## SECTION A

# WHY DO WE NEED A GOOD PUBLIC TRANSPORT SYSTEM?

By Peter Newman

Curtin University Sustainability Policy (CUSP) Institute

Western Australia

Rapid transit is being built and used for the following reasons:

### a. It assists cities in their wealth creation.

Car dependence is expensive. The link between the wealth of a city and its car use is very weak; it is certainly not statistically significant (only 18% of the variation is explained, (Newman & Kenworthy 1999). European cities tend to be the wealthiest in the world yet have half the car use of US cities; wealthy Asian cities like Hong Kong, Tokyo and Singapore have 10 times the per capita wealth of Bangkok, Jakarta, Kuala Lumpur, Manila, Surabaya, Seoul and Beijing, but per capita car use is less. Many wealthy cities have put their wealth into good transit infrastructure. The result is not a city that is poorer because it wastes money on public transport, as suggested by many economists (particularly Treasury officials). Indeed, the data suggest that the more a city has committed itself to public transport infrastructure, the less the city spends overall on transport; and the more a city has built itself around car dependence, the more of the city's wealth is wasted on just getting around (Newman & Kenworthy 1999). Car travel is estimated to cost around 85c per pass.km compared to 50–60c per pass.km in transit (House of Representatives 2005).

### b. It is more equitable.

There is an equity argument here too, as the poor in Australian and American cities are increasingly moving out to car-dependent areas where they save money on housing but lose heavily on transport, some families spending up to 40% of their income on transport (STPP & Center for Neighborhood Technology 2005). Households in car-dependent cities in the US are now spending more on transport than on their mortgages, which helps explain why oil price increases helped to create the subprime mortgage meltdown in late 2007. Continuing non-viability of such car-dependent urban sprawl threatens the abandonment of whole suburbs, similar to the kind of inner-city abandonment found in US cities in the 1960s.

On the other hand, transit-oriented developments (TODs) can offer cities economic advantages without this vulnerability. Much of the marketing benefit of TODs has been outlined by a Center for Transit Oriented Development (2005) study which showed that people living in TODs in the US had the same age and income as those not living in TODs but had one less car per household (0.9 cf. 1.7). This was found to lead to a 20% increase in their available household wealth. As a tool for marketing TODs, it is not just of value to households as local governments soon find that this extra available wealth is largely spent locally on local goods and services; buying a car would not do the same thing in terms of local economic benefits. Hence TODs are a means of helping create local economic development.

### c. It reduces the external costs of car dependence.

It has been well documented that car dependence is costly in terms of environmental, social and economic externalities — for example, McGlynn and Andrews (1991) suggest an extra 20c per pass.km would be needed to pay these costs. Government costs due to accidents, pollution, noise etc. have been estimated and compared to the government revenue benefits of the road system in Australia, and there was an overall 'road deficit' of $8 billion in the late 1990s (Laird et al. 2002). Added to this is what Nicholas Stern calls 'the biggest externality in history' — the cost of climate change, which is likely to become part of all future transport planning as the world seeks to find a way to stop runaway impacts from occurring.

### d. It reduces oil vulnerability.

The biggest looming problem of car dependence is oil vulnerability and here the 'coalition of the willing' are US and Australian cities, which have by far the biggest vulnerability to the global oil production peak (Newman 2007). The most recent record price of oil (when it reached $140 a barrel) appears to have signalled the peak in conventional oil and the start of a decline estimated at between 3% and 6% a year. Unconventional oil from the deep ocean and tar sands all cost over $100 a barrel and will also peak within a decade. The Australian oil supply has peaked and is declining at 11% per year. This can be seen as a major threat or an opportunity to lead in the race to being a less oil-dependent city (Newman, Beatley & Boyer 2009).

Cities vary in their vulnerability to this problem. US cities average around 2,000 litres per person per year; Australian, Canadian and New Zealand cities average around 1,000 litres; whilst European cities are closer to 450 litres and Asian cities are 275 litres per person per year on average.

Electric rail systems (with TOD built around stations) will withstand this crisis far better than urban areas with extensive car dependence. Electric rail continues to be the most efficient form of motorised transport as it alone does not have to carry its own fuel. The data from our Global Cities Database are outlined in Table A-1.

**Table A-1:** Fuel efficiency and occupancy by mode in global cities, 1990

| Mode | MJ per passenger kilometre (average all cities) | Measured average vehicle occupancy (average all cities) |
|---|---|---|
| Car | 2.91 | 1.52 |
| Bus | 1.56 | 13.83 |
| Heavy Rail (electric) | 0.44 | 30.96 |
| Heavy Rail (diesel) | 1.44 | 27.97 |
| Light Rail/Tram | 0.79 | 29.73 |

*Source: Newman and Kenworthy, 1999*

*(Note: Heavy-rail occupancy is per carriage.)*

### e. It saves time.

People do not want to travel more than an hour a day on average; this has become known as the Marchetti Principle (Marchetti, 1994). The switch to more sustainable modes of transport will not occur if it means people go beyond their travel time budget. Thus a city will only be truly moving towards a less car-dependent future if it can:

- build a rapid-transit system faster than road traffic down every corridor
- build centres where walking, biking or a short bus or car trip become the means of reaching local urban services as they are quick to reach.

TODs can thus be used to save time for local and long-distance travel. But TOD centres only attract the necessary development potential around them if they are linked by fast transit. Almost invariably this is electric rail, due to its speed (acceleration/deceleration, cruising speeds and egress/ingress speeds, which are all significantly better than buses, even in busways). Bus cities have transit speeds of around 20-25 k/h whilst rail cities have transit speeds of 35-40 k/h, which are competitive with overall traffic speeds (Kenworthy & Laube 1999). Rail gives transit an edge in speed, which is crucial to being competitive. In many developing-country cities and in some corridors where rail is not available, bus rapid transit is providing the extra speed required over the traffic, though rarely as fast or with the capacity advantages of rail. Buses provide the necessary flexibility around suburbs but work best at this local role rather than at line haul functions that require speed, capacity and certainty.

### f. It saves space.

The reason that many cities switch from buses to rail is that their city centres get completely jammed with very slow buses. The Bangkok effect or 'bus bunching' is due to a capacity factor that is even more obvious with cars. Table A-2 shows the relative capacities of modes.

**Table A-2:** Modal capacities

| Mode | Carrying capacity (people per hour) |
|---|---|
| Freeway lane | 2,500 |
| Bus lane | 5,000 to 7,000 |
| Light rail line | 10,000 to 20,000 |
| Heavy-rail line | 50,000 |

*Source: Vuchic, 2005*

Thus the space requirements of car dependence are 20 times those of rail. The costs of such space are considerable and help to explain why most central cities cannot function without rail access. If the 200,000 per day of people who access central Sydney had to get there by car it would mean an extra 65 freeway lanes and 782 ha for car parks. Rail makes spatially constrained cities work.

### g. It creates city spaces suitable for the knowledge/services economy.

The key to the new economy based on transactions between knowledge/services professionals is the ability to meet and interact. Electronic communication can be used to follow up the creative interactions that occur face to face. As the distinguished planner Sir Peter Hall said after assessing what it is in cities that creates economic innovation: 'The new world will depend as the old world did on creativity and creativity flourishes where people come together face to face.' (Hall 1997). This explains why car-dependent shopping centres are not attracting the new economy jobs and the older centres are. Cities therefore need centres in old and new suburbs that are dense, mixed and walkable, to create such interactions. This is the philosophy of the New Urbanists (Calthorpe 1993) and although their human-oriented urban designs are critical, so is the role of rail in creating spaces where bitumen is not the dominant land use.

### h. It creates certainty for investment.

Transit, especially rail, is fixed and it lasts a long time — certainly beyond the period that most investors need to get their investment back. Bus routes change, even bus lanes and busways are flexible, though major rail systems cannot easily be moved. Transport planners have been heavily oriented to flexibility but nothing can compete with the flexibility of cars if road space is sufficient — certainly no bus system can. But once road space is constrained, the existence of fixed rail systems becomes critical. If built, they provide the certainty investors need. Rail offers both a real transport solution and a real land investment opportunity. Cervero (2003) has shown in over 30 studies in the US that access to rail station land provides proven land value premiums. An Australian developer has created a fund for doing TOD in Perth, as its rail projects offer potential for at least 15% higher return in the areas around stations due to the attraction of the new rail system.

### g. It is preferred by increasingly urban-oriented younger people.

Commenting on why US cities began to decline in car use per person over the last 5 years (before the fuel price spike and the global financial crisis) a Brookings Institution study suggested that one factor was a demographic shift by younger people back into cities where they did not need a car (Puentes & Tomer 2009). Recent data confirms this by showing that car ownership amongst teenagers had dropped in the US from 15 million to 10 million. There undoubtedly is much life left in the automobile and its culture, especially in car-dependent suburbs where there is no choice, but given half a chance there is plenty of evidence, including in Perth, that people will choose to be less dependent on the car.

# References

Cervero, R 2003, *Transit oriented development in America: experiences, challenges and prospects,* Transportation Research Board, National Research Council, Washington DC.

Gorowitz, C 2007, *Affordable housing and TOD,* Report for WA Government TOD Committee, PATREC, Curtin University.

Hall, P 1997, 'Reflections past and future in planning cities,' *Australian Planner*, *vol. 34, no. 2, pp. 83–89.*

House of Representatives 2005, *Sustainable cities,* Australian Government, Canberra.

Kenworthy, JR & Laube, FB 1999, *An international sourcebook of automobile dependence in cities, 1960–1990*, University Press of Colorado, Niwot, Boulder.

Laird, P, Newman, P, Kenworthy, J & Bachels, M 2001, *Back on track: rethinking Australian and New Zealand transport policy,* University of NSW Press, Sydney.

Marchetti, C 1994, 'Anthropological invariants in travel behaviour', *Technical Forecasting and Social Change,* vol. 47, no. 1, pp. 75–78.

McGlynn, G & Andrews, J 1991, *The economic cost–benefits of urban scenarios that support ESD,* Australian Commission for the Future, Melbourne.

Newman, PWG & Kenworthy, JR 1999*, Sustainability and cities: overcoming automobile dependence,* Island Press, Washington DC.

Newman, P 2007 'Beyond peak oil: will our cities collapse?', *Journal of Urban Technology*, vol. 14, no. 2, pp. 15–30.

Newman, P, Beatley, T & Boyer, H 2009, *Resilient cities: responding to peak oil and climate change,* Island Press, Washington DC.

Puentes, R & Tomer, A 2009, *The road less travelled: an analysis of vehicle miles travelled trends in the US*, Metropolitan Infrastructure Initiatives series, Brookings Institution, Washington DC.

STPP & Center for Neighborhood Technology 2005, *Driven to spend: pumping dollars out of our households and communities,* CNT & Surface Transportation Policy Project, June 1, Chicago and Washington DC.

Vuchic, V 2005, *Urban transit: planning, operations and economics,* Wiley, Indianapolis.

## SECTION B

# THE KNOWLEDGE ECONOMY AND PUBLIC TRANSPORT[1]

By Michael Kane

Curtin University Sustainability Policy (CUSP) Institute

The Rudd Government has made clear in key policy decisions that Australia's long-term productivity, global competitiveness and improved social wellbeing rely heavily on the productivity of its cities (including its urban transport systems) and the nation's capacity to engage in the global digital economy (Infrastructure Australia 2009; Prime Minister Rudd 2009; The Department of Broadband, Communications and the Digital Economy 2009). How these two policy areas are intrinsically interrelated is addressed in this paper.

### The relationship between urban planning, information communication technology (ICT) and the knowledge economy

The emergence of the internet and the knowledge economy prior to the turn of the last century was touted by some as the 'end of geography' (see Graham 1998 for the early debate). However, the view that ICT and the internet would eliminate space was considered 'fantasy' by Warf (2001) and arguments that the internet would cause cities to lose their physicality and disperse or that the spatial theatre of the city would ever vanish was deemed 'unthinkable' by Page and Phillips (2003). Paradiso (2003), considering the literature on the geography of the internet and ICT infrastructure, found strong arguments for the contention that while the internet allows for more localised freedom, internet technology is not removed from the advantages of proximity and agglomeration nor from the traditional economic, social and political inequities. Therefore the importance of place, while reshaped, remains. Benefiting from technology is intrinsically linked to access to communication technologies. Levels of access are largely the result of broader economic, social, infrastructure and cultural inequalities creating a 'digital divide' in many countries (Warf 2001; Moss & Townsend 2000; Paradiso 2003; Kellerman 2004; Rutherford, Gillespie & Richardson 2004) including Australia (Department of Broadband 2009; Willis & Tranter 2002; and ABS 2006).

A range of other proximity factors that drive spatial location towards cities can be identified from the literature including:

- physical infrastructure of the internet proximity — the internet backbone (Moss and Townsend 2000; Warf 2001; and Rutherford et al 2004)
- knowledge content proximity (Kellerman 2002; Paradiso 2003; Storper & Venables 2002)
- technical network client support proximity (Kellerman 2002; Moriset 2003)
- labour market access and liveability proximity (Moss & Townsend 2000; Moriset 2003)
- need for trust and business security proximity (Storper & Venables 2002).

*[1] This section is taken from 'Devising public transport systems for 21$^{st}$ century economically productive cities', a paper by Michael Kane published in Australian Planner in 2010. It suggests a Knowledge Ring rail and bus on a barge across the river between Canning Bridge and UWA, instead of just the Knowledge Arc rail we have suggested. The important economic rationale remains the same.*

Proximity characteristics for ICT and the knowledge economy operate at differing levels of complexity at the city, firm, and individual level (Kellerman 2006). Kellerman (2006) has also argued that while there are strong spatial characteristics in the information age, it is nuanced in that there is also a developing mobility both at the firm and individual level that was not present in previous industrial and post industrial ages. Similarly Devriendt, Derudder and Witlox (2008) have argued that there is a nuanced spatial reality that co-exists. While there is a greater trend towards city to city digital city networking and interrelationships between key cities creating digital hubs, there is also a spatially free context. They refer to the different contexts as ‘cyberplaces’ as the internet physical fabric and ‘cyberspace’, which is the virtual, immaterial world where distance does not matter.

It has been argued that the spatial context of ICT and the knowledge economy will be transformative (Moss & Townsend 2000; Banister & Hickman 2006). Banister and Hickman (2006) argue technology is transforming cities as fundamentally as the agricultural and industrial revolutions. They foresee urban concentration at the international level with ‘technopoles’ of growth around airports and public transport while at the same time urban de-concentration and dispersal are also occurring. Kim, Claus, Rank and Xiao’s (2009) work on analysing the impact of a wide range of available technologies and their unit costs on urban form over the 20$^{th}$ century provides an explanation of how technology, including ICT, is driving and will continue to drive change in urban form. They found that in the period 1900–1950 the available technologies (rail, water sanitation, elevators and other building technologies) led to an increase in the growth and density of cities. For the period 1950–1980 (mainly driven by cars and freeway construction technologies) urban population increased by 72% but land use increased by 146%, and urban density dropped by 70%. The period 1980–2000 saw an increase in available ICT technologies. The dominance of these technologies allowed for a significant reduction in the lowering of urban density. This occurred because the lower costs of the available technologies provided the benefits of agglomeration and proximity to drive urban form back towards density. This last point is consistent with Ciccone and Hall (1996) finding that in the USA, in 1988, urban density, including that of labour, human and physical capital, had a positive effect on productivity.

### Agglomeration and the knowledge economy: the economic importance of urban density

The strong urban spatial context of ICT and its drive towards increased density is further confirmed when consideration is given to the agglomeration characteristics of the knowledge economy. The benefits of agglomeration have long been recognised though previously mainly understood in terms of industrial development and trade (Ottaviano & Puga 1997). Agglomeration benefits can be seen with ICT and the knowledge economy, with agglomeration occurring in particular regions and in particular parts of cities, usually the city core (Burger, Oort, Frenken and Van Der Knaap 2009; SGS 2008; Spiller 2003, 2005). In the UK, the Eddington Transport Study 2006 commissioned reports on the relationship between agglomeration and productivity that found agglomeration economies do exist and that they are substantial for the service sector (Graham 2005). In particular, high agglomeration values were found for business services and management consultancy, financial services and public services. Studies worldwide of ICT and other high technology industries also show strong tendencies to cluster or agglomerate with like industries (Saxenian 1994; Giovannetti; Neuhoff & Spagnolo 2005; Strange, Hejazi and Tang 2005).

The economic agglomeration effects of universities are also well recognised worldwide (Saxenian 1994; Rawat 2006; Sambidi 2007) as is the role of universities worldwide partnering with industry to deliver positive economic outcomes (Mayer 2007; Markkula & Sinko 2009). Mayer (2007) argues the importance of the contribution made by universities has been elevated in part by the decentralising and networking of corporate innovation. Mayer (2007) cautions about seeing universities as ‘engines of growth’, and rather sees their role as a pivotal component of underlying investment for innovation from which the knowledge economy draws. This underlying investment argument is probably best demonstrated for Australia in the Bradley Report’s (2009) reference to Access Economics’ finding that the supply of undergraduate qualifications in Australia will not keep up with demand. The Bradley Report found that Australia was falling behind other countries in performance and investment in higher education despite the strong links between productivity and skills levels of a nation's people. In Australia any discussion about universities and the knowledge economy should also note that education services are the country's third-largest export industry and the largest service export valued at $14.2 billion (ABS 2008).

Importantly, the nature of an industry is not only a consideration in understanding agglomeration. There also is an inherent relationship between transport and agglomeration (Eddington 2006; Graham 2005). The spatial concentration of any firm depends on the nature of transport provision, with transportation costs crucial to generating spatial concentration. Congestion in highly urbanised locations diminished returns to agglomeration. In this sense the economic benefits of agglomeration can be demonstrated as wider economic benefits of transport investment beyond the benefits accounted for in standard cost benefit appraisals (Graham 2005).

### The knowledge economy and spatial planning in Australia

Understanding how the internet and the knowledge economy will influence urban planning worldwide is still in its infancy. Paradiso (2003) argues that there is no definite analysis of the impact of the pervasive growth of technology on planning urban spaces. Similarly, Banister and Hickman (2006) argued that the hugely complex set of interdependencies in the transport, ICT and urban planning field are not well understood — and have been under-researched. While in the USA Kim et al. (2009) argue that the relationship between technology and urban growth has not been well understood by planners (see also Moss & Townsend 2000).

However, the recognition of the increasing dominance of networks in underpinning economic, communication and transport systems has had influence in spatial planning theory with the notions of a 'network city', 'connected centres' and 'networked cities' being reflected in European planning policies (Klaasen et al. 2007) and in aspects of Australian metropolitan planning policies (see particularly *City of Cities*, Perth's Network City, and Melbourne 2030). In Australia the influence of ICT and the knowledge economy and the concept of the global city was a major influence on Sydney's *City of Cities* report (Gleeson, Darbas, Johnston and Lawson 2004). Sydney's *City of Cities* metropolitan plan, of all the regional plans, has the highest focus on economic factors, including recognising the dominant role that Sydney plays as Australia's key global city. Sydney has 49.93% of advanced business service export jobs (yet with 21.89% of all jobs Australia-wide) while Perth has only 5.94% of advanced business service export jobs (with 7.31% of all jobs nationally) (SGS 2008). The 'Global Sydney' of the CBD and North Sydney is planned for an expansion along the 'global economic corridor' to the north-west and south of the CBD. In many ways though strategy reflects what is already occurring and the need for implementation of an aligned infrastructure strategy is still absent. Searle (2006) has argued that the *City of Cities* strategy takes a complacent view of Sydney's long term strength as a global economic base as it does not address what is needed to retain or enhance Sydney's global advantage. Bunker and Holloway also noted the imbalance between planned job and residential growth outside of global Sydney with the brunt of growth being in Western Sydney. In these Sydney metropolitan centres, while agglomeration activity and employment are proposed, they are not seen as having a global role and little information or reasoning is provided for the selection of the centres (Bunker & Holloway 2006). Without high levels of access into global Sydney, or strategies to grow the knowledge economy outside of global Sydney, a two-toned economy and society will be reinforced.

All of the other major metropolitan spatial plans are long term aspirational 'compact city' plans[2], which recognise the need to build up and diversify activity centres outside of their CBDs. This is consistent with supporting the knowledge economy. However, the focus is on major metropolitan activity centres to be planned around retail centres. The aim of the various schemes is to transform traditional shopping centres into

[2] *Perth's plan being Directions 2031 — formerly Network City; Melbourne 2030, Sydney – City of Cities and Brisbane's South East Queensland Regional Plan (SEQRP).*

mixed use regional activity centres with more than retail and service provisions (see notes to Principle 8.6 of SEQRP, Western Australian Planning Commission ('WAPC') 2009). In this sense outside of the CBDs the metropolitan spatial plans are focused on centres dominated by consumption rather than production. This is not to say there are not state governments or institutions with planning or other policies directed at innovation, clustering or growing their knowledge economy. The Murdoch Activity Centre Structure Plan is an example that combines hospitals, research facilities, commercial uses and Murdoch University around the new Murdoch rail station (WAPC 2007; see also Searle 2006; Department of Employment, Economic Development and Innovation 2009; Department of Industry and Resources 2007).

However, little of the various state innovation or knowledge economy strategies are reflected or prioritised in the metropolitan regional schemes, which are mainly focused on the role and hierarchy of activity centres. *Melbourne 2030* (2005) proposes a hierarchy of mixed use activity centres — Central (the six key transit cities were reclassified as Central Activities Districts (CADs) under Melbourne @ 5 Million (2008)), Principal, Major and Neighbourhood Activity Centres, all based around retail centres of various sizes. Although recognition is given to key universities, hospitals and the Tullamarine airport as Specialist Activity Centres, the planning is about reinforcing their economic role. Similarly the SEQRP (2009) update provides for the key activity centres outside the Brisbane CBD to be the major shopping centres, with universities and tertiary hospitals categorised as employment areas rather than major mixed use centres. Network City (WAPC 2004) for Perth provided for the key metropolitan activity centres to be the consumption oriented major shopping centres and major suburban town centres. However, Perth's universities including the two largest research universities, the University of Western Australia (UWA) and Curtin University of Technology (Curtin), and those tertiary hospitals not within the CBD were categorised as 'Other Centres'. Perth's *New Directions 2031* (2009) has elevated the outlying centres of Rockingham and Joondalup as primary centres only below the Perth CBD in the hierarchy. While Joondalup (with Edith Cowan University) and Rockingham (Murdoch University Rockingham campus) have tertiary institutions (and major shopping centres) the largest universities in the state are Curtin and UWA. Curtin and UWA are now in the category of specialist centres. Specialist centres have been elevated to the same status as the major activity centres (effectively the major suburban town centres and major shopping centres) with these two categories of centres classed as strategic centres.

While strong arguments can be made to recreate activity centres anchored by retail into mixed use centres, the reality is that these types of centres will be limited by their origins. Shopping centres do not provide environments for innovation or development of the knowledge economy. The corporate shopping centres by their nature, economically and culturally, provide the blandest representation of a monoculture and add very little to sense of place (Goodman 2007). In the USA shopping centres are seen as being technology adopters (Hopping 2000) as distinct from technology developers. In this sense they do not add to the productive economy. Arguments over the role of centres anchored by shopping centres, while important for the economic efficiency and sustainability of Australian cities, do not address how Australian cities are going to successfully compete in the knowledge economy in the future digital age.

### Translating the knowledge economy into a spatial context — ex-spatial centres

To relate the 21$^{st}$ century network knowledge economy to metropolitan spatial planning and public transport planning the author has developed the concept of 'ex-spatial centres'. Ex-spatial centres are centres of activity within a city that have a focus on the export or import of goods or services. That is, they are spatial areas within a city that have strong relationships or linkages with the world outside the city (hence ex-spatial). The ex-spatial centres are traditionally ports (goods), airports (services and goods) freight transports (goods), export focused, manufacturing industrial areas (goods) and CBDs (services).

This paper argues that the economic focus and priority of metropolitan planning and urban transport investment should be on creating highly accessible transit-oriented developments around key strategic ex-spatial centres that have a city-wide catchment with potential as knowledge economy production centres. Ex-spatial centres should be diverse in that they should contain, in addition to the university- and/or tertiary hospital-related activities, high density commercial and residential uses. These centres should also have elements of cultural, entertainment and retail use (though with lesser retail not in competition with major retail focused centres). Having mixed use, knowledge-based ex-spatial centres with high social and civic amenity is important not only because it supports higher density residential centres but because it provides economic productivity benefits. In reviewing the research on how the benefits of agglomeration with knowledge spillover actually occurs, the main finding Burger et al. (2009) made was that firms in economic agglomeration do not profit automatically from co-location and that spillover was mainly occurring between firms with strong social network relations. This means the fine grain civic and social infrastructure needs to be a key focus of the development of ex-spatial centres. The viewing of a city through the context of ex-spatial centres follows the reasoning of Jane Jacobs' seminal *The Economy of Cities* (Jacobs 1969) and the recognition that cities succeed because they produce and export goods and services through which they earn surpluses to pay for consumption. At its simplest it is recognition that cities need to have greater production capacity than consumption capacity.

### Public transport and knowledge centres

The role played by public transport for ex-spatial centres is vital. As Graham (2005) demonstrated, agglomeration and transport are integrally linked. This provides the transport capacity that allows for higher density, larger and more intense mixed use knowledge thus creating ex-spatial centres. Newman and Kenworthy (2006) (see also Newman 2007) determined that the combination of residents and jobs at a sufficient density in centres is important to generate sufficient scale for alternative transport uses to car patronage[3]. Similarly both scale and density are also important for encouraging economic outcomes for ex-spatial centres. Trubka (2009) when considering agglomeration benefits (using the link between productivity, employment density and size in Australia's capital cities) found that for a city such as Perth with its smaller population and low density, scale is also important. This is thought to be because where the overall scale of the city is small, or activity is dispersed, scale is required in a centre for the benefits of agglomeration to take effect. Outside CBDs there would appear logic in combining a university and a hospital or technology centre to create the core activities for a major centre. Burger et al. (2009) contend sometimes it is presumed agglomeration benefits will simply happen through the co-location of activities. The strategy for developing mixed use ex-spatial centres around universities or tertiary hospitals needs to therefore focus also on the centre's capacity to absorb and use a university's spillover effects (see Mayer 2007).

Overcoming the lack of relative accessibility of Perth's two largest universities, largest in both student and research terms (Higher Education Research Data Collection 2009), is a major consideration underpinning the Knowledge Ring (see table 1 for improved access times). UWA and Curtin have both recognised their need to become diverse, mixed use activity centres in their own right and while these proposals are consistent with the universities becoming strong ex-spatial centres, the major limitation on this objective has been identified as transport (UWA-UniverCity 2007 and Curtin University — Bentley Technology Park Masterplan 2007). While a number of ways of improving access to tertiary institutions will be required (including increased residential populations) the author contends that universities connected to fast long haul, high capacity networked rail that has a reach across metropolitan areas will be critical.

*[3] Data from Australia and overseas suggest a minimum of 35 people and jobs/ha is required and a centres of 1 km radius can support 10,000 people and jobs. A centre with a 3 km radius should support a 100,000 population and jobs (Newman 2007).*

Creating UWA/Queen Elizabeth II Hospital (QEII) and Curtin/Bentley Technology Park as major centres would appear to be logical when considering the agglomeration research by Trubka (2009). This concluded that there is need for both scale and density to achieve agglomeration benefits. The potential scale of the ex-spatial centres proposed can be gauged by the consideration of the Curtin University Bentley Technology Park Structure Plan which provides for a 314 hectare precinct with 50,000 workers, 500,000 $m^2$ of office space and 12,000 residents. The UWA UniverCity – A Strategic Action Plan envisaged the development of a university town extending from the Crawley Campus to Broadway and along Hampden Road to the QEII Hospital, a length of 2.4 km.

### Conclusion

Australia's cities are integral to the nation's economic future. This future is increasingly knowledge services operating within a technology driven network environment. It is critical, therefore, that the spatial planning frameworks and the public transport systems for Australia's major cities are conceived and planned to support knowledge production (more so than consumption) centres in our cities. This will require strengthening and developing intense knowledge-based, mixed use and diverse centres. This can be achieved through the development of radial-orbital networked rail-bus systems.

# References

Australian Bureau of Statistics 2006, *Perth: a social atlas 2006*, cat. no.2030.5, ABS, Canberra.

Australian Bureau of Statistics 2008, *Labour mobility and intentions, Western Australia*, October cat. no. 6209.5, ABS, Canberra.

Department of Industry and Resources 2007, *Bentley Technology Park Curtin University structure plan*, Government of Western Australia, Perth.

Barnes, G 2005, 'The importance of trip destination in determining transit share', *Journal of Public Transportation*, vol. 8, no. 2.

Bradley, D, Noonan, P, Nugent, H & Scales, B 2008, *Review of Australian higher education,* Department of Education, Employment and Workplace Relations, Canberra.

Department of Infrastructure and Planning 2009, *South East Queensland plan* (revised 2009), Queensland Government, Brisbane.

Banister, D & Hickman, R 2006, *How to design a more sustainable and fairer built environment (JU5): transport and communications*, Foresight Intelligent Infrastructure Systems Project, Office of Science and Technology.

Bunker, R & Holloway, D 2006, *How much of 'City of cities, a plan for Sydney's future' is likely to happen?*, City Futures Research Centre, Issues Paper No. 2, April 2006, Faculty of the Built Environment, University of New South Wales.

Cervero, R 2007, *Transit oriented development's ridership bonus: a product of self-selection and public policies*.

Ciccone, A & Hall, RE 1996, 'Productivity and the density of economic activity', *American Economic Review*, vol. 86, no. 1 (March).

Department of Broadband 2009, *Communications and the digital economy: Australia's digital economy: future directions*, final report 2009.

Department of Employment, Economic Development and Innovation 2009, *Smart communities: pilot guide 2009*, Queensland Government, Brisbane.

Department of Education, Employment Workplace Relations 2006, *Regional profile for Perth: labour market region*.

Department of Planning 2005, *City of cities: a plan for Sydney's future*, NSW Government, Sydney.

Department of Sustainability and Environment 2005, *Melbourne 2030*, www.dse.vic.gov.au/melbourne2030online/

Devriendt, L, Derudder, B & Witlox, F 2008, 'Cyberplace and cyberspace: two approaches to analysing digital intercity linkages', *Journal of Urban Technology*, vol. 15, no. 2, pp. 5–32.

Eddington, R 2006, *The Eddington transport study main report: transport's role in sustaining the UK's productivity and competiveness*, HM Treasury, Department of Transport.

Giovannetti, E, Neuhoff, K & Spagnolo, G 2005, *Agglomeration in internet co-operation peering agreements,* Cambridge Working Papers in Economics 0505, Faculty of Economics, University of Cambridge.

Glazebrook, G 2008, *The scope for enhancing public transport in Australian capital cities*, www.internationaltransportforum.org/2009/pdf/AUS_Glazebrook.pdf

Gleeson, B, Darbas, T, Johnson, L & Lawson, S 2004, *What is metropolitan planning?*, Urban Program Research Monograph 1 July.

Goodman, R 2005, 'Sustainable urban form and the shopping mall: an investigation of retail provision in new housing subdivisions in Melbourne's growth areas', Second Conference on the State of Australian Cities, November–December, Griffith University, Brisbane.

Graham, D 2005, *Investigating the link between productivity and agglomeration for UK industries,* Imperial College, London.

Graham, S 1998, 'The end of geography or the explosion of place? Conceptualising space, place and information technology', *Progress in Human Geography*, vol. 22, no. 2.

Higher Education Research Data Collection Time Series Data 1992–2007, August 2009, www.universitiesaustralia.edu.au/content.asp?page=/publications/stats/research.htm

Hopping, D 2000, 'Technology in retail', *Technology in Society,* vol. 22, pp. 63–74.

Infrastructure Australia 2009, *National infrastructure priorities: infrastructure for an economically, socially, and environmentally sustainable future*, May.

Jacobs, J 1969, *The economy of cities*, Jonathon Cape, London.

Kellerman, A 2006, *Personal mobilities*, Routledge, London and New York.

Kellerman, A 2002, *The internet on earth: A geography of information*, Wiley, London.

Kellerman, A 2004, 'Internet access and penetration: an international urban comparison', *Journal of Urban Technology,* vol. 11, issue 3, December, pp. 63–85.

Kenworthy, J & Laube, F 2001, *The millennium cities database for sustainable transport,* International Union of Public Transport, Brussels, and Institute for Sustainability and Technology Policy, Perth.

Kim, TJ, Claus, M, Rank, JS & Xiao, J 2009, 'Technology of cities: process of technology–land substitution in the twentieth century', *Journal of Urban Technology*, vol. 16, no.1, pp. 63–89.

Klaasen, IT, Rooij, RM & Van Schaick, J 2007, 'Network cities: operationalising a strong but confusing concept', ENHR Conference Sustainable Urban Areas, June 25–28, Rotterdam (Online Proceedings Workshop 20 — Spatial Planning and Governance at a Regional Level; www.enhr2007rotterdam.nl/pages/papersdownload.htm; abstract published in *Sustainable Urban Areas — Book of Abstracts*, p. 267).

Martinovich, P 2008, 'The integration of rail transit and land use in Western Australia: the planning behind Perth's expanded rail system', Conference on Railway Engineering, 7–10 September, Perth.

Markkula, M & Sinko, M 2009, *Knowledge economies and innovation society evolve around learning,* elearning papers, Helsinki University of Technology TKK.

Mayer, H 2007, 'What is the role of the university in creating a high technology reason', *Journal of Urban Technology*, vol. 14, no. 3, pp. 33–58.

Mees, P, Sorupia, E & Stone, J 2007, *Travel to work in Australian capital cities 1976–2006: an analysis of census data*, Australia Centre for Governance and Management of Urban Transport, Melbourne

Moriset, B 2003, 'The new economy in the city: emergence and location factors of internet-based companies in the metropolitan area of Lyon, France', *Urban Studies*, vol. 40, no. 11.

Moss, ML & Townsend, AM 2000, 'The Internet backbone and the American metropolis', *The Information Society*, vol. 16, pp. 35–47.

Newman, P & Kenworthy, K 1999, *Sustainability and cities: overcoming automobile dependence*, Island Press, Washington DC.

Newman, P 2007, *Planning for transit oriented development in Australian cities*, BDEP Environment Design Guide DES 15 November 2007.

Page, S & Phillips, B 2003, 'Telecommunications and urban design: representing Jersey City', *City*, vol. 7, no. 1 April.

Paradiso, M 2003, *Geography of the informational society: new culture of cyberspace?* International Geographical Union.

Rudd, K 2009, *Building a big Australia: future planning needs of our major cities*, address to the Business Council of Australia, October.

Puga, D & Ottaviano, G 1997, *Agglomeration in a global economy: a survey*, CEP Discussion Papers 0356, Centre for Economic Performance, LSE.

Rawat, A 2006, *Regional agglomeration — 'new growth theory' in the knowledge-based economy: university–industry interfacing in the evolution of high-tech clustering — some evidence from Bangalore,* http://webintec.ceram.fr/euromot2008/uploads/400/1-Euromot_08_Final_Paper_REGIONAL_AGGLOMERATION.doc

Rutherford, J, Gillespie, A & Richardson, R 2004, 'The territoriality of pan-European telecommunications backbone networks', *Journal of Urban Technology*, vol. 11, no. 3, pp. 1–34.

Sambidi, PR 2007, *Spatial econometric analysis of agglomeration economies associated with the geographical distribution of the US biotech industry*, electronic resource, Baton Rouge, La.: Louisiana State University.

Saxenian, AL 1994, *Regional advantage: culture and competition in Silicon Valley and Route 128*, Harvard University Press, Cambridge, Massachusetts.

Searle, G 2006, 'Is the *City of cities* metropolitan strategy the answer for Sydney?', *Urban Policy and Research*, vol. 24, no. 4, December, pp. 553–566.

Storper, M & Venables, AJ 2004, 'Buzz: face to face contact and the urban economy', *Journal of Economic Geography*, vol. 4, no. 4.

Strange, W, Hejazi, W & Tang, J 2006, 'The uncertain city: competitive instability, skills, innovation and the strategy of integration', *Journal of Urban Economics*, vol. 59, issue 3, May, pp. 331–351.

Scheuer, 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 — a case study of Perth before and after the Perth-to-Mandurah railway*, research monograph, www.abp.unimelb.edu.au/gamut/pdf/perth-snamuts-report.pdf

Spiller, M 2003, 'Urban agglomeration of advanced business services in Australia: some policy implications', 1st State of Australian Cities conference, 1–3 December, Sydney.

Spiller, M 2005, 'Models of innovation and implications for Australian regional development', 2nd State of Australian Cities Conference, 30 November – 2 December, Griffith University, Brisbane.

SGS 2008, '*East west transport link report, urban structure and Victoria's prosperity*', Department of Infrastructure, March.

Stone, J 2008, *Political factors in the rebuilding of mass transit: an investigation of failure in Melbourne since 1970 through comparisons with Perth and Vancouver*, PhD thesis, Institute for Social Research, Swinburne University of Technology.

Trubka, R 2009, *Productivity and the density of economic activity: preliminary estimates of agglomeration benefits in Australian cities,* http://innovation4cities.com/files/agglomeration-paper-_draft-1_.pdf

Chappell Lambert Everett 2007*, The University of Western Australia strategic asset review*, March.

WAPC 2004, *Network city*.

WAPC 2007, *Murdoch activity centre structure plan*, June 2007.

WAPC 2009, *Directions 2031* (draft), Western Australian Government.

Warf, B 2001, 'Segueways into cyberspace: multiple geographies of the digital divide', *Environment and Planning B: Planning and Design*, vol. 28, pp. 3–19.

Willis, S & Tranter, B 2002, *Beyond the digital divide: socio-economic dimensions of internet diffusion in Australia*, University of Tasmania.

## SECTION C

# WHY LIGHT RAIL, NOT BUSES?

By Jan Scheurer, Peter Newman and Jeff Kenworthy

This section will provide a rationale why an upgraded bus system, while desirable and important in its own right, will not be sufficient to address the magnitude of public transport service tasks associated with the Knowledge Arc project. From a perspective of international best practice, bus solutions cannot conceivably achieve similar results in passenger growth, sustainability outcomes and urban consolidation as rail solutions along a the most critical transport and activity corridors of a fast-growing metropolis.

Some of the arguments for this have already been provided in Section A — the need for a quality public transport system in a competitive global economy generally has meant that cities are moving to rail wherever possible. In US cities the data on growth in transport systems is shown in Figure C-1 below. Light rail is the biggest growth area. Bus is the slowest growing public transport mode.

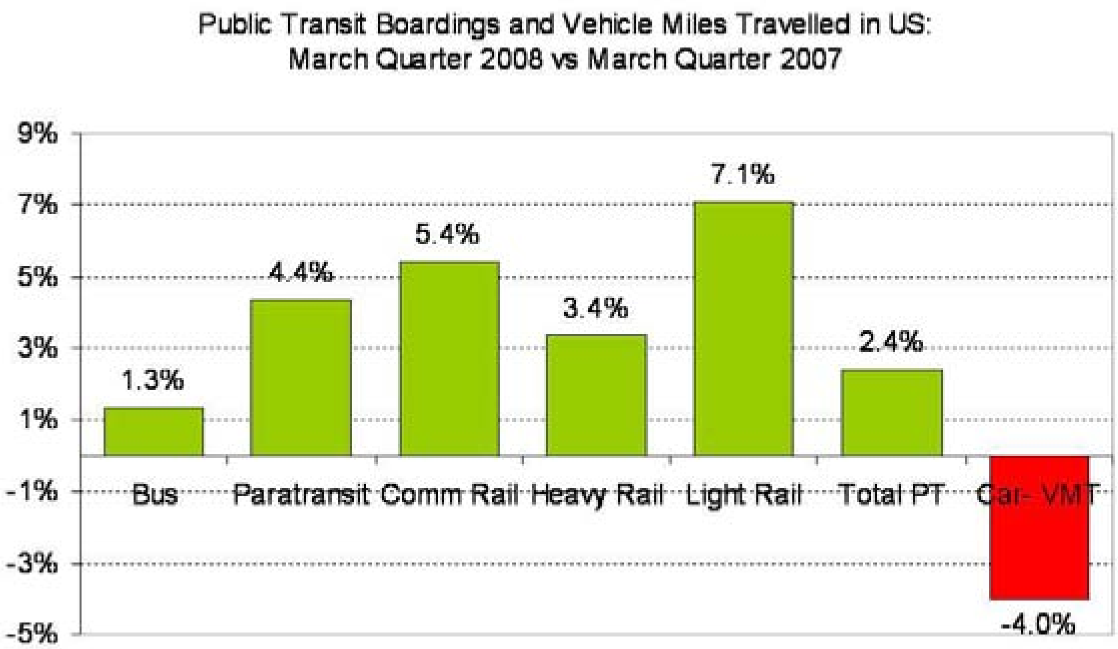



**Figure C-1:** Growth in transport systems in US cities

The trend towards fast electric rail in cities is now being called a 'Mega Trend' (Rubin 2009). Chinese cities have moved from their road building phase to building fast modern railways across the nation. China is committed to building 120,000 km of new rail by 2020. Investment will rise from ¥155 billion (US$22 billion) per year in 2006 to ¥1,000 billion annually by 2009 (US$143 billion), with around 6 million jobs involved. These projects are part of China's response to the recent global economic downturn (Dingding 2008). Beijing now has the world's biggest metro and there are 89 other Chinese cities building metros.

India is ramping up its metro construction and expansion through government investment of US$41 billion over the next ten years. Besides the ongoing metro projects in the cities of Delhi, Bangalore, Hyderabad, Mumbai and Chennai, new projects will be undertaken in eight more cities: Pune, Lucknow, Kanpur, Ahmedabad, Ludhiana, Kochi, Indore and Chandigarh. With rail projects worth $30 billion under construction or at bidding stage in Saudi Arabia, $25 billion in Qatar, $8.1 billion in UAE (Inter Emirates Railway), $7 billion in Abu Dhabi, $7 billion in Kuwait city metro and $7.1 billion in Jordan, it is evident that the emerging countries are seeing that the future is about rail investment.

### So why is rail so important?

The critical attraction of improved bus systems over rail or tram extensions to some transport planners is their lower infrastructure requirement. Buses use public roads at no specific cost to the operator or the public purse, and even where dedicated infrastructure for buses is provided, it does not have to form a continuous or congruent system to be at least partly effective, in the way that tram or rail tracks do. Therefore, bus improvements can be implemented in relatively short timeframes, and be pursued gradually, in very small steps if necessary. They can also be altered or removed relatively easily if they are unsuccessful or if it is deemed politically expedient to do so. In some cities, notably Adelaide, Ottawa and Brisbane, Curitiba, Bogotá and a growing number of developing cities, dedicated busways have been built that allow for bus operation at levels of speed and convenience similar to light rail, and requiring roughly comparable investment costs (Cervero 1998). Operating costs, while influenced by a variety of factors, tend to be lower for bus systems at lower and medium levels of patronage, and lower for rail systems where patronage rises above a certain threshold. This is due to the greater flexibility of bus systems to respond to lower demand through modulation of service frequencies without the burden of leaving infrastructure underutilised, and the greater flexibility of rail systems to pick up higher demand through modulation of train length/vehicle size and occupancy rates, providing higher capacity without increasing frequencies (and the number of drivers).

While demand remains relatively modest, improved bus systems are inherently attractive to both operators and infrastructure funding bodies. But where demand is expected to grow by a factor of multiples, the strengths of rail over buses regain more prominence.

The threshold of 30 buses, equivalent to a 2-minute frequency, is critical in understanding this issue. For the passenger, such frequency marks the level at which average waiting times have reached their practical minimum; additional services are unable to reduce this measure further if dwell times at bus stops and traffic signals are taken into account. For the operator, this is the frequency at which buses will begin to run in bunches even where on-street bus priority has been maximised (where it has not been maximised, this effect may start to kick in at much lower frequencies). This is because of the aforementioned effect of dwell times at bus stops as well as the impracticality to afford each vehicle traffic light priority at intersections while still maintaining these intersections functional for motorised traffic (Fox 2009).

Service frequencies higher than every two minutes on surface modes are thus inefficient for both passengers and operators and should be avoided wherever possible. This is where light rail invariably outperforms buses: On average, LRT systems make use of larger vehicles (trains) than bus systems, not least because they can be operated in dual or triple traction as far as the route alignment and platform lengths allow (i.e. provide a capacity of up to 600 passengers per working). Even busway or BRT systems (see below) can be, and in most cases are, operated by standard-size articulated buses (100–150 passengers per working). As a result, a saturated bus timetable (30 or more departures per hour per direction) would provide a similar capacity to an LRT system running every 5 or 7.5 minutes, which is still a very attractive frequency to passengers. There are LRT vehicles that are comparable in size to an articulated bus, purchased, for example, for Melbourne in 2002–03, and more recently for Portland’s and Seattle’s streetcar routes serving inner-city revitalisation areas. Most contemporary LRT vehicles, however, allow for passenger capacities considerably higher than that.

In brief, the capabilities of rail systems over buses are as follows:

- Large numbers of passengers can be carried with fewer vehicles and staff, and the congestion threshold is significantly higher.
- Commercial speed and timetable reliability are generally higher with rail systems.
- Rail networks are inherently more legible and more easily understood than bus systems, especially for non-regular users and visitors.
- Rail vehicles offer smoother rides than rubber-tyred buses, electric traction is more appealing to both passengers and land uses along the route than diesel haulage, and local pollution impacts are eliminated.
- The permanence of rail systems (versus the relative flexibility in changing bus routes) is an impetus for long-term location decisions of users and landowners, and their implementation is regarded as a strong commitment by authorities to the potential of a particular area.
- Rail systems, in the way they are implemented as entire new lines or extensions, can be more convincingly marketed as a superior transport product in their own right than improved bus services, which will still be regarded as rather trivial by many potential users.
- In a land use environment where market forces are allowed to exert at least some influence and where urban growth or restructuring potential is present, the combination of all these factors contributes to increasing land values and enhanced development activity around rail lines and stations. This reinforces the infrastructure's role as a self-feeding catalyst to urban development to an extent which is not experienced in bus systems (Vuchic 2007).

Hence, while buses are clearly capable of offering high-quality public transport services, the choice of rail on routes with the potential for high patronage offers additional synergies. This is true for the interplay of land use and transport infrastructure, as summarised by Paaswell and Berechman (1982):

> Buses take people to where activities are and can follow the movement of activities over a wide geographic pattern. On a rapid transit line, there is a more active land use-transportation relationship. Large numbers of people are concentrated at specific spots, and activities become linked to the stops. Transit induces changes in station areas that often would not occur if no transit were there.

It is, however, also true in a political environment and in the interaction of users and providers of public transport. Hass-Klau et al. (2003) report that across a sample of 214 cities world-wide, there is a consistent trend for public transport users to consider trams a more attractive and superior mode than buses. Accordingly, the authors of the study assert that while complementary transport management measures (parking policy, urban design, land use priorities) are crucial for the success of any public transport improvement, they are even more important, yet less likely to occur, in the context of bus-based programs. A comparison of 47 medium-sized European cities show that the tram cities (53% of the sample) gained an average of 20% in public transport patronage between 1986 and 1996, while the bus-only cities (47% of the sample) lost almost 6% on average during the same period. Ample evidence is given of greater appreciation of land values and rents, better marketability of residential and office space, lower parking provision both through the market and by government regulation, lower rates of car ownership among residents, and greater worker productivity and employee retention at sites with light rail or tram access over sites with bus-only access. Trams are also more easily integrated with pedestrianisation schemes in activity centres than buses, and thus often associated with urban design transformations that benefit a city's appearance, user-friendliness and popularity. Hass-Klau et al. conclude:

> [Light Rail's] main advantages turn out to be what are often considered to be disadvantages — its high cost and inflexibility. In political terms, these attributes give it a high profile as a symbol of commitment in the early stages, and make it a confident, futuristic symbol of the city when it is implemented. Inflexibility becomes redefined as 'security' — the population is confident that a change of political power or financial situation will not result in the new system being taken away from them, and can therefore plan their lives knowing that the system will be there in the future. […] Therefore it remains the mode of choice as an instrument for strategic transformation of urban transport in cities led by confident and forward-looking administrations who understand the concept of integrated transport planning. By the same argument, the main disadvantages of relying on conventional buses are what are usually assumed to be advantages — its cheapness and flexibility (ibid. p. 5).

Transit systems that are competitive with road traffic in terms of travel time are required across the metropolitan area if we are to cope with the new challenge of moving Perth to benefit from a less car dependent future. With high-performance rail systems, the best European and Asian cities with the highest ratio of transit to traffic speeds have achieved a transit option that is faster than the car down the main city corridors. Rail systems are faster in every city in our 84 city sample by 10–20 kph over bus systems as buses rarely average over 20–25 kph. Busways with a designated lane can be quicker than traffic in car saturated cities (see below), but in lower density car dependent cities it is important to use the extra speed of rail to establish an advantage over cars in traffic. This is one of the key reasons why railways are being built in over 100 US cities (Newman et al. 2009).

Rail is also important as it has a density-inducing effect around stations, which can help to provide the focused centres so critical to overcoming car dependence. Thus transformative change of the kind that is needed to rebuild car dependent cities comes from new, electric rail systems as they provide a faster option than cars and can help build transit-oriented centres. They also do not use oil or emit greenhouse gases (if the electricity is from renewably-based electricity or greenpower). Washington DC's rail system was built in 1976 as a service for government employees. It has since grown to cover 168 km of track with 86 stations and has become a key factor in shaping housing and employment patterns. The Balston corridor has become a global model for TOD oriented planning. In these areas the train is clearly faster than driving. Further expansion to under-served areas such as the auto-only Tyson's Corners, Virginia are in the planning stage as people in this corridor can now see the advantages in having a rail option available.

### Busways and bus rapid transit (BRT)

In the New World, two developed cities decided to implement busway systems in favour of light rail during the 1980s as the backbone of their public transport system (Ottawa) or to serve a significant urban corridor (Adelaide). Both examples show mixed results at best for the performance of the public transport system as a whole. The introduction of Ottawa's busway system, rather than continuing an emerging trend of growing transit patronage, did in fact coincide with its reversal (Mees 2010). Public transit trips per capita in that city dropped from a substantial 155 in 1980, shortly before the first busway opened, to 110 in 1995 before recovering to around 120 in 2005. While providing attractive and relatively frequent transfer-free links to peak-hour commuters between scattered suburbs and the CBD, Ottawa's busway system reverts to a trunk and feeder style network at all other times, with built-in requirements to transfer at facilities that are not consistently adequate, and low frequencies on the suburban feeder routes (ibid.). With system-wide average transit speeds of 24 kph compared to 46 kph for road traffic (in 1995), the busway system fails to deliver the competitive edge that would allow it to claw back further market share from the car (Kenworthy and Laube 2001). A strongly enforced urban intensification policy around the busway routes, though not without a few good results, appears to have largely met a grudging response with developers (Newman 1997). In 2008, a political decision was made to convert Ottawa's main busway to light rail operation. Important factors for this policy shift were the level of bus congestion on city streets from buses leaving the busways to access the

CBD, the need to build off-peak patronage in order to make a real difference to mode choice across Ottawa, and the desire to provide more attractive public transport service for travellers to non-CBD destinations (Mees 2010).

Adelaide's O-Bahn was built as a 12 km radial corridor on an abandoned freeway reserve, using guided busway technology and providing transfer-free and relatively fast connections to the north-eastern suburbs of the city. The scheme was the result of ongoing studies and political debates on public transport improvements in that corridor, with O-Bahn winning over light rail after a change of government. Patronage has developed to satisfaction but appears to have plateaued after initial strong increases in the 30% range, roughly in line with population growth along the corridor (Wayte 1988; Cervero 1998; Mees 2010). While the outer end of the busway is located near a pre-existing suburban shopping, administrative and education centre, no further market response to intensify development around the busway, or to orientate land uses specifically to the facility, has been evident since. Rather, conventional low-density suburban development in the north-eastern corridor was encouraged with the added bonus of a bus service with superior standards (Wayte 1988). Like in Ottawa, the suburban routes that lead into the busway are generally operated at frequencies that are not attractive to car-owning passengers, and many routes require a transfer at the O-Bahn interchanges during off-peak times. Unlike Ottawa, Adelaide did not expand its busway infrastructure beyond the initial scheme and has shifted its focus towards modernising and extending its ageing tram and train infrastructure in recent years, with the aim of providing a high-performance, integrated and electrified heavy and light rail system. The existing busway, however, is not likely to be converted to rail in the foreseeable future (Mees 2010).

Bus rapid transit or BRT is said to be filling a niche in transport between rail and conventional buses. Its main features are enclosed lanes, isolated stops, level boarding, frequent service, large capacity, signal priority and intelligent control systems. As they can fit on to present road systems they can be cheaper than rail and are considerably cheaper than subways or overhead rail. Ottawa, Curitiba and Bogotá were the first cities to demonstrate BRT's on a large scale to great acclaim from the transport experts of the world and to local citizens. BRT's niche is that it can be like a rail system in passing all the traffic and thus with its extra speed it can carry up to 20,000 people an hour down its corridors or more — though this requires very crowded buses. Buses by themselves in traffic can rarely reach 5,000 people per hour and are very slow. In many third world cities the niche has been filled by thousands of small buses, such as mini taxis, and these have completely crammed all city streets. BRTs can offer a greener transport option that is faster than traffic or mini taxis.

The limitations to BRT are that bus bunching at the destination points and stations can occur as the time to embark and disembark is slower than trains. Eventually, the greater capacity and operational efficiency of rail (due to size of carriages, speed and ease of embarkation) are needed in most large cities. As elaborated above, this is now occurring in Ottawa, Canada as well as in Curitiba, Brazil, which are both planning for rail to replace their BRT systems. Curitiba became a pioneer and an icon in the developing world for demonstrating its BRT, alongside a long-standing urban growth strategy along linear corridors; however, the numbers of bus users are declining as the system has reached its limits and people have begun to turn to cars as they are quicker. 'That competition is very hard,' says Paulo Schmidt, the president of URBS, the government agency responsible for the rapid-bus system. During peak hours, buses on the main routes are already arriving at almost 30-second intervals; any more buses, and the system would collapse. While acknowledging his iconoclasm in questioning the sufficiency of Curitiba's trademark bus network, Schmidt nevertheless says a light-rail system is needed to complement it (Mees 2010).

Buses can also have emissions and noise problems so are less able to attract dense development around their stations, though this can be overcome with emissions regulations (especially by favouring CNG) and by noise insulation in buildings.

BRTs can also be an excuse for some governments not to fund rail systems. In America many cities are building rail as they can get strong community support through ballots for raising the funds. However, the usual process of obtaining funds from the US Federal Transit Administration has become almost impossible for rail when there is any chance of BRT since it is significantly cheaper to implement. BRT is often the only option in third world cities where it is almost impossible to build other than over or under the city. However, for wealthy American cities the situation is different: an alternative to the car must be clearly better, buses in the past have not provided such solutions and the most important outcome is to build up land use around stations — electric rail systems are likely to be the only solution to provide the kind of resilience needed for the future. The Dulles Rail extension has been threatened due to suggestions from the Federal Government that funding BRT would be preferred over a metro rail extension; however, the Dulles Rail Extension Now coalition has also shown how significant is the hope that can be generated around a new rail system.

Many cities built in the 19th century around rail, such as European cities and older cities of the US, Australia and Latin America, still remain in Transit City form. However, transit systems need to keep pace with their city's growth if they are to respond to peak oil and climate change, thus new rolling stock and new lines into car dependent suburbs are required to keep the city ahead of the increase in car use. Once a good transit option is available, the regional area can begin to be planned around the stations so that cities in the suburbs can provide most local destinations and most other regional destinations can be reached by transit. For these cities, the first step is finding a source of transit funding. This is difficult as in many car dependent cities the funding process has all been about building and maintaining roads. While some progress has been made diverting federal and state funds to transit projects, transportation budgets have been stretched thin as many cities are experiencing an infrastructure crisis and are struggling to maintain and upgrade existing roads and bridges. This was brought into focus by the Minneapolis bridge collapse in 2007.

To solve this funding problem cities have had to find innovative solutions such as financing transit through the use of taxes or direct payments from land development, as in Copenhagen's new rail system, or through a congestion tax as in London. Funding transit in congested cities can be like Hong Kong and Tokyo where the intensive requirements around stations means that the transit can be funded almost entirely from land redevelopment. In poorer cities the use of development funds for mass transit can increasingly be justified through the transformation of their urban economy. Peak oil and climate change will increasingly be part of that rationale. No city has yet done that convincingly without using rail at its base.

# References

Cervero, R 1998, *The transit metropolis. a global inquiry,* Island Press, Washington DC, USA.

Dingding, X 2008, 'Blueprint of railways development', *China Daily,* 17 November.

Fox, G 2009, 'LRT versus buses: why Portland chose light rail', *Tramways and Urban Transit,* vol. 72, no. 862, pp. 390–392.

Hass-Klau et al. 2003, *Bus or light rail: making the right choice — a financial, operational and demand comparison of light rail, guided buses, busways and bus lanes*, Environmental and Transport Planning, Brighton, UK, and Bergische Universität Wuppertal, Germany.

Kenworthy, J & Laube, F 2001, *The millennium cities database for sustainable transport,* International Union of Public Transport, Brussels, Belgium, and ISTP, Murdoch University, Perth.

Mees, P 2010, *Transport for suburbia. beyond the automobile age,* Earthscan, London, UK.

Newman, P 1997, *An assessment of Brisbane's busway/HOV strategy,* ISTP, Murdoch University, Perth.

Newman, P, Beatley, T & Boyer, H 2009, *Resilient cities: responding to peak oil and climate change,* Island Press, Washington DC.

Paaswell, RE & Berechman, J 1982, 'Light rail and development: constraints and conditions', *Light Rail Transit: Planning, Design and Implementation,* Special Report 195, Transportation Research Board, Washington DC.

Rubin, J 2009, *Why your world is about to get a whole lot smaller: oil and globalisation,* Random House, New York.

Vuchic, VR 2007, *Urban transit: systems and technology*, John Wiley and Sons, Hoboken, New Jersey.

Wayte, A 1988, 'Adelaide's automated busways', in W Attoe (ed.) *Transit, land use and urban form*, Centre for the Study of American Architecture, Austin, Texas.

# SECTION D

# SPATIAL NETWORK ANALYSIS FOR MULTIMODAL URBAN TRANSPORT SYSTEMS (SNAMUTS) FOR THE KNOWLEDGE ARC LIGHT RAIL SYSTEM

By Jan Scheurer

## Introduction

This section uses the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) methodology to assess the impact of a proposed light rail starter route between Crawley UWA and Curtin University-Canning Bridge on the land use-transport system in Perth.

The proposed route links the university/health and knowledge precincts of Crawley UWA — QE II and WA Tech Park — Curtin University, passing through West Perth, the CBD (including Perth Central station), East Perth and the WACA/Gateway precinct, and the Albany Highway corridor in Victoria Park. Beyond Curtin University, the route links to Canning Bridge train station.

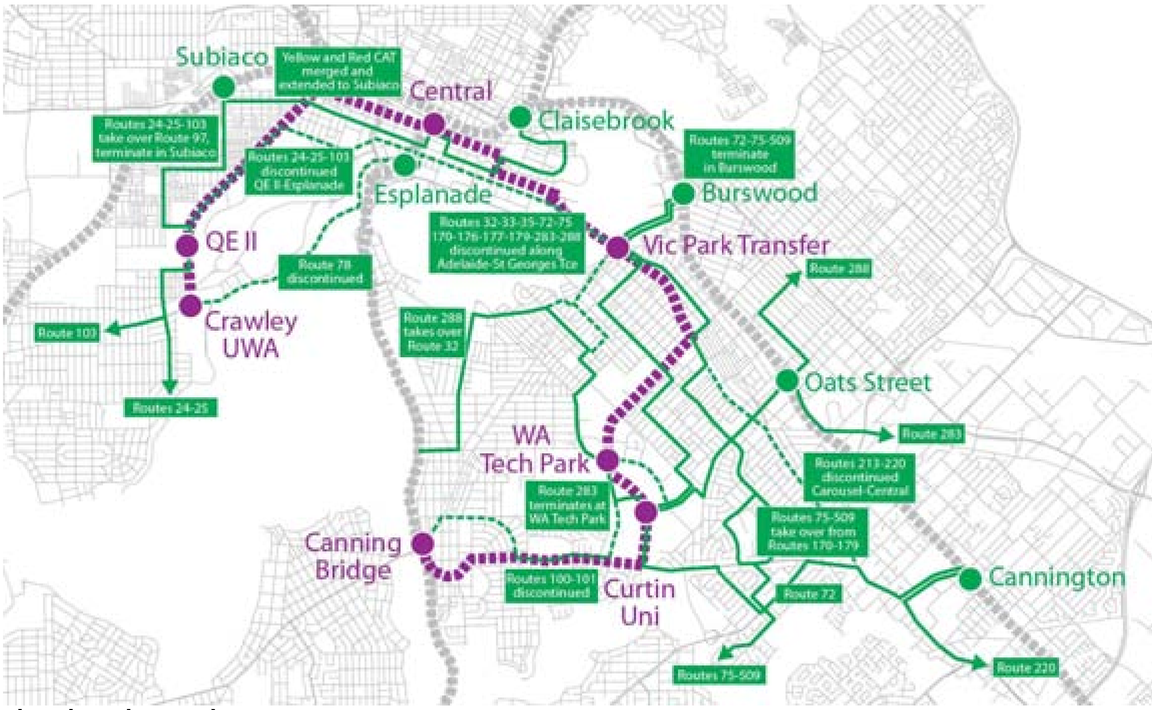
This analysis assumes an end-to-end travel time of the proposed LRT route of 46 minutes, equivalent to a commercial speed of around 30 km/h, and a service frequency during the weekday interpeak period of 7.5 minutes (eight services per an hour per direction).

A range of adaptations to the existing bus network have also been assumed, particularly to eliminate duplication of routes with LRT and to capitalise on the creation or upgrade of multimodal transfer hubs. These changes are illustrated in Map D-1, while a full list of bus network changes is included in the appendix.

LRT is intended to catalyse a number of land use intensification projects in strategic centres along the proposed route. The SNAMUTS tool makes assumptions about such projects by taking in revised figures for the catchment sizes of activity nodes for residents, employees and tertiary students. Map D-2 and Table D-1 provide an overview of the catchment sizes of the nodes along or adjacent to the LRT corridors. The figures for existing uses are derived from ABS census data (2006), the Commercial and Industrial Land Use survey, student figures from the Department of Education and the STEM land use model. The land use figures in all other activity nodes across the metropolitan area are assumed to remain constant between the before and after LRT cases in order to isolate the specific effect of the proposed LRT route on the land use-transport system.

**Map D-1:** Location of Knowledge Arc LRT route and adaptation of bus network.

**Note: LRT route in purple, bus routes in green (continuous lines = route changes, dashed lines = reduced service or**




**abandoned routes)**

**Map D-2:** Activity nodes along Knowledge Arc LRT Route, specifying projected changes in numbers of activities (residents, jobs and tertiary students) between 2009 and 2029

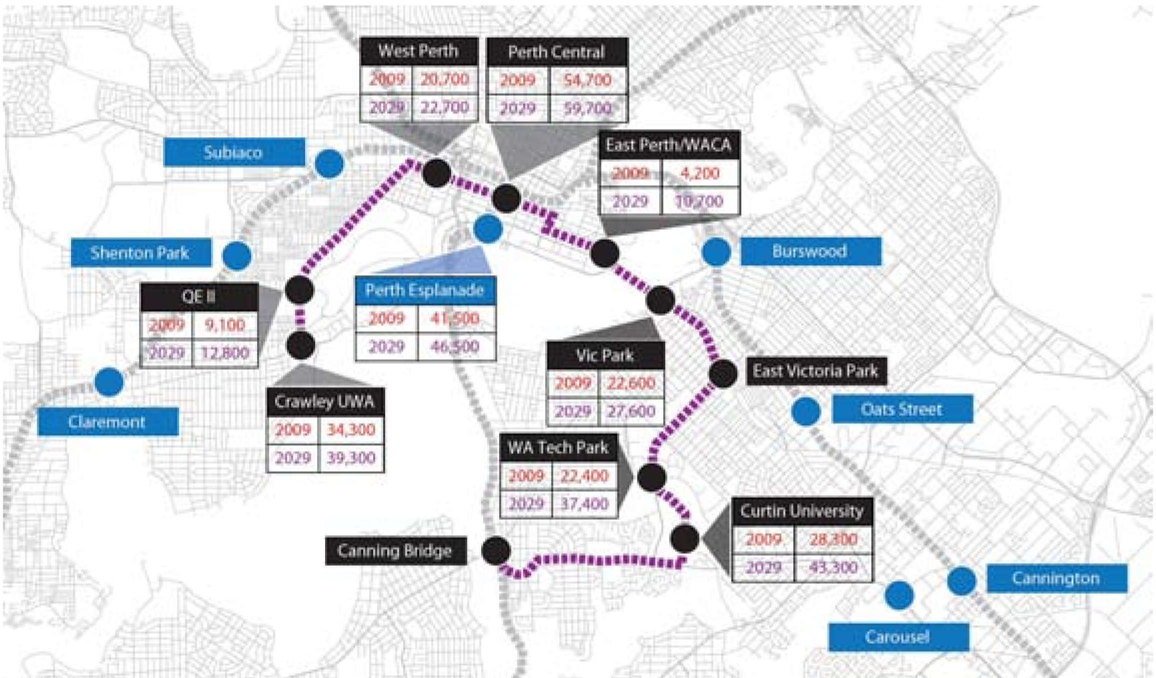


**Table D-1:** Land use assumptions (sum of residents, employees and tertiary students) for the catchment areas of selected activity nodes before and after the introduction of the Knowledge Arc LRT route

| | LRT before | LRT after |
|---|---|---|
| Bentley Tech Park | 22,442 | 37,442 |
| Burswood | 21,713 | 21,713 |
| Canning Bridge | 17,286 | 17,286 |
| Cannington | 23,660 | 23,660 |
| Carousel | 10,466 | 10,466 |
| Claisebrook | 14,950 | 14,950 |
| Claremont | 14,294 | 14,294 |
| Crawley UWA | 34,329 | 39,329 |
| Curtin University | 28,297 | 43,297 |
| East Perth | 4,214 | 10,714 |
| East Victoria Park | 5,175 | 5,175 |
| Oats Street | 17,291 | 17,291 |
| Perth Central | 54,712 | 59,712 |
| Perth Esplanade | 41,547 | 46,547 |
| QE II | 9,097 | 12,781 |
| Shenton Park | 18,089 | 18,089 |
| Subiaco | 24,038 | 24,038 |
| Victoria Park (Albany Highway) | 22,581 | 27,581 |
| West Perth | 20,696 | 22,696 |
| **Total LRT catchment** | **404,873** | **467,058** |
| **Total metropolitan** | **2,385,360** | **2,447,545** |

### Impediment values and the base network

The key inputs into the SNAMUTS tool start with the compilation of a base network. This is developed by considering how to measure the ease of movement on a public transport network in ways that come close to user perceptions and motivations. Importantly, there is a need to view the individual traveller as someone who has a choice to use the car over public transport, and thus to consider the factors driving that choice between modes. We assert that public transport users are only marginally interested in geographical distance: the main factors of travel impediment (or spatial separation) are travel time, and the ubiquity of travel opportunities (service frequency).

Furthermore, to build a network model, there is a need to define an applicable service period and a minimum service standard. As in previous SNAMUTS applications for Perth (Scheurer & Curtin 2008; Curtin & Scheurer 2009) this analysis will use the travel times and service frequencies of the weekday interpeak period (Mondays to Fridays between about 10.00 and 15.00) for reference; with the rationale that this is the period during a normal weekly cycle when the greatest diversity of travel purposes occurs simultaneously. Service levels during this period are thus critical in determining how competitive public transport is with the 'go anywhere, anytime, for any reason' standard usually associated with car travel.

Like in the aforementioned previous applications, the minimum service standard for the inclusion of routes into the SNAMUTS model was set at a frequency of 30 minutes or better during the weekday interpeak period, and operation of the route seven days a week (on weekends, headways can be greater than 30 minutes). This cut-off level is defined to limit the complexity of the network used in the analysis and to improve the readability of the results; in addition, a 30-minute frequency can also be regarded as the minimum where passengers would consider the service a regular one that can be used for different travel needs without excessive forward planning.

Lastly, SNAMUTS needs to decide what constitutes a transfer point on the transport network to determine potential movement paths. Not every physical intersection of routes can rightly be considered a useable transfer facility: there is a need for co-location of bus stops with train stations or each other, or failing that, at least a visual link with sufficient and effective signposting as well as relatively barrier-free pedestrian access.

SNAMUTS uses 94 activity nodes for the Perth network in 2009. These nodes have been determined from higher-order activity centres or corridors identified in strategic planning documents including Network City and Directions 2031 (WAPC 2004; WAPC 2009), and from travel survey data showing concentrations of travel destinations. Apart from such centres, some major multimodal transfer facilities (rail, bus, park and ride) outside designated activity centres are also included in this count; examples include Whitfords or Bull Creek.

Each of the 94 activity nodes has a defined walkable catchment, used to determine its geographical expansion in terms of residents, jobs and tertiary students (at the place of education) that can be accessed conveniently on foot from minimum-service public transport services. Convenient walkable access in this context is defined as a ten-minute radius (800 m) around rail stations and a five-minute linear corridor (400 m) around bus routes. However, the walkable catchment associated with a given activity node does not only relate to its centre point (e.g. a specific rail-bus interchange), but is based on areas of influence. Thus it also incorporates, for instance, the 800 m radii of adjacent rail stations and the 400 m linear corridors along surface routes leading towards other destinations, up to a geographical midpoint or other prominent feature (e.g. a water body or a council boundary) that separates the activity node in question from its neighbours. Each census collection district (CCD) that is fully or predominantly located within walkable catchments thus defined is allocated to one, and only one, activity node. From this procedure, a clearly defined catchment size in terms of activities (residents, jobs and tertiary students) emerges for each node, together adding up to the total number of metropolitan residents, jobs and students that enjoy walking distance coverage by public transport at the defined minimum standard. An overview of the defined catchment sizes of each activity node along or near the LRT corridors can be found in Table D-1.

Each transport link connecting a pair of neighbouring network nodes (a network node is either a designated activity node, another defined transfer point or a route terminus) is assigned an ‘impediment value’ to measure the ease of movement between adjacent centres on the network. The impediment value is a proxy value for travel disutility, or ease of movement, and is determined by dividing the average weekday interpeak travel time in minutes (derived from published timetables) by the average frequency of services per hour, and then multiplying the result by a coefficient of 8 to be better able to read the numbers. Note that the service frequency used for surface routes in the SNAMUTS tool is capped at 30 per hour per direction, following the logic that higher frequencies in mixed-traffic environments (or merely sharing signalised intersections with general traffic) will invariably lead to several vehicles operating in bunches and thus offering no additional benefit to passengers in terms of reduced waiting times. Travel impediment in this definition can be reduced either by increasing the frequency or by reducing the travel time of the service (or by a combination of both). The lower the impediment value, the greater the ease of movement along the associated route segment, and the greater the public transport accessibility between the nodes the segment connects.

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

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

### System data for scenarios

Table D-2 summarises the service intensity, or operational input, across the metropolitan public transport network during the weekday interpeak period in four scenarios. Scenarios *LRT before* and *LRT after* depict the service levels found on the Transperth routes that meet the minimum service standards in July 2009, with only the LRT route and the associated adaptations to the bus routes added in the *LRT after* scenario. *FRB before* and *FRB after* are derived from the frequency boost scenario from earlier SNAMUTS work (Curtin and Scheurer 2009). These scenarios are based on introducing (restoring in the case of the inner section of the north-south rail line) 7.5-minute off-peak frequencies along much of the rail network and on some critical bus routes; across the rest of the network, frequencies are harmonised throughout to 15/30-minute standards. The frequency boost scenarios measure network performance based on a package of improvements that can be achieved in the short term, using existing rolling stock and requiring no or only a small number of minor infrastructure upgrades. They are included here for two reasons: firstly, to illustrate their impact in comparison to that of the insertion of an LRT system without service upgrades to the rest of the network; and secondly, to test how both initiatives — frequency boost and LRT — perform if pursued in combination. Hence, the scenario *FRB before* includes the frequency boost measures without the introduction of light rail, while the scenario *FRB after* includes the Knowledge Arc LRT system as well as associated adaptations to the bus network.

The measure for service intensity in Table D-2 is defined as the number of revenue service hours per hour per mode offered across the network during the weekday interpeak period. Essentially, this indicator seeks to know how many trains (regardless of the number of carriages making up each train) and buses are required to be in revenue service simultaneously to deliver the current or envisioned timetable. In total, the requirement for operational input drops by 3% after LRT is introduced while service levels on the remaining modes, apart from the bus network adaptations, remain nearly unchanged; this is due to a saving of 22 buses over the status quo. In comparison, the FRB service initiatives amount to an additional operational input in the order of 28%, including 10 trains and 65 buses. If these frequency boost initiatives are combined with the introduction of light rail (and the associated bus network adaptations) the total figure for additional operational input drops to 22%, or 29 less buses over the FRB network without light rail. In each case including light rail, the operational requirements amount to 12 LRT trains.

**Table D-2:** Service input per scenario

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Service intensity: train | 25 | 26 (+4%) | 35 (+40%) | 35 (+40%) |
| Service intensity: LRT | - | 12 | - | 12 |
| Service intensity: bus | 252 | 230 (-9%) | 319 (+27%) | 290 (+15%) |
| **Service intensity: total** | **277** | **268 (-3%)** | **354 (+28%)** | **338 (+22%)** |
| Service intensity: train | 25 | 26 (+4%) | 35 (+40%) | 35 (+40%) |
| Service intensity: LRT | - | 12 | - | 12 |

### Degree centrality index

The degree centrality by transfers index (or topological centrality) describes the greatest level of directness with which journeys can be made on the public transport network. In our model, degree centrality is a *topological index*: it measures the average minimum number of transfers, or degrees of separation, required to access every other node on the network. Or in other words: *what is the degree of directness a node is linked into the network with — or: how many transfers separate a node from the rest of the network?* Lower figures indicate greater centrality.

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

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

Degree centrality attempts to measure passenger convenience as well as operational efficiency by assessing the minimum number of transfers passengers are forced to make as they move between activity nodes, and simultaneously by determining how well the network integrates modes of different performance into a hierarchical system. These qualities can sometimes neutralise each other when expressed in figures. Wherever one or more (faster or higher-performance) transfer links between two centres coexists with one or more (slower or lower-performance) transfer-free alternatives, the lowest-transfer option is included in this count.

Table D-3 summarises the results for the 19 activity nodes along or adjacent to the LRT corridors, and for the network as a whole (with each activity node across metropolitan Perth illustrated in Maps 3 to 6). The network average overall barely changes; however, among the 19 LRT corridor nodes there is a small improvement. This is due to the LRT corridor connecting up a number of centres that currently do not offer transfer-free journeys between one another, an effect most strongly felt in West Perth, Bentley Tech Park and QE II, as well as Burswood, which is not on the LRT route but benefits from an enhanced transfer node function for buses rerouted away from duplicating LRT. Other nodes along the LRT corridor do not improve on this index, and two nodes — Claremont and Perth Esplanade — actually decline, again owing to the removal of some bus routes parallel to LRT. However, the standard deviation measure appears to suggest that nodes within the LRT corridor are actually becoming more similar in terms of degree centrality, which can be regarded as a positive sign of network integration among this group of nodes. In contrast, for the network as a whole this is not the case: the results of this index appear to suggest that the impact of introducing LRT for minimising transfers is limited to the corridors served by the new mode.

The comparison with the *FRB before* scenario shows that a comparable impact on the sub-network around the LRT corridors regarding transfer needs can be made by service improvements to existing routes; in this case, a benefit of similar magnitude (if modest) extends to the entire metropolitan network, though the tremendous differences in accessibility among activity nodes across Perth remain unaddressed. A combination of the FRB measures and the introduction of LRT (*FRB after*) leads to further slight improvements in the performance among the LRT corridor nodes.

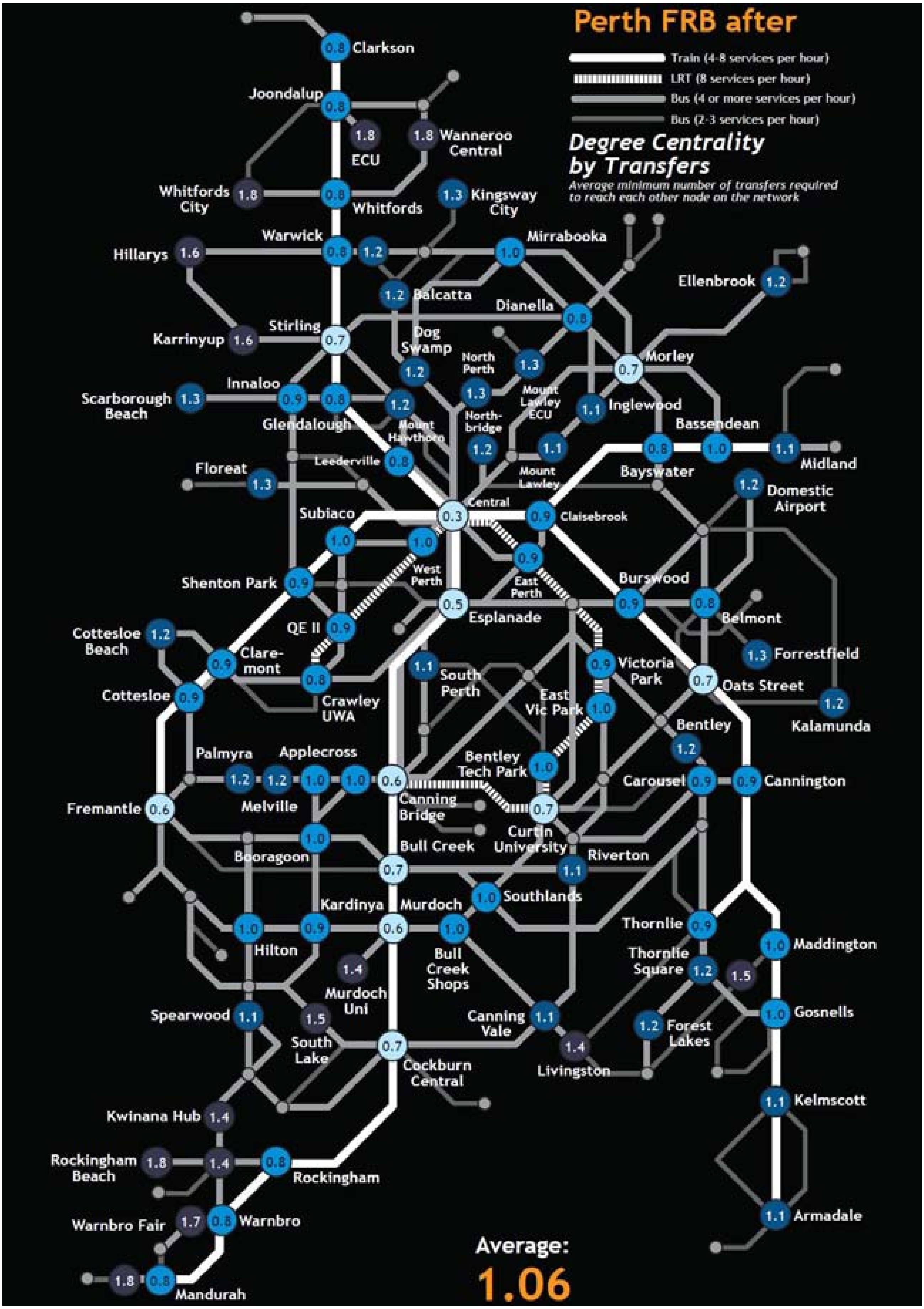
**Table D-3:** Degree centrality index for LRT catchment area

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 1.08 | 0.97 | 0.97 | 0.97 |
| Burswood | 1.05 | 0.92 | 0.98 | 0.92 |
| Canning Bridge | 0.72 | 0.67 | 0.70 | 0.62 |
| Cannington | 0.90 | 0.90 | 0.85 | 0.88 |
| Carousel | 0.91 | 0.91 | 0.89 | 0.89 |
| Claisebrook | 0.91 | 0.90 | 0.89 | 0.89 |
| Claremont | 0.90 | 0.94 | 0.89 | 0.90 |
| Crawley UWA | 0.92 | 0.86 | 0.91 | 0.85 |
| Curtin University | 0.84 | 0.76 | 0.76 | 0.73 |
| East Perth | 1.10 | 1.02 | 0.96 | 0.94 |
| East Victoria Park | 1.00 | 1.00 | 1.04 | 1.00 |
| Oats Street | 0.77 | 0.77 | 0.72 | 0.71 |
| Perth Central | 0.31 | 0.31 | 0.32 | 0.32 |
| Perth Esplanade | 0.39 | 0.46 | 0.40 | 0.45 |
| QE II | 0.99 | 0.88 | 0.98 | 0.87 |
| Shenton Park | 0.90 | 0.90 | 0.89 | 0.89 |
| Subiaco | 1.10 | 1.09 | 1.03 | 1.04 |
| Victoria Park (Albany Highway) | 1.01 | 0.92 | 0.96 | 0.91 |
| West Perth | 1.27 | 1.05 | 1.25 | 1.03 |
| **Average LRT catchment** | **0.90** | **0.86** | **0.86** | **0.83** |
| *Standard deviation LRT catchment* | *0.23* | *0.19* | *0.22* | *0.19* |
| **Average network** | **1.10** | **1.10** | **1.06** | **1.06** |
| *Standard deviation network* | *0.31* | *0.32* | *0.30* | *0.30* |

**Maps D-3, D-4:** Degree centrality index per activity node at current service levels, before and after the introduction of the Knowledge Arc LRT route

Perth after LRT
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Degree Centrality by Transfers
Average minimum number of transfers required to reach each other node on the network
Clarkson
Joondalup
ECU
Wanneroo
Whitfords City
Whitfords
Kingsway City
Warwick
Hillarys
Mirrabooka
Balcatta
Ellenbrook
Dianella
Stirling
Karrinyup
Dog Swamp
Mount Lawley ECU
North Perth
Morley
Innaloo
Scarborough Beach
Glendalough
Mount Hawthorn
North-bridge
Mount Lawley
Inglewood
Bassendean
Leederville
Bayswater
Midland
Floreat
Central
Claisebrook
Subiaco
Domestic Airport
Shenton Park
West Perth
East Perth
Burswood
Belmont
QE II
Esplanade
Cottesloe Beach
South Perth
Victoria Park
Forrestfield
Cottesloe
Claremont
Crawley UWA
East Vic Park
Oats Street
Kalamunda
Palmyra
Applecross
Canning Bridge
Bentley Tech Park
Bentley
Cannington
Carousel
Fremantle
Melville
Curtin University
Booragoon
Bull Creek
Riverton
Kardinya
Murdoch
Southlands
Thornlie
Maddington
Hilton
Bull Creek Shops
Thornlie Square
Murdoch Uni
Forest Lakes
Spearwood
South Lake
Canning Vale
Gosnells
Cockburn Central
Livingston
Kelmscott
Kwinana Hub
Rockingham Beach
Rockingham
Warnbro Fair
Warnbro
Armadale
Average:
1.10
Mandurah

**Maps D-5, D-6:** Degree centrality index per activity node at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route




## Closeness centrality index

The closeness centrality by impediment (or metric centrality) index is defined as the average proxy distance, or impediment, between the node in question and all other nodes within the network. This *metric index* is adapted to public transport networks by using the impediment measure of travel time divided by service frequency as described above. In essence, it asks *how closely to the others a node is situated within the network — or: what is the ease of movement between a node and the rest of the network?* Lower figures indicate greater centrality.

$$CC_i = \sum L_{ij}/(N-1) \quad [3]$$

where:

$CC_i$ = closeness centrality of node i
$L_{ij}$ = cumulative impediment between nodes i and j, with $j \in N$ and $i \neq j$
N = all activity nodes in the network

Performance improvements to the closeness centrality index reflect the simultaneous impacts of reduced travel times and higher service frequencies across the network. Reduced travel times can occur either by priority or speed enhancements along existing routes, and/or by reconfigurations of the network to allow for travel routes that are closer to geographical desire lines and thus eliminate the need for time-consuming detours. This indicator allows for up to three transfers per journey and prioritises trips with a greater number of transfers wherever these allow for a reduced cumulative impediment.

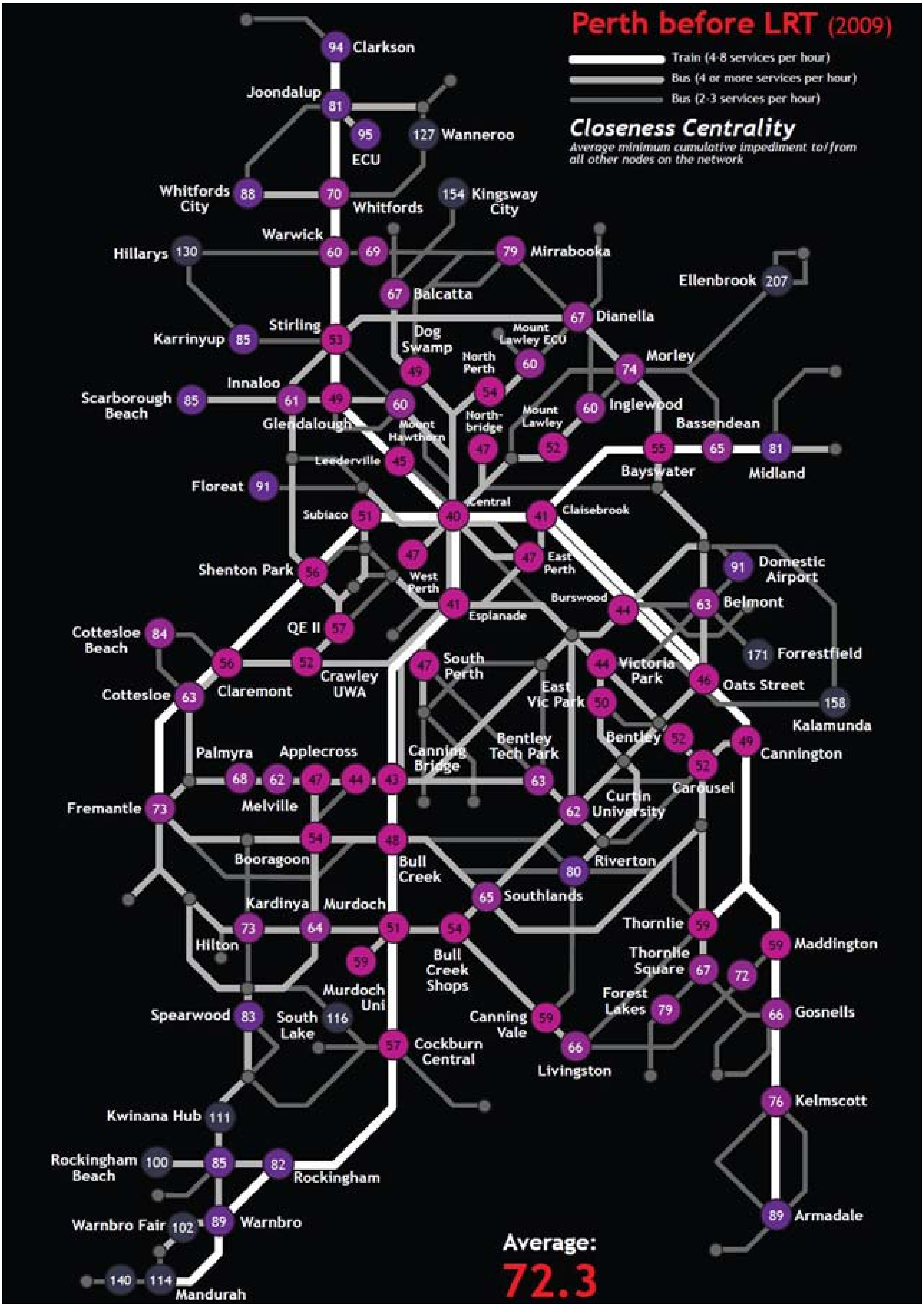
Table D-4 shows a small network-wide improvement on this indicator as LRT is introduced to the system while maintaining current service levels (*LRT after*). Among the sub-network of 19 LRT corridor centres, this effect is somewhat more pronounced; importantly, there is clear cohesion occurring for the closeness centrality values among this subset. This is a sign of a more uniform accessibility standard being promoted along the LRT corridor by way of the new mode, and hence a critical step towards better ease of movement among all the major hubs of activity in these parts of the city. Bentley Tech Park, Curtin University and East Victoria Park are the greatest beneficiaries on this index; north of the river, West Perth and QE II record a notable improvement.

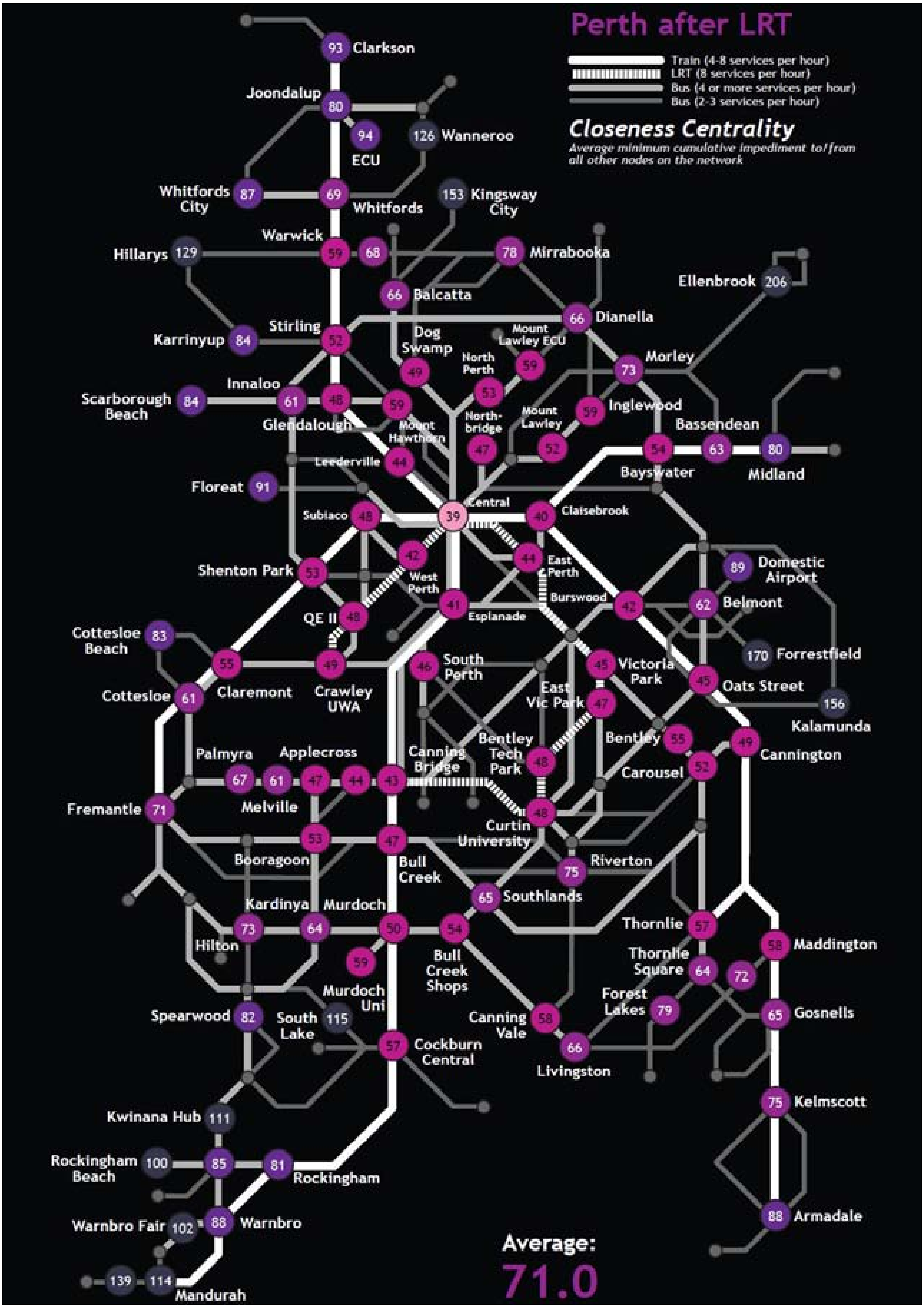
The comparison with the results of the *FRB before* scenario, however, illustrate the limitations of a new LRT route in enhancing closeness centrality when compared to the 'lower-hanging fruit' of network performance: in fact, the reinstatement of 7.5-minute rail frequencies between Whitfords and Cockburn Central alone (which were reduced to 15-minute frequencies in mid-2009) would result in a network average in the order of 65 on this index (Curtin & Scheurer 2009), significantly better than the average of 71 in the *LRT after* case. The remaining frequency boost measures would reduce this figure further to just over 52. Of the 19 activity nodes along or around the LRT corridor, every single one performs better in the *FRB before* than the *LRT after* scenario, with the exception of Bentley Tech Park where the scores draw even. Conversely, the combination of the frequency boost and the LRT route (*FRB after*) shows that the LRT route targets precisely those activity nodes that perform relatively sluggishly on the frequency boost measures alone, and contributes critically to a achieving a new benchmark of accessibility along Perth's Knowledge Arc.

**Table D-4:** Closeness centrality index for key activity centres

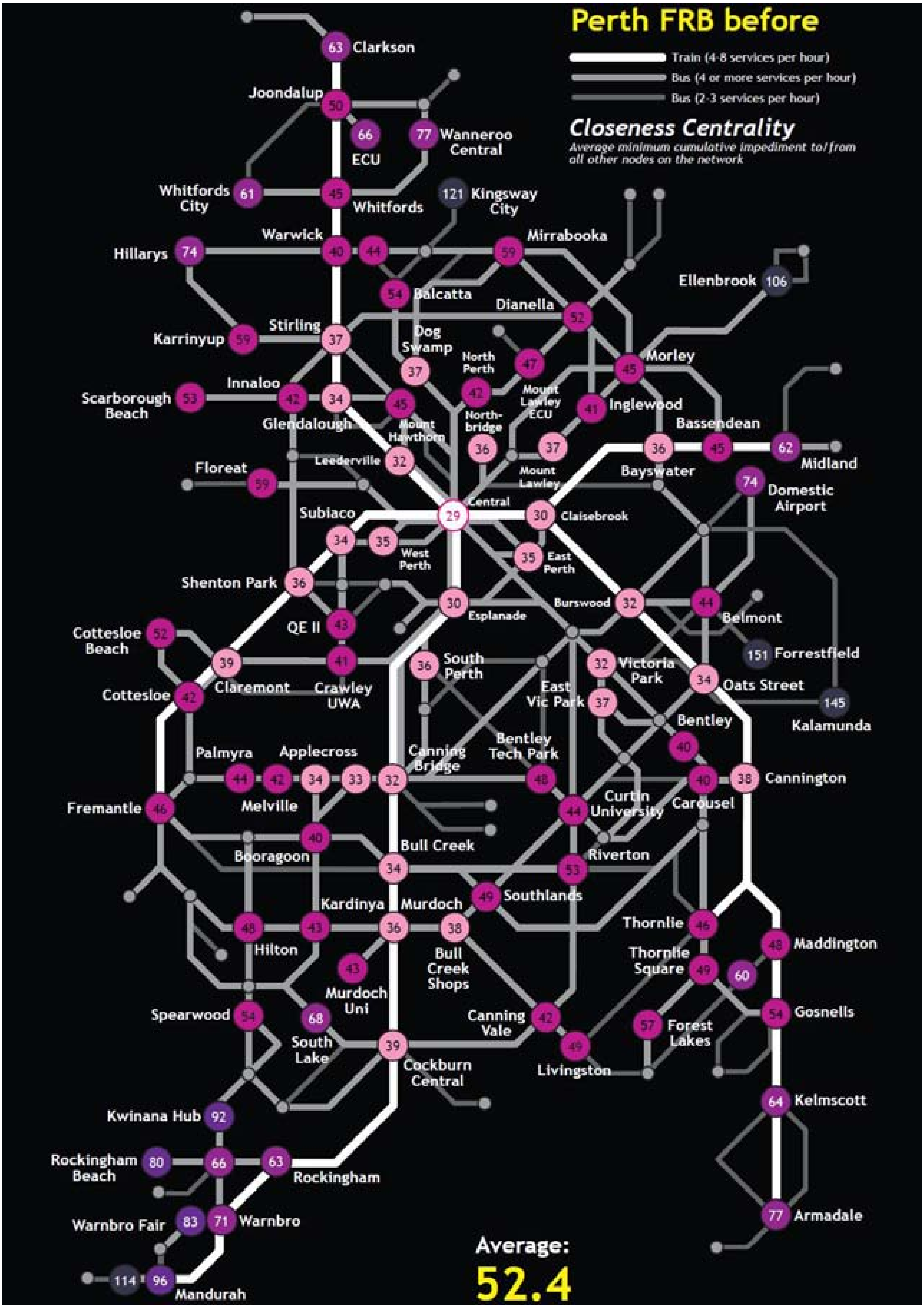
| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 62.7 | 48.4 | 48.4 | 37.0 |
| Burswood | 44.4 | 42.0 | 31.6 | 31.2 |
| Canning Bridge | 43.3 | 42.7 | 32.2 | 31.8 |
| Cannington | 49.4 | 48.6 | 37.9 | 37.7 |
| Carousel | 52.2 | 51.7 | 39.7 | 40.2 |
| Claisebrook | 41.2 | 40.1 | 30.1 | 29.8 |
| Claremont | 56.0 | 54.7 | 39.0 | 38.8 |
| Crawley UWA | 51.6 | 49.3 | 41.0 | 39.2 |
| Curtin University | 61.8 | 47.9 | 44.3 | 37.8 |
| East Perth | 46.8 | 44.4 | 35.0 | 33.5 |
| East Victoria Park | 60.4 | 47.0 | 36.9 | 36.1 |
| Oats Street | 46.1 | 45.1 | 34.5 | 34.3 |
| Perth Central | 39.8 | 39.2 | 28.7 | 28.5 |
| Perth Esplanade | 40.8 | 40.6 | 29.7 | 29.4 |
| QE II | 57.5 | 47.8 | 43.3 | 37.6 |
| Shenton Park | 55.6 | 53.0 | 35.6 | 35.5 |
| Subiaco | 51.3 | 48.0 | 33.8 | 33.5 |
| Victoria Park (Albany Highway) | 44.2 | 44.8 | 32.5 | 33.1 |
| West Perth | 47.2 | 41.6 | 35.1 | 31.1 |
| **Average LRT catchment** | **49.6** | **46.2** | **36.3** | **34.6** |
| *Standard deviation LRT catchment* | *6.8* | *4.4* | *5.3* | *3.6* |
| **Average network** | **72.3** | **71.0** | **52.4** | **51.9** |
| *Standard deviation network* | *30.1* | *30.3* | *23.2* | *23.3* |

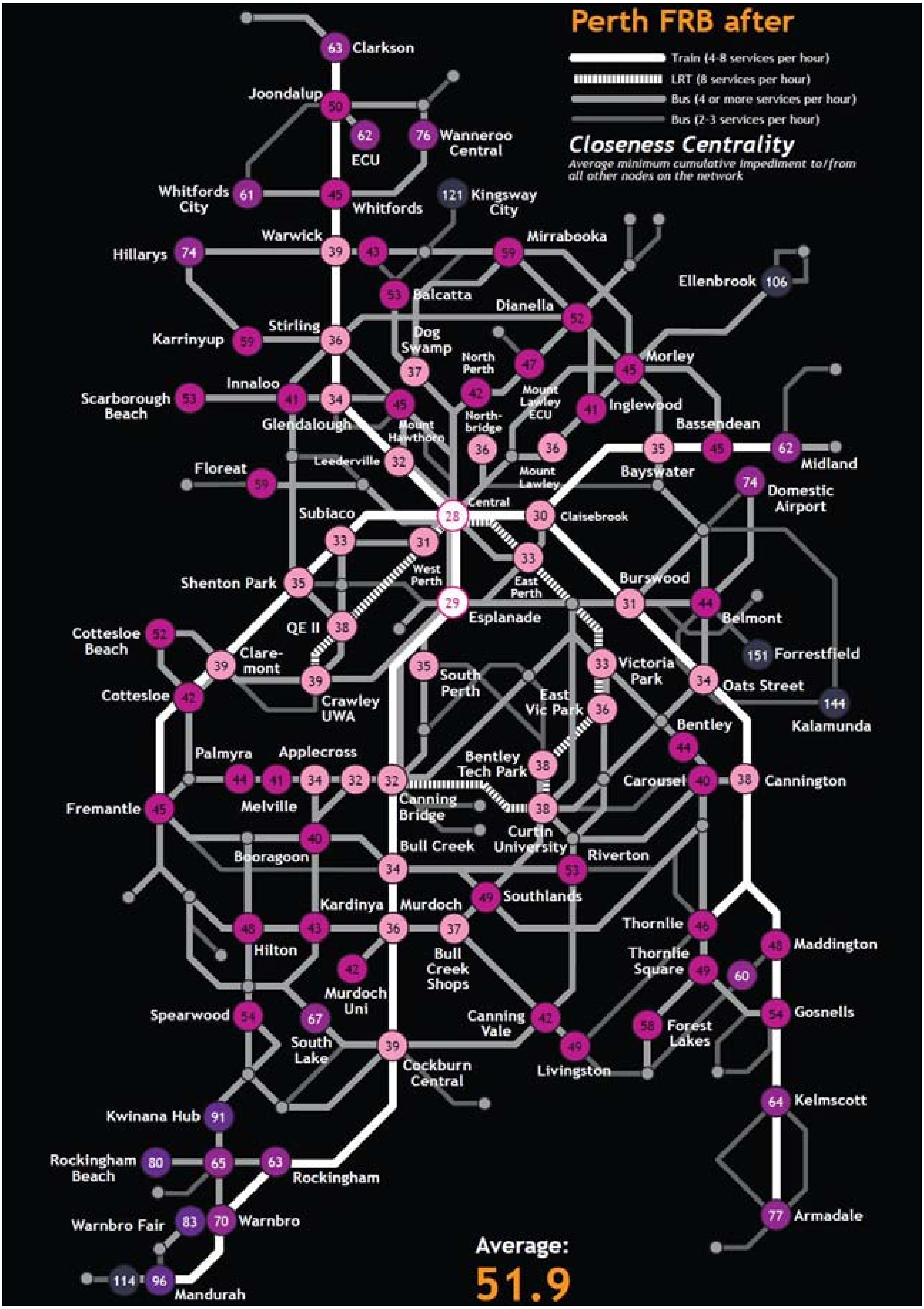
**Maps D-7, D-8:** Closeness centrality index per activity node at current service levels before and after the introduction of the Knowledge Arc LRT route




Perth after LRT
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Closeness Centrality
Average minimum cumulative impediment to/from all other nodes on the network
93 Clarkson
Joondalup 80
94 ECU
126 Wanneroo
Whitfords City 87
69 Whitfords
153 Kingsway City
Warwick
Hillarys 129
59
68
78 Mirrabooka
66 Balcatta
Ellenbrook 206
Stirling
66 Dianella
Karrinyup 84
52
Dog Swamp
Mount Lawley ECU
Morley
North Perth
49
59
73
Innaloo
53
Scarborough Beach 84
61
48
59
Mount Lawley
Inglewood
Bassendean
Glendalough
Mount Hawthorn
North-bridge
59
Leederville 44
47
52
54
63
80
Midland
Floreat 91
Bayswater
Central
Subiaco 48
39
40 Claisebrook
42
44 East Perth
89 Domestic Airport
Shenton Park 53
West Perth
Burswood
42
62 Belmont
QE II 48
41 Esplanade
Cottesloe Beach 83
170 Forrestfield
55
49
46 South Perth
45 Victoria Park
45 Oats Street
Cottesloe 61
Claremont
Crawley UWA
East Vic Park 47
156 Kalamunda
Bentley 55
49 Cannington
Palmyra
Applecross
Canning Bridge
Bentley Tech Park
48
Carousel 52
67
61
47
44
43
Fremantle 71
Melville
48
Curtin University
53
47
Booragoon
Bull Creek
75 Riverton
Kardinya
Murdoch
65 Southlands
73
64
50
54
Thornlie 57
58 Maddington
Hilton
Bull Creek Shops
59
Thornlie Square 64
72
Murdoch Uni
Forest Lakes 79
Spearwood 82
South Lake 115
Canning Vale 58
65 Gosnells
57 Cockburn Central
66 Livingston
75 Kelmscott
Kwinana Hub 111
Rockingham Beach 100
85
81 Rockingham
88 Armadale
Warnbro Fair 102
88 Warnbro
Average:
71.0
139
114
Mandurah

**Maps D-9, D-10:** Closeness centrality index per activity node at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route




Perth FRB after
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Closeness Centrality
Average minimum cumulative impediment to/from all other nodes on the network
63 Clarkson
Joondalup 50
62 ECU
76 Wanneroo Central
Whitfords City 61
45 Whitfords
121 Kingsway City
Warwick 39
Hillarys 74
43
59 Mirrabooka
53 Balcatta
Ellenbrook 106
Dianella 52
Karrinyup 59
Stirling 36
Dog Swamp 37
North Perth 47
45 Morley
Scarborough Beach 53
Innaloo 41
34
45
42
Mount Lawley ECU
41 Inglewood
Glendalough
Mount Hawthorn
North-bridge
Bassendean
Floreat 59
Leederville 32
36
36
35
45
62 Midland
Mount Lawley
Bayswater
74 Domestic Airport
Subiaco
Central 28
30 Claisebrook
33
31
33
West Perth
East Perth
Shenton Park 35
Burswood
29
31
44
Esplanade
Belmont
Cottesloe Beach 52
QE II 38
151 Forrestfield
39 Clare-mont
33 Victoria Park
35 South Perth
34 Oats Street
Cottesloe 42
39 Crawley UWA
East Vic Park 36
144 Kalamunda
Bentley
44
Palmyra
Applecross
Bentley Tech Park 38
44 41 34 32 32
Carousel 40
38 Cannington
Fremantle 45
Melville
Canning Bridge
38
40
Curtin University
Bull Creek
Booragoon
34
53 Riverton
49 Southlands
Kardinya
Murdoch
Thornlie 46
48
43
36
37
Hilton
Bull Creek Shops
Thornlie Square 49
60
48 Maddington
42
Murdoch Uni
Spearwood 54
67
Canning Vale 42
58 Forest Lakes
54 Gosnells
South Lake
39
49
Cockburn Central
Livingston
64 Kelmscott
Kwinana Hub 91
Rockingham Beach 80
65
63 Rockingham
Warnbro Fair 83
70 Warnbro
77 Armadale
Average:
51.9
114
96
Mandurah

### Global and local efficiency change

**Global efficiency change** is the comparison of the entire network before and after an intervention or series of interventions, in this case the introduction of the LRT route and/or the package of measures included in the frequency boost scenarios. **Local efficiency change** refers to the same comparison on a node-by-node basis. This index is defined as the ratio of the actual inverse average shortest path length between the node in question and all other nodes after the intervention over the same measure before. The measure is weighted by the product of the defined catchment size of the pair of nodes in question (measured in residents, jobs and tertiary students); following the logic that connectivity between larger nodes has a greater bearing on the efficiency of the network than between smaller nodes. Since the total number of metropolitan residents, jobs and/or students after the introduction of LRT changes over the status quo due to projected land use intensification effects, this index is also corrected accordingly by dividing the results by the square of the increase/decrease ratio in metropolitan activities. The efficiency change measures have been designed to deliver a meaningful assessment of network reconfiguration or expansion scenarios. The essence of this index is to assess *how well a particular network performs in comparison with historic or future land use-transport configurations — or: by how much does ease of movement across the network improve/deteriorate?*

$$\Delta CE_i = \frac{(act_{M,b})^2 * \sum((act_{i,a} * act_{j,a})/L_{ij,a})}{(act_{M,a})^2 * \sum((act_{i,b} * act_{j,b})/L_{ij,b})} \qquad [4]$$

where:

$\Delta CE_i$ = change in local efficiency centrality of node i
$act_{i,b}$ = number of residents, jobs and students in defined local catchment of node i before the intervention
$act_{i,a}$ = number of residents, jobs and students in defined local catchment of node i after the intervention
$act_{j,b}$ = number of residents, jobs and students in defined local catchment of node j before the intervention, with $j \in N$ and $i \neq j$
$act_{j,a}$ = number of residents, jobs and students in defined local catchment of node j after the intervention, with $j \in N$ and $i \neq j$
$act_{M,b}$ = number of residents, jobs and students in total metropolitan area before the intervention
$act_{M,a}$ = number of residents, jobs and students in total metropolitan area after the intervention
$L_{ij,b}$ = cumulative impediment between nodes i and j before the intervention, with $j \in N$ and $i \neq j$
$L_{ij,a}$ = cumulative impediment between nodes i and j after the intervention, with $j \in N$ and $i \neq j$
N = all activity nodes on the network

Table D-5 shows that the global efficiency gain as a result of the introduction of LRT is 12%. In terms of local efficiency, Bentley Tech Park, Curtin University and East Perth show the greatest improvement, followed by QE II. Note that the scores on this indicator will go up from two separate influences: better ease of movement along critical links to and from the reference node, and growth in catchment size (i.e. land use intensification) of the node in question and of other nodes in the vicinity, linked by low-impediment network segments.

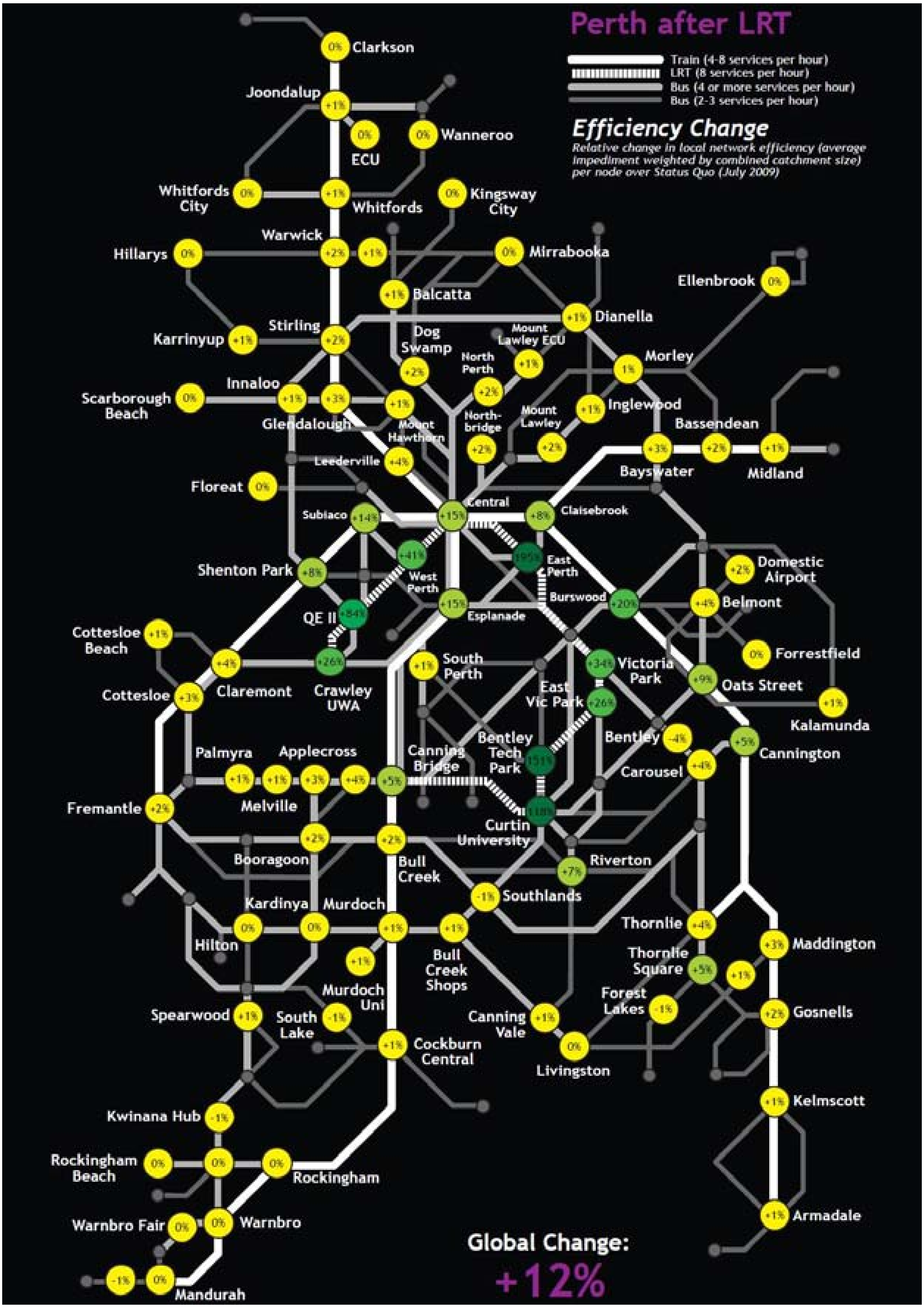
Map D-11 shows how the efficiency gains in the *LRT after* scenario are mainly concentrated along the LRT corridors, while delivering only small improvements across the rest of the metropolitan area. In essence, the LRT proposal has an impressive impact on efficiency of movement along and around the Knowledge Arc, but has little bearing on it for locations away from this corridor. This contrasts, for example, with the experience from the Perth to Mandurah rail line, which improved network accessibility even in areas at a considerable distance from the new railway (Scheurer & Curtis 2008).

The *FRB before* scenario (Map D-12) achieves a global efficiency impact nearly four times as large as the *LRT after* scenario, and distributes its local efficiency effects far more evenly across the 19 activity nodes along and around the LRT corridor (Table D-5). Introducing LRT on top of the frequency boost (*FRB after*) results in a smaller margin of efficiency gain compared to taking the same step within the current network (Map D-13); however, the improvements in accessibility for the main beneficiaries (Bentley Tech Park, Curtin University and East Perth) are still very significant.

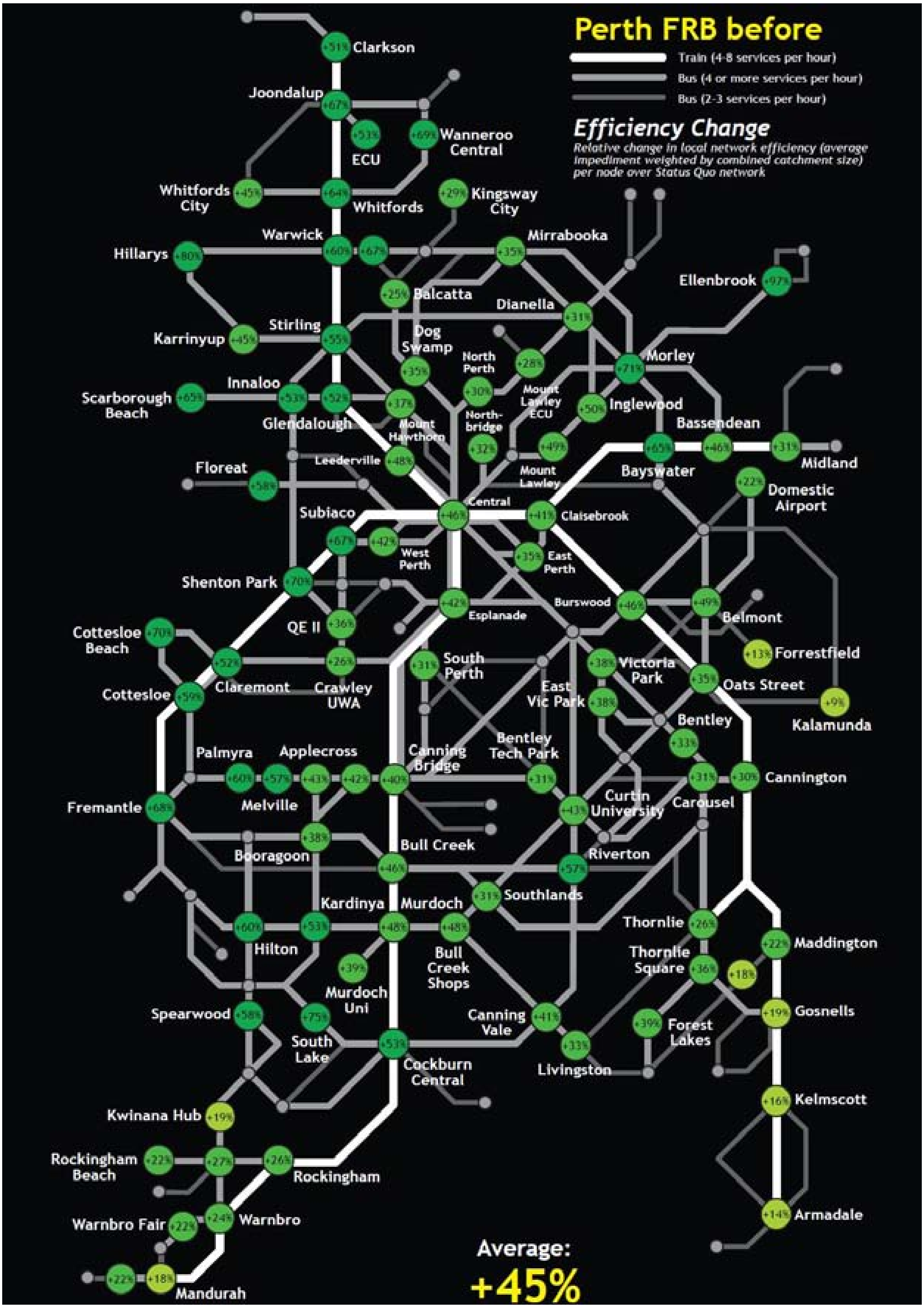
**Table D-5:** Local efficiency change for key activity centres

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | +151% | +31% | +205% | +133% |
| Burswood | +20% | +46% | +54% | +6% |
| Canning Bridge | +5% | +40% | +43% | +2% |
| Cannington | +5% | +30% | +29% | 0% |
| Carousel | +4% | +31% | +27% | -3% |
| Claisebrook | +8% | +41% | +43% | +1% |
| Claremont | +4% | +52% | +51% | -1% |
| Crawley UWA | +26% | +26% | +52% | +20% |
| Curtin University | +118% | +43% | +168% | +87% |
| East Perth | +195% | +35% | +273% | +176% |
| East Victoria Park | +26% | +38% | +55% | +12% |
| Oats Street | +9% | +35% | +36% | +1% |
| Perth Central | +15% | +46% | +60% | +10% |
| Perth Esplanade | +15% | +42% | +61% | +13% |
| QE II | +84% | +36% | +113% | +57% |
| Shenton Park | +8% | +70% | +69% | -1% |
| Subiaco | +14% | +67% | +67% | 0% |
| Victoria Park (Albany Highway) | +34% | +38% | +73% | +26% |
| West Perth | +41% | +42% | +84% | +30% |
| **Global change** | **+12%** | **+45%** | **+55%** | **+7%** |

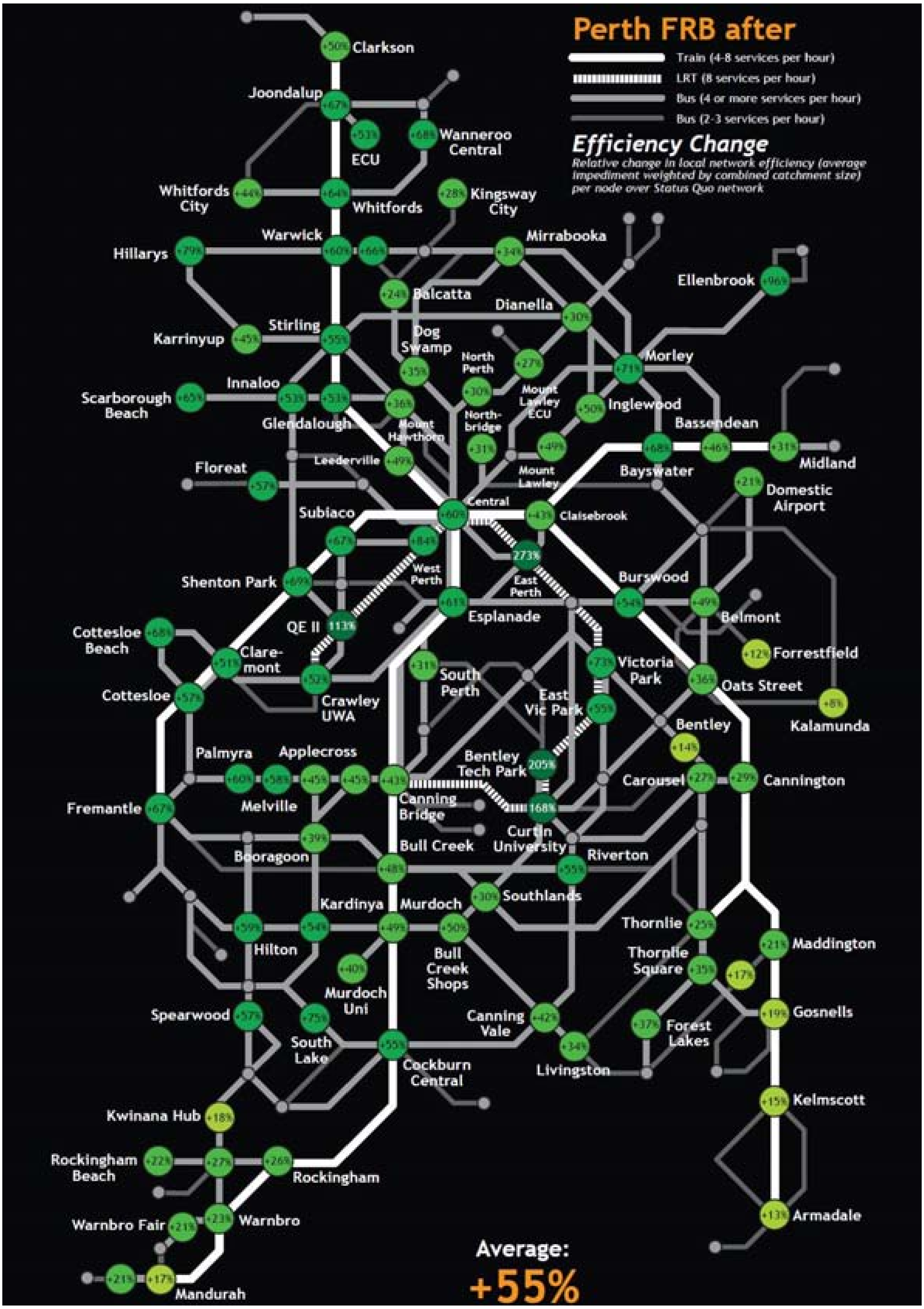
**Map D-11:** Local efficiency change index per activity node over 2009 as a result of the introduction of the Knowledge Arc LRT route



**Map D-12:** Local efficiency change index per activity node over 2009 as a result of the frequency boost (FRB) scenario



**Map D-13:** Local efficiency change index per activity node over 2009 as a result of the frequency boost (FRB) scenario in combination with the introduction of the Knowledge Arc LRT route



### Thirty-minute contour catchment index

The contour catchment counts the percentage of total metropolitan activities (residents, jobs and tertiary students) within the defined walkable catchment area of activity nodes that can be reached from the reference node within a public transport travel time of 30 minutes or less and a maximum of one transfer. For transfer journeys, a 15-minute frequency or better is required on both legs, and a 7.5-minute penalty applies for making the transfer.

**$CI_i$ = act($c_i$)/act(m) [5]**

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
act(m) = total number of residents and jobs in metropolitan area

The contour catchment indicator is responsive to three key influences: travel speed along network segments; one-transfer network connectivity between routes operated every 15 minutes or better; and land use concentration in the catchment areas of nodes. Unlike in the closeness centrality and efficiency gain index, however, high service frequencies (beyond the 15-minute threshold) cannot make up for slow speeds when focussing on contour catchments.

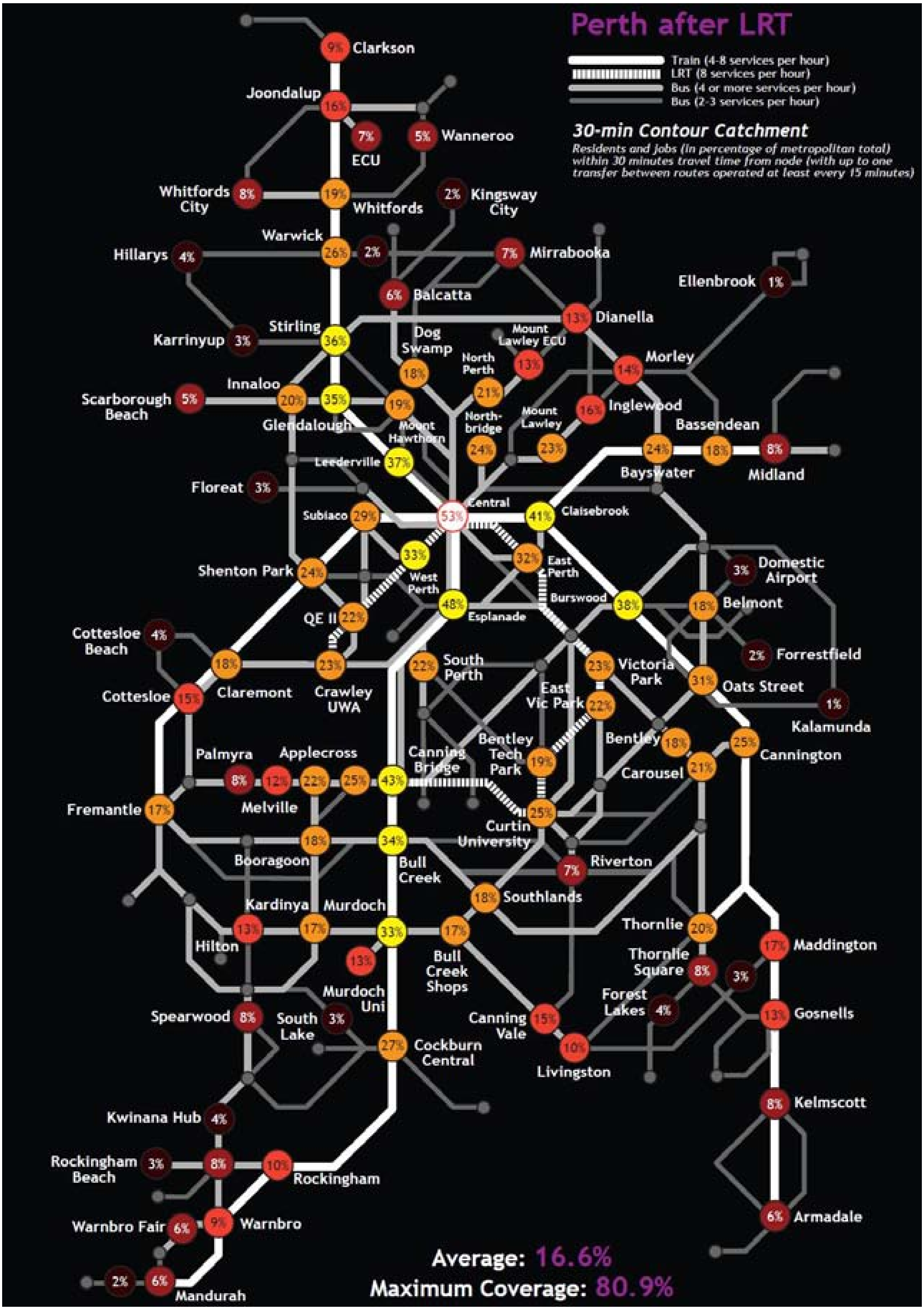
The average improvement on this index by more than two percentage points metropolitan-wide, and by six percentage points within the group of 19 activity nodes along and around the LRT corridor is a significant achievement: it illustrates the magnitude of travel time improvements enabled by the new mode (as long as the projected travel time assumptions prove realistic in practice). As such, LRT helps the Knowledge Arc corridor to attain more spatial and functional cohesion; this is expressed in the narrowing standard deviation measure. Furthermore, the benefit is not restricted to the nodes directly linked by LRT but extends beyond to its neighbours.

On this index, the *FRB before* scenario lags behind the *LRT after* scenario, not least because the frequency boost as such does not include major travel time savings (with the exception of some semi-express running on rail lines). For the subset of 19 centres along and around the LRT corridor, this shortfall becomes quite significant and also translates into further entrenchment of accessibility inequity among these centres; however, the combination of the frequency boost and LRT introduction (*FRB after*) can reverse this trend.

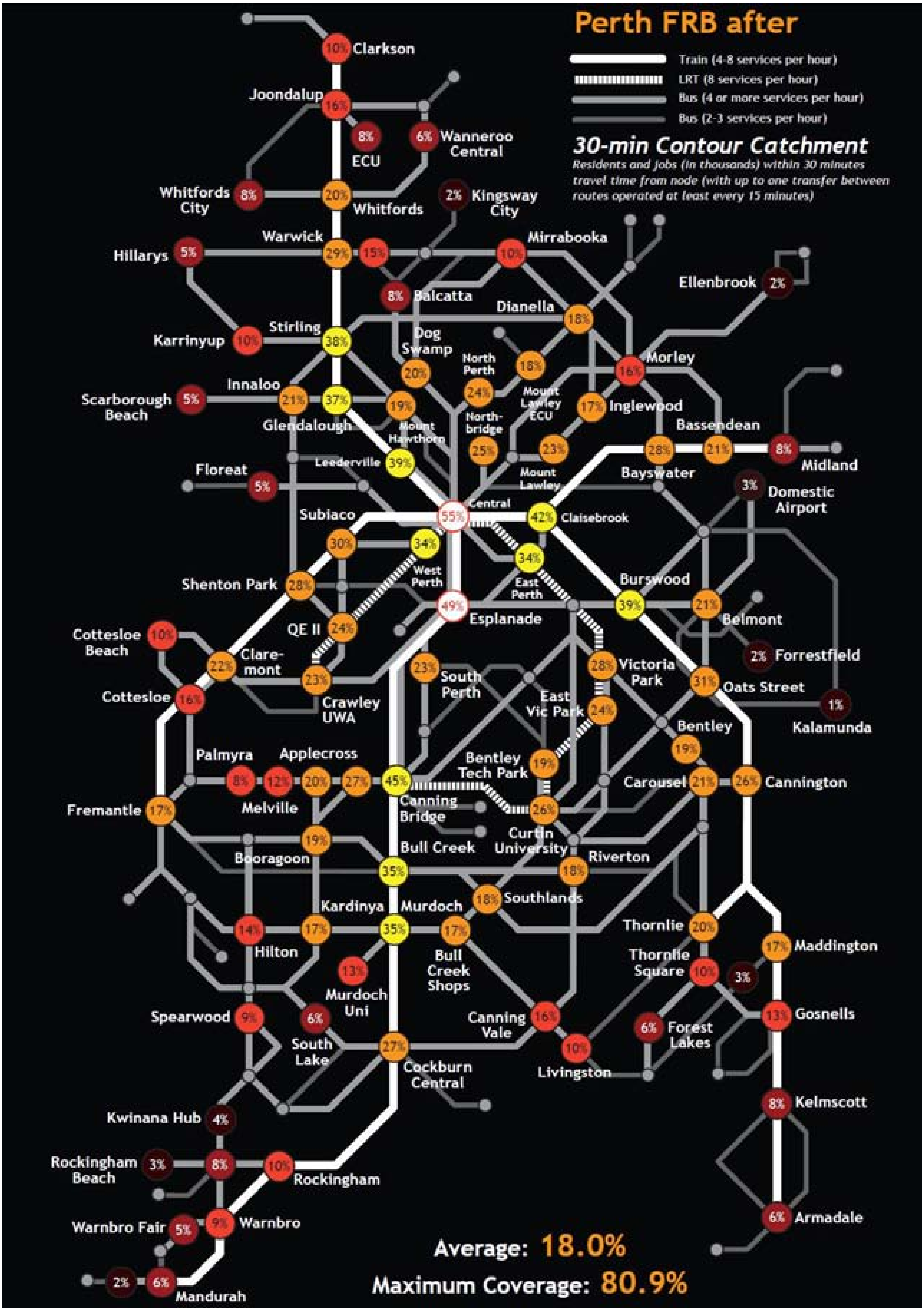
**Table D-6:** Local efficiency change for key activity centres

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 13.0% | 19.4% | 14.5% | 19.3% |
| Burswood | 32.4% | 38.4% | 34.6% | 39.4% |
| Canning Bridge | 40.6% | 42.8% | 43.1% | 45.3% |
| Cannington | 22.0% | 24.9% | 23.3% | 25.7% |
| Carousel | 17.7% | 21.5% | 19.3% | 21.5% |
| Claisebrook | 36.2% | 41.4% | 38.0% | 41.7% |
| Claremont | 16.8% | 18.3% | 21.1% | 21.9% |
| Crawley UWA | 15.8% | 22.7% | 16.3% | 23.3% |
| Curtin University | 18.5% | 24.7% | 19.5% | 25.7% |
| East Perth | 21.8% | 31.8% | 21.6% | 34.3% |
| East Victoria Park | 10.8% | 21.8% | 14.0% | 23.5% |
| Oats Street | 28.3% | 30.7% | 29.2% | 31.4% |
| Perth Central | 50.3% | 52.9% | 53.5% | 55.3% |
| Perth Esplanade | 44.0% | 48.3% | 48.0% | 49.3% |
| QE II | 12.1% | 22.0% | 14.3% | 23.5% |
| Shenton Park | 23.1% | 24.2% | 26.9% | 28.5% |
| Subiaco | 27.5% | 29.1% | 29.6% | 30.4% |
| Victoria Park (Albany Highway) | 15.3% | 28.0% | 19.0% | 28.4% |
| West Perth | 15.1% | 33.3% | 17.4% | 33.6% |
| **Average LRT catchment** | **24.3%** | **30.3%** | **26.5%** | **31.7%** |
| *Standard deviation LRT catchment* | *11.6%* | *10.1%* | *11.9%* | *10.2%* |
| **Average network** | **14.5%** | **16.6%** | **16.5%** | **18.0%** |
| *Standard deviation network* | *10.4%* | *11.6%* | *10.6%* | *11.7%* |

**Maps D-14, D-15:** 30-minute contour catchment index per activity node at current service levels before and after the introduction of the Knowledge Arc LRT route


Perth after LRT
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
30-min Contour Catchment
Residents and jobs (in percentage of metropolitan total) within 30 minutes travel time from node (with up to one transfer between routes operated at least every 15 minutes)
Clarkson
Joondalup
ECU
Wanneroo
Whitfords City
Whitfords
Kingsway City
Warwick
Hillarys
Mirrabooka
Balcatta
Ellenbrook
Dianella
Stirling
Karrinyup
Dog Swamp
Mount Lawley ECU
North Perth
Morley
Innaloo
Scarborough Beach
Glendalough
Mount Hawthorn
North-bridge
Mount Lawley
Inglewood
Bassendean
Bayswater
Midland
Leederville
Floreat
Subiaco
Central
Claisebrook
Shenton Park
West Perth
East Perth
Domestic Airport
QE II
Esplanade
Burswood
Belmont
Cottesloe Beach
Cottesloe
Claremont
Crawley UWA
South Perth
Victoria Park
Forrestfield
East Vic Park
Oats Street
Kalamunda
Palmyra
Applecross
Canning Bridge
Bentley Tech Park
Bentley
Carousel
Cannington
Fremantle
Melville
Curtin University
Booragoon
Bull Creek
Riverton
Southlands
Kardinya
Murdoch
Thornlie
Maddington
Hilton
Bull Creek Shops
Thornlie Square
Murdoch Uni
Forest Lakes
Spearwood
South Lake
Canning Vale
Gosnells
Cockburn Central
Livingston
Kwinana Hub
Kelmscott
Rockingham Beach
Rockingham
Warnbro Fair
Warnbro
Armadale
Mandurah
Average: 16.6%
Maximum Coverage: 80.9%

**Maps D-16, D-17:** 30-minute contour catchment index per activity node at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route


Perth FRB after
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
30-min Contour Catchment
Residents and jobs (in thousands) within 30 minutes travel time from node (with up to one transfer between routes operated at least every 15 minutes)
10% Clarkson
Joondalup 16%
8% ECU
6% Wanneroo Central
Whitfords City 8%
20% Whitfords
2% Kingsway City
Warwick 29%
15%
Mirrabooka 10%
Hillarys 5%
8% Balcatta
Dianella 18%
Ellenbrook 2%
Stirling 38%
Karrinyup 10%
Dog Swamp 20%
North Perth 18%
Morley 16%
Innaloo 21%
37%
Scarborough Beach 5%
Glendalough
19% Mount Hawthorn
24% North-bridge
Mount Lawley ECU
17% Inglewood
Bassendean
Floreat 5%
Leederville 39%
25%
23% Mount Lawley
28% Bayswater
21%
8% Midland
3% Domestic Airport
Subiaco
Central 55%
42% Claisebrook
30%
34% West Perth
34% East Perth
Shenton Park 28%
Burswood 39%
21% Belmont
Cottesloe Beach 10%
QE II 24%
49% Esplanade
2% Forrestfield
22% Clare-mont
23% Crawley UWA
23% South Perth
28% Victoria Park
Cottesloe 16%
East Vic Park 24%
31% Oats Street
1% Kalamunda
Palmyra 8%
Applecross 12% 20% 27%
Bentley
45%
Bentley Tech Park 19%
19%
Carousel 21%
26% Cannington
Fremantle 17%
Melville
Canning Bridge
26%
Curtin University
19% Booragoon
Bull Creek
Riverton
35%
18%
18% Southlands
Kardinya 17%
Murdoch 35%
Thornlie 20%
14% Hilton
17% Bull Creek Shops
17% Maddington
Thornlie Square 10%
3%
13% Murdoch Uni
Spearwood 9%
6% South Lake
Canning Vale 16%
6% Forest Lakes
13% Gosnells
27% Cockburn Central
10% Livingston
Kwinana Hub 4%
8% Kelmscott
Rockingham Beach 3%
8%
10% Rockingham
Warnbro Fair 5%
9% Warnbro
6% Armadale
2% 6% Mandurah
Average: 18.0%
Maximum Coverage: 80.9%

### *Congested speed comparison ratio*

The speed comparison index measures public transport's competitiveness with road transport in free-flow or congested conditions by determining the travel time of the preferred public transport path between each pair of nodes, and drawing a ratio with the equivalent travel time on the road system. The key function of this index is to ask: *how competitive is public transport travel with road travel?* The measures for road system performance have been derived from earlier SNAMUTS work for Perth (Scheurer & Curtis 2008; Curtis & Scheurer 2009). For comparative public transport travel times, this index, like the contour catchment indicator above, assumes average transfer times across the network of 7.5 minutes per transfer.

$$\mathbf{CS_{i,c} = \sum(t_{ij,pt}/t_{ij,rc})/(N-1)} \quad [6]$$

where:

$CS_{i,c}$ = speed comparison ratio of node i (congested)
$t_{ij,pt}$ = travel time between node i and j on public transport, with $i, j \in N$ and $i \neq j$
$t_{ij,rc}$ = travel time between node i and j by road in congested conditions, with $i, j \in N$ and $i \neq j$
N = all activity nodes in the network

Changes on this indicator are relatively marginal, though it is notable that public transport does become slightly more speed-competitive across the metropolitan area as a result of the introduction of LRT, and that this effect is more pronounced among the 19 activity nodes along and around the LRT corridor (Table D-6). Travel time ratios within this subset become far more similar from one centre to the next, with Bentley Tech Park, Curtin University, East Perth, East Victoria Park, QE II and West Perth moving decidedly closer to the average and in some cases beyond that.

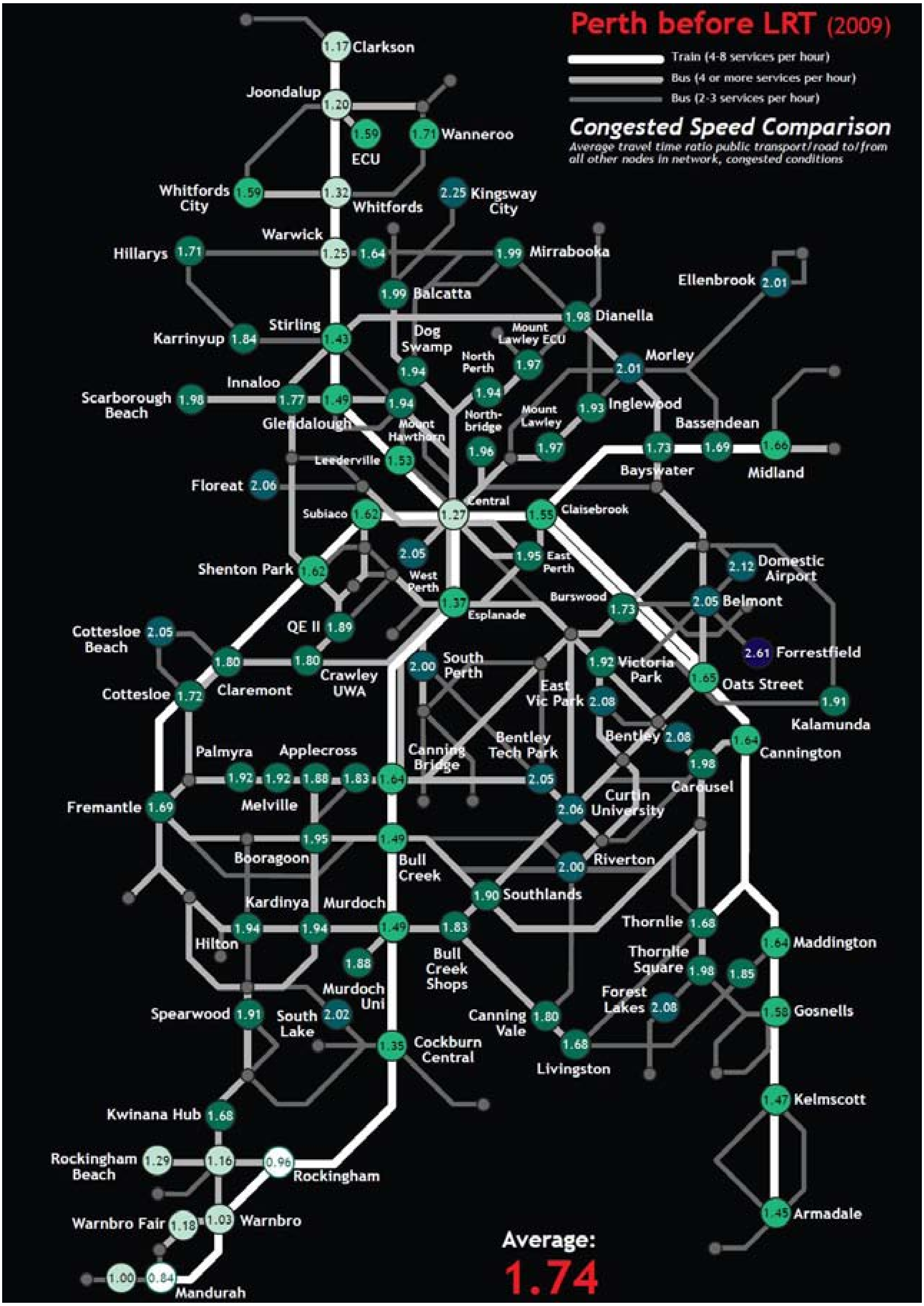
The effect of the frequency boost on its own (*FRB before*) on speed competitiveness is slightly larger for the entire network and slightly smaller for the LRT corridor subset than in the LRT after case. The combination of the frequency boost and the LRT route (*FRB after*) can clearly capitalise on the progress made from both packages of improvements.

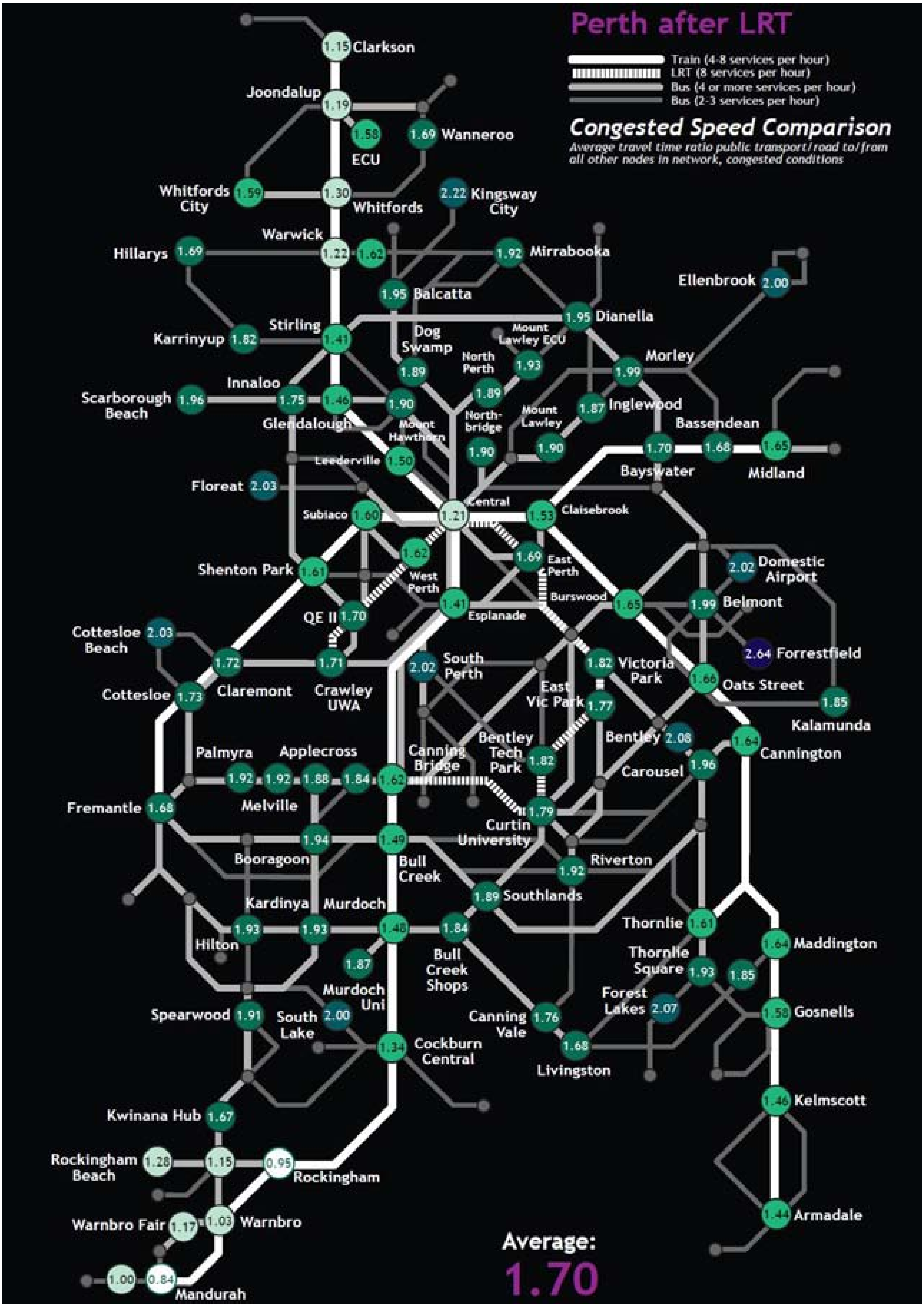
**Table D-7:** Speed comparison ratio for key activity centres

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 2.05 | 1.82 | 2.04 | 1.83 |
| Burswood | 1.73 | 1.65 | 1.64 | 1.61 |
| Canning Bridge | 1.64 | 1.62 | 1.46 | 1.47 |
| Cannington | 1.64 | 1.64 | 1.62 | 1.62 |
| Carousel | 1.97 | 1.96 | 1.93 | 1.93 |
| Claisebrook | 1.55 | 1.53 | 1.48 | 1.45 |
| Claremont | 1.80 | 1.72 | 1.53 | 1.51 |
| Crawley UWA | 1.80 | 1.71 | 1.78 | 1.67 |
| Curtin University | 2.06 | 1.79 | 2.05 | 1.73 |
| East Perth | 1.95 | 1.69 | 1.86 | 1.66 |
| East Victoria Park | 2.08 | 1.77 | 2.01 | 1.71 |
| Oats Street | 1.65 | 1.66 | 1.62 | 1.62 |
| Perth Central | 1.27 | 1.21 | 1.21 | 1.17 |
| Perth Esplanade | 1.37 | 1.41 | 1.37 | 1.38 |
| QE II | 1.88 | 1.70 | 1.87 | 1.66 |

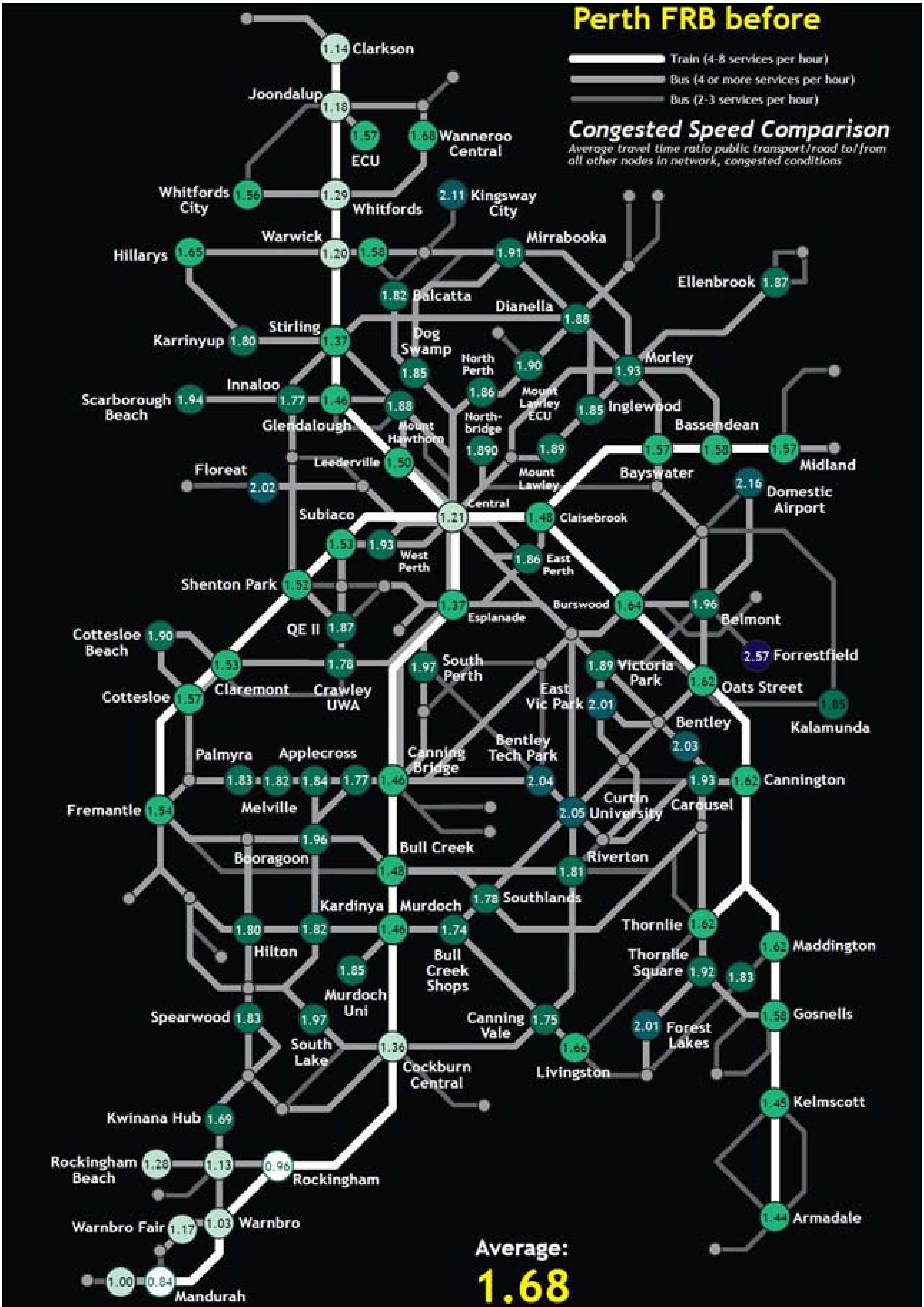
| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Shenton Park | 1.62 | 1.61 | 1.52 | 1.49 |
| Subiaco | 1.62 | 1.60 | 1.53 | 1.51 |
| Victoria Park (Albany Highway) | 1.92 | 1.82 | 1.89 | 1.80 |
| West Perth | 2.05 | 1.62 | 1.93 | 1.56 |
| **Average LRT catchment** | **1.77** | **1.66** | **1.70** | **1.60** |
| *Standard deviation LRT catchment* | *0.24* | *0.16* | *0.25* | *0.17* |
| **Average network** | **1.74** | **1.70** | **1.68** | **1.65** |
| *Standard deviation network* | *0.31* | *0.30* | *0.30* | *0.29* |

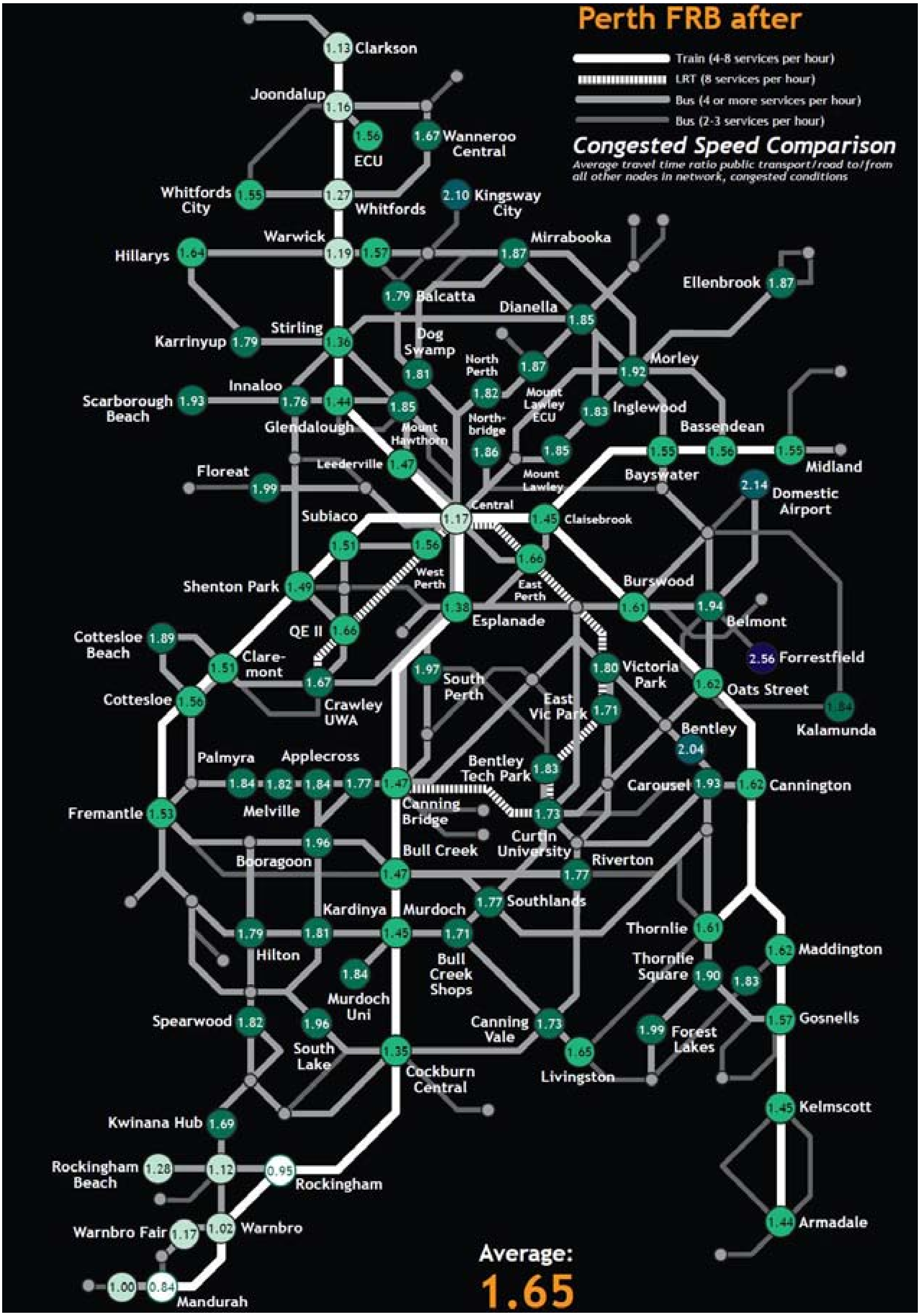
**Maps D-18, D-19:** Speed comparison ratio per activity node at current service levels before and after the introduction of the Knowledge Arc LRT route




Perth after LRT
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Congested Speed Comparison
Average travel time ratio public transport/road to/from all other nodes in network, congested conditions
Average:
1.70

**Maps D-20, D-21:** Speed comparison ratio per activity node at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route




Perth FRB after
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Congested Speed Comparison
Average travel time ratio public transport/road to/from all other nodes in network, congested conditions
1.13 Clarkson
Joondalup 1.16
1.56 ECU
1.67 Wanneroo Central
Whitfords City 1.55
1.27 Whitfords
2.10 Kingsway City
Hillarys 1.64
Warwick 1.19
1.57
Mirrabooka 1.87
Ellenbrook 1.87
1.79 Balcatta
Dianella 1.85
Karrinyup 1.79
Stirling 1.36
Dog Swamp 1.81
North Perth 1.87
Morley 1.92
Scarborough Beach 1.93
Innaloo 1.76
1.44
1.85
1.82
Mount Lawley ECU
1.83 Inglewood
Bassendean
Glendalough
Mount Hawthorn
North-bridge 1.86
1.85
1.55 Bayswater
1.56
1.55 Midland
Floreat 1.99
Leederville 1.47
Mount Lawley
2.14 Domestic Airport
Subiaco
1.17 Central
1.45 Claisebrook
1.51
1.56
1.66
Shenton Park 1.49
West Perth
East Perth
Burswood 1.61
1.94
Belmont
1.38 Esplanade
Cottesloe Beach 1.89
QE II 1.66
2.56 Forrestfield
1.51 Clare-mont
1.67
1.97 South Perth
1.80 Victoria Park
1.62 Oats Street
Cottesloe 1.56
Crawley UWA
East Vic Park 1.71
1.84 Kalamunda
Bentley 2.04
Palmyra
Applecross
Bentley Tech Park 1.83
1.84 1.82 1.84 1.77 1.47
Carousel 1.93
1.62 Cannington
Fremantle 1.53
Melville
Canning Bridge
1.73
Curtin University
1.96
Bull Creek
Booragoon
Riverton
1.47
1.77
1.77 Southlands
Kardinya
Murdoch
Thornlie 1.61
1.79 Hilton
1.81
1.45
1.71 Bull Creek Shops
1.62 Maddington
Thornlie Square 1.90
1.83
1.84
Murdoch Uni
Spearwood 1.82
1.96
Canning Vale 1.73
1.57 Gosnells
1.99 Forest Lakes
South Lake
1.35
1.65 Livingston
Cockburn Central
1.45 Kelmscott
Kwinana Hub 1.69
Rockingham Beach 1.28
1.12
0.95 Rockingham
1.44 Armadale
Warnbro Fair 1.17
1.02 Warnbro
Average:
1.65
1.00 0.84
Mandurah

### *Betweenness centrality index*

The betweenness centrality index is presented here in two formats: by route segment and by node. Segmental betweenness, while using quantitative measures, is primarily a qualitative indicator: it portrays where on the network the most attractive travel opportunities are concentrated. To arrive at the results illustrated in Maps D-22 to D-25 a GIS-based wayfinding procedure is applied to determine the most attractive network path between any pair of nodes. The most attractive path, in this context, emerges as the path with the lower overall travel time (including transfer penalties as in previous indicators) out of a comparison of the path with the lowest number of transfers (degree centrality index) and the path with the lowest cumulative travel impediment (closeness centrality index). The number of paths that pass through the network segment in question is then expressed as a percentage of the total, weighted by cumulative impediment and combined activity node size. Thus segmental betweenness centrality is defined as the proportion of preferred paths between any two nodes within the network that traverse a particular network segment, out of the total number of network paths. The weighting procedure multiplies each network path by a factor consisting of the product of the nodal catchments' number of activities for the two nodes at either end of the path, divided by the cumulative impediment between the two nodes. The percentage values associated with each route segment refer to the totality of all network paths, including their weighting. This step tries to capture the varying significance of node-to-node paths according to the catchment size of the nodes in question, as well as a gravity or distance decay component that prioritises node-to-node paths in line with ease of movement. It reflects the notion that public transport users may opt to make journeys based less on geographical distance, but on travel time and opportunity. This index is critical for public transport network analysis, since it can capture the relative importance of transfer nodes as well as route segments from a supply perspective, and assist in evaluating and modelling route and interchange capacity. Its key intent is to determine *how significant a node or segment is to facilitate movement across the network — or: how are travel opportunities geographically distributed across the network?*

$$\mathbf{CB_{k,w}} = \frac{\sum(p_{ij}(k) * (act_i * act_j)/L_{ij})}{\sum(p_{ij} * (act_i * act_{j,})/L_{ij})} \qquad \textbf{[7]}$$

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

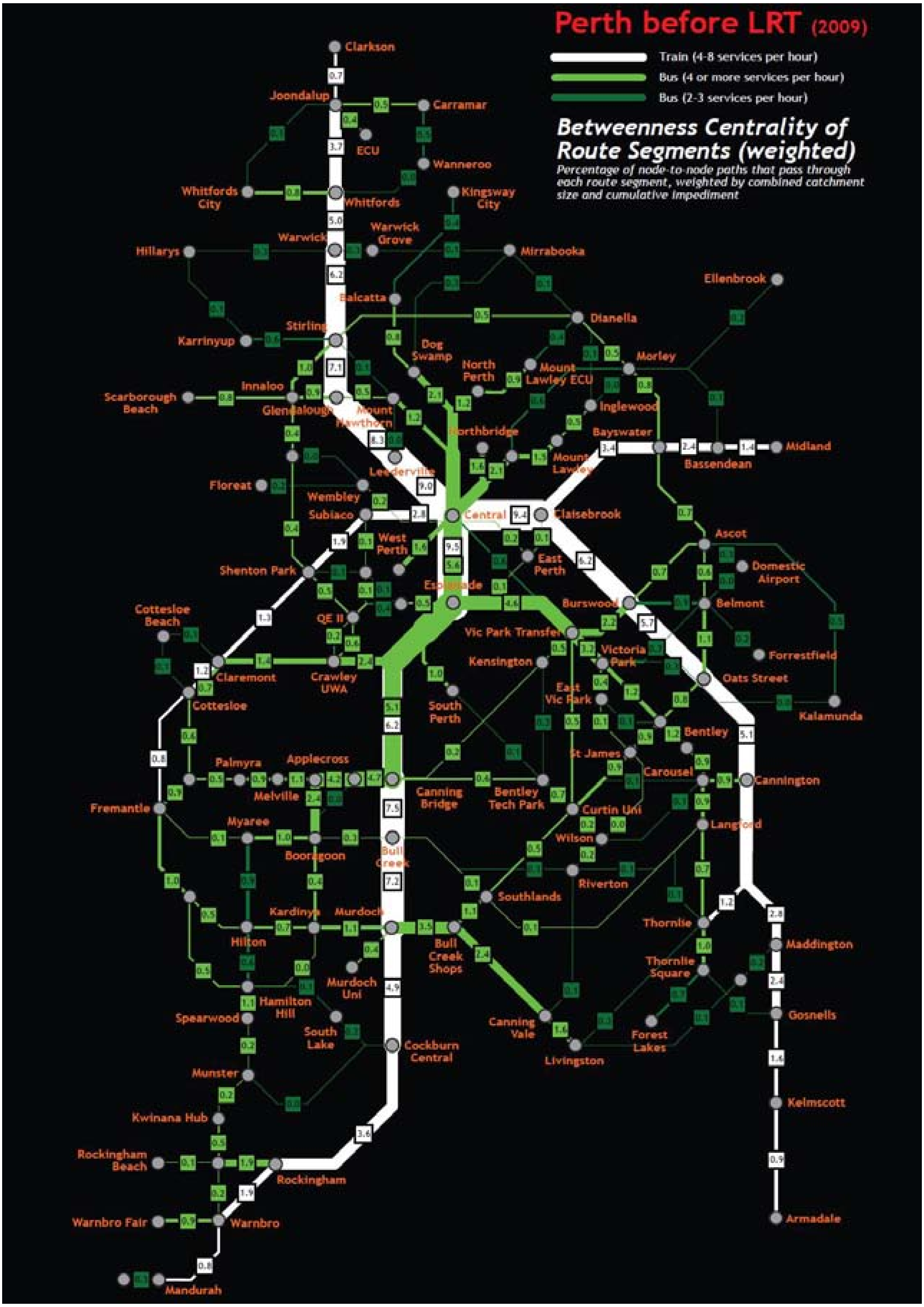
$L_{ij}$ = minimum cumulative impediment between nodes i and j

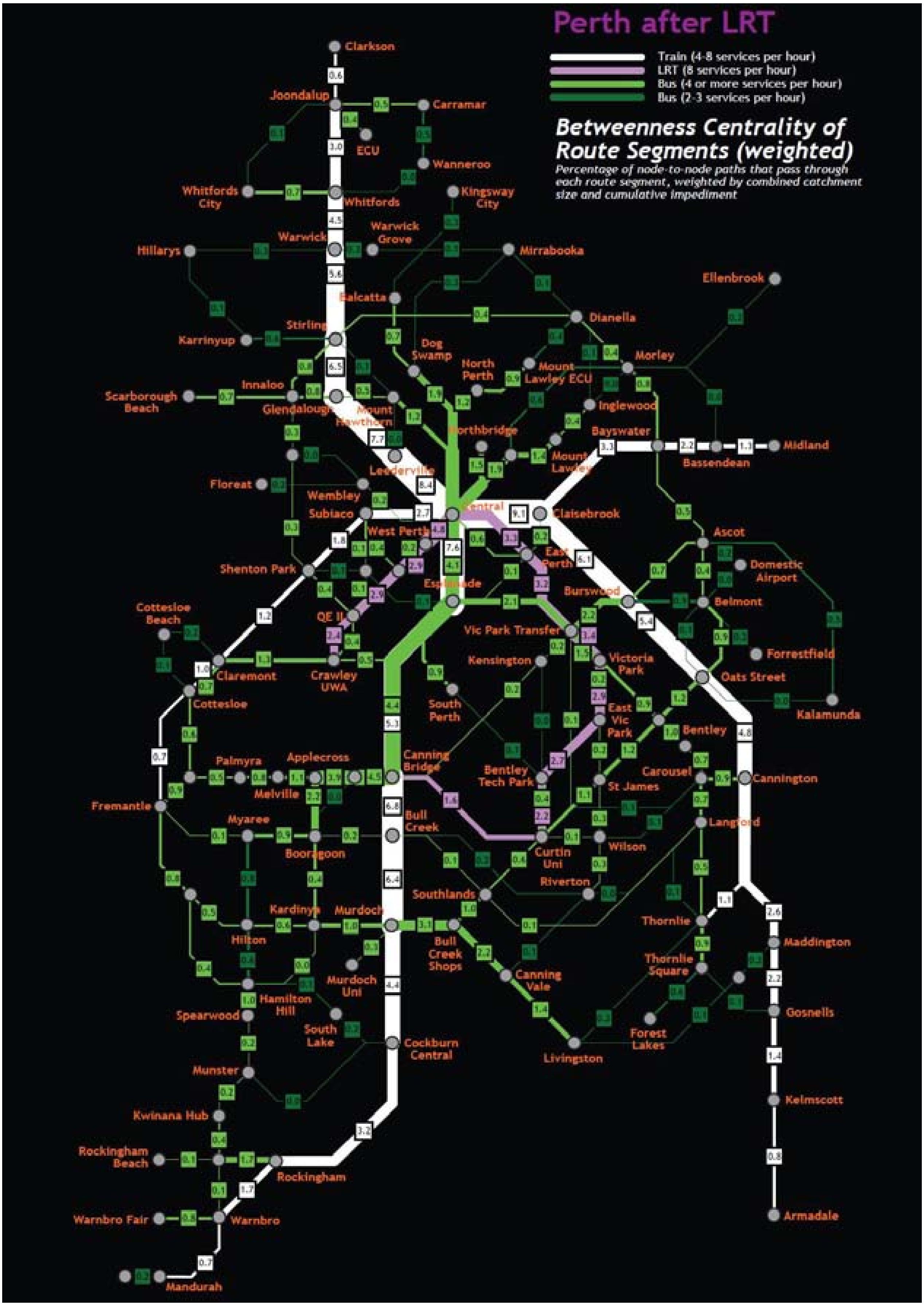
N = all activity nodes in the network

The following maps show network diagrams with segmental betweenness scores (sum of both directions) for the *LRT before, LRT after, FRB before* and *FRB after* cases. Note that those network segments that do not attract any preferred paths in this index have been omitted from the maps (wherever a score of 0.0 is shown, this indicates a score greater than zero but below 0.05). Such segments can be understood as not having a function in providing connections between the 94 largest activity nodes (but they may well have a function in providing local access to neighbourhoods or smaller centres).

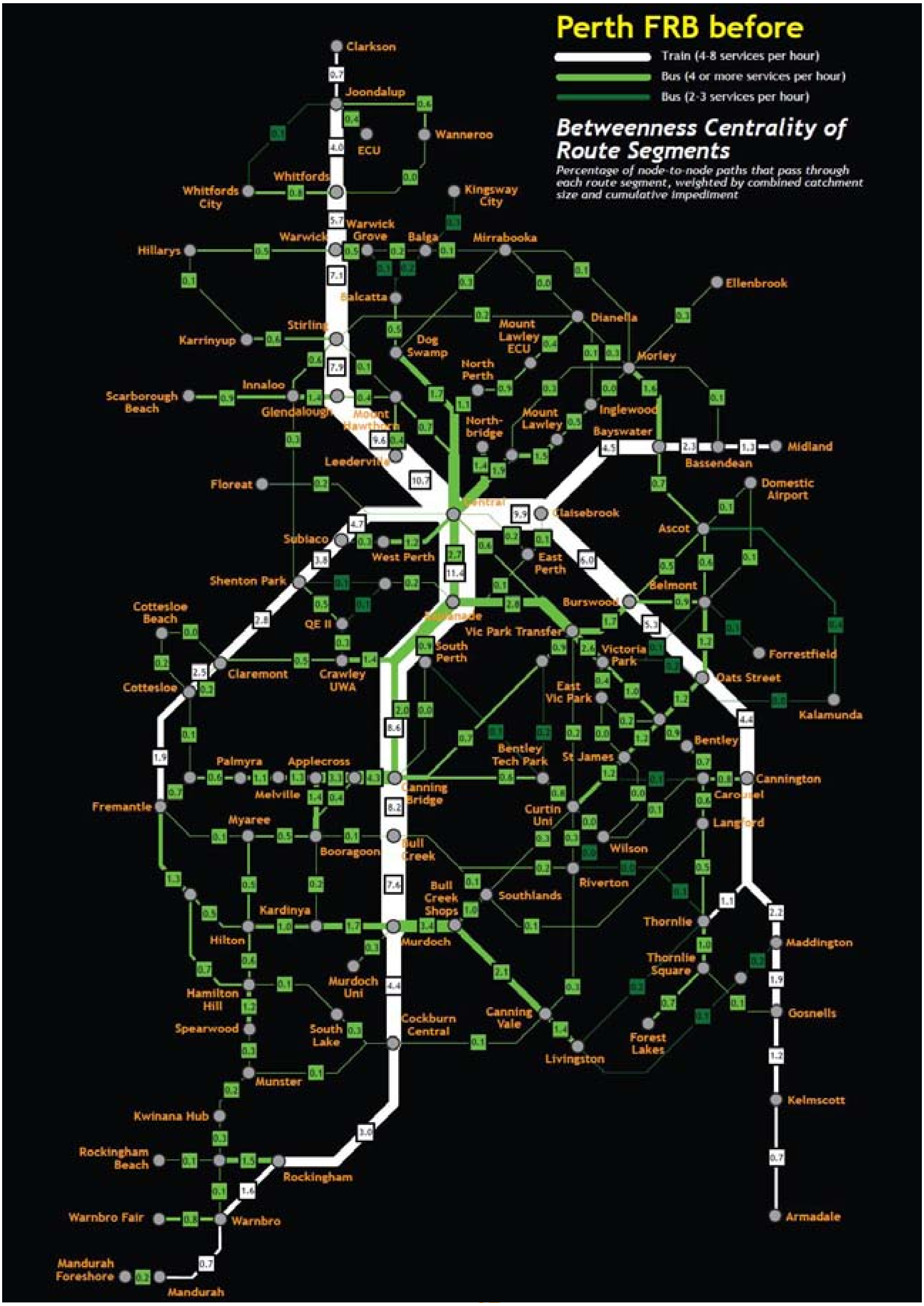
A major new piece of infrastructure, such as an LRT route, will need to be assessed against its capability to attract network significance, that is to capture a certain percentage of opportunities for movement. In other words, the viability of LRT segments connecting designated activity nodes but showing poorly on the betweenness index could rightly be called into question. The results, however, are encouraging for the entire length of the proposed Knowledge Arc route: linking 10 out of Perth's 94 activity nodes, its betweenness scores are consistently at a level comparable to the Fremantle to Midland rail line. The weakest segment, between Canning Bridge and Curtin University, still more than doubles in significance compared to its current operation by bus route 100. Bus corridors parallel to light rail, particularly along Mounts Bay Road and Adelaide Terrace, experience critical relief and a reduction of the betweenness scores to a level more appropriate to bus routes. Even the central segments of the heavy rail network, the strongest performers on this index, drop slightly in relative terms, which could be read as a direct indication that the proposed LRT route is well placed to provide a host of new travel opportunities and thus expand public transport into new market segments. The strongest segment between Perth Central and West Perth forms part of an obvious gap in the existing network (there is no direct public transport connection between the heart of West Perth and neighbouring inner suburbs to the south and west), yet its network significance still does not appear excessive to a point where it would pose a threat that light rail could be overwhelmed with associated demand.

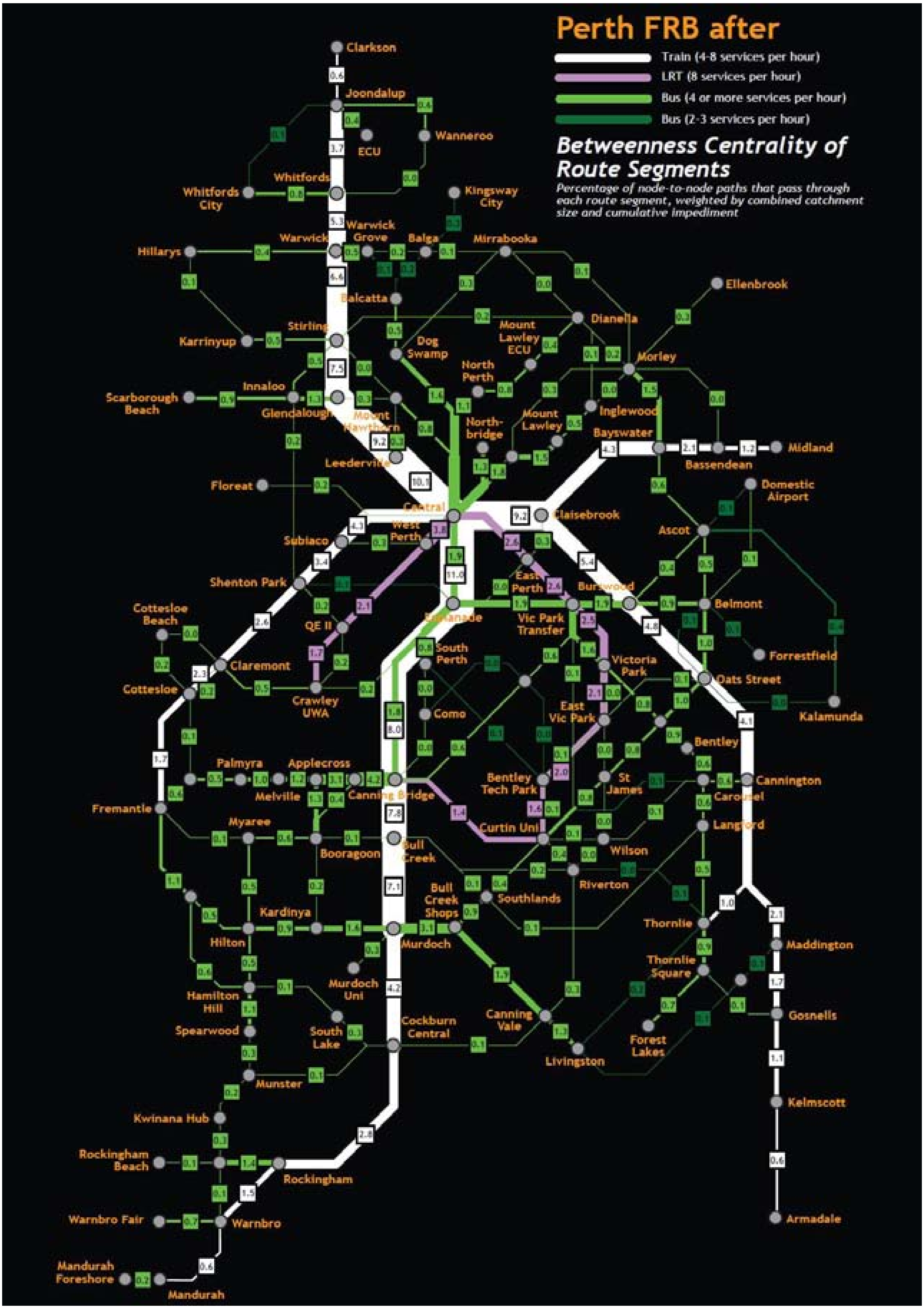
**Maps D-22, D-23:** Segmental betweenness centrality index at current service levels before and after the introduction of the Knowledge Arc LRT route




Perth after LRT
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Betweenness Centrality of Route Segments (weighted)
Percentage of node-to-node paths that pass through each route segment, weighted by combined catchment size and cumulative impediment
Clarkson
Joondalup
Carramar
ECU
Wanneroo
Whitfords City
Whitfords
Kingsway City
Warwick
Warwick Grove
Hillarys
Mirrabooka
Ellenbrook
Balcatta
Dianella
Stirling
Karrinyup
Dog Swamp
North Perth
Morley
Mount Lawley ECU
Scarborough Beach
Innaloo
Glendalough
Mount Hawthorn
Inglewood
Northbridge
Bayswater
Midland
Bassendean
Floreat
Leederville
Mount Lawley
Wembley
Subiaco
Central
Claisebrook
West Perth
Ascot
East Perth
Domestic Airport
Shenton Park
Esplanade
Belmont
Burswood
Cottesloe Beach
QE II
Vic Park Transfer
Forrestfield
Claremont
Crawley UWA
Kensington
Victoria Park
Oats Street
Cottesloe
South Perth
East Vic Park
Kalamunda
Bentley
Palmyra
Applecross
Canning Bridge
Bentley Tech Park
Carousel
Cannington
Melville
St James
Fremantle
Myaree
Bull Creek
Langford
Booragoon
Curtin Uni
Wilson
Riverton
Southlands
Kardinya
Murdoch
Thornlie
Maddington
Hilton
Bull Creek Shops
Thornlie Square
Canning Vale
Murdoch Uni
Hamilton Hill
Spearwood
Gosnells
South Lake
Forest Lakes
Cockburn Central
Livingston
Munster
Kelmscott
Kwinana Hub
Rockingham Beach
Rockingham
Warnbro Fair
Warnbro
Armadale
Mandurah

**Maps D-24, D-25:** Segmental betweenness centrality index at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route




Perth FRB after
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Betweenness Centrality of Route Segments
Percentage of node-to-node paths that pass through each route segment, weighted by combined catchment size and cumulative impediment
Clarkson
Joondalup
ECU
Wanneroo
Whitfords City
Whitfords
Kingsway City
Warwick
Warwick Grove
Balga
Mirrabooka
Hillarys
Ellenbrook
Balcatta
Dianella
Stirling
Karrinyup
Dog Swamp
Mount Lawley ECU
Morley
North Perth
Innaloo
Scarborough Beach
Glendalough
Mount Hawthorn
Inglewood
Mount Lawley
Bayswater
North-bridge
Midland
Bassendean
Leederville
Floreat
Domestic Airport
Central
Claisebrook
West Perth
Ascot
Subiaco
East Perth
Burswood
Shenton Park
Belmont
Vic Park Transfer
Esplanade
Cottesloe Beach
QE II
South Perth
Forrestfield
Claremont
Victoria Park
Oats Street
Cottesloe
Crawley UWA
Como
East Vic Park
Kalamunda
Bentley
Palmyra
Applecross
Bentley Tech Park
St James
Cannington
Melville
Canning Bridge
Carousel
Fremantle
Curtin Uni
Langford
Myaree
Bull Creek
Booragoon
Wilson
Riverton
Bull Creek Shops
Southlands
Kardinya
Thornlie
Hilton
Murdoch
Maddington
Thornlie Square
Murdoch Uni
Hamilton Hill
Canning Vale
Cockburn Central
Spearwood
South Lake
Gosnells
Forest Lakes
Livingston
Munster
Kelmscott
Kwinana Hub
Rockingham Beach
Rockingham
Warnbro Fair
Warnbro
Armadale
Mandurah Foreshore
Mandurah

### Nodal betweenness centrality index

The nodal betweenness centrality index illustrates the relative significance of each activity node for attracting potential travel paths that start, end or pass through there. Higher figures indicate greater relative significance.

In Table D-8 a critical achievement of the LRT corridor proposal becomes apparent. A number of important activity nodes, particularly Bentley Tech Park, Curtin University, East Perth, East Victoria Park, QE II and West Perth, experience a tremendous boost in terms of network integration: it could be argued that they shift from the margins to a much more prominent 'crossroads' position in the public transport movement economy (Hillier 1996). This should have the effect of spreading pressure for land use intensification more evenly along the Knowledge Arc by relieving the traditionally most accessible hubs from some development pressure while opening up new areas to a greater diversity of land use opportunities.

The frequency boost without LRT scenario (*FRB before*) is unable to achieve a similar effect, except perhaps for the rail nodes in Subiaco, Shenton Park and Claremont. The combination scenario (*FRB after*) smoothens both trends to some degree.

Also notable is the relatively poor performance of Crawley UWA in this index, owing predominantly to its waterfront/peninsular location that is necessarily unable to attract movement from as wide a range of directions as most other activity nodes. In contrast, the performance of Burswood is remarkable and illustrates a particularly easy potential win for land-use-transport integration, if all Armadale and Thornlie trains were made to stop and a functional rail-bus interchange provided at this location.

**Table D-8:** Nodal betweenness centrality index for key activity centres

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 1.6% | 5.3% | 1.7% | 3.8% |
| Burswood | 6.2% | 15.3% | 14.4% | 13.3% |
| Canning Bridge | 24.4% | 22.7% | 24.4% | 23.7% |
| Cannington | 10.0% | 9.2% | 8.5% | 7.8% |
| Carousel | 2.8% | 2.3% | 2.3% | 1.9% |
| Claisebrook | 19.1% | 18.7% | 20.5% | 19.2% |
| Claremont | 4.8% | 4.4% | 6.1% | 5.7% |
| Crawley UWA | 4.6% | 3.4% | 2.3% | 2.6% |
| Curtin University | 2.9% | 6.2% | 3.0% | 4.8% |
| East Perth | 0.3% | 6.8% | 0.3% | 5.5% |
| East Victoria Park | 0.6% | 5.9% | 0.6% | 4.3% |
| Oats Street | 13.0% | 12.4% | 12.1% | 10.9% |
| Perth Central | 47.1% | 47.7% | 48.4% | 49.6% |
| Perth Esplanade | 34.9% | 25.0% | 30.0% | 25.8% |
| QE II | 1.6% | 6.1% | 0.9% | 4.3% |
| Shenton Park | 4.2% | 3.8% | 7.5% | 6.6% |
| Subiaco | 4.7% | 4.9% | 8.8% | 8.0% |
| Victoria Park (Albany Highway) | 5.2% | 8.8% | 4.3% | 7.1% |
| West Perth | 1.6% | 7.8% | 1.5% | 6.0% |
| **Average LRT catchment** | **10.0%** | **11.4%** | **10.4%** | **11.1%** |
| *Standard deviation LRT catchment* | *12.8%* | *11.0%* | *12.6%* | *11.6%* |

### Betweenness centrality index per mode and at/within CBD cordon

It is also possible to aggregate the segmental betweenness counts from Maps D-22 to D-25 for each public transport mode (weighted by the scheduled travel time of each segment) and express this as a proportion of all network segments (Table D-9). On the whole, LRT takes over network significance from the bus system while leaving the relative significance of heavy rail intact. The frequency boost scenarios result in an additional shift of network significance from bus to heavy rail: in the combination scenario, the network is clearly dominated by the two rail modes on this indicator.

Somewhat paradoxically, the light rail route appears to shift some network significance away from the CBD even though it passes right through it. However, this is likely to be due to the solid betweenness scores achieved on LRT segments outside the CBD, and the relief provided to bus routes on CBD approaches.

**Table D-9:** Aggregate proportion of segmental betweenness centrality scores for each mode and for CBD segments

| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Betweenness segments train | 41.8% | 41.2% | 48.7% | 47.8% |
| Betweenness segments LRT | - | 9.7% | - | 7.9% |
| Betweenness segments bus | 58.2% | 49.1% | 51.3% | 44.3% |
| Betweenness segments CBD | 27.5% | 24.6% | 26.0% | 25.0% |

### Connectivity index for selected centres

The nodal connectivity index considers the connectivity of the network at activity nodes by multiplying the number of links to nearest neighbours converging in the node by the number of public transport departures per hour, weighted by mode using a mode-specific average load factor. This index tries to capture the property of an activity node to entice (or force) public transport passengers to spend time there during their journey and potentially patronise the land use facilities located there. In other words: *how well integrated is a node within the web of travel opportunities and how well situated is the node for making transfers and breaks of journey?* Higher figures indicate greater centrality.

$$\mathbf{CV_i = (\sum a_{ij}-2) * (o_r f_r(i)/50+o_l f_l(i)/50+o_b f_b(i)/50)} \quad \textbf{[8]}$$

where:

$CV_i$ = connectivity index for node i
$a_{ij}$ = links converging in node i, with $j \in N(i)$ and $i \neq j$
$N(i)$ = network nodes adjacent (nearest neighbours) to node i
$f_r(i)$ = number of rail departures per hour per direction from node i
$f_l(i)$ = number of light rail departures per hour per direction from node i
$f_b(i)$ = number of bus departures per hour per direction from node i
$o_r$ = average network-wide load factor rail (passenger-km divided by revenue train-km)
$o_l$ = average network-wide load factor light rail (passenger-km divided by revenue train-km)
$o_b$ = average network-wide load factor bus (passenger-km divided by revenue vehicle-km)

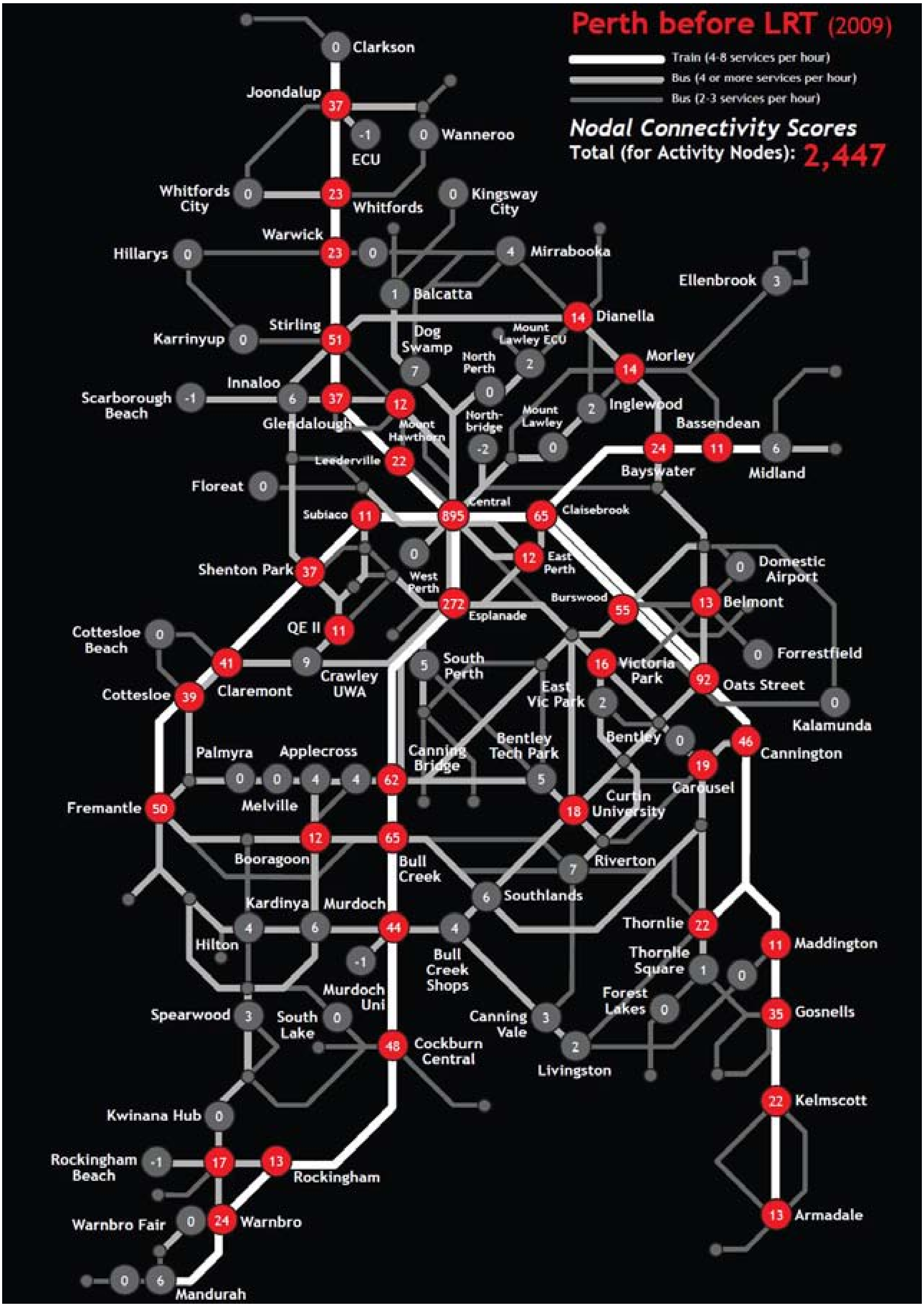
The load factor coefficients used for this index are 9.32 for bus, 28.0 for LRT and 65.0 for heavy rail. They are derived from a network-wide average of passenger km per mode divided by revenue train km or vehicle km in the case of bus and heavy rail, and an estimate based on likely relative vehicle size for LRT. Put simply, they are a proxy for the average number of passengers found on each bus or in each train (counting all train or LRT carriages) in revenue service across the network.

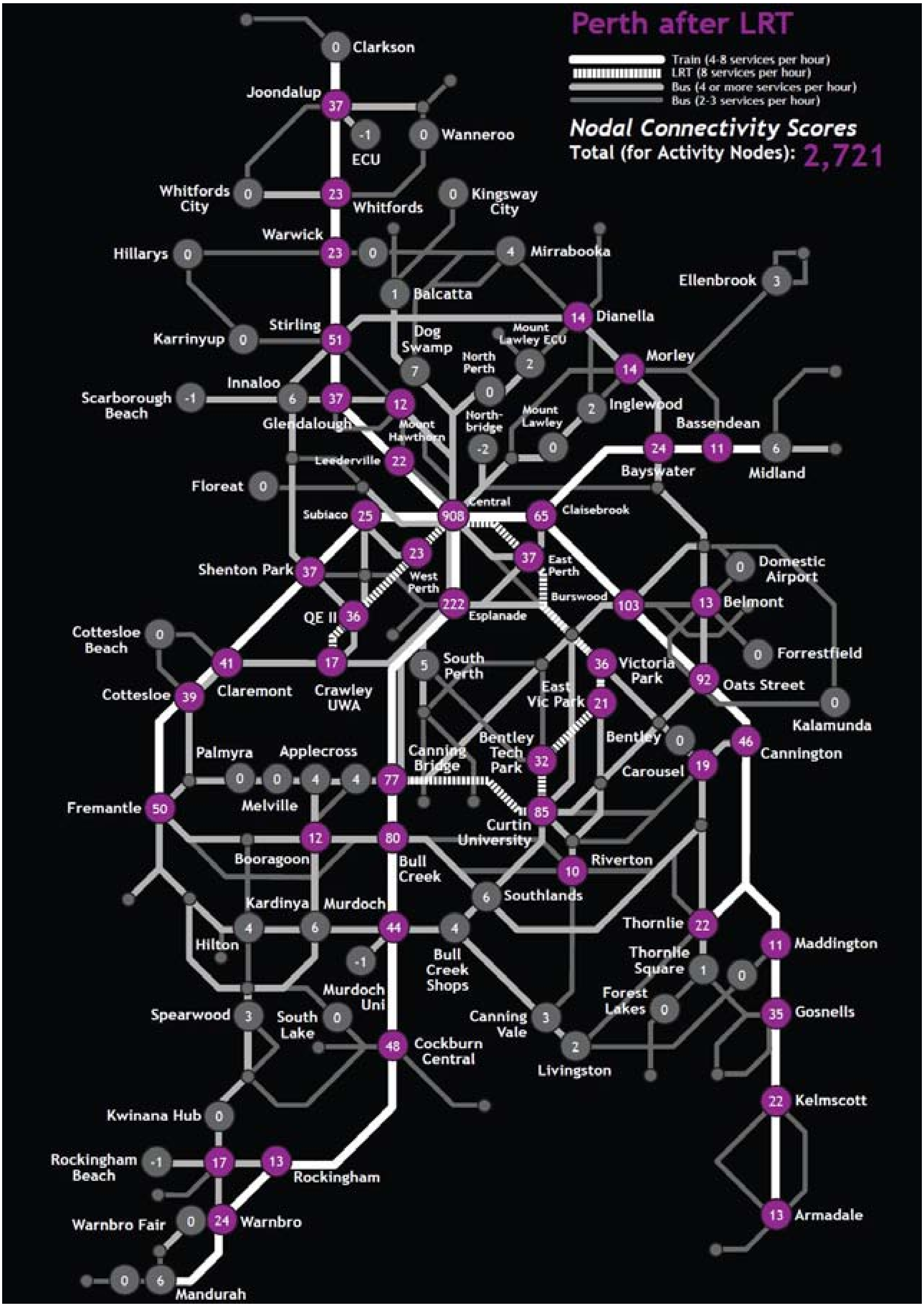
The results of this index heavily favour high-capacity modes as well as centres where a large number of routes from different directions converge. Thus Perth Central consistently captures over 30% of the network-wide cumulative score on this index, a dominance only slightly dented in the combination (*FRB after*) scenario. As a result of the introduction of LRT, a surge in this index can be observed particularly for Burswood and Curtin University, both elevated to the status of major multimodal interchanges. Bentley Tech Park, East Victoria Park and West Perth register on this indicator for the first time at a level of significance.

**Table D-9:** Nodal connectivity index for key activity centres

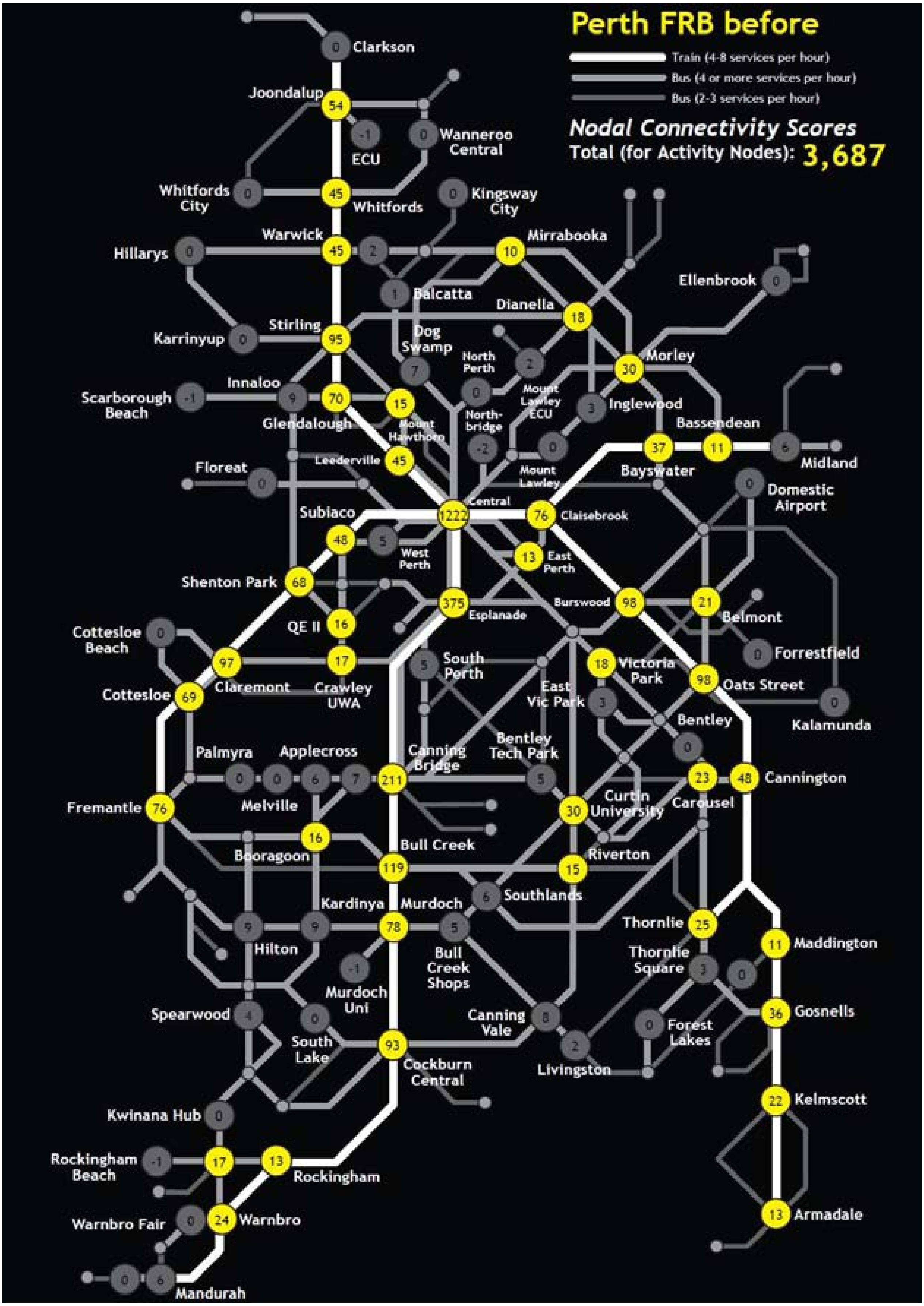
| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 5 | 32 | 5 | 42 |
| Burswood | 55 | 103 | 98 | 104 |
| Canning Bridge | 62 | 77 | 211 | 237 |
| Cannington | 46 | 46 | 48 | 46 |
| Carousel | 19 | 19 | 23 | 19 |
| Claisebrook | 65 | 65 | 76 | 75 |
| Claremont | 41 | 41 | 97 | 97 |
| Crawley UWA | 9 | 17 | 17 | 26 |
| Curtin University | 18 | 85 | 30 | 99 |
| East Perth | 12 | 37 | 13 | 38 |
| East Victoria Park | 2 | 21 | 3 | 45 |
| Oats Street | 92 | 95 | 98 | 98 |
| Perth Central | 895 | 908 | 1,222 | 1,198 |
| Perth Esplanade | 272 | 222 | 375 | 338 |
| QE II | 12 | 36 | 16 | 36 |
| Shenton Park | 37 | 37 | 68 | 68 |
| Subiaco | 11 | 25 | 48 | 46 |
| Victoria Park (Albany Highway) | 16 | 36 | 18 | 51 |
| West Perth | - | 23 | 5 | 23 |
| **Total LRT catchment** | **1,670** | **1,925** | **2,471** | **2,685** |
| **Total network** | **2,605** | **2,954** | **3,889** | **4,154** |

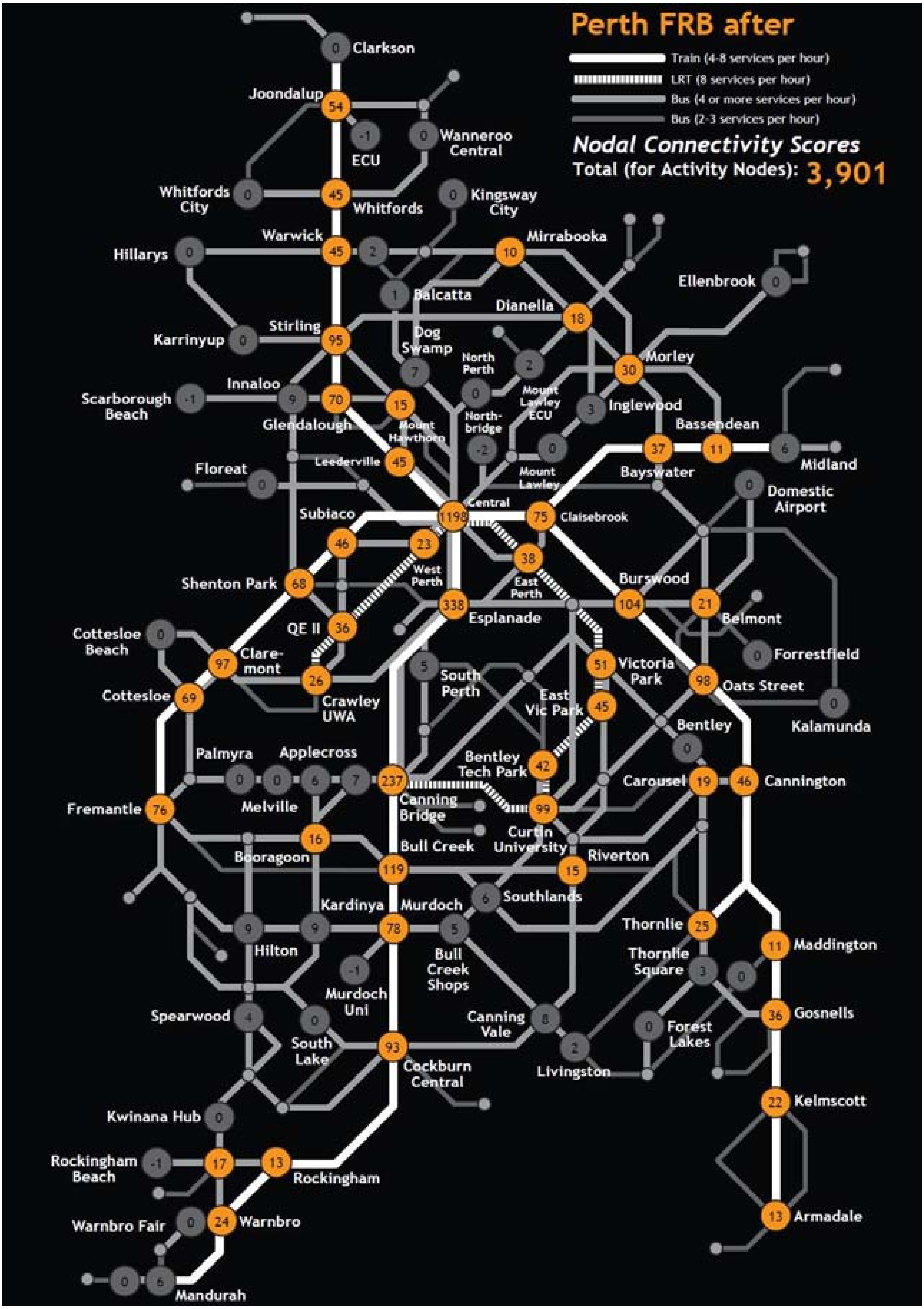
**Maps D-26, D-27:** Nodal connectivity index at current service levels before and after the introduction of the Knowledge Arc LRT route




Perth after LRT
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Nodal Connectivity Scores
Total (for Activity Nodes): 2,721
Clarkson
Joondalup
Wanneroo
ECU
Whitfords City
Whitfords
Kingsway City
Warwick
Hillarys
Mirrabooka
Balcatta
Ellenbrook
Dianella
Stirling
Karrinyup
Dog Swamp
Mount Lawley ECU
North Perth
Morley
Innaloo
Scarborough Beach
Glendalough
Mount Hawthorn
North-bridge
Mount Lawley
Inglewood
Bassendean
Bayswater
Midland
Leederville
Floreat
Subiaco
Central
Claisebrook
Shenton Park
West Perth
East Perth
Domestic Airport
QE II
Esplanade
Burswood
Belmont
Cottesloe Beach
Forrestfield
Claremont
South Perth
Victoria Park
Cottesloe
Crawley UWA
Oats Street
East Vic Park
Kalamunda
Palmyra
Applecross
Canning Bridge
Bentley Tech Park
Bentley
Cannington
Carousel
Fremantle
Melville
Curtin University
Booragoon
Bull Creek
Riverton
Kardinya
Murdoch
Southlands
Thornlie
Maddington
Hilton
Bull Creek Shops
Thornlie Square
Murdoch Uni
Forest Lakes
Spearwood
South Lake
Canning Vale
Gosnells
Cockburn Central
Livingston
Kelmscott
Kwinana Hub
Rockingham Beach
Rockingham
Warnbro Fair
Warnbro
Armadale
Mandurah

**Maps D-28, D-29:** Nodal connectivity index at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route




Perth FRB after
Train (4-8 services per hour)
LRT (8 services per hour)
Bus (4 or more services per hour)
Bus (2-3 services per hour)
Nodal Connectivity Scores
Total (for Activity Nodes): 3,901
Clarkson
Joondalup
ECU
Wanneroo Central
Whitfords City
Whitfords
Kingsway City
Hillarys
Warwick
Mirrabooka
Balcatta
Ellenbrook
Dianella
Karrinyup
Stirling
Dog Swamp
North Perth
Morley
Innaloo
Scarborough Beach
Glendalough
Mount Hawthorn
North-bridge
Mount Lawley ECU
Inglewood
Bassendean
Midland
Floreat
Leederville
Mount Lawley
Bayswater
Domestic Airport
Subiaco
Central
Claisebrook
West Perth
East Perth
Burswood
Shenton Park
Esplanade
Belmont
Cottesloe Beach
QE II
Forrestfield
Clare-mont
Victoria Park
Oats Street
Cottesloe
South Perth
Crawley UWA
East Vic Park
Bentley
Kalamunda
Palmyra
Applecross
Bentley Tech Park
Carousel
Cannington
Fremantle
Melville
Canning Bridge
Curtin University
Bull Creek
Booragoon
Riverton
Southlands
Kardinya
Murdoch
Thornlie
Maddington
Hilton
Bull Creek Shops
Thornlie Square
Murdoch Uni
Spearwood
Canning Vale
Gosnells
South Lake
Forest Lakes
Cockburn Central
Livingston
Kelmscott
Kwinana Hub
Rockingham Beach
Rockingham
Warnbro Fair
Warnbro
Armadale
Mandurah

### Composite SNAMUTS index for selected centres

The composite SNAMUTS accessibility index allocates between 0 and 7.5 points for each of the indicators Degree Centrality, Closeness Centrality, Contour Catchment, Congested Speed Comparison, Nodal Betweenness and Connectivity to generate a single measure. Higher figures indicate better accessibility, up to a theoretical maximum of 45. The calculation occurs according to the following formulas:

**Table D-10:** Conversion formulas of component indicators for the Composite SNAMUTS Accessibility Index

| Measure | Conversion formula |
|---|---|
| Degree Centrality $CD_i$ | $CD(s) = 2/CD_i$ |
| Closeness Centrality $CC_i$ | $CC(s) = 150/CC_i$ |
| 45-minute Contour Catchment $CI_i$ | $CI(s) = 7*CI_i$ |
| Congested Speed Ratio $CS_i$ | $CS(s) = 5/CS_i$ |
| Nodal Betweenness $CB_{i,n}$ | $CB(s) = \sqrt{(100*CB_{i,n})}$ |
| Connectivity $CV_i$ | $CV(s) = \log_3(CV_i)$ |

Table D-11 shows the scores for each of the 19 activity nodes along and around the LRT corridor. Note that the figures are based on an arbitrary system of conversion and weighting; they are not suitable to calculate percentage increases or declines in accessibility, but rather to compare centres and scenarios against each other, and to develop benchmarks of public transport accessibility standards. As such, we use absolute increases in this index as a scale for measuring accessibility improvements.

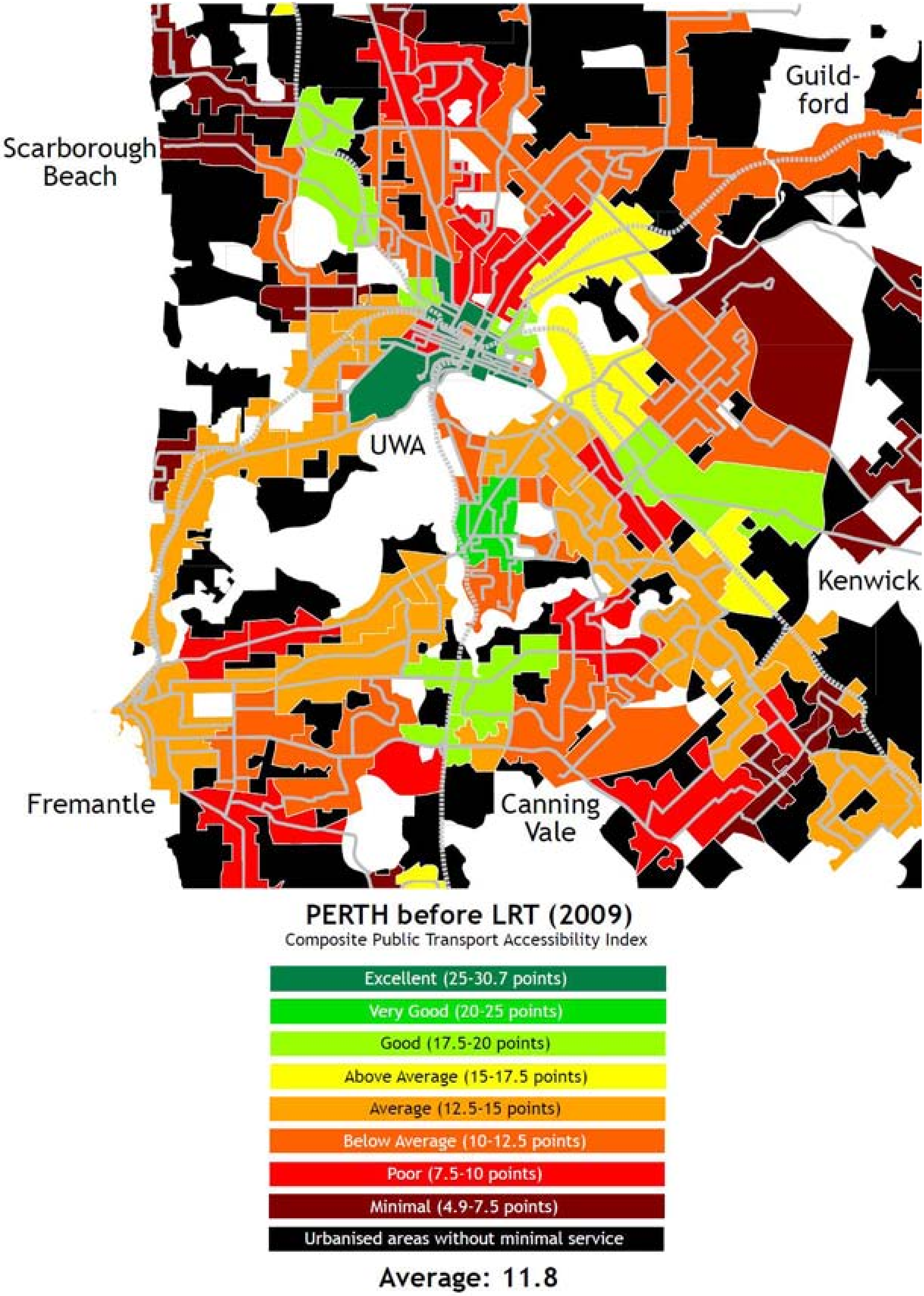
In line with the discussion on previous indicators, the overall effect of the introduction of the Knowledge Arc LRT route on the metropolitan public transport network is relatively small at a gain of 0.4 points. In comparison, the *FRB before* scenario achieves a gain of 1.4 points and the combination scenario (*FRB after*), 1.7 points. Among the subset of 19 activity nodes along or near the Knowledge Arc, the improvement is more pronounced at 2.0 points for both the *LRT after* and *FRB before* scenarios, and 3.6 points for the *FRB after* scenario. The greatest beneficiaries in the *LRT after* scenario are West Perth (+7.1), East Victoria Park (+5.2) and East Perth (+4.3), followed only at fourth to sixth rank by Bentley Tech Park, Curtin University and QE II as the major growth centres on the LRT corridor. Perth Central grows by a margin of 0.5, while Perth Esplanade actually declines by 1.7, largely because the LRT corridor draws travel opportunities away from that node. A declining standard deviation measure indicates that accessibility among this group of nodes becomes more similar and less hierarchical.

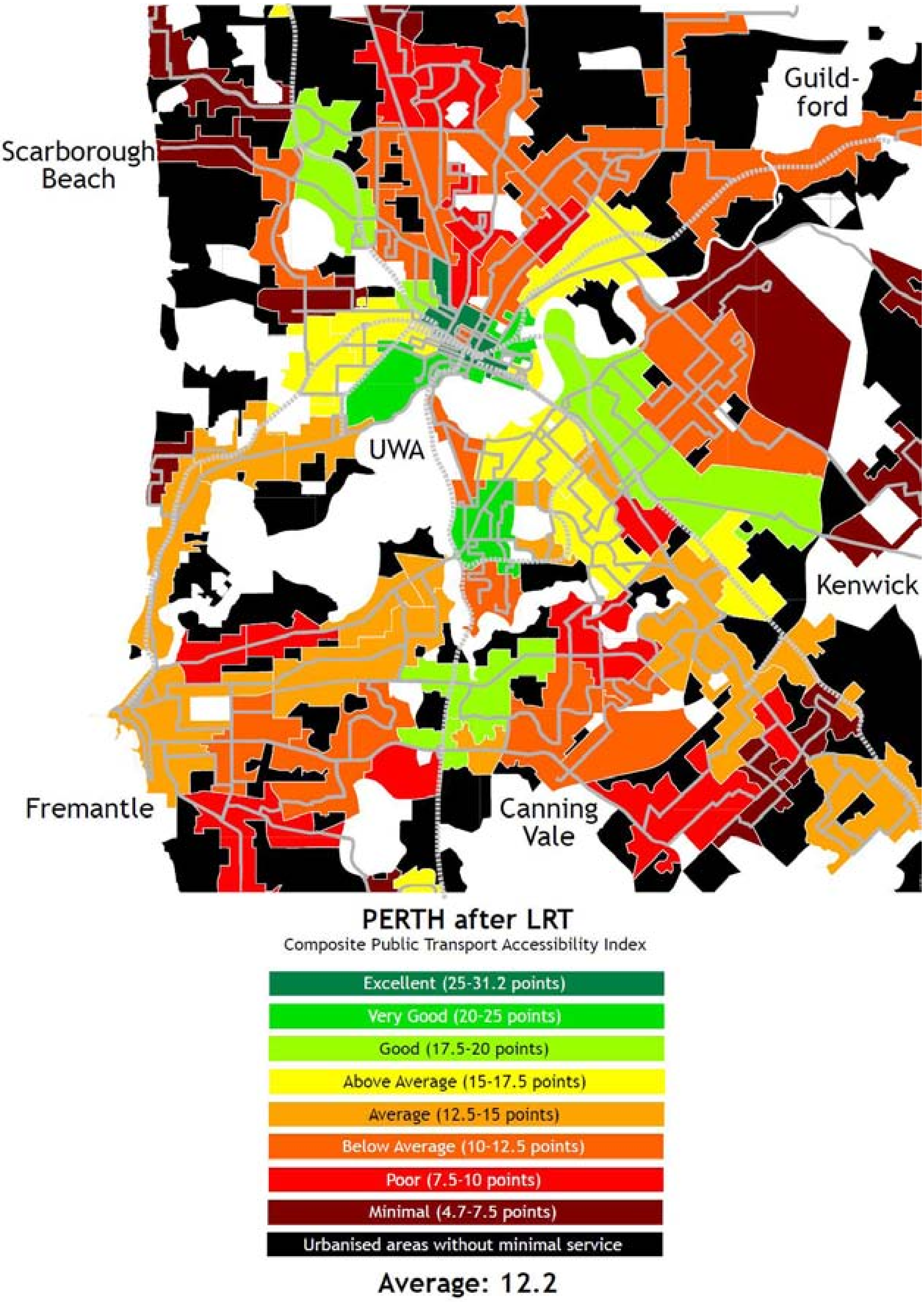
In the *FRB before* scenario, the greatest improvements in accessibility on the composite index are recorded in Subiaco (+4.1) and Burswood (+3.6) though generally the increases are more even. In the *FRB after* scenario, the order of beneficiaries has similarities to the *LRT after* scenario.

**Table D-11:** Nodal connectivity index for key activity centres

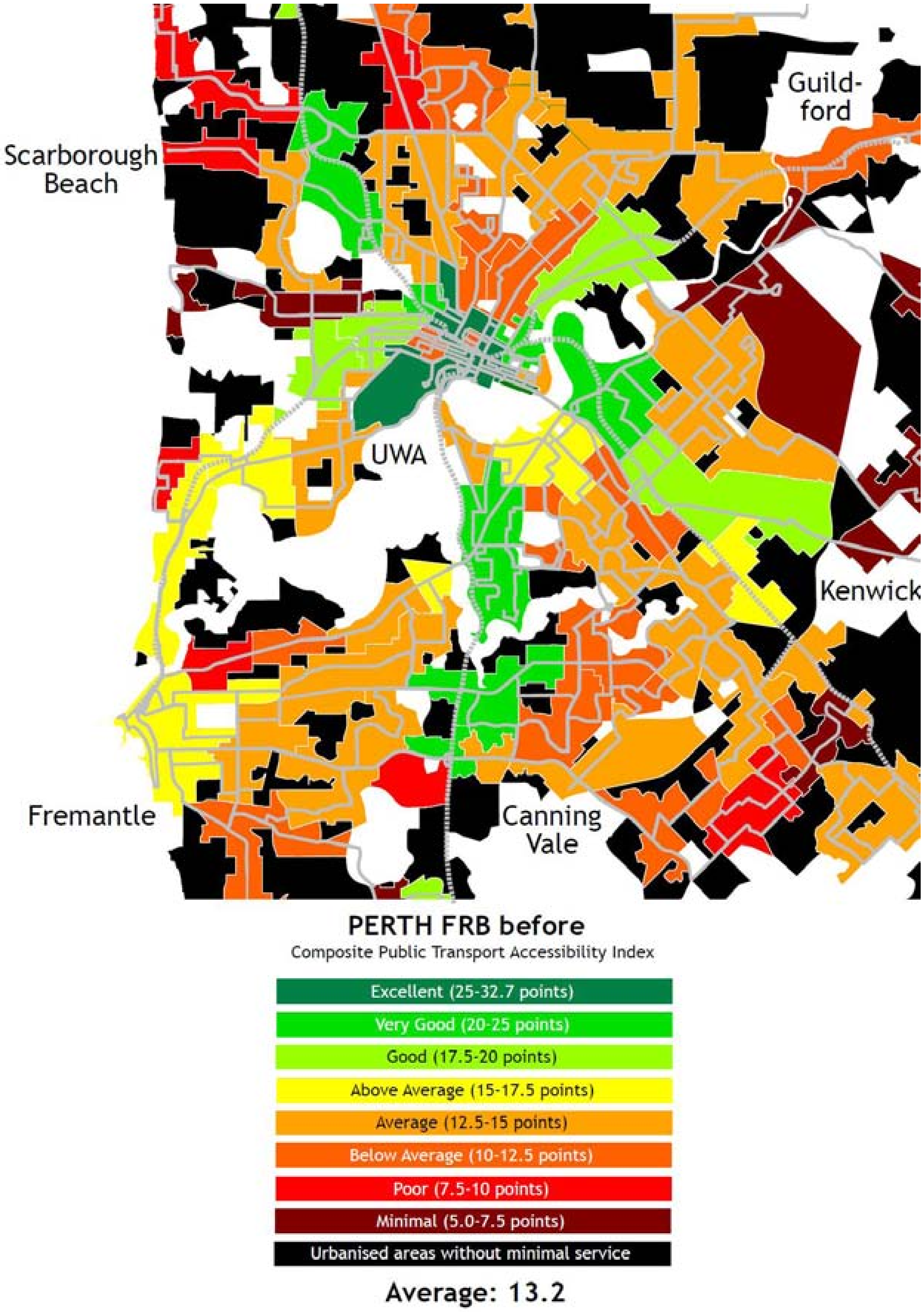
| | LRT before | LRT after | FRB before | FRB after |
|---|---|---|---|---|
| Bentley Tech Park | 10.4 | 14.7 | 11.4 | 15.5 |
| Burswood | 16.6 | 19.6 | 20.2 | 20.7 |
| Canning Bridge | 20.8 | 21.3 | 23.8 | 24.3 |
| Cannington | 16.5 | 16.6 | 17.5 | 17.4 |
| Carousel | 13.2 | 13.3 | 14.4 | 14.1 |
| Claisebrook | 19.7 | 20.2 | 21.7 | 21.9 |
| Claremont | 14.4 | 14.5 | 17.5 | 17.5 |
| Crawley UWA | 13.1 | 14.3 | 13.9 | 15.4 |
| Curtin University | 12.9 | 16.8 | 14.6 | 17.8 |
| East Perth | 12.1 | 16.4 | 13.5 | 17.7 |
| East Victoria Park | 9.5 | 14.7 | 11.2 | 16.3 |
| Oats Street | 18.6 | 18.7 | 19.9 | 20.0 |
| Perth Central | 30.7 | 31.2 | 32.7 | 33.1 |
| Perth Esplanade | 26.6 | 24.9 | 28.0 | 27.0 |
| QE II | 11.7 | 15.6 | 12.6 | 16.3 |
| Shenton Park | 14.9 | 15.1 | 18.2 | 18.2 |
| Subiaco | 14.1 | 15.3 | 18.2 | 18.2 |
| Victoria Park (Albany Highway) | 13.8 | 16.4 | 15.4 | 17.7 |
| West Perth | 9.5 | 16.6 | 12.4 | 17.6 |
| **Average LRT catchment** | **15.7** | **17.7** | **17.7** | **19.3** |
| *Standard deviation LRT catchment* | *5.6* | *4.3* | *5.7* | *4.6* |

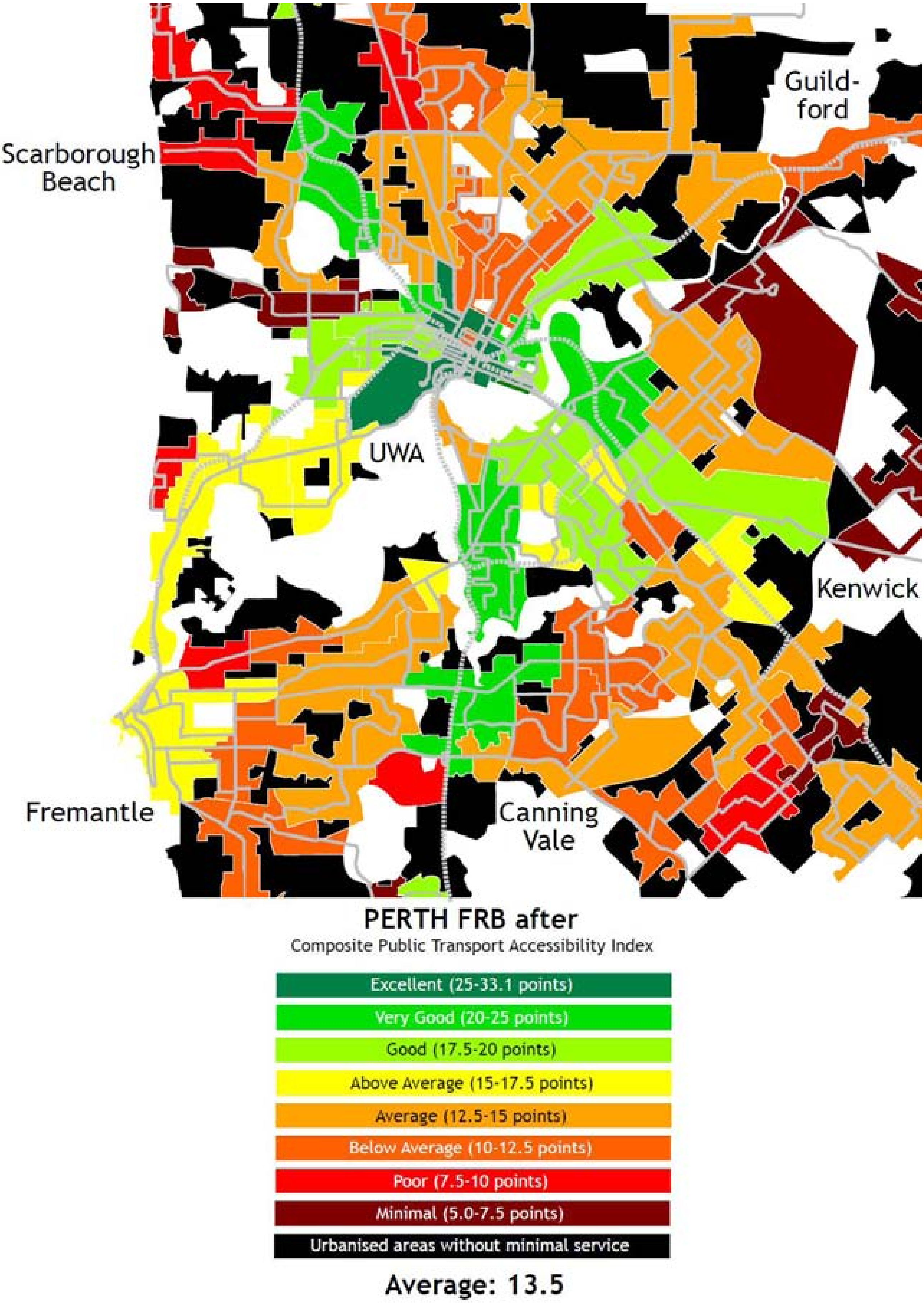
**Maps D-30, D-31:** Composite SNAMUTS accessibility index at current service levels before and after the introduction of the Knowledge Arc LRT route




Guild-
ford
Scarborough
Beach
UWA
Kenwick
Fremantle
Canning
Vale
PERTH after LRT
Composite Public Transport Accessibility Index
Excellent (25-31.2 points)
Very Good (20-25 points)
Good (17.5-20 points)
Above Average (15-17.5 points)
Average (12.5-15 points)
Below Average (10-12.5 points)
Poor (7.5-10 points)
Minimal (4.7-7.5 points)
Urbanised areas without minimal service
Average: 12.2

**Maps D-32, D-33:** Composite SNAMUTS accessibility index at frequency boost (FRB) service levels before and after the introduction of the Knowledge Arc LRT route




Scarborough Beach
Guild-ford
UWA
Kenwick
Fremantle
Canning Vale
PERTH FRB after
Composite Public Transport Accessibility Index
Excellent (25-33.1 points)
Very Good (20-25 points)
Good (17.5-20 points)
Above Average (15-17.5 points)
Average (12.5-15 points)
Below Average (10-12.5 points)
Poor (7.5-10 points)
Minimal (5.0-7.5 points)
Urbanised areas without minimal service
Average: 13.5

### Conclusions and recommendations

Applying the SNAMUTS tool to the Knowledge Arc LRT proposal led to the following findings:

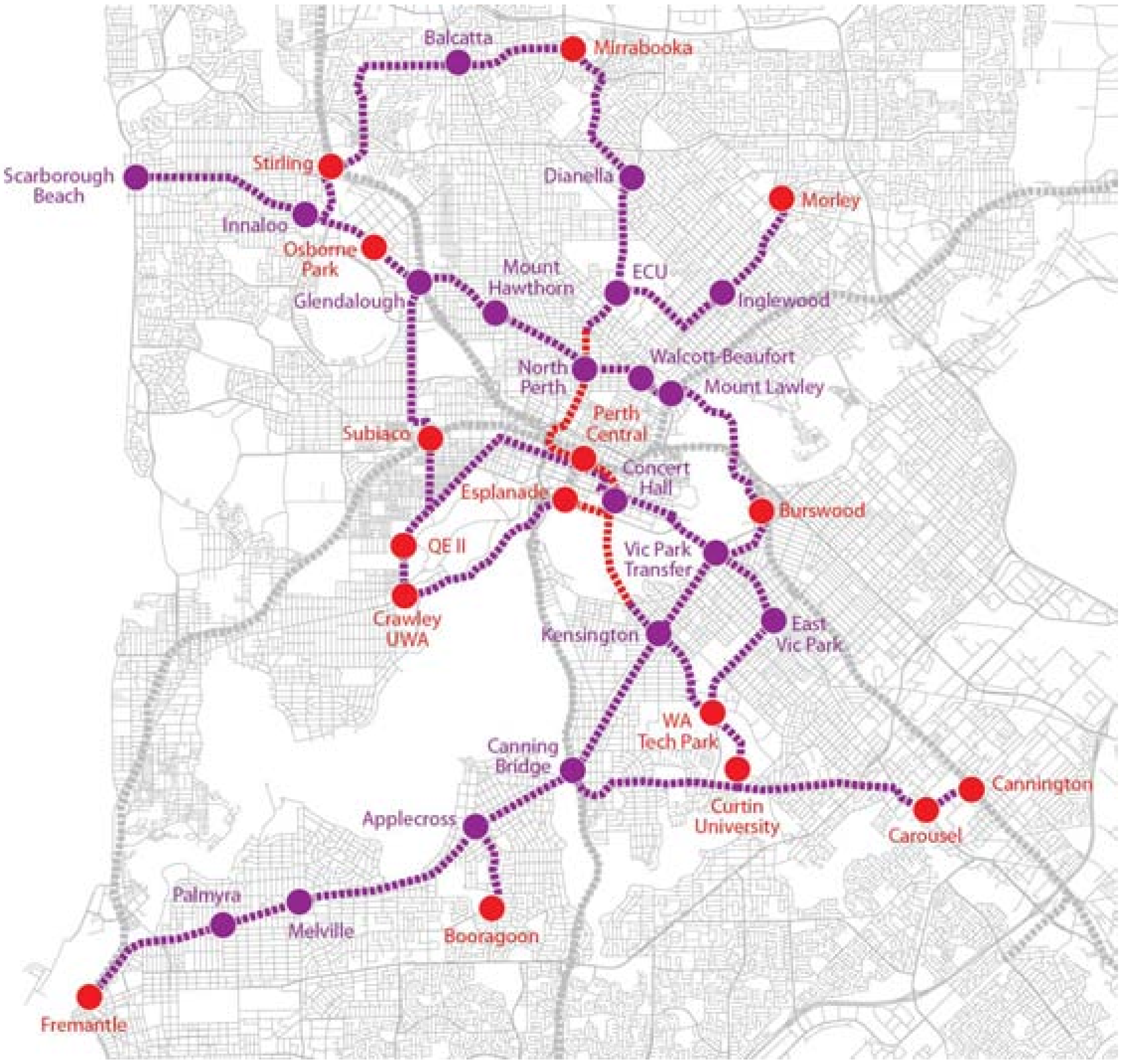
- The LRT route creates a number of new and attractive transfer-free connections between Knowledge Arc centres.
- The LRT route has a tangible impact on enhancing ease of movement to and from centres along the Knowledge Arc.
- The gain in network efficiency associated with the introduction of the LRT route is largely confined to centres along the Knowledge Arc and in its immediate vicinity; it is more prominent for centres on the Curtin University branch than for centres on the UWA branch.
- The LRT route effectively expands the 30-minute contour lines of public transport accessibility for centres along the Knowledge Arc and beyond.
- Speed competitiveness with road travel is enhanced particularly for those centres along the Knowledge Arc that are currently most disadvantaged in this respect.
- The LRT proposal along the Knowledge Arc succeeds extremely well in drawing travel opportunities to its entire length, relieving bus and rail routes with potential capacity constraints and accessing new market segments for public transport, as well as new land use development opportunities, by geographically expanding the reach of the public transport 'movement economy'.
- The LRT proposal results in significant new public transport hubs at Curtin University and Burswood, while enhancing connectivity along the length of the Knowledge Arc corridor.
- Overall, the LRT route has a redistributing effect on spatial inequities of accessibility along the Knowledge Arc corridor and in its vicinity, establishing new and consistent accessibility benchmarks across centres in the inner west, inner south-east and CBD fringe. Activity clusters in West Perth, East Perth, Albany Highway (Vic Park) and Curtin University-Bentley Tech Park are the greatest beneficiaries. There is a less significant, though still tangible, effect on UWA-QE II.
- As the light rail network grows beyond the Knowledge Arc route, consider an LRT proposal based on a north-south rather than an east-west central city trunk line, with an underground section under the CBD and Swan River, also taking in ECU-Mount Lawley Campus into a Knowledge Triangle (see Map D-34).

The target network proposal in Map D-34 describes a longer-term vision for a comprehensive light rail network across metropolitan Perth. It complements the initial Knowledge Arc route and is recommended for implementation once the centres at Curtin University-Bentley Tech Park and UWA-QE II have started to show the effects of significantly increased land use clustering, facilitated by the Knowledge Arc project. The proposal envisions a four-route LRT network whose busiest components are capable of being operated in double traction (60–70 m trains, providing a passenger capacity per coupled LRT set equivalent to up to eight standard buses) and designed for commercial speeds similar to those on the older heavy rail lines (Fremantle, Midland and Armadale/Thornlie). For this purpose, a trunk route connecting ECU-Mount Lawley campus and the CBD river foreshore is suggested, including tunnelling under Fitzgerald Street and the CBD with new underground stations in North Perth (Angove Street), Northbridge (Newcastle Street), Perth Central and Concert Hall (Victoria Avenue). Branches would continue above ground from Concert Hall via Perth Esplanade and along Mounts Bay Road to UWA and QE II, and after tunnelling the Swan River along Douglas Avenue and Hayman Road to Curtin University and Cannington. North of ECU-Mount Lawley, separate branches would follow Central Avenue and Beaufort Street to Morley, and Alexander Drive and Dianella Drive to Mirrabooka. In a second stage, the termini at QE II and Mirrabooka would be linked in an inner orbital loop via Subiaco, Glendalough, Osborne Park, Stirling and Balcatta.

A further (above-ground and mostly on-street) light rail arc would be created along the wishbone-shaped corridor from Scarborough Beach and Osborne Park-Glendalough around CBD fringe areas in North Perth, Mount Lawley, Burswood and Victoria Park to continue along Canning Highway towards Booragoon and Fremantle.

This network links twelve strategic activity centres (as identified in the Directions 2031 document), generally within a maximum travel time of 30 minutes, five of which are currently without rail access. It provides attractive transfer-free links through the CBD, enabling similar connectivity benefits as achieved by the north-south and east-west rail lines in the existing network. Furthermore, it allows for the capture of radial journeys to and from inner suburbs and CBD fringe areas currently not on the rail network (such as North Perth, South Perth and the activity clusters within Mount Lawley and Victoria Park) as well as linking these attractively located smaller centres with each other without the need to travel through, or transfer in, the CBD. Overall, this target network represents an opportunity for greatly enhancing public transport's market share at the expense of the car by providing excellent accessibility for those parts of Perth where growing traffic congestion in combination with inadequate public transport is inhibiting the practical potential as well as public acceptance of significant land use intensification. Furthermore, it will act as a safeguard against excessive future congestion effects on the public transport system itself: while the addition of four or five new LRT lines radiating from the CBD may appear extravagant at first sight, a total number of nine or ten rail corridors converging in the centre is in fact not an uncommon configuration for a metropolis heading towards a population size of more than 3 million, particularly in the light of the tremendous accessibility tasks already performed by the existing five radial rail lines.

**Map D-34:** Long-term vision for Perth's LRT network.




*Note: Red segments are underground, purple segments are above ground. Red dots are strategic centres identified in the Direction 2031 document, purple dots are other significant activity centres or transfer hubs.*

# References

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 and Curtin University of Technology, Perth, Western Australia, available online at www.abp.unimelb.edu.au/gamut/pdf/perth-snamuts-future-scenarios-19june09.pdf

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, Western Australia, available online at www.abp.unimelb.edu.au/gamut/pdf/perth-snamuts-report.pdf

Western Australian Planning Commission 2004, *Network city: a community planning strategy for Perth and Peel,* Perth.

Western Australian Planning Commission 2009, *Directions 2031: draft spatial framework for Perth and Peel*, Perth.

## SECTION E

# HOW DO YOU PAY FOR A LIGHT RAIL?

By Peter Newman and Brian McMahon

When rail is built it immediately increases the value of land around it. Value capture techniques such as special rates can create the possibility of public-private partnerships around rail-based TODs that can then be used to help pay for the rail system. Examples are now developing of how the finance system can assist with building something like Perth's Knowledge Arc Light Rail. Examples are found in other parts of the world, for example the whole Hong Kong system makes a profit through its land development functions; however a mechanism has not yet been facilitated in Australia until the recent decision to build the Gold Coast Light Rail using this process.

Why would you bother involving the private sector in such a rail building exercise?

Building a rail line entirely as a transport proposition by a state government can mean that it is optimised around rail operations without any consideration for the linking of centres or building of TODs. This has mostly been the history of rail development in Australia and the US in recent years. However if the private sector were to build it in partnership with government, with land development financing, rail would automatically be integrated with land use as that would be the major way of paying for it. Privately funded rail (even if only part funded) will have an eye to attracting customers through adding dense, mixed use TODs around its stations. Thus public-private funding arrangements for rail are likely to be an inherently more effective way of creating TODs than state funding alone.

### Recognising the value of transit

Jenkins, Fleming and Garling (2009) outline a transit funding model based on recognising the value of transit and hence how to achieve its funding. The authors suggest that there are a range of beneficiaries from a transit system and if these are quantified then the true value of a transit system usually far outweighs its costs. The beneficiaries include the transit users (unlike a road system these are often a minor part of the value), land owners, tenants and developers (examples of this range between 20% and 100% of the ultimate cost of building a transit system), road users (e.g. 43% of the value of the City Rail system in NSW flows to road users through reduced congestion), and national and regional economies (including social and environmental benefits, which is why governments fund the major part of the transit system in most cities). Thus after funding is achieved then contracts need to be drawn up that can adequately express this value. For TODs this means contracts need to be created that tap into the land value associated with the transit system (and not only with the station area land). When this is done there is a mutually beneficial relationship established that can help fund the rail system.

### Public Private Partnerships

LRT with TODs are ideal to develop as a Public Private Partnership (PPP) with the land component being tied into the funding and operational aspects of the TOD. This is increasingly the way that TODs and transit are being funded in the US and is the approach being taken by Infrastructure Australia. One TOD at Chatswood was built using 'value transfer PPP' (Blake Dawson, 2008) – see box below. However the experience with delivering TOD contracts like this is not extensive in Australia.

**Chatswood Value Transfer PPP**

There can be a significant source of funding for required rail infrastructure through 'Value Transfer PPPs' as in the very successful Chatswood Transport Interchange PPP. This has created a new railway station and bus interchange along with a retail and residential complex that makes a small city around and over the station. It was created by selling the air rights over the station in exchange for the developer creating the station, bus plaza and pedestrian precinct around the station. The air rights were used to build two 50 storey apartment blocks that were sold off the plan.

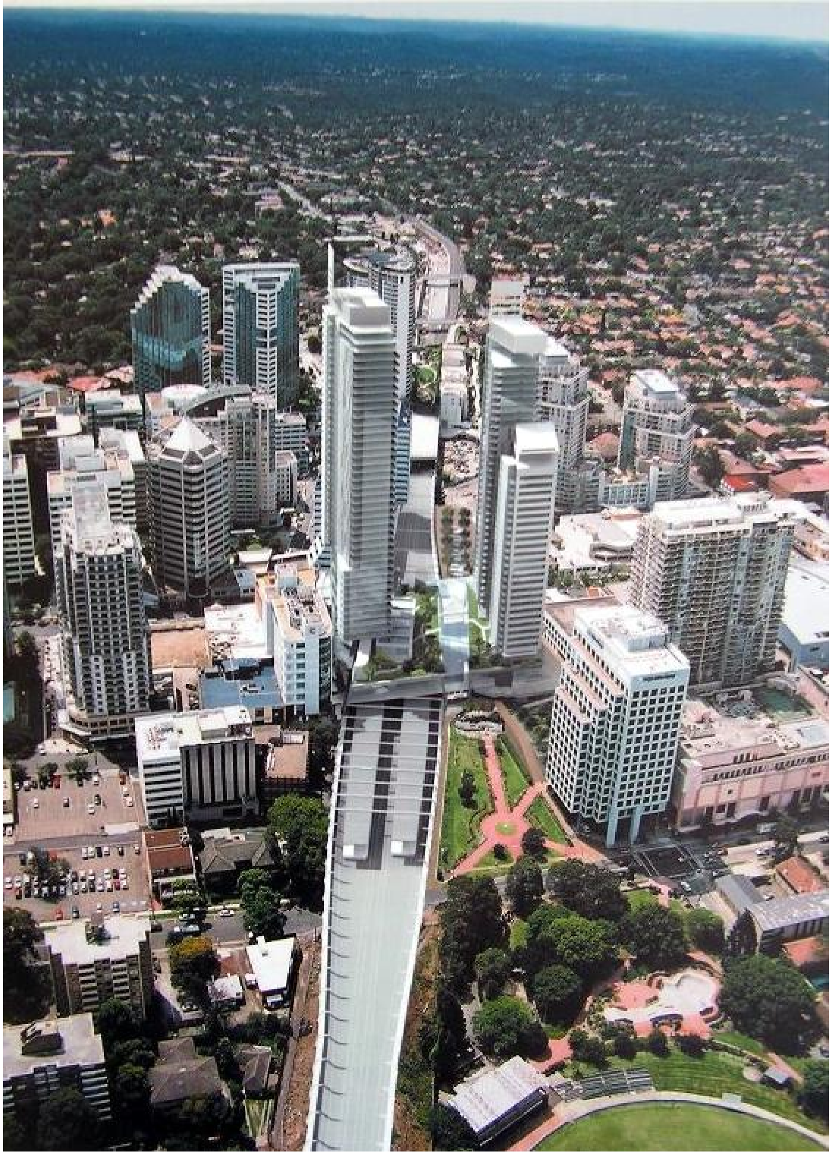


**Figure 4:** Chatswood TOD showing PPP developments over the station.

There is a need to create performance contracts with public financing instruments as in other PPPs but there is a culture of transit operators wanting to be independent from land use and from the rigours of PPPs and just to rely on public funds. However when this happens TODs rarely are achieved.

On the other hand it is also not good if a TOD is built as the main focus and a transit operator is not provided with walkable station surrounds or that do not enable all modes to seamlessly link into the transit system.

The solution to this would seem to be Alliance Contracting with its ability to bring together all the key stakeholders. This is the approach being taken by the Gold Coast City Council on their new Light Rail Transit system that will be built in combination with TODs but with the potential operator being the main contractor.

### Joint Development - Highest and Best Transit Use

Joint development is a potential technique for providing a more flexible and balanced approach to TOD planning and investment in the US but with potential for application elsewhere. Joint development is an income producing real estate project on land owned by transit agencies involving another party, most often a private developer. It generally is a sub-area of a larger TOD. In the United States, it specifically refers to lands in which the Federal Transit Administration (FTA) has an interest or has provided funds for its acquisition as a third party.

In 1997, the FTA revised its rules to improve the opportunities for joint development and TODs. The guidelines now permit transit agencies to sell land purchased by federal grants, such as park and ride lots, and to reinvest the funds in transit projects. Prior to 1997, the proceeds were required to be returned to the FTA.

The new guidelines encourage transit agencies to undertake transit-oriented joint development projects either under property acquired under previous or new grants. In response, transit agencies in several US metropolitan areas, including Washington, DC, Portland, San Francisco, Atlanta, Los Angeles and San Diego, aggressively use joint development to foster growth in TODs and ridership.

The proceeds from the sale or lease of the land can be used in a variety of ways. One option is to invest in a transportation project that enhances economic development or incorporates private investment, including commercial and residential development. The funds can be used for improving pedestrian and bicycle access to a transit facility or the renovation and improvement of historic transportation facilities.

By allowing transit agencies to direct the sale proceeds to eligible projects, the federal government is effectively investing in TODs as long as certain conditions are met. For example, the transit agency must retain control over the joint development. In addition, the funds must be used to ‘help shape the community that is being served by the transit system.’

Eligible projects for spending the proceeds are related either physically or functionally to transit. Physically related projects include those built on air-rights over a station or built within or adjacent to transit facilities. Functionally related projects are those linked by activity and use to transit services or facilities. It is also functionally related if it provides a benefit to the public and enhances use of or access to transit. Functional relationships do not extend beyond the distance most people reasonably can be expected to walk to use a transit service (i.e., 800m from the centre of a transit facility). However, this can be negotiated on a case-by-case basis with the FTA.

Agencies are required to negotiate a fair and equitable return in the form of cash and other benefits. The payment can be one-time or ongoing revenue, but it must equal or exceed the fair market value of the property. Importantly, the provision allows transit agencies to make sales to developers based not on the ‘highest and best use’ according to revenue returns but on the ‘highest and best transit use.’ Thus, projects which offer the highest payback in terms of ridership or another benefit can be developed. In either case, the valuer is to take into account the local transportation, land use and economic development plans and FTA concurrence with the final transfer value is required.

A property's highest and best use is the use that results in the highest expected selling price. The valuation relies on what is reasonably 'sale-able', legally viable, physically possible and financially feasible. Alternatively, **highest and best transit use** recognizes that value to government is not in the selling price alone. Instead, financial return is balanced with other benefits, such as increasing ridership, strengthening connections between trips or reducing trip durations that improve the value of the development to transit.

The concept of highest and best transit use warrants use in Australia to foster TODs. At the state level, treasuries typically seek the highest immediate payback on the sale or lease of state-owned lands. Undeveloped, state-owned properties, as well as lands to be acquired with state funds, within potential TODs are generally sold based on this philosophy. In turn, the resultant development underperforms in terms of TOD benefits.

Federal investments in infrastructure can also require grantees to demonstrate a resulting highest and best transit use. In lieu of limiting federal funding to building infrastructure, funding eligibility could be extended to acquiring and jointly developing land around transit stops as TODs. If the federal government requires equity in the project, the highest and best transit use principle could be applied to ensure the desired outcomes.

The main delivery mechanism in contracting a PPP-based LRT based on TODs is to establish that a TOD can increase the value and hence yield from a development. This concept is set out in the figures below. Figure 1 shows that a normal TOD is likely to be seen by a developer as having a 'yield gap' compared to a normal greenfield development; this is perceived to be lower in potential profit due to the complexities, extra amenity requirements and length of time for build out, that would be seen as associated with such projects.

Thus, the extra 'TOD uplift' that is found to be associated with a TOD (Figure 2) enables the developer to in fact produce a much higher yield than would normally be found.

The importance in recognising this TOD uplift is that governments can be confident that they can proceed with contracts that require TODs, and private developers can be confident that they will achieve good returns. In Portland the Metro will provide grants to developers that can demonstrate that they will increase transit patronage through their development. Part of the grant is to provide help in calculating the TOD uplift associated with their development that a developer can then take to their financier to ensure they receive the necessary funds to enable the TOD to proceed. This is the benefit of partnership processes associated with TODs.

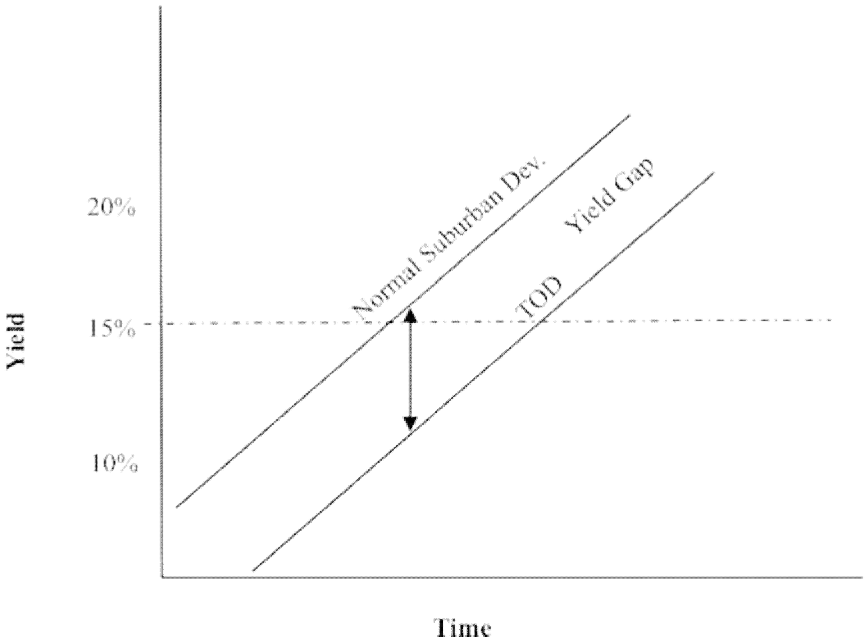



**Figure 5:** The 'perceived' yield gap associated with TODs.

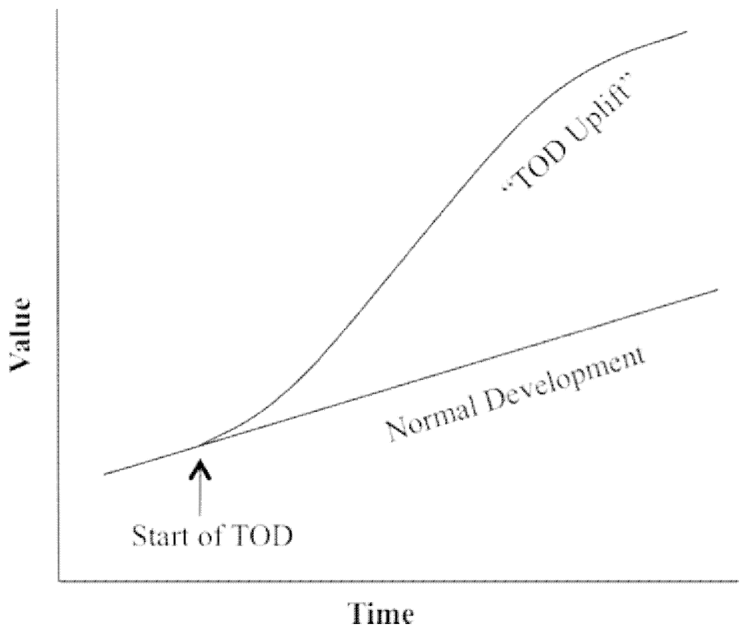



**Figure 6:** The 'actual' TOD uplift associated with TODs that can enable financing for such projects.

The market uplift or premium for TODs is reasonably strong, as seen in Table 1 below there is a strong proven market for TODs where research from the US shows stronger returns across a number of development markets.

**Table E-1:** TOD Property Uplift (United States)

| US Range of TOD Property Uplift or Premiums | | |
|---|---|---|
| Land Uses | Low Range | High Range |
| Single Family Residential | **+2%**<br>w/in 200 ft of station<br>(San Diego Trolley, 1992) | **+32%**<br>w/in 100 ft of station<br>(St. Louis MetroLink Light Rail, 2004) |
| Condominium | **+2%**<br>w/in 2,640 ft of station<br>(San Diego Trolley, 2001) | **+18%**<br>w/in 2,640 ft of station<br>(San Diego Trolley, 2001) |
| Apartment | **+0% to 4%**<br>w/in 2,640 ft of station<br>(San Diego Trolley, 2001) | **+45%**<br>w/in 1,320 ft of station<br>(VTA Light Rail, 2004) |
| Office | **+9%**<br>w/in 300 ft of station<br>(Washington Metrorail, 1981) | **+120%**<br>w/in 1,320 ft of station<br>(VTA Light Rail, 2004) |
| Retail | **+1%**<br>w/in 500 ft of station<br>(BART, 1978) | **+167%**<br>w/in 200 ft of station<br>(San Diego Trolley, 2004) |

Finally, in order to build an LRT through TODs will need government agency collaboration. TODs often require more than one agency either in infrastructure design and delivery or in the approvals process. The complexity of agency requirements, and often lack of agency collaboration, often makes successful TOD delivery either too difficult or too time consuming, thus deferring private sector interest. To improve this ‘contract’ arrangements need to be put in place where agency to agency collaboration is ensured, including a more streamline government delivery mechanism for TODs.

# References

Blake Dawson 2008, ‘The new world of value transfer PPPs’, *Infrastructure: Policy, Finance and Investment*, May, pp. 12–13.

Jenkins, M, Fleming, D & Garling, R 2009, ‘Transit value and funding’, discussion paper, Parsons Brinckerhoff, Sydney.