

# **Making Melbourne's public transport network multi-directional: Can the associated accessibility boost mobilise latent potential for ridership and city-building?**

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## **Abstract**

As in most Australasian cities, Melbourne's public transport system has a strong radial orientation and despite the introduction of orbital SmartBus routes, displays weaknesses in facilitating cross-suburban travel. This is true for outer, middle and inner suburbs. Some intensifying CBD fringe areas also suffer from missing public transport links into adjacent neighbourhoods in a non-radial direction. Often, where orbital links do exist, they may be indirect and infrequent, aimed at servicing an excessive range of demand through meandering route structures. This situation for public transport can be contrasted with infrastructure plans for roads. For example, the controversial, now-cancelled East West Link, an inner orbital tollway project that was rationalised by a substantial forecast for road movement along its corridor, included no capacity-boosting component for public transport modes on the same route.

This paper draws on the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool to identify the potential network function, and its impact on overall spatial accessibility, that could be achieved if a denser web of orbital tram and bus routes were added to Melbourne's projected public transport system in 2026 (after the expected completion of the Metro rail tunnel). In a theoretical exercise along the Squaresville model popularised by Thompson (1977), Mees (2000) and Nielsen et al (2005), the benefits of public transport network multi-directionality are considered, quantified and applied to Melbourne's real-world urban fabric. The analysis shows that missing orbital links are associated with significant unmet opportunities for public transport to attract latent demand and break into new market segments. The broader impacts of introducing additional tram and high-frequency bus routes into existing streetscapes and urban intensification areas are considered, suggesting a rethink of the design and functionality of the arterial road corridors required for such upgraded public transport infrastructures.

*Keywords:* Public Transport, Network Design, Accessibility, Urban Intensification

## **Introduction: Melbourne's incomplete public transport network**

Melbourne's present-day fixed-route public transport network was primarily constructed during the late 19<sup>th</sup> and the first half of the 20<sup>th</sup> century, prior to the advent of mass motorisation. In an era when trains and trams had a virtual monopoly for urban travel over distances beyond walking and cycling range, commercial competition between modes and operators for principal passenger flows led to the establishment of parallel routes along mostly radial corridors.<sup>1</sup> This network structure, pictured in Figures 1 and 2, dominated Melbourne's public transport system in the early post-war period and, despite some route extensions to urban growth areas and the insertion of the rail City Loop in the 1980s, remains fundamentally unchanged to this day. As a result, movement opportunities along Melbourne's public transport network are strongly dominated by radial directions, both for journeys between city centre and suburbs and between suburbs located along the same radial corridor.

Opportunities for cross-suburban movement between origins and destinations along different radial corridors remain relatively scarce. The introduction of several orbital SmartBus routes in the late 2000s has ameliorated this weakness to some extent in selected middle and outer suburbs. These services, however, do not achieve travel speeds that are competitive with car travel along the same routes, and it remains unclear how much of their travel demand is derived from genuine orbital journeys in relation to feeder journeys to and from radial train lines. In the inner and middle suburbs as far outwards as circumferential SmartBus route 903, few significant improvements to network structure and service levels to facilitate non-radial journeys have been undertaken in several decades.<sup>2</sup> The result is that Melbourne's public transport is classically representative of an urban transit network created by a long history of individual incremental decisions, rather than in the context of an overarching metropolitan strategic outcome. Walker (2008) describes several similar systems worldwide, and asserts that such networks may exhibit considerable potential for reform in terms of both user-friendliness and operational efficiency through the strategic re-orientation of existing service resources.

The relative stagnancy of Melbourne's public transport network structure during a period of rapid urban growth and the proliferation of the private car contrasts with the situation in other cities such as Vienna (pictured in Figures 3 and 4). Here, the post-war period saw a fundamental transformation of the public transport network towards a more multi-modal and multi-directional template: as more radial and orbital metro and suburban rail lines were added, the tram network was partially thinned and reconfigured to act in concert (as feeder, distributor and intermediate mode) with the growing, higher-speed and higher-performance heavy rail network. As a consequence, Vienna's public transport system has continuously increased the portion of each trip that can be made on the fastest modes, and allows for

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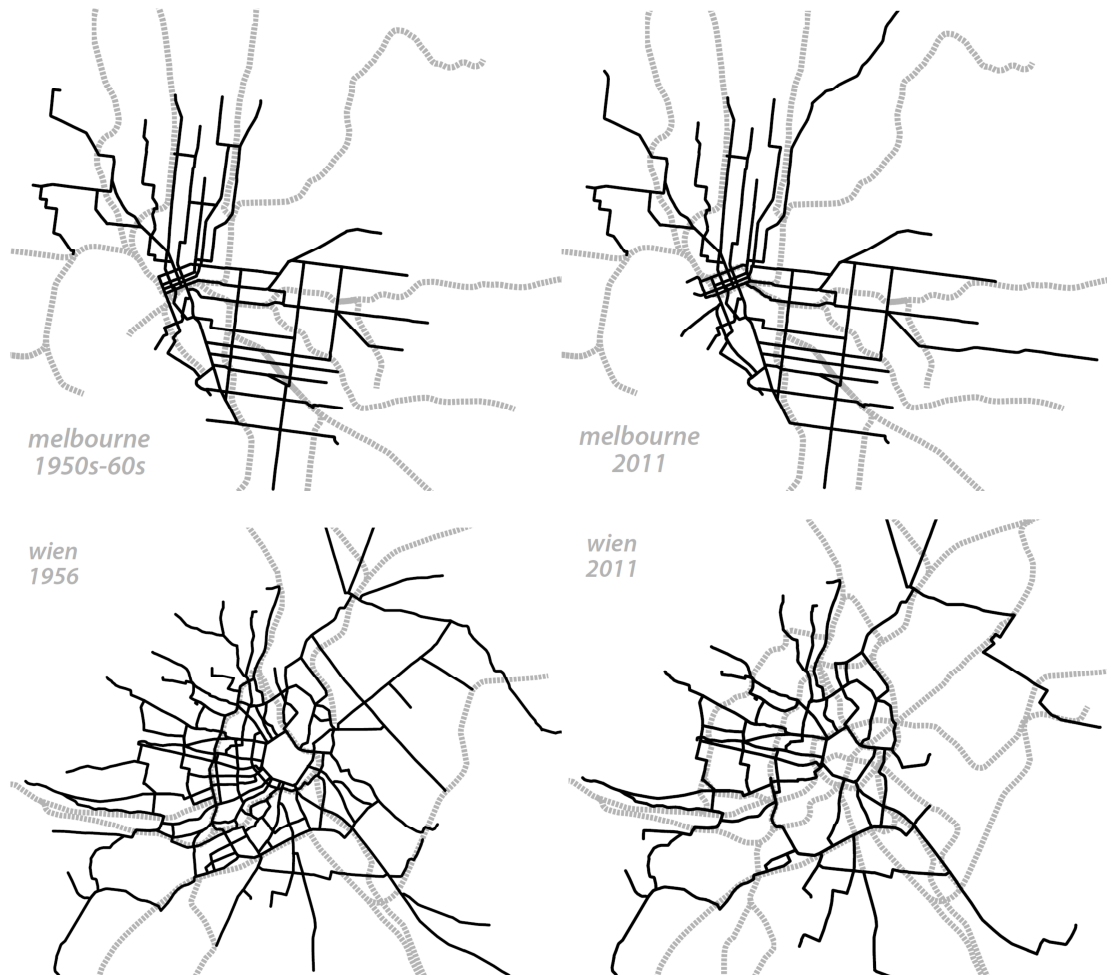
<sup>1</sup> In the late 19<sup>th</sup> century, several orbital rail lines were built in Melbourne, but these were largely short-lived and with the exception of the Camberwell to Alamein shuttle still in operation today, had all ceased passenger service by 1950.

<sup>2</sup> A rare exception is the route 401 shuttle between North Melbourne station and Melbourne University, however this route only operates on weekdays and thus primarily targets specific user groups – students and regular-hours employees at the university and the Parkville medical precinct rather than residents along the route, hospital shift workers or visitors to the Carlton restaurant and entertainment precinct.

excellent multi-directional movement with minimum friction along geographical desire lines across the core city. Public transport's rate of usage (37% of all journeys in 2011) eclipses that of the car (29%) (Wiener Stadtwerke, 2012).

**Figures 1, 2:** Outline of Melbourne's fixed-route public transport network (trams in black, suburban rail in grey) in the 1950s/60s and in 2011

**Figures 3, 4:** Outline of Vienna's fixed-route public transport network (trams in black, metro and suburban rail in grey) in 1956 and 2011



We assert that there is no evidence of any significant inclination among Melbourne policy makers, nor community advocates or independent experts, to envision a transformation of the city's public transport network structure comparable to what Vienna and many other cities have achieved over the past several decades. This is despite the policy rhetoric of major planning documents since the 1980s that Melbourne should be a world class public transport city (Curtis and Low, 2012). In 2003, a Department of Infrastructure document known as the North Central City Corridor (NCCC) Study (DOI, 2003a) assessed future transport needs for the portions of the Cities of Melbourne and Yarra between Victoria Street (the CBD edge) and Brunswick Road (approximately 3.5 km north). The document noted that while the public transport mode share for journeys with either origin or destination outside the study area was 16% in 2001 (with a non-motorised mode share of 21%), the figure dropped to a mere 4% for journeys fully within the study area (with a non-motorised

mode share of 61%). Effectively, this means that for motorised trips only, cars captured 80% of journeys into or out of the study area and a significant 90% of journeys fully within the study area. This dominance of motor vehicles illustrates an inadequacy of the public transport network in its current form to service the mobility and accessibility needs of the population in this centrally located, medium-density and mixed-use section of metropolitan Melbourne. In addition, car trips remain relatively easy to undertake, though mounting traffic congestion and the declining availability and affordability of parking in and beyond the CBD suggest that this ease will further subside as Melbourne's population continues to grow. The effects will be felt in inner suburbs and major suburban activity centres as well as the immediate city centre. Either perspective, however, highlights the weakness of integrated transport planning in Melbourne, which is at odds with stated policy directions (DOI, 2003; DOT, 2008; State of Victoria, 2014).

While the DOI, in its NCCC study, rejected the notion that a high-capacity inner orbital road link through the study area would be a worthwhile investment, a project to link the Eastern Freeway and City Link by way of a tollway tunnel re-emerged in the 2008 East West Link Needs Assessment, also known as the Eddington Report (Eddington, 2008). The proposal was not included among the investment priorities in the State Government's Victorian Transport Plan later in the same year (DOT, 2008), but it was then resurrected as a primary investment priority in 2011, following a change of state government. The East West tollway tunnel proposal became one of the most dominant battlegrounds of the 2014 state election campaign, divided proponents and opponents along partisan lines and contributed to the defeat of the Napthine Liberal government after a single term of government. The incoming Andrews Labor government then cancelled the project within their first year in office (Bosler, 2014; Stone and Scheurer, 2014; Legacy, 2015).

From the perspective of this research paper, we assert that it is remarkable how a high-capacity urban road project, projected to service significant car-based mobility needs funnelled through Melbourne's inner suburbs in an orbital direction, could rise to such policy prominence without a more holistic planning approach being employed. An holistic planning approach would have involved the evaluation of mobility options, including the potential viability of a similarly high-capacity public transport link along the same corridor. The absence of such a process is surprising, since it is not for a lack of community debate about public transport alternatives in general terms. This is seen, for example, in the long-standing proposal for a Doncaster rail line in the median of the existing section of the Eastern Freeway as an alternative to the East West Link. The East West Link project report itself argued that the undergrounding of road traffic along Alexandra Parade and Princes Street would allow for greater priority and service reliability on existing tram lines (LMA, 2013). These debate contributions, however, while proposing valuable improvements, conceive public transport's dominant role only as a facilitator of radial movement and dismiss the potential for public transport to form a backbone for full multi-directional accessibility, at least within Melbourne's inner-ring suburbs. It appears as though a particular division of tasks between urban transport modes – public transport to get in and out of the CBD, walking and cycling for the neighbourhood range, car for everything else – is an entrenched heuristic for policy makers and advocates alike.

In this paper, we question this approach and seek to extend the way in which transport planning is conceptualised. This is critical for a fast-growing city with mounting congestion problems on all modes of transport. We examine whether, how and where public transport

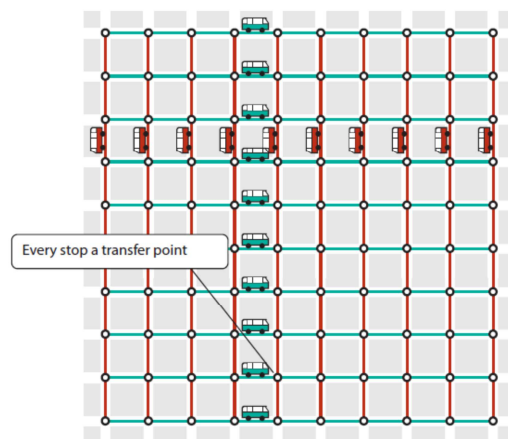


can capture movement opportunities that the current network structure is unsuited to serve. We will first approach this inquiry in conceptual form considering the schematic model of Squaresville and testing a range of public transport network configurations for their accessibility outcomes. Then, we transfer these insights to the real-world transport and land use system in Melbourne to illustrate the substantial gains to accessibility and resilience that could be made if more high-frequency tram and bus lines were added to the public transport network.

## Squaresville: How network configuration influences accessibility outcomes

The concept of Squaresville as an analytical illustration of the performance characteristics of different public transport network configurations was introduced by Mees (2000, 2010) and further popularised by Nielsen et al (2005). However, it can be traced back to the work of Thompson (1977) who critiqued the widespread practice of US transit agencies to operate radial, CBD-focused public transport systems. He argued that a grid configuration of transit networks (following the dominant pattern of road networks in US cities), in contrast to the more common layout where all routes would lead through the CBD area, would allow public transport to achieve a comparable mode share for non-radial as for radial journeys while requiring only a modest additional outlay of operational resources (in the order of 25 per cent while keeping service frequencies constant).

Mees (2000) and later Nielsen et al (2005) use a hypothetical, grid-shaped city of 10x10 (100) squares to illustrate the comparative effects of bidirectional (north-south only) and multidirectional (north-south and east-west) network configurations. In the former case, ten parallel bus lines follow Squaresville's north-south arterials but have no connection with each other. Public transport movement options are thus restricted to only nine (out of a potential ninety-nine) destinations from each point of origin. If service frequencies on these ten north-south lines were doubled, public transport movement options to the nine existing destinations on each line would become somewhat more attractive but the remaining ninety destinations would still remain out of reach. However, if the same resources were utilised to establish a set of ten additional bus lines following Squaresville's east-west arterial roads, providing transfers to the north-south lines at every intersection, then all ninety-nine potential



destinations would become accessible though the public transport system from each point of origin (eighteen by direct journeys and the remaining eighty-one by one-transfer journeys). Both Mees and Nielsen argue strongly for the superiority of the latter solution as a worthwhile use of additional operational resources, since the resulting 'network effect' is deemed to serve a far greater number of additional users than mere line-by-line frequency improvements without addressing the deficits in the network structure (Figure 5)

**Figure 5:** Squaresville bus network (source: Nielsen et al, 2005)

The Squaresville comparison of a bidirectional versus a multidirectional grid system could be criticised as an unrealistic representation of an actual public transport network, since very few agencies would operate a scatter of isolated lines without any form of connection to each other. Thus the example likely overstates the magnitude of the network effect achieved by transitioning from the bidirectional to the multidirectional stage in real-world transit systems. However, Thompson's reasoning of the superiority of a multidirectional grid over a radial network (where transfers between all lines are possible but only at a central location on the network, rather than distributed through the grid) warrants closer examination in this context, since many actual systems in the US (and elsewhere) have not evolved drastically from their radial orientation in the four decades since his work was written, while the body of literature to assess the shortfalls of this network pattern has grown. For example, El-Hifnawi (2002) demonstrated the potential of orbital lines to relieve congestion by better serving non-radial trips and bypassing slow, congested inner-city line segments. Walker (2008) developed a system reform strategy based on re-distributing existing resources previously used for radial and meandering lines into a more 'square', high-frequency network.

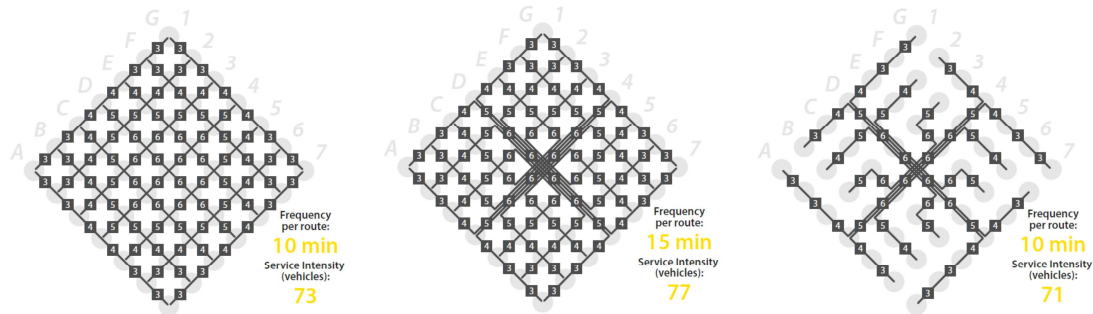
In the following overview, we have revisited Squaresville in a comparison of three different network configurations and assessed them using the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool. These depict:

- a **non-hierarchical grid network** of seven north-south and seven east-west lines,
- a **multiple-connected radial network** whose diametrical lines all lead through the city centre but also connect to each other in a lattice pattern at the suburban intersections of the arterial road grid, and
- a **singular-connected radial network** whose diametrical lines all terminate at isolated suburban nodes and only meet in the city centre (and in some cases along trunk routes leading into the city centre).

All three configurations are based on a grid of 7x7 nodes (labelled A1 to G7; 49 nodes in total), which are assumed to have a catchment of 10,000 residents and jobs each, with the exception of the central node (D4) where the catchment is assumed to be 20,000 residents and jobs (the result is a total of 500,000 residents and jobs). Note that these assumptions, like the layout of Squaresville, are by necessity highly schematic and only in very generalised terms representative of the more convoluted conditions on the ground in actual cities. In this way they serve as a means of testing the network scenarios.

Squaresville's public transport routes are assumed to be operated by standard buses (50 places – seated plus some standing). Since Squaresville may historically have grown concentrically and continue to be characterised by less generous road infrastructure and a greater presence of slow modes (walking and cycling) in older, centrally located districts than along the periphery, travel times between adjacent grid cells are assumed to vary (between 3 and 6 minutes), increasing with growing proximity to the central node (Figures 6-8). The total number of vehicles required to operate the network (service intensity) is held within a narrow band between 71-77 for each network configuration. This translates into 10-minute service frequencies on each line for the non-hierarchical grid network and the singular-connected radial network. For the multiple-connected radial network whose aggregate line length is the longest, service frequencies drop to 15 minutes.

**Figures 6, 7, 8 Squaresville:** network configuration and travel times for the non-hierarchical grid network (left), multiple-connected radial network (centre) and singular-connected radial network (right)

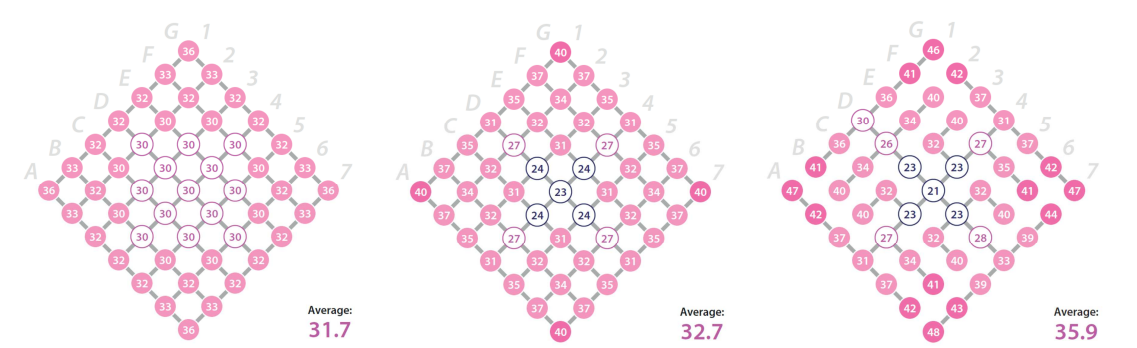


The three alternative network configurations perform in accessibility terms as follows. Figures 9-20 depict the SNAMUTS results for closeness centrality, 30-minute contour catchments, betweenness centrality and network resilience.

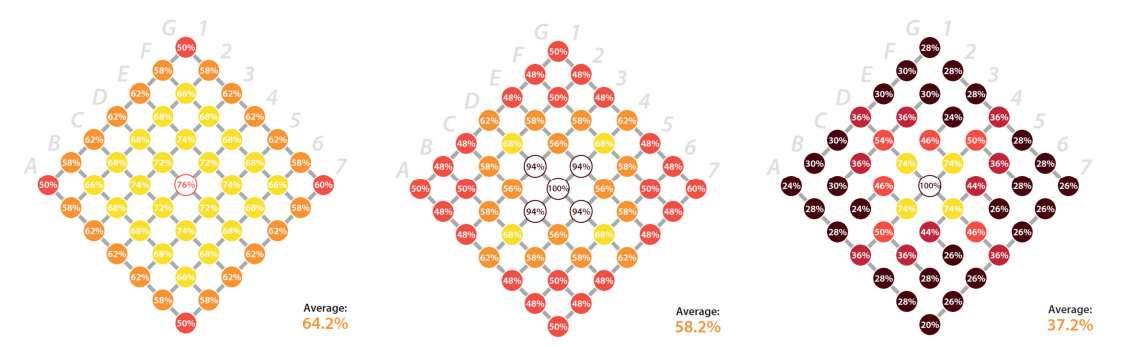
- Closeness centrality depicts the average ease of movement between any pair of nodes on the network by measuring spatial resistance derived from travel times and service frequency. This index treats each node-to-node relation in the city equally, as it is concerned with the structural properties of the network rather than the user experience. Lower nodal figures indicate greater centrality, lower average figures better network-wide accessibility.
- The contour catchment measures the proportion of citywide residents and jobs that can be accessed by a public transport journey of 30 minutes or less from the reference node, and as an average across the network. Higher figures indicate greater accessibility.
- Betweenness centrality counts the number of preferred journey paths at each node and route segment and illustrates how important each network element is for facilitating public transport movement across the city. This index weights node-to-node relations by catchment size and travel impediment (closeness) as proxies for the relative likelihood that the corresponding trip will be taken on public transport. Higher nodal results and thicker segments indicate greater network significance; a higher global betweenness result indicates a better overall penetration of the urban fabric with public transport movement opportunities.
- Resilience draws the ratio between the (segmental) betweenness measure and the actual passenger capacity offered on each route segment, pinpointing weak spots where network significance exerts pressure on capacity. Route segments are represented on the diagrams in traffic light colours and on a numeric scale from +30 (most resilient/dark green) to open-ended negative (least resilient/maroon).

For a detailed description of each index please refer to Curtis and Scheurer (2016) and [www.snamuts.com](http://www.snamuts.com).

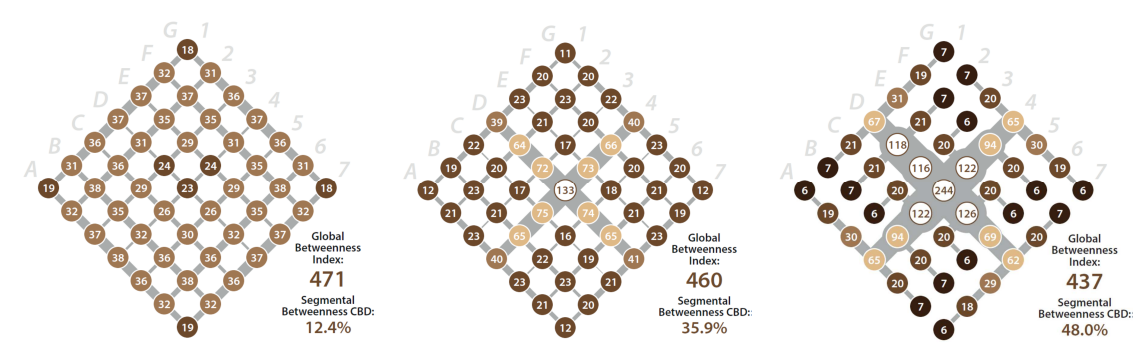
**Figures 9, 10, 11 Squaresville:** closeness centrality results for the non-hierarchical grid network (left), multiple-connected radial network (centre) and singular-connected radial network (right)



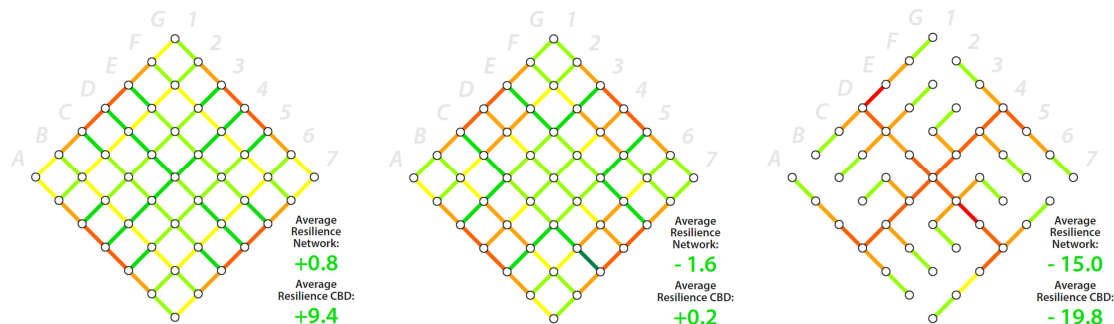
**Figures 12, 13, 14 Squaresville:** 30-minute contour catchments (in percentage of city-wide residents and jobs) for the non-hierarchical grid network (left), multiply connected radial network (centre) and singularly connected radial network (right)



**Figures 15, 16, 17 Squaresville:** betweenness centrality results for the non-hierarchical grid network (left), multiple-connected radial network (centre) and singular-connected radial network (right)



**Figures 18, 19, 20 Squaresville:** resilience results for the non-hierarchical grid network (left), multiple-connected radial network (centre) and singular-connected radial network (right). Green segments indicate high resilience (between 0 and +30), yellow and orange segments medium resilience (between -30 and 0) and red and maroon segments poor resilience (below -30)



On each index, the non-hierarchical grid network achieves the best average results and the singular-connected radial network the poorest.<sup>3</sup> However, the singular-connected radial network achieves the best closeness result (ease of movement) for the central city nodes (D4 and its immediate neighbours), while the multiple-connected radial network achieves the largest 30-minute travel time contours for the same group of nodes. From these findings, it is easy to understand why transit agencies that primarily view public transport's role as facilitating journeys to and from CBD areas would opt to develop radially oriented networks rather than dispersed ones since they seek to maximise accessibility to the CBD. The disbenefit of this approach, however, can be seen in the betweenness and resilience index results, which illustrate the magnitude to which the radially oriented networks depend on directing journey paths through the central area (betweenness centrality) and the pressures this causes (resilience). This is particularly true for the singular-connected radial network, which has eliminated almost all alternative journey paths that could bypass the potential congestion at the centre. While continuing to service every activity node, this network configuration also leaves large linear sections of the grid-shaped arterial road system unutilised by public transport routes. Again, it is easy to understand how this practice may minimise public transport usage for journeys between suburban nodes that are not on the same bus line, and how it may simultaneously convey a sense of capacity crisis for those network functions it does serve well, namely journeys to and from the CBD. Cities often address this conundrum by adding ever more services to the radial lines, and/or by converting the busiest lines to a higher-capacity mode such as rail, while failing to investigate and realise the accessibility benefits and added resilience that may be

<sup>3</sup> Note that the results of the betweenness and resilience indicators do not show a fully symmetrical distribution of nodal values across the network, despite the network configuration, travel times and service frequencies conforming to a symmetrical pattern in the non-hierarchical and multiple-connected grid networks. This is because in these two configurations, a number of node-to-node relations on the network offer a choice between (usually two) journey paths with identical total travel times and service frequencies. In the calculation of the betweenness index, these alternative journey options sometimes receive uneven allocations of preferred travel paths. The cumulative effect of these irregularities on the network-wide results, however, is relatively minor and can be read as a proxy for demand variations on alternative journey paths that in real-life public transport networks may be associated with their varying legibility to the user or varying individual preferences.

associated with a greater dispersion of network paths away from established public transport trunk lines.

The conservatism in public transport network planning demonstrated above contrasts with the approach most cities in Australia and elsewhere have taken to freeway and arterial road network development since the 1960s. Previously radially oriented road infrastructure was typically expanded into highly multi-directional networks during this time. It was commonplace to construct high-capacity orbital links in the absence of evidence for significant prior travel demand along those corridors. For public transport to compete with the private vehicle for a greater range of urban journeys, it is imperative that public transport network planning adopts a similar mindset, one which identifies and capitalises on latent demand opportunities for network growth.

## **Melbourne in 2026: Where will current public transport investment and land use trends lead?**

Melbourne's transit system remains highly affected by overreliance on public transport routes that were established in the early part of the 20<sup>th</sup> century when the city had only a fraction of its current population and geographical expansion. Simultaneously, there has been a reluctance by decision makers to close the resulting 'accessibility gaps'. This section will discuss how these shortfalls may lead to further deterioration in accessibility performance and network resilience as Melbourne continues to grow. We assert that this will limit the potential for public transport to access new segments of the travel market at the expense of the private car. Our analysis is considered alongside a land use-transport scenario that depicts the likely shape of Melbourne's public transport network and urban form in 2026, assuming currently discussed infrastructure projects, service initiatives and land use trends come to fruition. By 2026, it is estimated that the population in the metropolitan area will have grown by 1.3 million over 2011 and have reached a total of 5.3 million people (DPTLI, 2014).

The key components of network changes (over 2015) considered in this scenario are:

1. The second stage of the Metropolitan Rail Network Development Plan (PTV, 2012) which includes an additional metro rail tunnel between Footscray and South Yarra via stations in Arden, Parkville, Melbourne Central, Flinders Street and Domain to link the Sunbury and Dandenong rail trunk lines, as well as the rollout of minimum 10-minute daytime frequencies on the majority of existing lines. The South Morang line will be extended to Mernda.
2. A comprehensive package of tram network and service improvements, including a link along Park Street (South Melbourne) to allow for some St Kilda Road services to reach the CBD via Clarendon and Spencer Streets rather than Swanston Street, and a tram extension from Docklands (Victoria Harbour) across the Yarra into the Fishermans Bend Urban Renewal Area. Additionally, minimum daytime frequencies of 10-minute frequencies will prevail on all tram lines. Tram lines that already exceeded 10-minute frequencies in 2015 will continue at that frequency.
3. All bus lines and their service levels remain unchanged over 2015.

Figures 21-22 show the segmental betweenness and resilience results of the 2026 Trend network. Over 2015, the significance of rail to facilitate movement across the metropolitan

region will increase compared to trams and particularly buses, in line with the Metro Rail tunnel and the widespread service improvements on the rail system (Tables 1, 2). On average across Melbourne, the additional services improve the resilience of the rail system which more than compensates for the additional travel opportunities facilitated by higher frequencies and population growth. This picture, however, is not geographically even. A before-after betweenness comparison of the CBD (Table 1) reveals that Melbourne's transit system will become even more reliant on this small and congestion-prone portion of the network than it is today. Average resilience figures for the CBD drop significantly (Table 2). Pressures specifically mount on the Craigieburn and Sandringham lines, the Clifton Hill and Burnley trunk lines and the southern approach of the Metro Rail tunnel, as well as the majority of tram lines in the central area. Bus lines with the poorest resilience values include the Elgin-Johnston Street/Studley Park Road corridor in the inner north, Hoddle Street in the inner east, the Eastern Freeway routes to Doncaster and Manningham, the Bell Street corridor in the mid-northern suburbs and the Springvale Road corridor in the mid-eastern suburbs. On these trends, much of Melbourne's public transport can be expected to suffer chronic overcrowding effects, and/or a lower-than-desirable mode share as customers continue to use cars for journeys where this is not prohibitively inconvenient. In any case, the potential for public transport to become a real backbone of urban mobility continues to be as insufficiently exploited as it is today. We assert that a different network configuration can offer a viable pathway out of this dilemma.

**Table 1:** Betweenness centrality results in 2015 and the 2026 Trend scenario

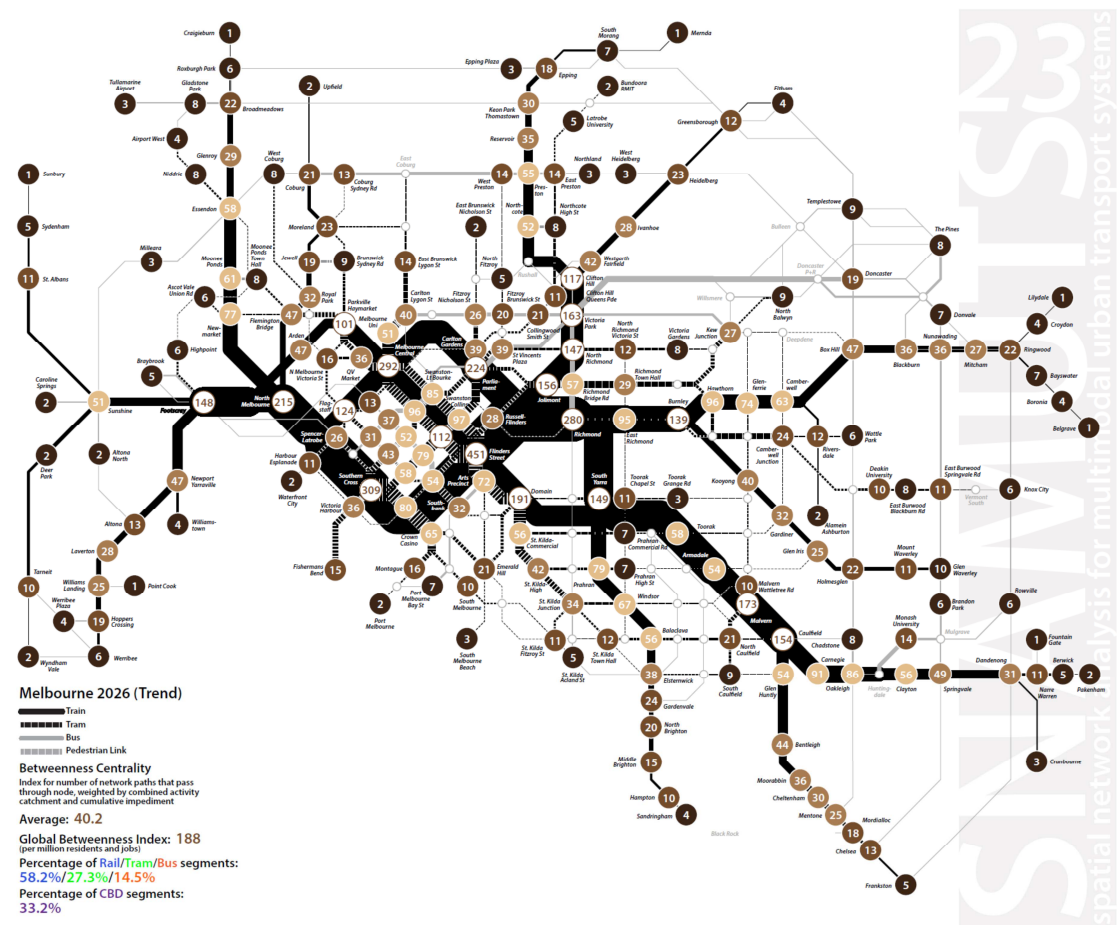
Melbourne SNAMUTS 23	2015	2026 Trend
Global betweenness (per million residents and jobs)	176	188
Average nodal betweenness, <b>network</b>	31.7	40.2
Proportion of network-wide segmental betweenness, <b>train/tram/bus</b>	53.4%/28.7%/18.0%	58.2%/27.3%/14.5%
Proportion of network-wide segmental betweenness, <b>CBD</b>	31.0%	33.2%

**Table 2:** Resilience results in 2015 and the 2026 Trend scenario

Melbourne SNAMUTS 23	2015	2026 Trend
Average resilience <b>(network)</b>	+7.4	+6.3
Average resilience <b>(train/tram/bus)</b>	+9.6/+10.6/+3.1	+11.4/+7.8/+1.4
Average resilience <b>(CBD)</b>	+7.3	+1.2

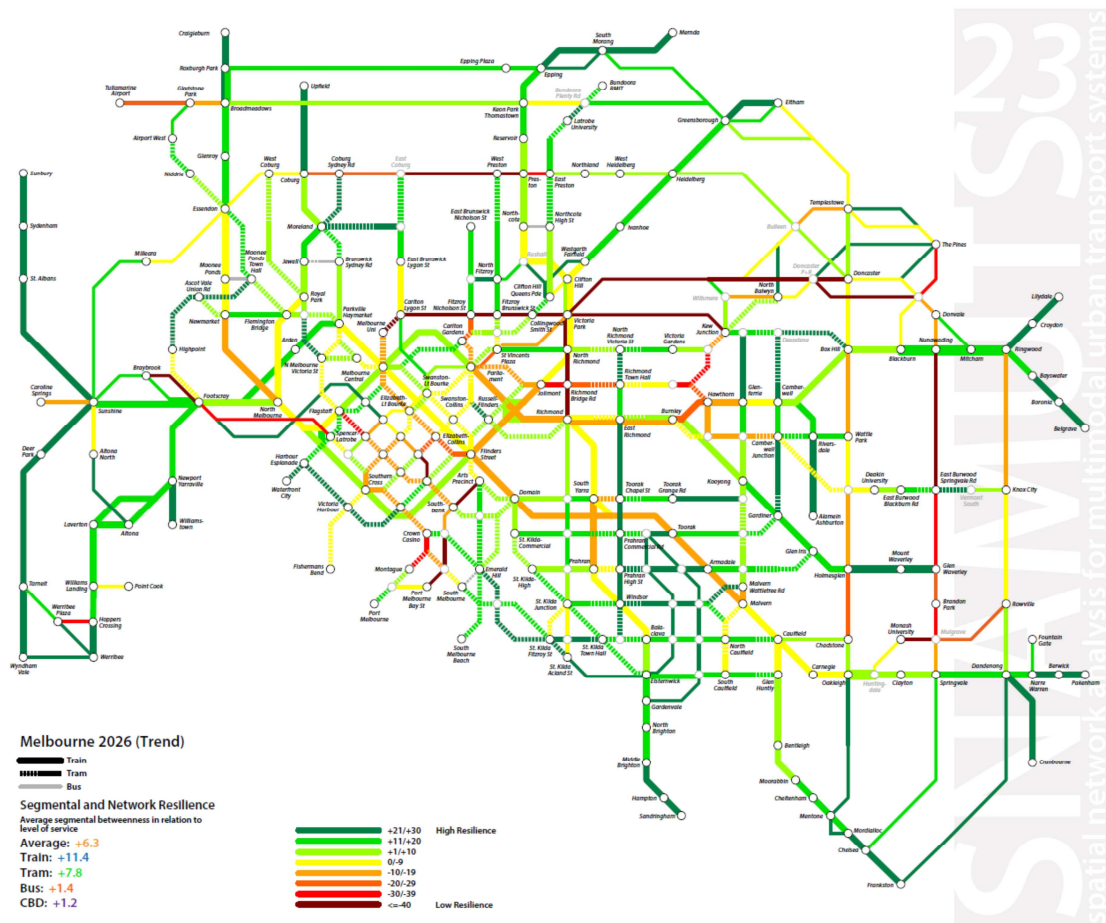


Figure 21 Melbourne: Betweenness centrality results in the 2026 Trend scenario





**Figure 22 Melbourne:** Segmental and network resilience results in the 2026 Trend scenario



## Melbourne in 2026: The addition of orbital lines

This section describes an iterative exercise to add more multidirectional elements to Melbourne's surface public transport network consistent with Thompson's early insights of the 1970s. Melbourne differs from the bi-directional Squaresville model discussed above both in its street geometry – which is predominantly grid-shaped but also includes some diagonals, and discontinuities created by rivers and coastlines – and by providing some connectivity for its transit system, where transfers are generally possible between all radial lines, though mostly only within the CBD area. Beyond the CBD, there are long stretches of parallel lines without perpendicular connections – for example, the group of seven north-south tram and three rail lines between the Craigieburn rail corridor and Northcote's High Street in the city's inner north. The only east-west bus route at the SNAMUTS minimum standard<sup>4</sup> that provides transfers to all these radial lines beyond the CBD edge runs 7 km north along Bell Street (SmartBus 903), where some of the radial tram routes have their outer termini. In the inner and mid-east of Melbourne, there is a greater number of orbital (north-south) lines, but they are similarly characterised by larger than ideal spatial gaps

<sup>4</sup> The SNAMUTS minimum standard, required for inclusion of a line into the analysis, stipulates a minimum daytime service frequency on weekdays of 3 departures per hour per direction on buses and trams, and 2 departures per hour per direction on trains and ferries. On weekends slightly lower standards apply (see [www.snamuts.com](http://www.snamuts.com) for more detail).

between corridors (with frequent service) and in some cases, cover only a portion of a north-south arterial road that displays no such discontinuities for private car users. We assess the effect on accessibility and resilience across Melbourne's network by filling these gaps in order to generate a true lattice-shaped network. This would enable customers to move in a multi-directional fashion across the entirety of Melbourne's inner and middle suburbs.

Drawing on previous work (Scheurer, Bergmaier and McPherson, 2006) as well as research projects for the Cities of Melbourne, Manningham and Port Phillip between 2010 and 2015, a network of additional orbital lines was conceptualised and tested for its impact on SNAMUTS betweenness and resilience measures in several iterations. In the first step, three orbital tram lines, five orbital bus lines and a small number of further tram extensions and improvements to the outer branches of bus lines were included (please refer to the appendix of this paper for a detailed list). The choice of mode for each proposal rests on the assumption that Victoria's capacity for delivering heavy rail extensions in inner Melbourne will be entirely taken up until 2026 with the construction of the north-south metro rail tunnel. Thus all proposals for network expansion in this scenario concern surface modes – trams where the lines in question easily combine with or close gaps within the existing tram network (such that existing lines can be extended or combined into new configurations), buses in all other cases. Wherever new lines cover or duplicate sections of existing bus or tram lines, these are generally discontinued or shortened. Travel times on new lines reflect those found on existing lines along the same route in the 2015 timetable.

Subsequent iterations aimed to determine frequency improvements and/or modifications to the network configuration required to improve the resilience performance of both new and existing lines. Ideally, no train, tram or bus line on the network should return a negative average resilience value across all route segments on the line in both directions (although particular sections of each line may still fall below this standard). This is how the network configuration and service levels for the final version of the scenario were determined (see this paper's appendix for a detailed list of assumptions in Step 2). In most cases, service frequencies on low-resilience routes or portions of routes were improved or additional lines added to particular segments; in one case (along Burke Road between Camberwell and Caulfield), a modal upgrade from bus to tram was deemed necessary as the resilience standard detailed above could not be achieved by a bus line.

According to the service intensity index, these measures lead to an additional requirement of 8 trains (a 7 per cent increase), 68 trams (23 per cent increase) and 107 buses (48 per cent increase) compared to the 2026 Trend scenario. Note that the figure for buses is overstated, as it does not count bus routes already in existence but not meeting the SNAMUTS minimum standard in the Trend scenario (such as route 703).

Table 3 shows that the orbital network elements lead to a slight recovery in the relative network significance of trams and buses at the expense of trains, reversing the trend observed for the 2026 Trend scenario compared to the status quo. A more significant shift is found in the network's reliance on channelling movement through the CBD area: this function drops markedly over both the 2026 Trend scenario and the status quo. The orbital network measures thus achieve their inherent rationale of generating opportunities to divert journeys away from the easily congested centre of the city. Simultaneously, resilience figures recover network-wide, for each of the three main transport modes and for the CBD area (Table 4).

Of concern, however, is whether this beneficial effect translates into a robust rationale for the necessary investment and additional operational resources associated with the new tram and bus routes, and whether it actually resolves congestion across the network. At issue is whether tram extensions and new bus lines represent value for money. While the SNAMUTS methodology is not designed to answer this question directly, a superior accessibility performance of the additional network elements can be regarded as a 'wider economic benefit' of a transport investment item, a category increasingly used in the assessment of infrastructure proposals (Johansson, 2008).

**Table 3:** Betweenness centrality results in 2015 and the 2026 scenarios

Melbourne SNAMUTS 23	2015	2026 Trend	2026 Optimised Network
Global betweenness (per million residents and jobs)	176	188	202
Average nodal betweenness, network	31.7	40.2	41.5
Proportion of network-wide segmental betweenness, train/tram/bus	53.4%/28.7%/18.0%	58.2%/27.3%/14.5%	54.7%/29.1%/16.1%
Proportion of network-wide segmental betweenness, CBD	31.0%	33.2%	28.9%

**Table 4:** Resilience results in 2015 and the 2026 scenarios

Melbourne SNAMUTS 23	2015	2026 Trend	2026 Optimised Network
Average resilience (network)	+7.4	+6.3	+9.0
Average resilience (train/tram/bus)	+9.6/+10.6/+3.1	+11.4/+7.8/+1.4	+12.8/+9.3/+7.3
Average resilience (CBD)	+7.3	+1.2	+5.8

A worthwhile query to confirm whether or not the new orbital lines succeed in relieving radial lines from pressure through the land-use transport system is to examine the line-specific increment in resilience performance between the 2026 Trend and the 2026 Optimised Network scenario. With the exception of the Camberwell to Alamein shuttle (whose resilience already is and remains in the highest category), all existing rail lines record an improvement in resilience. This is most pronounced on the lines using the new metro rail tunnel (Sunbury to Dandenong), which receives additional services in this scenario, and the Ringwood lines where this can mostly be traced to the interwoven orbital network elements, particularly the trams along Burke Road and Glenferrie Road, and the new or improved bus routes connecting at Camberwell, Blackburn, Nunawading and Burnley.

On the existing tram network, average improvements in resilience are seen for all lines except route 109 (which has a very small drop). The greatest shifts are present on the Elizabeth Street routes (19, 57, 59), and routes 70 and 75 through Camberwell Junction. In both cases, significant pressure relief is generated by the additional orbital routes in the inner north-west and in Boroondara. These additional travel options have the effect of

deflecting non-CBD-bound journey paths away from the radial routes (or portions of radial routes) and help them match their geographical desire lines more closely. Further, they make such non-radial journeys more attractive by reducing total travel times and in some cases, relying on lines with greater service frequency. This reduces the travel impediment for such journeys, which in turn positively influences the betweenness measure. The growth in the global betweenness measure (Table 3), representing the extent to which public transport movement opportunities penetrate the urban fabric across the metropolitan area, reflects the network-wide impact of such measures to disentangle and boost multi-directional travel options across Melbourne.

The magnitude to which this effect manifests on some of the suggested new orbital routes is highly significant and attests to the need for a level of holistic accessibility analysis, which appears absent in current everyday practice of public authorities. Figure 23 illustrates how the Elgin-Johnston Street and Studley Park Road route in particular is characterised by some of the highest segmental betweenness values across Melbourne's entire tram network, second only to parts of Swanston Street-St Kilda Road and Spencer-Clarendon Street. The new tram links along Dean, Dawson, Park and Hoddle Street in the inner north, and Burke Road in the east, also consistently return segmental betweenness values within the uppermost two quintiles of all Melbourne tram segments. By comparison, the tram links across Bolte Bridge to Fishermans Bend and Montague Street, between Footscray and Docklands and through Elwood are weaker performers in terms of network significance, though it is arguable that their local access function for major urban redevelopment areas would likely carry greater weight on a decision whether or not to implement them than their ability to connect disparate parts of the city. Among the suggested new or upgraded bus links, the routes between Latrobe University and Camberwell and along Chandler Highway-Burnley Street achieve a more prominent position on the network than routes across the West Gate Bridge and along the Port Phillip waterfront, between Essendon and Ivanhoe and between Middle Brighton and Blackburn.

This remarkable betweenness performance of possible future public transport links where none (or only low-frequency, discontinuous bus routes) exist today has significance in practical terms for planning and decision-making. The SNAMUTS analysis highlights the occurrence of unmet potential for public transport in the land use-transport interplay. Victoria's strategic planning framework over the past 15 years or more has stressed the importance of maximising public transport's mode share and of reigning in or reversing the growth of private motorised vehicle use in Melbourne (DOI, 2003; DOT, 2008; State of Victoria, 2014). To meet these goals, it is imperative that such unmet potential is mobilised and the market of associated journeys is attracted to public transport to the greatest possible extent.

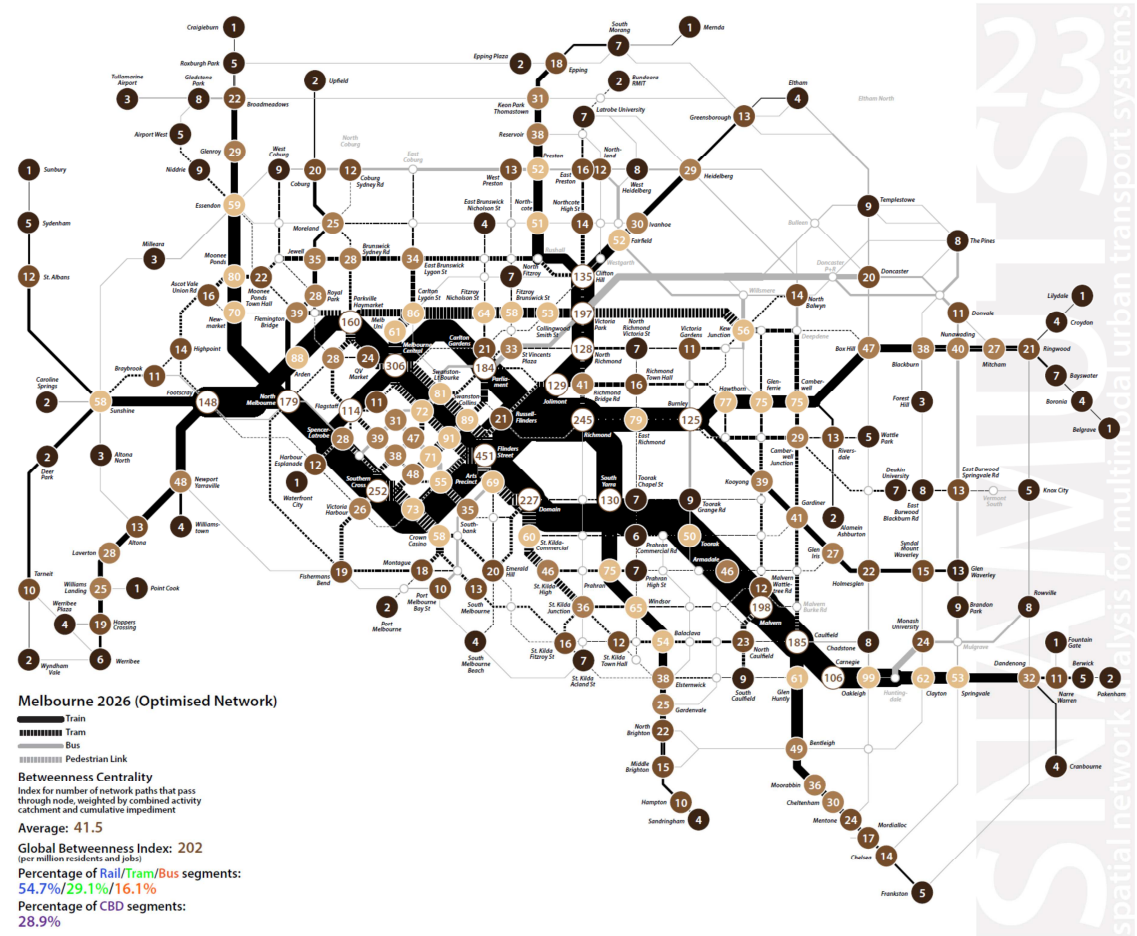
As shown above along the more schematic example of Squaresville, a more geographically and geometrically 'complete' network particularly in the inner areas of a city will allow for public transport to compete more effectively with the car and expand choices for customers that rely on it for the majority of their journeys. In Melbourne's case, it will contribute to overcoming car dependence for an enlarged portion of the city (Newman and Kenworthy, 2015). This is illustrated in the SNAMUTS composite maps for the inner area (Figures 25-26), which take in the results of six SNAMUTS component indicators and show overall public transport accessibility performance in traffic light colours on a scale from 0 to 60 (with higher figures indicating better accessibility): across metropolitan Melbourne, public transport

accessibility performance improves by more than half a colour bracket on average as a result of the added orbital links.

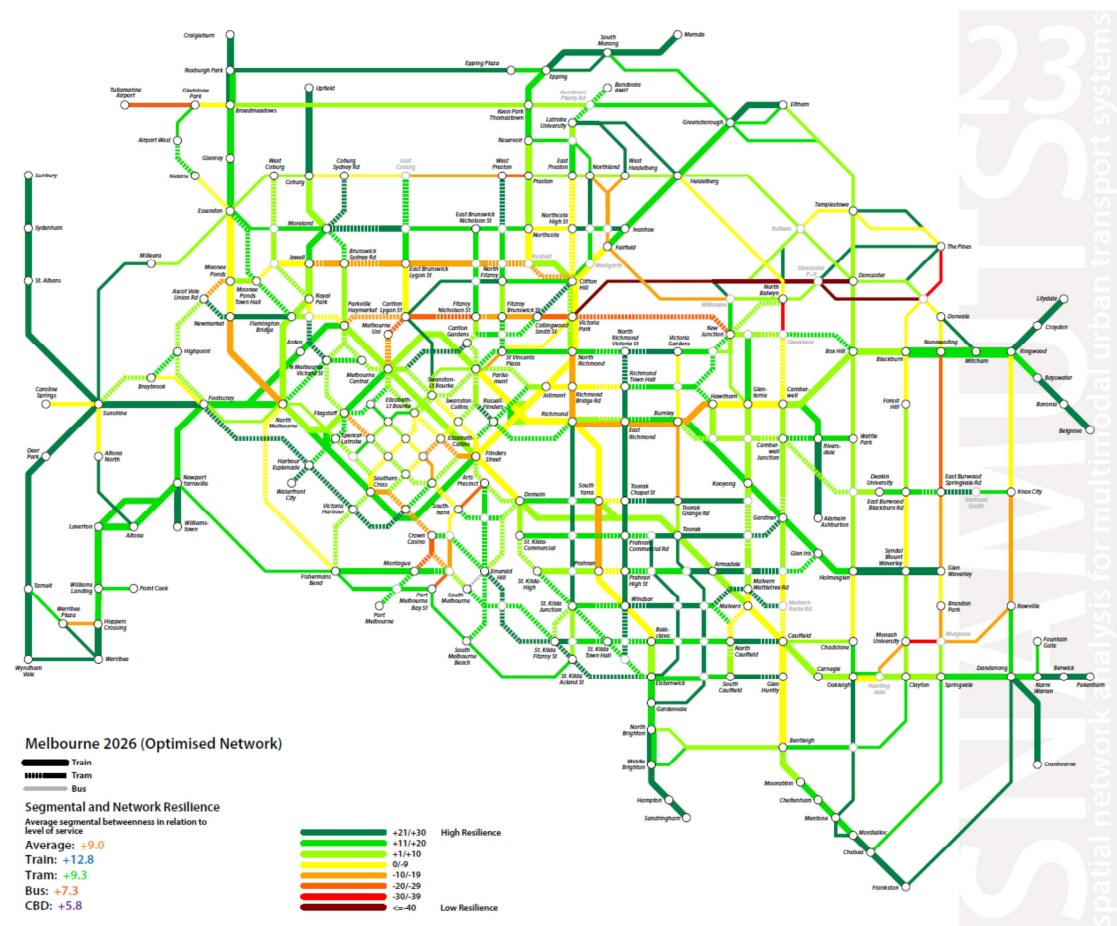
Public transport’s enhanced comparative benefits are most easily understood when comparing selected travel times in 2026 between inner and middle nodes without and with the addition of the orbital routes. For example, the presence of a tram route between Parkville interchange and the Elgin-Johnston Street corridor will slash the journey between Footscray and Fitzroy from 36 to 21 minutes; a tram route along Park and Hoddle Streets will place Brunswick within 23 minutes (down from 32) of Richmond; and a tram link north along Burke Road from Caulfield will reduce a 45-minute journey between Carnegie and Camberwell Junction to 27 minutes (in each case counting the time it takes to make a transfer where required).

The addition of these new high-quality routes will create a broad range of transfer points across an arc of inner and middle districts surrounding Melbourne’s central core. Not only will each of these nodes provide multi-axis public transport accessibility, they will also create potential for transit-oriented place development and improvements to the legibility of public transport facilities in local urban environments (Woyciechowicz and Shliselberg, 2005).

Figure 23 Melbourne: Betweenness centrality results in the 2026 Optimised Network scenario

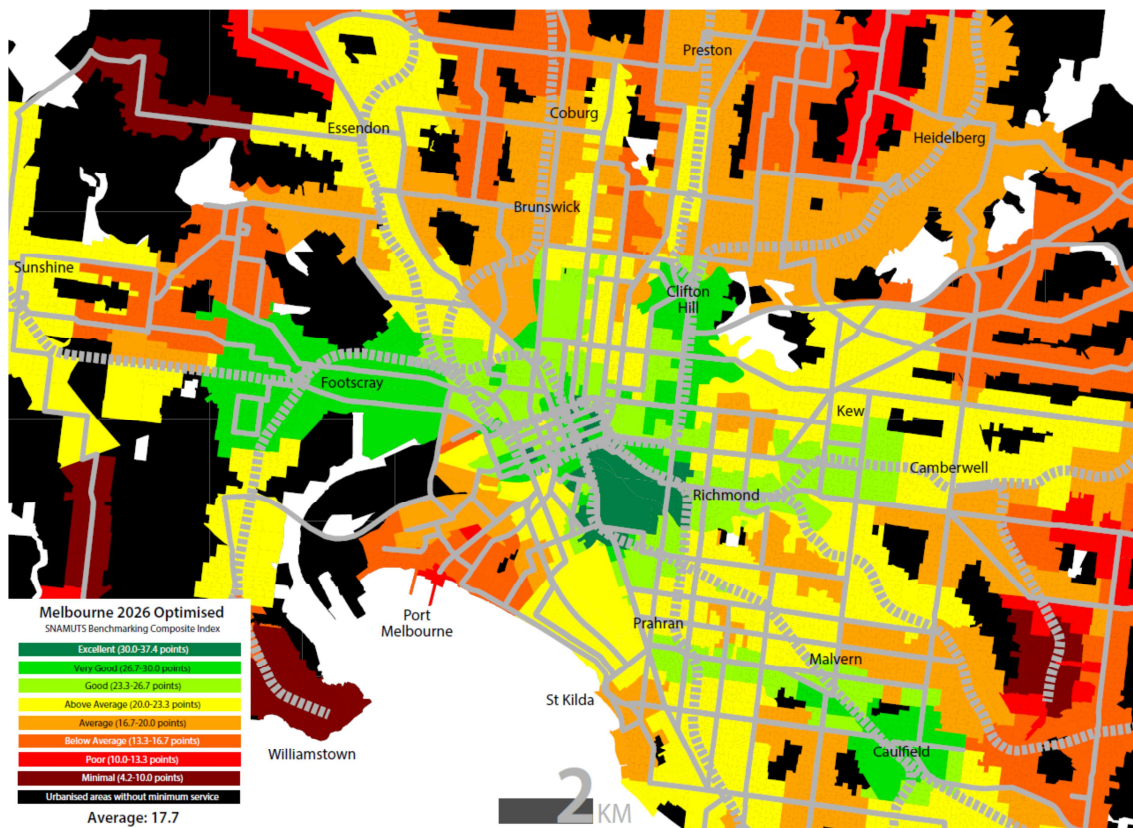
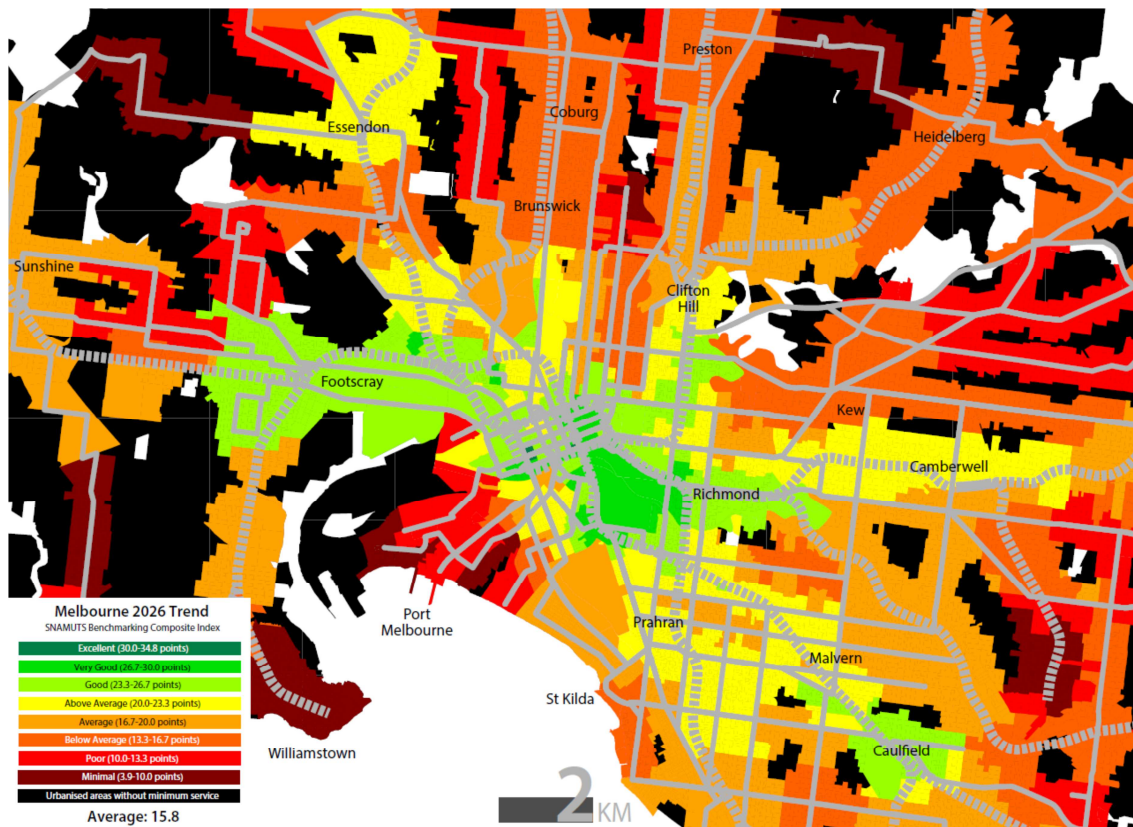


**Figure 24 Melbourne:** Segmental and network resilience results in the 2026 Optimised Network scenario



**Figures 25, 26 Melbourne** (next page): SNAMUTS composite index for inner Melbourne in the 2026 Trend and 2026 Optimised Network scenarios





## **Discussion and conclusion: The potential for increased multi-directionality across inner Melbourne's network**

This research demonstrates that there are significant supply gaps in Melbourne's current public transport network, and that these affect inner areas as well as outer areas (but it is only the latter where this shortfall is more broadly recognised in the policy debate). Filling these gaps with a greater number of orbital tram and bus routes has substantial accessibility benefits and will enable the public transport network to absorb a greater rate of patronage and mode share growth, especially in inner areas where constraints to car use are most prevalent. This approach requires a departure from the traditional practice of pursuing public transport improvements on an isolated project-by-project basis and a shift towards considering the benefits of such improvements in the context of the holistic network. Such a change of planning perspective is elaborated by Mees (2010), Dodson et al (2011) and Stone and Scheurer (2014).

The prospect of significantly improved and expanded on-street public transport in inner areas, however, raises the question of how existing road space can be adapted to facilitate the high performance expected from these new routes. For example, the Optimised Network scenario discussed above envisions a daytime service frequency of 24 trams per hour per direction along sections of Elgin and Johnston Streets, a level of service currently only found within parts of the CBD and along St Kilda Road. At present, Johnston Street, a typical inner arterial road with a width of 20 metres between property lines, accommodates between four and five traffic lanes, two of which revert to parking outside peak hours, and some sections of peak-period bus priority lanes. Thus it is primarily configured to maximise road traffic throughput during peak hours. Current daytime public transport service levels on weekdays amount to 6 buses per hour per direction. Clearly, the introduction of trams at several times this frequency will require a significant reduction of the corridor's road traffic function if tram services are to operate efficiently. On other suggested new tram corridors, potential reservations already exist (proposed route 82 between Brunswick and Clifton Hill largely follows the linear park along the former inner circle rail line), or there is an opportunity to share much wider road reserves. This particularly concerns Hoddle Street, though it is conspicuous how current state government policy is predominantly concerned with further increasing private vehicle capacity along this corridor, rather than establishing a stronger public transport link (VicRoads, 2016).

This nexus raises a wider question of how the allocation of space and traffic priority between public and private, motorised and non-motorised modes needs to shift in inner Melbourne to enable a more resilient public transport network to offer a more complete range of opportunities of movement to passengers. Road space along inner urban arterials is contested among various interest groups and the needs of multiple users. An important question is then how these disparate interests be can reconciled and assembled in support of a fairly radical transformation of the design and functionality of some of Melbourne's key inner urban activity corridors. It is outside the scope of this paper to provide detailed responses to this question, but in closing we assert that the associated planning challenge and search for viable solutions that take into account the needs of 21<sup>st</sup> century urban mobility are not new and not unique to Melbourne, or Australia. Improving public transport network designs have benefits beyond simple mobility; public transport is a foundation for innovative new land use and urban design outcomes. Adams (2009), Scheurer and Woodcock (2011)



and Dovey et al (2013) have discussed the urban design implications, implementation challenges and impacts on public transport services associated with urban intensification around Melbourne's tram corridors. Elsewhere in the world, cities such as Helsinki (City of Helsinki, 2013) and Barcelona (Ajuntament de Barcelona, 2014) are moving forward by incorporating the large-scale transformation of motorised vehicle space into mixed-use streetscapes with priority for pedestrians, cyclists and public transport into their metropolitan and transport strategies under the key terms of 'boulevardisation' (Helsinki) and 'superilles' (superblocks, Barcelona). Both cities aim to allocate road space in a closer proportion to the aspirational significance of the mode for urban mobility, and note that the current percentage of road space allocation to private motorised vehicles is significantly higher than their effective mode share (or contribution to the urban transport task). There is thus an emerging global trend to reconfigure entire urban districts for the needs of a next-generation public transport system in conjunction with high-quality and highly accessible, pedestrian and cyclist-friendly public and movement spaces. We have demonstrated which reforms in public transport network configuration could enable Melbourne to become an Australian pioneer in this trend.

## Acknowledgements

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## Appendix

Additional tram and bus routes included in the 2026 Optimised Network scenario (Step 1). All routes are assumed to operate every 10 minutes (6 departures per hour per direction) during the day on weekdays, except where stated otherwise.

- Tram 66: Malvern – North Melbourne via Carlisle Street, St Kilda Light Rail, Fishermans Bend and Bolte Bridge (using existing tracks between Malvern and South Melbourne);
- Tram 69: North Melbourne – East Brighton via Parkville, Elgin-Johnston Streets, Kew Junction, Cobham, Glenferrie and Hawthorn Roads (using existing tracks between Kew and East Brighton);
- Tram 75: extended from Docklands (Etihad Stadium) via Footscray Road to Highpoint (using existing tracks between Footscray and Highpoint);
- Tram 82: Sunshine – Richmond via Highpoint, Moonee Ponds, Brunswick, Clifton Hill and Hoddle Street (using existing tracks between Highpoint and Moonee Ponds);
- Tram 96 and/or 16: extended from St Kilda Beach to Elsternwick via Elwood;
- Bus 246: Richmond – Newport via St Kilda Junction, Beaconsfield Parade, Port Melbourne, Fishermans Bend and West Gate Bridge;
- Bus 250/251 City –Northland and Latrobe University (existing lines, every 20 minutes each, improved to SNAMUTS minimum standard);
- Bus 510: Essendon – Ivanhoe via Moreland, East Brunswick, and Northcote (every 15 minutes);
- Bus 620: Latrobe University – Caulfield via Heidelberg, North Balwyn and Burke Road;

- Bus 703 Middle Brighton – Blackburn via Bentleigh, Clayton and Monash University (existing line, every 15 minutes, improved to SNAMUTS minimum standard);
- Bus 904: Reservoir – Gardenvale via Northland, Fairfield, Kew Junction, Victoria Gardens, Burnley Street, Toorak and Orrong Road.

Additional tram and bus routes and frequency improvements included in the 2026 Optimised Network scenario (Step 2):

- Sunbury/Dandenong train lines: central section of a future (post-2026) additional rail line between Tullamarine Airport and Rowville to operate by 2026, providing combined 5-minute daytime frequencies between Sunshine and Oakleigh via the new metro rail tunnel.
- Tram 16: Elsternwick – Melbourne University extended along Elgin-Johnston Street, Kew Junction, Deepdene, Camberwell and Burke Road to Caulfield (existing tracks between Kew Junction and Gardiner), inter-peak frequency improved from 6 to 9 trams per hour.
- Tram 58: new weekday route linking Parkville and Domain via William Street and Southbank (existing tracks of route 55, doubling frequency to 12 trams per hour)
- Tram 69: North Melbourne – East Brighton, inter-peak frequency improved from 6 to 9 trams per hour;
- Tram 82: Sunshine – Richmond, inter-peak frequency improved from 6 to 9 trams per hour;
- Tram 89: new weekday route linking Moonee Ponds and Clifton Hill via Flemington Road, Parkville and Elgin-Johnston Street (along existing and new tracks listed previously, boosting frequency on parts of routes 59, 69 and 86);
- Bus 200/207: remaining sections Glenferrie – Bulleen/Doncaster via North Balwyn, inter-peak frequency improved from 3 to 4 buses per hour per route;
- Bus 216/219: Brighton (New Street) – Sunshine, inter-peak frequency improved from 4 to 6 buses per hour;
- Bus 234: Garden City – CBD (Queen Street), inter-peak frequency improved from 4 to 9 buses per hour;
- Bus 620: curtailed to the section between Latrobe University and Camberwell;
- Bus 900: Caulfield – Rowville, inter-peak frequency improved from 4 to 9 buses per hour;
- Bus 902: Airport West – Chelsea, inter-peak frequency improved from 4 to 6 buses per hour (9 buses per hour between Doncaster and Springvale);
- Bus 903: Altona – Mordialloc, inter-peak frequency improved from 4 to 6 buses per hour (9 buses per hour between Coburg and Heidelberg);
- Bus 904: Reservoir – Gardenvale, inter-peak frequency improved from 6 to 9 buses per hour between Northland and Toorak;
- Bus 905/906/907: CBD (Lonsdale Street) – The Pines/Warrandyte/Mitcham, inter-peak frequency improved from 4 to 6 buses per hour per route.