

**Public Transport and Land Use Integration in Melbourne and Hamburg:
Can Comparative Network Performance Provide a Sense of Future
Direction?**

Public Transport and Land Use Integration in Melbourne and Hamburg: Can Comparative Network Performance Provide a Sense of Future Direction?

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Abstract

In 2001, Victoria's State Government passed a target to more than double the market share of public transport in Melbourne, to a level equivalent to that found in similar-sized Hamburg (Germany) and a number of other European cities (DOI, 2002). Since then (policy-driven or not), Melbourne has experienced strong growth in usage of the system. This paper presents the application of a detailed GIS-based spatial analysis tool to determine how the public transport networks in both cities are configured, how responsive they are to the geographical distribution and concentration of residents and jobs across the urban structure, and how capable to provide accessibility and convenience of travel across the metropolitan area. A review of network performance indicators will explore in quantifiable measures why Hamburg's public transport, notwithstanding specific setbacks and weaknesses over the past few decades, has traditionally been more significant and successful in the urban transport market than Melbourne's. The spatial analysis tool will help clarify whether the recent upward trend in Melbourne's passenger numbers represents a sustained change in the way the city is used, and whether the interplay of land use and transport has departed from previous patterns. Is there a qualitative shift under way that will allow Melbourne to close the gap to Hamburg, or are further transformative steps required to create a more public transport-oriented city where local and metropolitan accessibility between the city's opportunities can keep up with Melbourne's European counterparts?

Public Transport and Land Use Integration in Melbourne and Hamburg: Can Comparative Network Performance Provide a Sense of Future Direction?

Introduction

In 2001, Victoria's State Government passed a target to more than double the market share of public transport in Melbourne, to a level equivalent to that found in similar-sized Hamburg (Germany) and a number of other European cities (DOI, 2002). Since then (policy-driven or not), Melbourne has experienced strong growth in usage of the system (DTF, 2009). This paper presents the application of a detailed GIS-based spatial analysis tool to determine how the public transport networks in both cities are configured, how responsive they are to the geographical distribution and concentration of residents and jobs across the urban structure, and how capable to provide accessibility and convenience of travel across the metropolitan area. A review of network performance indicators will explore in quantifiable measures why Hamburg's public transport, notwithstanding specific setbacks and weaknesses over the past few decades, has traditionally been more significant and successful in the urban transport market than Melbourne's (Kenworthy and Laube, 2001). In conclusion, the spatial analysis tool will help clarify whether the recent upward trend in Melbourne's passenger numbers represents a sustained change in the way the city is used, and whether the interplay of land use and transport has departed from previous patterns. Is there a qualitative shift under way that will allow Melbourne to close the gap to Hamburg, or are further transformative steps required to create a more public transport-oriented city where local and metropolitan accessibility between the city's opportunities can keep up with Melbourne's European counterparts?

Understanding and Measuring Accessibility

The concept of accessibility has been developed, and cast into measurable indicators, in parallel with the concept of mobility. While mobility is concerned with the performance of transport systems in their own right, accessibility adds the interplay of transport systems and land use patterns as a further layer of analysis (Litman, 2003). Accessibility measures are thus capable of assessing feedback effects between transport infrastructure and modal participation on the one hand, and urban form and the spatial distribution of activities on the other hand.

Bertolini, LeClercq and Kapoen (2005) define accessibility as 'the amount and diversity of places that can be reached within a given travel time and/or cost' (p209), and sustainable accessibility as accessibility 'with as little as possible use of non-renewable, or difficult to renew, resources, including land and infrastructure' (p212).

Accessibility is a multifaceted concept, not readily packaged into a one-size-fits-all indicator or index: in Litman's (2003) words, 'there is no single way to measure transportation performance that is both convenient and comprehensive' (p32). Geurs and van Eck (2001) distinguish, among others, between infrastructure-based and activity-based accessibility indicators and maintain that while the infrastructure-based type is easiest to measure and interpret, it is also the most limited when it comes to capturing the interplay of land use and transport infrastructure. Conversely, the activity-based indicator type includes the land use component from the outset, but tends to be more complex and sometimes suffers from poorer legibility. Baradaran and Ramjerdi (2001), too, classify accessibility measures into several categories, which can and do overlap in practice and pose the challenge of compiling indices that merge the insights from several valid and relevant perspectives (Geurs and van Wee, 2004) while still remaining simple enough to be used as planning and communication tools among practitioners and laypeople with diverse skills (Bertolini et al, 2005).

Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS)

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).

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 across such urbanised regions to arrive at more accurate measures of network performance. Thus SNAMUTS evaluates regional-scale land use-transport integration and thus, 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 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. Thus a higher-frequency public transport service reduces the disutility of the trip while being subject to a principle of diminishing returns. 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 Melbourne 2030 (DOI, 2002) or Perth's Network City (WAPC, 2004), 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 Western Australian 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.

Public Transport in Melbourne and Hamburg

Previous SNAMUTS applications undertook comparisons between different stages of evolution of the land use-transport system, but to date they have been confined to the same city. While network configuration and the distribution of residents and jobs in Perth in 2031 may change quite dramatically from the status quo, they still refer to the same geographical context and

thus to a viable and coherent reference base. But can SNAMUTS indicators be used to make valid comparisons of public transport network performance and land use-transport integration in different cities? This paper will attempt to answer this question by introducing the results from an exercise in building SNAMUTS databases for Melbourne and Hamburg.

Melbourne, the capital of Victoria, is Australia's second largest city and currently occupies third place in the global liveability ranking published annually by the Economist Intelligence Unit (EIU, 2009). A sprawling, low-density city by world standards (Kenworthy and Laube, 2001), Melbourne has experienced high rates of population and job growth in recent years. This growth is accommodated both by tightly managed but relatively permissive outer urban expansion as well as the intensification of existing urban areas. The current metropolitan strategy, Melbourne 2030 and its recent update, Melbourne @ 5 million (DOI, 2002; DPCD, 2008) identify 115 major and principal activity centres as potential growth nodes, and set an urban growth boundary to control (but not necessarily constrain) the outer expansion of the city. At the 2006 census, there were 3.59 million residents and 1.51 million jobs in the metropolitan area, comprising 31 local government areas and covering a total land area of 8,882 sq km. Within the innermost 15 local government areas on a land area of 690 sq km, there were 1.62 million residents and 0.90 million jobs (ABS, 2007).

Melbourne has traditionally been associated with a high-profile public transport system, owing to the city's post-war decision to retain its extensive tram operation, and the presence of a similarly sizeable radial suburban rail network. However, public transport rapidly lost market share to the car between 1950 and 1980 and captured only around 7% of all trips in the metropolitan area between 1980 and 2005. Most transport investment during this period focussed on expanding road capacity in both existing and new urban areas and resulted in increases in traffic volumes and congestion over and beyond the rate of population growth (Mees, 2000; Gleeson, Curtis and Low, 2003; Davison and Yelland, 2004). Since 2005, public transport usage in Melbourne has shown a remarkable resurgence, with annual growth in patronage around 10% and indications that public transport's proportion of all trips is heading into double digits again (Betts, 2009), thus approaching an earlier strategic goal to achieve a modal share of 15% by 2020 (Scheurer, 2005). In response to the growing significance of public transport, there are now increasing efforts by State and Federal Government to address the long-standing backlog in modernisation and expansion of the system.

Hamburg forms an independent city-state within the Federal Republic of Germany and is the second largest municipal area by population in the country. On the Economist's global liveability table, it currently takes 14th place, the highest ranking among German cities (EIU, 2009). Located to reap strong benefits from the fall of the Iron Curtain and the expansion of the European Union to Scandinavia and former Eastern Bloc countries in the 1990s and 2000s, Hamburg managed to reverse a period of population and economic decline in the 1970s and 1980s, associated with the transition from a dominance of maritime industries (Hamburg is home to the second largest European seaport) towards a hub for the service and knowledge economy.

In European terms, Hamburg is a low-density city, more similar in urban form to its Scandinavian neighbours than to denser central European cities of comparable size such as Brussels, Munich or Vienna (Kenworthy and Laube, 2001). However, overall urban density is still roughly twice that of Melbourne. The metropolitan area comprises the city state of Hamburg, stretching over an area of 755 sq km with 1.74 million residents and 0.73 million jobs, and seven neighbouring counties in the adjacent states of Schleswig-Holstein and Lower Saxony. Including Hamburg proper, these cover a land area of 8,627 sq km and are home to 3.33 million residents and 1.13 million jobs (Statistikamt Nord, 2005; LSKN, 2009).

Public transport in Hamburg looks back on a mixed history of successes and shortfalls, adding up to an average performance among its European counterparts. In the 1960s, Hamburg became an international pioneer by setting up the first regional public transport agency to coordinate network/service planning and fare integration between operators which had previously acted as competitors. Simultaneously however, the urban transport system underwent drastic changes. Post-war reconstruction - about half the city's building stock had been destroyed by 1945 - enabled the creation of a car-friendly arterial road network, accompanied by the gradual closure

and conversion to bus operation of a once-extensive tram system during the 1960s and 1970s. Conversely, the rapid transit network - there are two metro systems in Hamburg - was significantly expanded in capacity with a number of new routes both in the inner city and to access suburban growth corridors. Nonetheless, public transport in Hamburg was subject to patronage decline during the 1950s and 1960s, and stagnation during the 1970s and 1980s. In 1995, Hamburg's modal share by trips between car (60%), public transport (15%) and walking/cycling (25%) was almost identical to the aspirational target included in Melbourne 2030 (Kenworthy and Laube, 2001; DOI, 2002). Hamburg entered a new growth trajectory for public transport during the 1990s, which has recently accelerated in pace, but significant investment into system expansion, having nearly ground to a halt after 1991, only returned in the mid-2000s. The bus network was comprehensively reconfigured for greater legibility, efficiency and connectivity, integrated planning and ticketing was expanded to cover the entire Hamburg-plus-seven-counties metropolitan region, and several metro extensions were recently opened or are under construction. Hamburg also has firm plans to introduce a second-generation tram system over the next decade.

Comparative SNAMUTS Results for Melbourne and Hamburg

Base Maps with Impediment Values

Figure 1 and 2 show the base network in both cities, with activity nodes and route segments including their impediment values. There are 169 activity nodes in the Melbourne network, and 170 in Hamburg. As explained above, the impediment value is a proxy measure for distance and consists of the average travel time in minutes divided by the lowest service frequency during the weekday interpeak period, that is Mondays to Fridays between 9.30 and 15.30 (as advertised in public timetables), and multiplied by a factor of 8 to achieve greater readability of the figures. Lower values indicate lower impediment, or spatial/service resistance. Note that the networks have been compiled using a minimum service standard, which has been set at a 20-minute frequency on weekdays (interpeak) and a 30-minute frequency on weekends (during the day). In Hamburg, most of the network is operated at synchronised 10-minute intervals seven days a week until 23.00, with 5-minute service on the core metro routes during business hours and 20-minute service on some suburban routes outside peak hours. In Melbourne, there is greater variation in service frequencies: Most tram routes are operated at 7.5-, 10- or 12-minute intervals, while rail and bus routes usually have frequencies of 15 or 20 minutes, and these don't always match at transfer points. Some outer rail links such as Dandenong to Pakenham or Eltham to Hurstbridge are operated at intervals greater than 20 minutes and are hence not included in the SNAMUTS network.

In Hamburg, some bus routes are branded as express bus routes and attract a supplementary fare. For this project, it was decided to take the SNAMUTS indicators separately for the network without express bus routes (Standard Class), and the network including express bus routes (First Class). The indicators presented in this paper refer to the Standard Class network.

Maps 1 and 2: Public transport in Melbourne and Hamburg in 2008, with modes, service levels and impediment values per route segment.

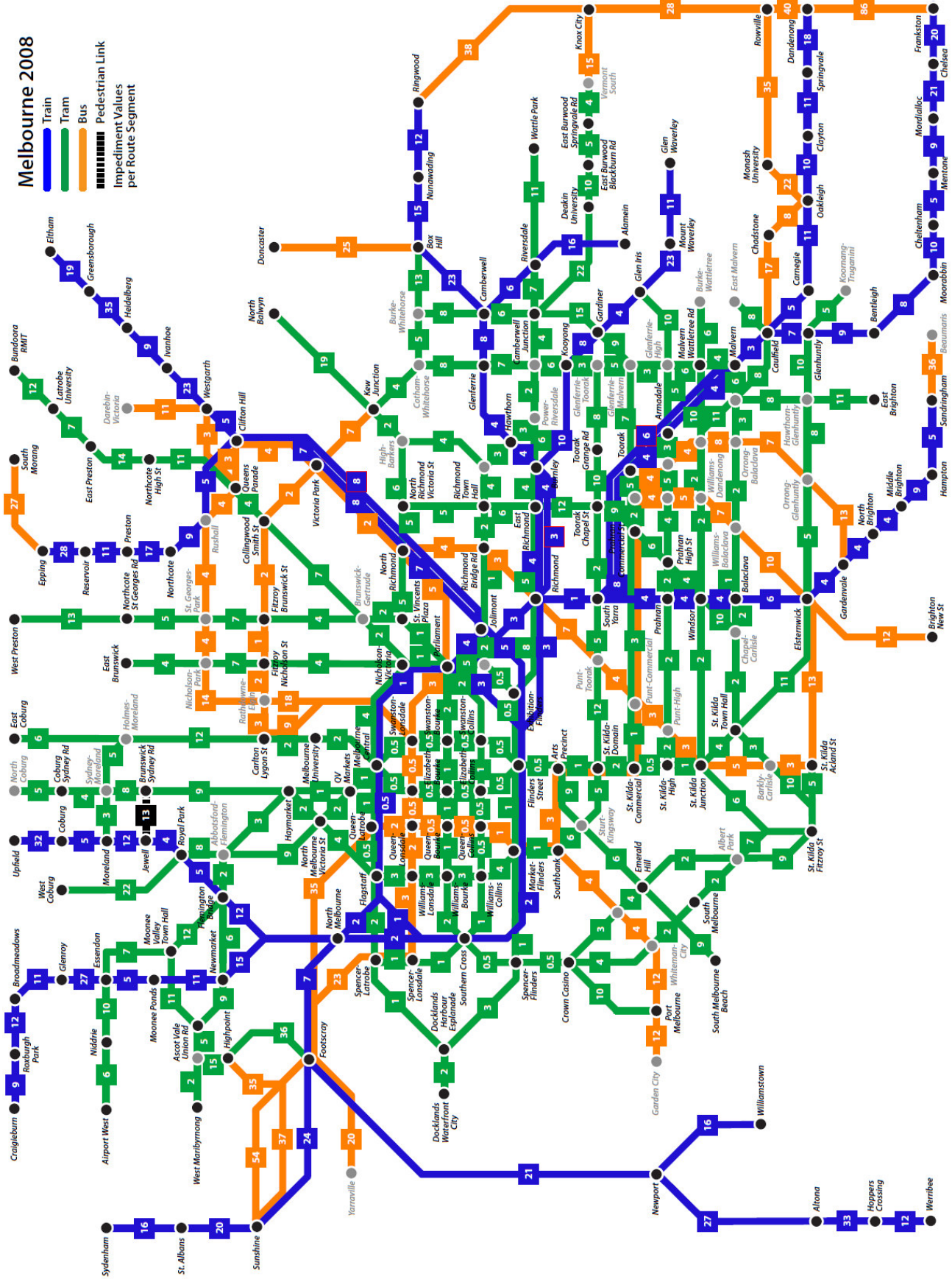
$$d_{ij} = 8t_{ij}/f_{ij} \text{ [1]}$$

where:

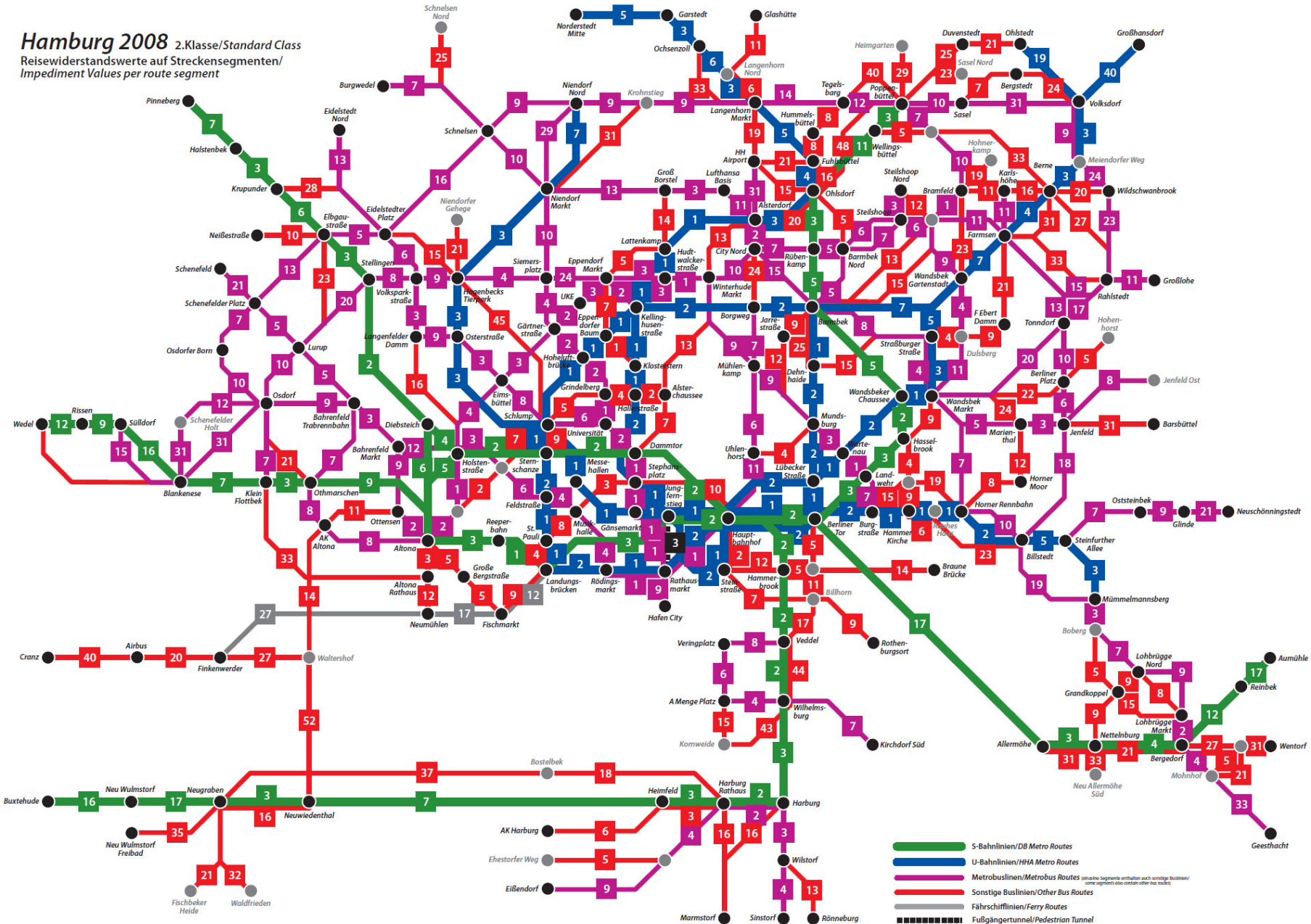
- d_{ij} = Impediment value of route segment between nodes i and j (average of both directions)
- t_{ij} = Travel time between nodes i and j in minutes (average of both directions)
- f_{ij} = Service frequency in departures per hour per direction between nodes i and j

Melbourne 2008

- Train
- Tram
- Bus
- Impediment Values per Route Segment



Hamburg 2008 2.Klasse/Standard Class
 Reisewiderstandswerte auf Streckensegmenten/
 Impediment Values per route segment



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. In some cases, this procedure preferences transfer journeys over direct journeys; 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 entire network. Lower figures indicate greater centrality. Maps 3 and 4 show the results for both cities.

The average closeness centrality value in Melbourne is 48.3 and in Hamburg 34.8, a significant difference of 13.5. The values for particular activity nodes in Melbourne range from 26 to 132, and in Hamburg from 20 to 90. There are 49 nodes (29%) on the Melbourne network with a value of 30 or below, 24 of which are located in the immediate CBD area (Hoddle Grid). In Hamburg, there are 83 nodes (49%) with a value of 30 or below, of which 12 are located in the CBD (within or at the edge of the Altstadt, Neustadt and HafenCity precincts). In Melbourne, this threshold of 30 draws a cordon largely through CBD fringe locations such as Carlton, Richmond or St Kilda Road, generally at a maximum radius of 2 to 4 km from the CBD edge. In Hamburg, the circle is much wider: along metro corridors, the same threshold is generally only reached at a distance of 10 km or more, and it applies to all but one node within the metro circle route (U3) at a concentric distance of 5-6 km from the centre.

Maps 3 and 4: Closeness centrality indexes for activity nodes on Melbourne's and Hamburg's public transport networks in 2008.

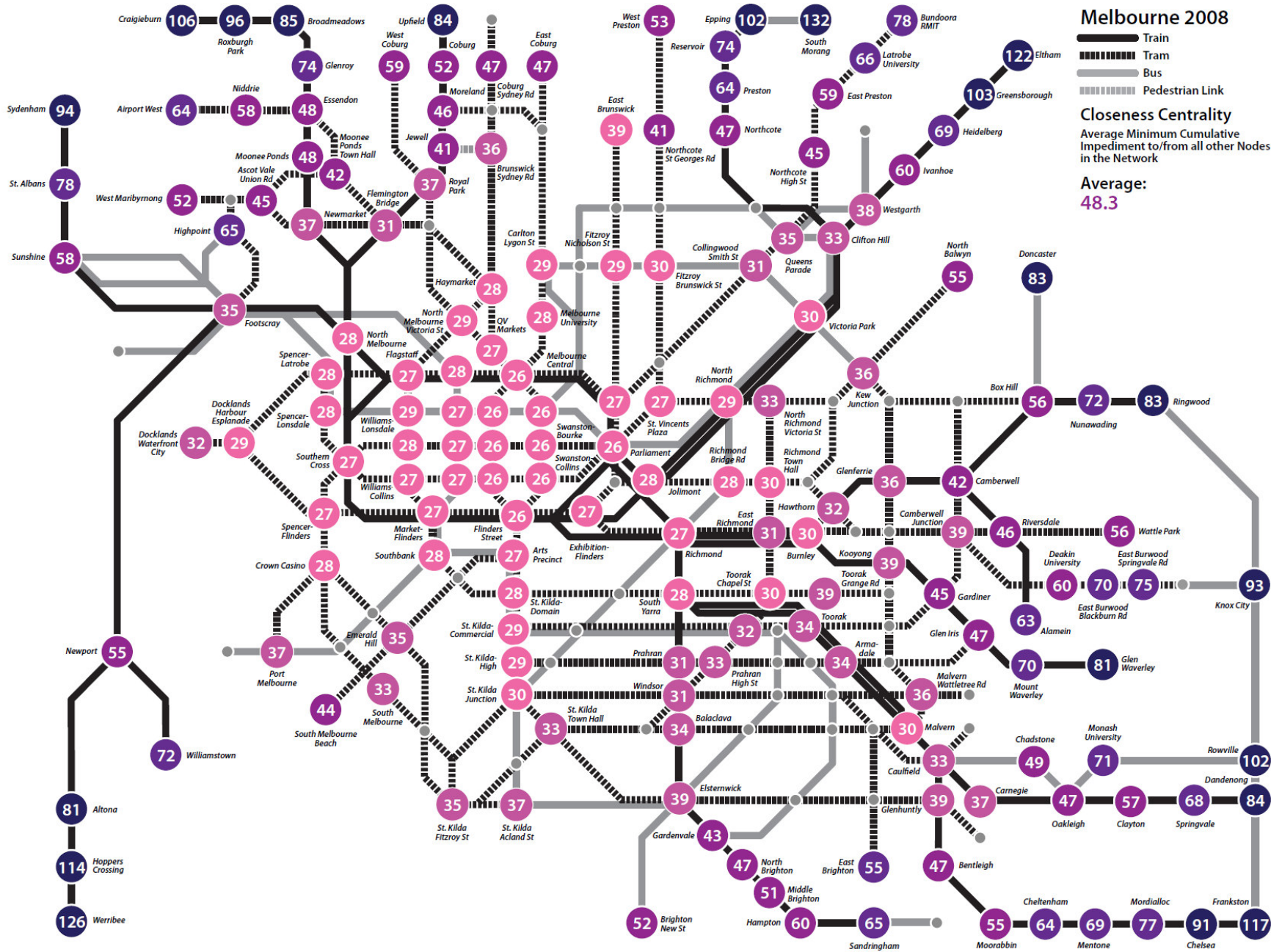
$$CC_i = \sum L_{ij} / (N-1) \quad [2]$$

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



Melbourne 2008

- Train
- Tram
- Bus
- Pedestrian Link

Closeness Centrality

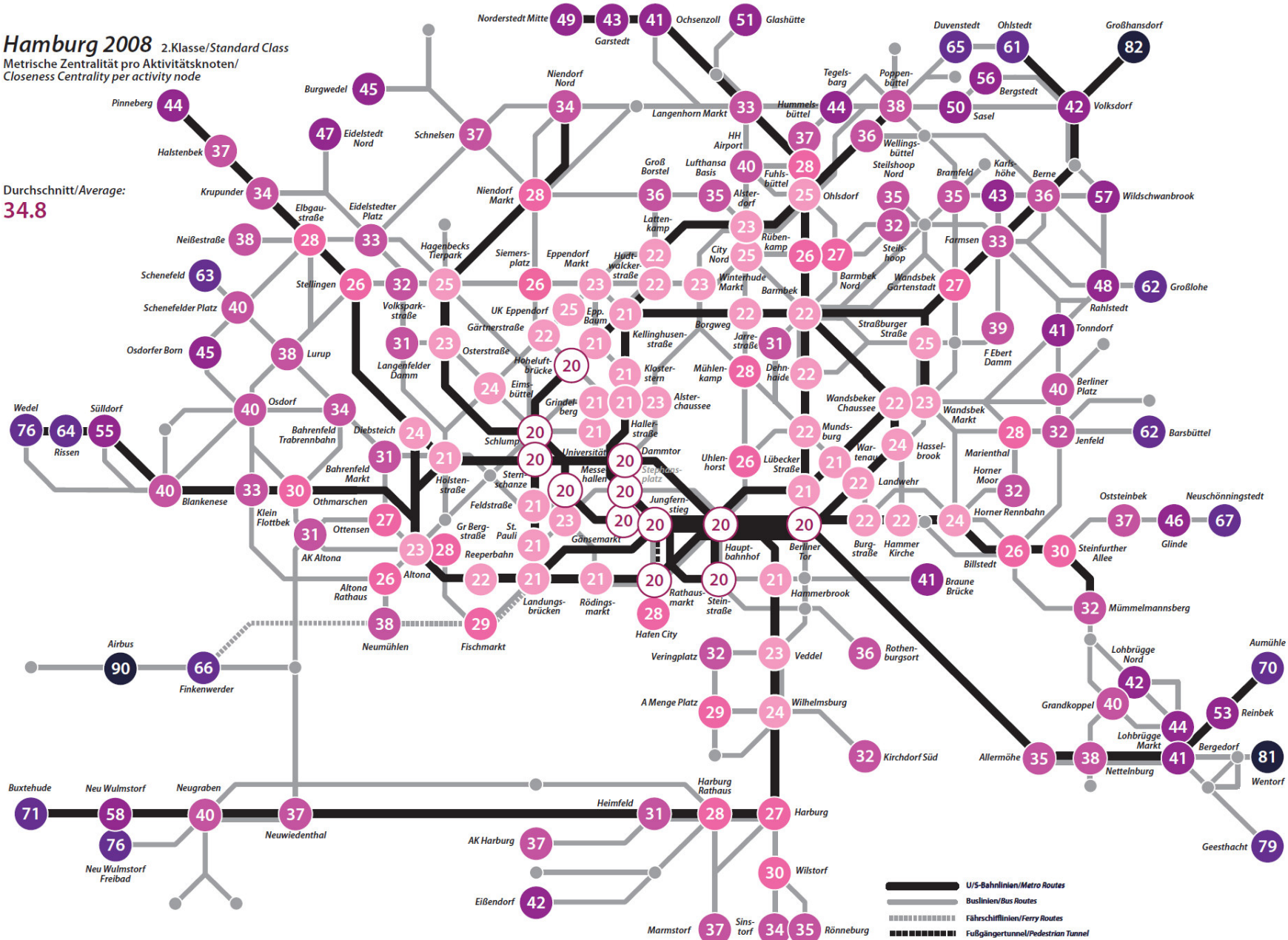
Average Minimum Cumulative Impediment to/from all other Nodes in the Network

Average: 48.3

Hamburg 2008 2.Klasse/Standard Class

Metrische Zentralität pro Aktivitätsknoten/
Closeness Centrality per activity node

Durchschnitt/Average:
34.8



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 5 and 6 depict the average figures per node and globally for the Melbourne and Hamburg networks.

The average degree centrality index for Melbourne is 0.95 while for Hamburg it is 1.20. This figure describes the average minimum number of segments between transfers required to travel between any pair of activity nodes. There is a two-sided message here: on the one hand, the results show that Melbourne's network is less transfer-dependent, offering more direct links between different nodes and routes than Hamburg. On the other hand, it could be argued that Hamburg's network has been optimised to a greater extent in order to resemble a more hierarchical, hub-and-spokes type system, where buses routinely act as feeders to rail at dedicated suburban interchanges, and as orbital connectors. In Melbourne, there are only very limited occasions where trams or even high-frequency buses fill this niche: the majority of routes on all three modes, at least at the minimum standard used in the SNAMUTS model, are radial in nature and lead all the way into the CBD, where most transfer opportunities are concentrated.

A specific approach in this context was used for Hamburg's six metro stations where trains are scheduled to meet for timed cross-platform interchanges, meaning that two trains regularly pull up simultaneously at either side of a platform, allowing their passengers to make transfers without an associated loss in travel time, or the need to find their way to a different platform. Such occasions are only counted as quarter transfers (transfer score of 0.25) and do not enter the count for a maximum of three transfers per path.

Maps 5 and 6: Degree centrality indexes for activity nodes on Melbourne's and Hamburg's public transport networks in 2008.

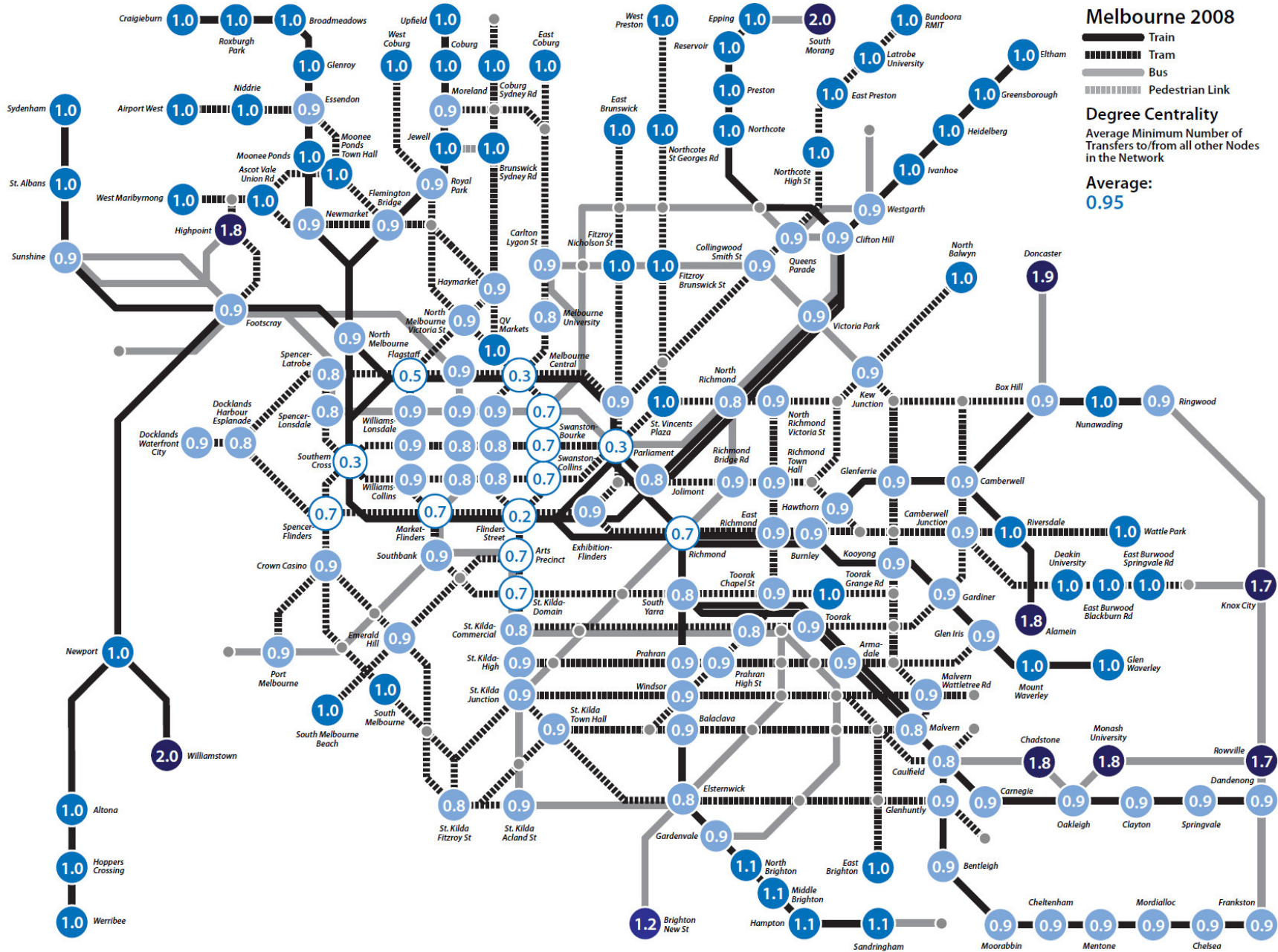
$$CD_i = \sum p_{\min,ij} / (N-1) \quad [3]$$

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

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 (with timed cross-platform transfers not counted), and only where both legs of the transfer trip are operated at least every 15 minutes. A flat penalty of 7.5 minutes in Melbourne and 5 minutes in Hamburg 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 and better matching frequencies (10 minute standard across the network) as well as greater timetable coordination in the Hamburg system. Maps 7 and 8 show the 30-minute contour catchments for each node on the Melbourne and Hamburg networks.

The average contour catchment in Melbourne is 448,000 residents and jobs, equivalent to 8.8% of the metropolitan total, while in Hamburg it is almost twice as high at 824,000 residents and jobs, or 18.5% of the metropolitan total. Fifty-seven Hamburg nodes are within 30 minutes public transport travel time of a quarter or more of all residents and jobs in the metropolitan area, while in Melbourne, only four nodes meet this benchmark. These significant differences can be associated with the greater compactness of Hamburg's urban form over Melbourne's, with activity centres generally spaced more closely together and developed to higher density. It demonstrates a greater level of route connectivity across the network in Hamburg over Melbourne, including outside the CBD area where Melbourne is characterised by significant weaknesses in this respect. Lastly, it may reflect greater speeds and smoother transfers on many critical links in Hamburg, while Melbourne's average public transport speeds remains relatively low in an international context (Scheurer, Kenworthy and Newman, 2005).

Maps 7 and 8: 30-minute contour catchments for activity nodes on Melbourne's and Hamburg's public transport networks in 2008.

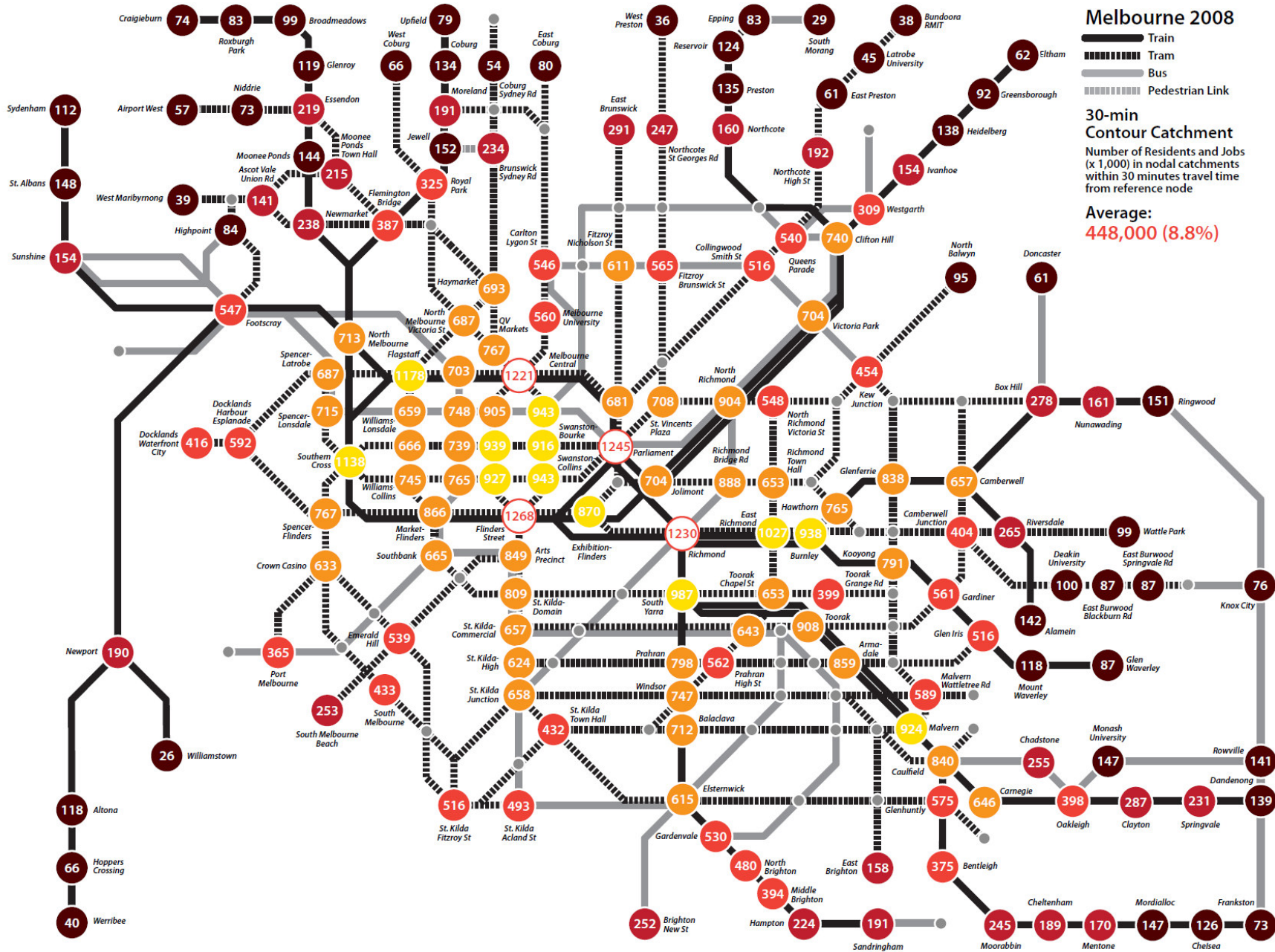
$$CI_i = \text{act}(c_i) \quad [4]$$

where:

CI_i = Contour catchment index of node i

c_i = 30-minute travel time contour of node i

$\text{act}(c)$ = Number of residents and jobs within contour c



Melbourne 2008

- Train
- Tram
- Bus
- Pedestrian Link

30-min Contour Catchment

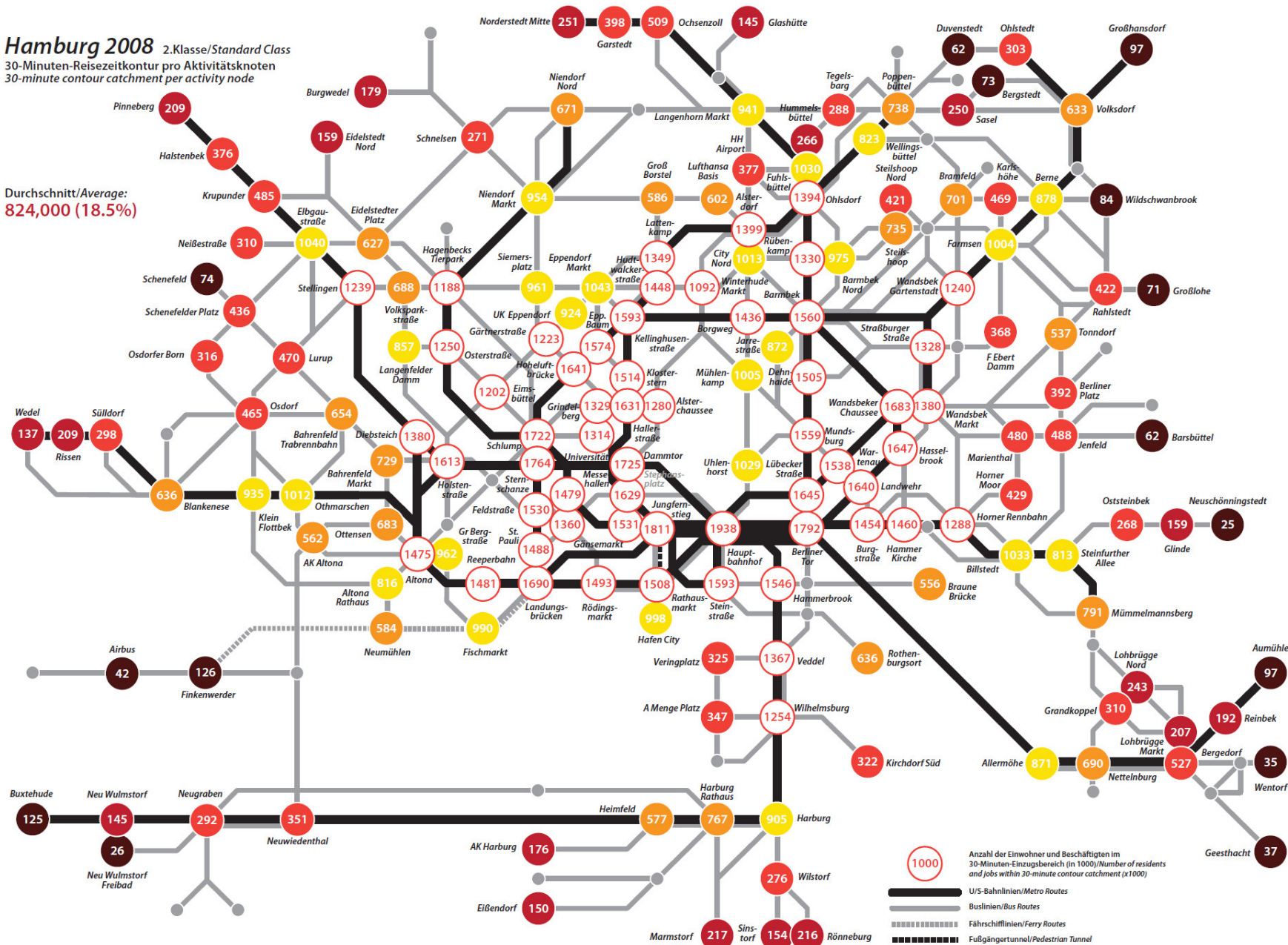
Number of Residents and Jobs (x 1,000) in nodal catchments within 30 minutes travel time from reference node

Average: **448,000 (8.8%)**

Hamburg 2008 2.Klasse/Standard Class

30-Minuten-Reisezeitkontur pro Aktivitätsknoten
30-minute contour catchment per activity node

Durchschnitt/Average:
824,000 (18.5%)



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 9 and 10 show the betweenness centrality indexes for both cities.

According to the betweenness centrality index, in Hamburg 69% of the strategic significance in the network can be found on metro segments and 30% on bus segments. In Melbourne, tram segments carry the bulk of this measure at 54%, with train segments at 38% and bus segments at a mere 8%. In both cities, the betweenness scores per segment have been weighted by travel time to arrive at this distribution. Thus for Hamburg it could be argued that the majority of travel opportunities are catered for by the higher-performing modes. The only bus routes approaching the performance of rail links in the betweenness index are those earmarked for conversion to tram operation in the future.

Also remarkable in Hamburg is the strong performance of the inner metro orbital route (U3) between Barmbek and Sternschanze, elevating the latter (and quite modest) transfer facility in a CBD fringe location to one of the most critical nodes in deflecting travel opportunities away from the CBD area itself.

In Melbourne, about 15% of the network-wide betweenness score occurs on tram routes within the CBD area. Intuitively, this level of significance is unsurprising to a public transport user: the tram system, not least because of its close integration into the pedestrian street-level environment, provides exquisite accessibility across the city centre. But in performance terms, the tram system is an intermediate mode: it can and does achieve tasks that would overwhelm a bus system, but it is also inherently slower and of lower passenger capacity than the train system. Melbourne's betweenness scores show extraordinary high values of significance for the north-south tram lines along Elizabeth and Swanston Streets, and further along St Kilda Road. The city has plans for an underground rail link along this corridor and is currently seeking financial support from Federal Government for this purpose (DOT, 2008). From this index, such a project appears to have substantial merit, though perhaps even more so for its ability to facilitate faster movement and better connectivity in the Haymarket to St Kilda Road corridor specifically, than for the oft-stated need, quite controversial among transport experts (Mees, 2007), to create relief for an allegedly overcrowded existing rail system in central Melbourne.

On many radial corridors in Melbourne, particularly in the mid-northern and eastern suburbs, there are parallel rail and tram routes, which both appear to pick up a reasonable amount of network significance but do not appear to distribute this task very effectively towards the higher-performing mode (heavy rail). Network performance is hampered here by the failure of these routes to provide attractive rail-tram transfer points and the relatively low service frequencies on the rail system. Both issues, however, could be addressed to significant benefit without excessive infrastructure upgrades (Scheurer, Bergmaier and McPherson, 2006).

Only a few bus routes in Melbourne have a service standard that meets the threshold used in the SNAMUTS model, even though this is slowly improving. Some orbital links that do appear, especially in the inner north, have betweenness scores similar to those on tram lines in the vicinity, and tangibly higher than on orbital tram or bus routes in the inner south-eastern

suburbs, where there is already a denser and more interwoven surface network. Conversion of these routes to tram operation is not currently on the agenda of either State or Local Governments, however, such measures could potentially deliver some efficiency benefits with attractive through routes eliminating bus-tram transfers.

Maps 9 and 10: Betweenness centrality indexes for the public transport networks in Melbourne and Hamburg in 2008, 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.

$$CB_{k,w} = \frac{\sum(p_{ij}(k) \cdot (act_i \cdot act_j) / L_{ij})}{\sum(p_{ij} \cdot (act_i \cdot act_j) / L_{ij})} \quad [5]$$

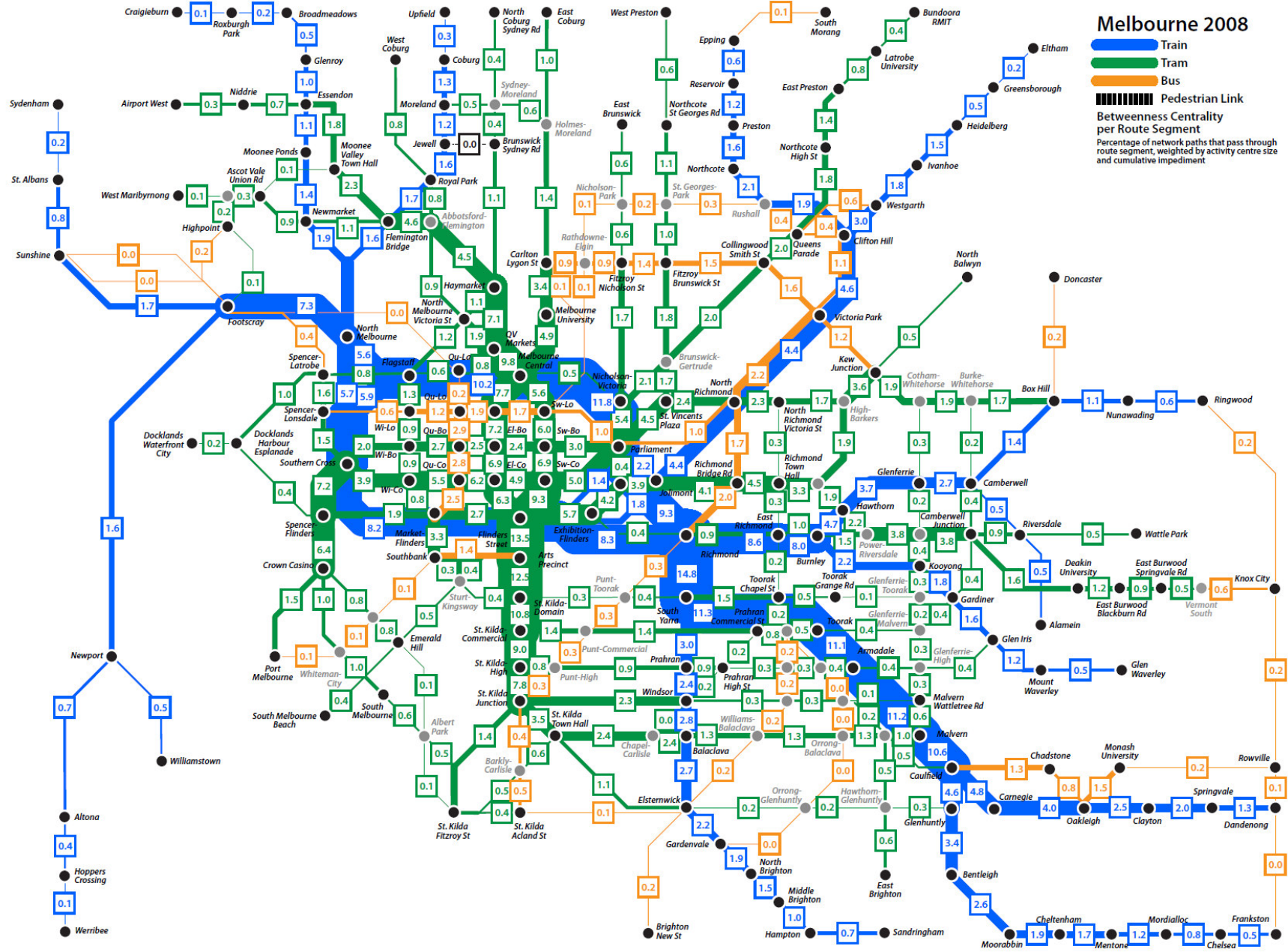
where:

- $CB_{k,w}$ = 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 ∈ N and i ≠ j
- P_{ij} = All paths in the network, for all i, j ∈ N and i ≠ 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

Melbourne 2008

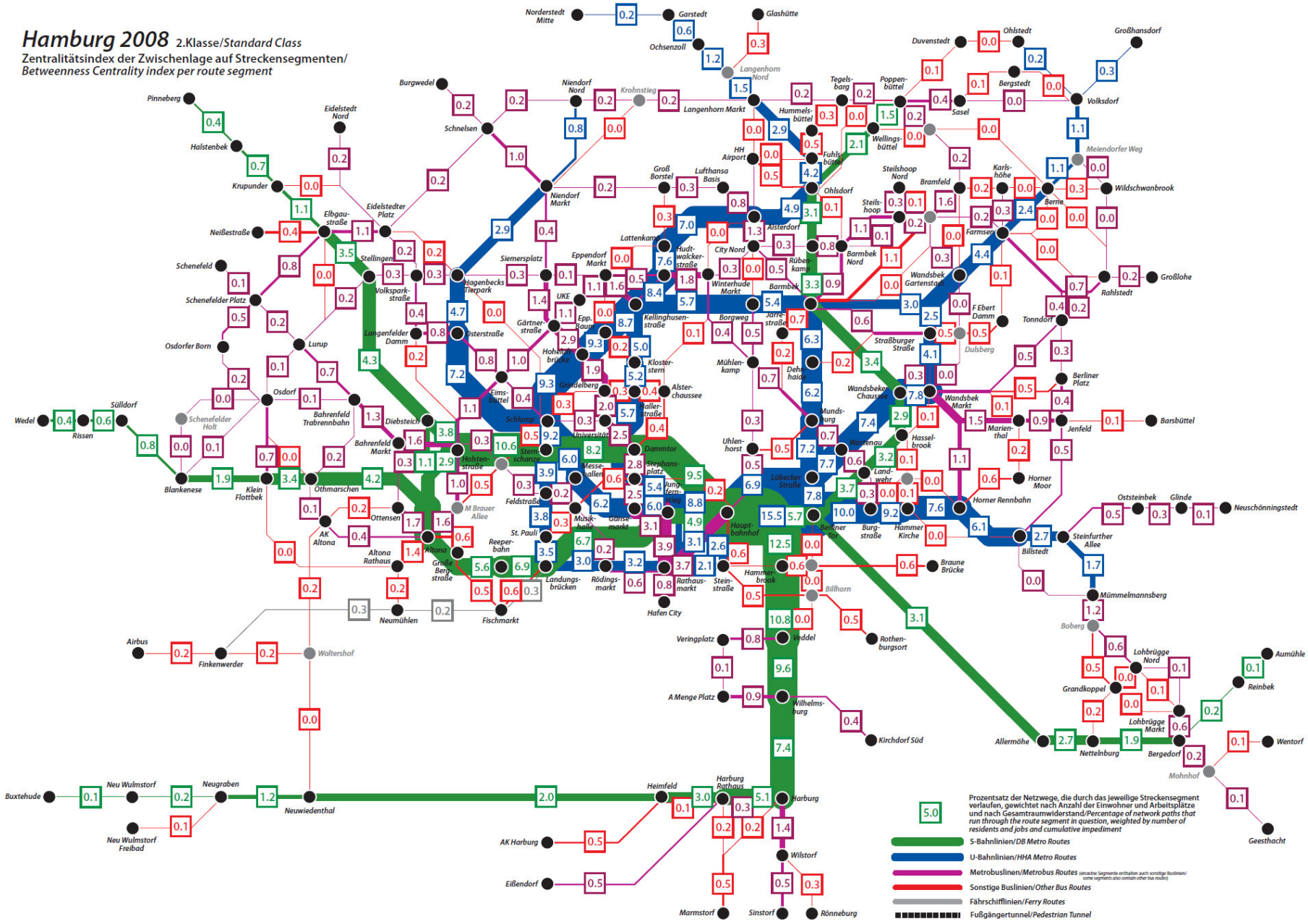
- █ Train
- █ Tram
- █ Bus
- Pedestrian Link

Betweenness Centrality per Route Segment
Percentage of network paths that pass through route segment, weighted by activity centre size and cumulative impediment



Hamburg 2008 2.Klasse/Standard Class

Zentralitätsindex der Zwischenlage auf Streckensegmenten/
Betweenness Centrality index per route segment



Melbourne @ 5 million: Towards a European Level of Public Transport Orientation?

SNAMUTS is a tool designed to assess the impact of network and land use changes in the past and the future. This is the case regardless of whether these are the outcome of deliberate planning efforts such as policy decisions to expand or cut public transport service or to pursue transit-oriented development schemes, or of self-regulated processes such as the deterioration of service quality due to traffic congestion or market-led urban development along or away from public transport facilities. Such longitudinal analyses will help us with the original purpose of the study, namely to determine whether Melbourne, with a policy target to achieve a modal share of public transport by 2020 that is equivalent to that of Hamburg in 1995, is making sufficient progress on this trajectory. What further changes to the Melbourne network, and to the city's land use patterns, are required to prepare the city's public transport for a sustained role of at least twice the significance it had before the current surge in patronage started around 2005?

The degree centrality index has shown that Melbourne already offers connections with fewer transfers on average than Hamburg, even though many of these are based on time-consuming detours away from geographical desire lines. A more interconnected orbital bus network as pioneered by projects such as Route 903, opened in April 2009, will perhaps not change the scores of this index dramatically, but will offer more choices of routes for many journeys and thus the potential for time savings and a more even distribution of trips away from congested routes and nodes. Similar effects can be expected from the creation of more and better multi-modal interchanges and the creation of new links on the tram system, in some cases involving the construction of relatively minor, gap-filling connections between adjacent nodes.

In the closeness centrality index, Melbourne is lagging significantly behind Hamburg and has a substantial struggle ahead in order to close this gap. Since closeness centrality is based on impediment values, a composite index in its own right (Gudmundsson, 2001), there are several approaches towards enhancing performance. These include faster travel speeds, achieved by more semi-express services on the train network and by traffic priority measures for trams and buses; better service frequencies particularly on the train system, where some capacity upgrades are required to achieve high frequencies of 15 minutes or better across the network; and greater network connectivity along the network and service configuration principles advocated by Mees (2000), Nielsen (2005) and Vuchic (2005), aiming at a legible network structure that is efficient to operate, easy to navigate, offers a choice of routes wherever possible and can compete with the car for travel convenience.

The most significant performance gap between Melbourne and Hamburg can be found in the average size of 30-minute contour catchments of activity nodes. Simultaneously, these pose formidable challenges to improve. Like travel impediment, however, contour catchment size is a composite index, combining both infrastructure and activity measures as discussed by Geurs and van Eck (2001), and can thus be manipulated in several ways. Among these are, once again, faster travel speeds to expand the 30-minute contour line and thus capture more land use activities; an increased number of services at 15-minute intervals which, by the SNAMUTS definition, enables transfers to be made to a greater number of routes and thus also expands the contour line; and greater land use density within the contour line, achieved by planned or ad-hoc urban intensification, to increase the number of residents and jobs even while the contour line itself remains unchanged.

In this context, there is currently an interagency project initiated by the City of Melbourne with a view to accommodating one million additional residents within walking distance of Melbourne's tram network while respecting the preservation of heritage buildings and open spaces (Adams, 2009). Conversely, the State Government announced in mid-2009 that another 40,000 hectares of Greenfield land at the urban fringe will be rezoned to accommodate more low-density housing estates (DPCD, 2009) which, despite one of these corridors including a new rail line, are notoriously problematic to service with high-quality public transport. In this context, one of the most significant figures from the SNAMUTS set to watch is that of overall coverage of residents and jobs across metropolitan Melbourne within walking distance from minimum-standard public transport services, which in 2008 stood at 41%. Quite separately to the performance of the network as such, this figure will also need to increase if Melbourne was to close the gap to

Hamburg (where it was 54% in 2008). In a city whose growth occurs predominantly in new outer suburbs on Greenfield land, the price for greater overall public transport coverage at minimum service standards is a tremendous increase in the number of services required without an equivalent return in network performance. The betweenness index points to a somewhat paradoxical insight here: a fast-growing urban fringe serviced primarily by radial network extensions translates into disproportionate additional strain on the most central elements of the network (Curtin and Scheurer, 2009). In a city whose growth is configured around existing and incrementally expanding public transport infrastructure with a focus on locations with high accessibility, there is every chance to capitalise on synergies between land use and public transport and thus achieve an improvement in network performance that is greater in magnitude than the additional operational effort (ibid). This could make the expenditure for new tram and bus routes, integrated multimodal transfer facilities, rail capacity upgrades and perhaps even new rail tunnels an investment in a more sustainable, accessible and better functioning city.

In general terms, SNAMUTS attempts to build a discursive tool that assists in popularising the complex concepts of accessibility with practitioners and interested members of the public, and in stimulating a debate about viable and sustainable future trajectories of land use and infrastructure development in cities. In future steps, we hope to expand the methodology to better integrate the specific parameters for accessibility by private road travel and non-motorised modes besides public transport, and to create an interactive, web-based tool to allow users to elaborate and test their own SNAMUTS scenarios.

References

- Adams R (2009) Future Infrastructure. How might Australian cities be reconfigured to meet the challenges of climate change? Architecture Australia, January/February 2009
- Australian Bureau of Statistics (ABS, 2007) Census of Population and Housing 2006. Available online at www.abs.gov.au
- Baradaran S, Ramjerdi F (2001) Performance of Accessibility Measures in Europe. Journal of Transportation and Statistics, September/December 2001
- 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, pp 207-220
- Betts J (2009) Victorian Transport Budget 2009-10. Address to the Metropolitan Transport Forum (MTF), 3 June
- 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. Department of Planning and Infrastructure (DPI) and Curtin University of Technology, Perth (WA)
- Department of Infrastructure (DOI, 2002) Melbourne 2030. Planning for Sustainable Growth. Melbourne (VIC)
- Department of Planning and Community Development (DPCD, 2008) Melbourne 2030 - A Planning Update: Melbourne @ 5 Million. Melbourne (VIC)
- Department of Planning and Community Development (DPCD, 2009) Delivering Melbourne's Newest Sustainable Communities. Melbourne (VIC)
- Department of Transport (DOT, 2008) The Victorian Transport Plan. Melbourne (VIC)
- Department of Treasury and Finance (DTF, 2009) Victorian State Budget 2009-10. Melbourne (VIC)
- Economist Intelligence Unit (2009) Liveability Ranking. Worldwide Cost of Living Survey, available online at www.eiu.com

- Geurs K T, van Eck J R (2001) Accessibility Measures: Review and Applications. Rijksinstituut voor Volksgezondheid en Milieu (National Institute of Public Health and the Environment, RIVM) and Urban Research Centre, Utrecht University. Bilthoven/Utrecht, Netherlands
- Geurs K T, van Wee B (2004) Accessibility Evaluation of Land-Use and Transport Strategies: Review and Research Directions. *Journal of Transport Geography*, Vol 12, pp 127-140
- Gleeson B, Curtis C, Low N (2003) Barriers to Sustainable Transport in Australia. Chapter 12 in Low N, Gleeson B (2003, Eds) *Making Urban Transport Sustainable*. Palgrave Macmillan, New York (NY), USA
- Gudmundsson H (2001) Indicators and Performance Measures for Transportation, Environment and Sustainability in North America. National Environmental Research Institute, Roskilde, Denmark
- Kenworthy J, Laube F (2001) The Millennium Cities Database for Sustainable Cities. Union Internationale des Transports Publics (UITP), Bruxelles, Belgium and Institute for Sustainability and Technology Policy (ISTP), Murdoch University, Perth (WA)
- Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen (LSKN, 2009) Flächenerhebung, tatsächliche Nutzung. Hannover, Germany, available online at www1.nls.niedersachsen.de/statistik
- Latora V, Marchiori M (2002) Is the Boston Subway a Small-World Network? *Physica A*, Vol 314, No 1-4
- Litman T (2003) Measuring Transportation: Traffic, Mobility and Accessibility. *ITE Journal*, Vol 73, No 10, pp 28-32
- Marchetti C (1994) Anthropological Invariants in Travel Behaviour. *Technical Forecasting and Social Change*, Vol 47, pp 75-78
- Mees P (2000) A Very Public Solution. *Transport in the Dispersed City*. Melbourne University Press, Melbourne (VIC)
- Mees P (2007) Rail Infrastructure Capacity Constraints in Melbourne: An Engineering Problem or a Political Problem? 3rd State of Australian Cities Congress, Adelaide, 30 November-2 December
- 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
- Prud'homme R, Lee C (1999) Size, Sprawl and the Efficiency of Cities. *Urban Studies*, Vol 36, pp 1849-1858
- 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, Bergmaier R, McPherson J (2006) Keeping People Moving in Melbourne's North-East. Metropolitan Transport Forum (MTF), Melbourne (VIC)
- 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, 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 of Technology, Perth (WA), available online at www.abp.unimelb.edu.au/gamut/pdf/perth-snamuts-report.pdf
- Scheurer J, Kenworthy J, Newman P (2005) *Most Liveable and Best Connected*. The Economic Benefits of Investing in Public Transport in Melbourne. Metropolitan Transport Forum (MTF), Melbourne (VIC)
- 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
- Statistikamt Nord (2005) Bodenflächen in Schleswig-Holstein und Hamburg nach Art der tatsächlichen Nutzung. Hamburg/Kiel, Germany, available online at www.statistik-nord.de
- Vuchic V R (2005) *Urban Transit: Operation, Planning and Economics*. Wiley, Hoboken (NJ), USA

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

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Software

MapInfo Professional 9.5, MapBasic 8.5, Adobe Illustrator CS4, Microsoft Excel 2003/2007