ assumptions for strategic transport-land use integration. Its envisioned share of growth in established areas is not likely to be achieved on current trends, and the nature of this (re-)development, despite some excellent intensification projects currently being pursued in strategic nodes such as Stirling town centre, is on the whole likely to be more scattered and less focused around public transport facilities than stipulated in the scenario. Real-life performance of the public transport system in 2030, even if all the infrastructure elements of the CWB scenario are being delivered, can thus be expected trail the figures presented in this paper to some extent.

But secondly, the SNAMUTS results for the scenarios also show that Perth’s inability to become like Copenhagen in terms of public transport movement and accessibility in the foreseeable future cannot serve as a viable excuse for policy inaction, or slow action on improving the public transport-land use interplay. Instead, the exercises described in this paper demonstrate the contributions an ambitious expansion program for public transport service and infrastructure can make towards providing greater and more attractive transport choices to more users across Perth. Moreover, they strongly suggest that the efficient functioning of the metropolis, as well as its performance in terms of sustainability objectives and carbon emission reductions, depend critically on providing public transport service levels that are common practice in comparably wealthy cities such as Copenhagen, and on continuity in expanding the network, including the rail system, to keep up with (if not pre-empt) the considerable pace of population and employment growth projected for Perth.

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References

[ABS] Australian Bureau of Statistics (2010) National Regional Profile 2004-2008 and Census 2006, available online at www.abs.gov.au

Bertolini L (2005) Cities and Transport: Exploring the Need for New Planning Approaches. Chapter 5 in Albrechts L, Mandelbaum S J (2005, Eds) The Network Society. A New Context for Planning. Routledge, Oxford, UK

Bertolini L, Le Clercq F, Kapoen L (2005) Sustainable Accessibility: A Conceptual Framework to Integrate Transport and Land Use Plan-Making. Two Test- Applications in the Netherlands and a Reflection on the Way Forward. Transport Policy, Vol 12

Crucitti P, Latora V, Porta S (2006) Centrality in Networks of Urban Streets. Chaos, Vol 16

Curtis C, Scheurer J (2009) Network City Activity Centres. Developing an Analysis, Conception and Communication Tool for Integrated Land Use and Transport Planning in the Perth Metropolitan Area. Research Monograph, Department of Planning and Infrastructure (DPI) and Curtin University of Technology, Perth (WA), available online at www.abp.unimelb.edu.au/gamut/pdf/perth-snamuts-future-scenarios-19june09.pdf

[DST] Danmarks Statistik (2010) Statistisk Årbog 2009, available online at www.dst.dk

Department of Transport (1995) Perth Metropolitan Transport Strategy 1995-2029. Perth (WA)

James B, Brög W (2003) TravelSmart/Individualised Marketing in Perth, Western Australia. Chapter 29 in Tolley R (2003, Ed) Sustainable Transport. Planning for Walking and Cycling in Urban Environments. Woodhead Publishing, Cambridge, UK

Kenworthy J, Laube F (2001) The Millennium Cities Database for Sustainable Transport. International Association of Public Transport (UTIP), Bruxelles, Belgium and Institute for Sustainability and Technology Policy (ISTP), Perth (WA)

Latora V, Marchiori M (2002) Is the Boston Subway a Small-World Network? Physica A, Vol 314, No 1-4

Marchetti C (1994) Anthropological invariants in travel behaviour, Technical Forecasting and Social Change, Vol 47, No 1

Mees P (2010) Transport for Suburbia. Beyond the Automobile Age. Earthscan, London, UK

Newman P, Kenworthy J (1999) Sustainability and Cities. Overcoming Automobile Dependence. Island Press, Washington (DC), USA

Newman P, Scheurer J et al (2010) The Knowledge Arc Light Rail: A Concept for Delivering the Next Phase of Public Transport in Perth. Curtin University Sustainability Policy Institute (CUSP), Parsons Brinckerhoff

Nielsen G (2005) HiTrans Best Practice Guide 2: Planning the Networks. HiTrans, Rogaland, Norway

Porta S, Crucitti P, Latora V (2006a) The Network Analysis of Urban Streets: A Dual Approach. Physica A, Statistical Mechanics and its Applications, Vol 369, No 2

Porta S, Crucitti P, Latora V (2006b) The Network Analysis of Urban Streets: A Primal Approach. Environment and Planning B: Planning and Design, Vol 33, pp 705-725

Prud'homme R, Lee C (1999) Size, Sprawl and the Efficiency of Cities. Urban Studies, Vol 36, No 11

Scheurer J (2001) Urban Ecology, Innovations in Housing Policy and the Future of Cities: Towards Sustainability in Neighbourhood Communities. PhD Thesis, Murdoch University, Perth (WA)

Scheurer J (2005) Travel Behaviour and Mode Share Targets in Australian Cities: Are we on Track? Urban Policy and Research, Vol 23, No 4

Scheurer J (2008) Discursive Modelling for Land Use-Transport Integration: An Explorative Case Study from Perth, Western Australia. ACSP-AESOP Joint Congress, Chicago (IL), USA, 6-11 July

Scheurer J (2009) Public Transport and Land Use Integration in Melbourne and Hamburg: Can Comparative Network Performance Provide a Sense of Future Direction? 4th State of Australian Cities Conference, Perth (WA), 28-30 November

Scheurer J, Bergmaier R, McPherson J (2006) Keeping People Moving in Melbourne's North-East. Metropolitan Transport Forum (MTF), Melbourne (VIC)

Scheurer J, Curtis C (2008) Spatial Network Analysis of Multimodal Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure. Research Monograph, Curtin University Sustainability Policy Institute (CUSP) and Centre for Governance and Management of Urban Transport (GAMUT), Perth (WA)/Melbourne (VIC), available online at www.abp.unimelb.edu.au/gamut/pdf/perth-snamuts-report.pdf

Scheurer J, Curtis C, Porta S (2007) Spatial Network Analysis of Public Transport Systems: Developing a Strategic Planning Tool to Assess the Congruence of Movement and Urban Structure in Australian Cities. Australasian Transport Research Forum, Melbourne, 25-27 September

Scheurer J, Porta S (2006) Centrality and Connectivity in Public Transport Networks and their Significance for Transport Sustainability in Cities. World Planning Schools Congress, Mexico DF, 13-16 July

Svensson O (1981) Dansk Byplan Guide. Miljøministeriet, Planstyrelsen, Dansk Byplanlaboratorium, Copenhagen, Denmark

[WAPC] Western Australian Planning Commission (2004) Network City. A Community Planning Strategy for Perth and Peel. Perth (WA)

[WAPC] Western Australian Planning Commission (2009) Directions 2031. Draft Spatial Framework for Perth and Peel. Perth (WA)

Appendix: Indicator Formulas

Closeness Centrality

$CC_i = \sum L_{ij}/(N-1)$ [1]

where:

CC_i = Closeness centrality of node i

L_{ij} = Minimum cumulative impediment between nodes i and j, with $j \in N$ and $i \neq j$

N = All activity nodes in the network

Degree Centrality

$CD_i = \sum p_{min,ij}/(N-1)$ [2]

where:

CD_i = Degree centrality of node i

$p_{min,ij}$ = Minimum number of transfers required between nodes i and j, with $j \in N$ and $i \neq j$

N = All activity nodes in the network

Contour Catchments

$CI_i = act(c_i)$ [3]

where:

CI_i = Contour catchment index of node i

c_i = 30-minute travel time contour of node i

act(c) = Number of residents and jobs within contour c

Betweenness Centrality

$$CB_{k,w} = \frac{\sum(p_{ij}(k) * (act_i * act_j)/L_{ij})}{\sum(p_{ij} * (act_i * act_{j,})/L_{ij})} \quad [4]$$

where:

$CB_{k,w}$ = Betweenness centrality (weighted) for route segment k

$P_{ij}(k)$ = Paths between nodes i and j that pass through segment k, for all i, $j \in N$ and $i \neq j$

P_{ij} = All paths in the network, for all i, $j \in N$ and $i \neq j$

act_i = Number of residents and jobs in defined local catchment of node i

act_j = Number of residents and jobs in defined local catchment of node j

L_{ij} = Minimum cumulative impediment between nodes i and j

N = All activity nodes in the network