Australasian Transport Research Forum 2021 Proceedings
8-10 December, Brisbane, Australia
Publication website: http://www.atrf.info

The impact of bus network reform on the resilience of Melbourne's public transport system

Dr Jan Scheurer[1], Dr Ian Woodcock[2]

[1]RMIT University

[2]Swinburne University of Technology

Email for correspondence: jan.scheurer@rmit.edu.au

Abstract

Melbourne's Public Transport advocates have argued since the 1990s the most cost-effective and equitable way to achieve long-desired mode shifts to public transport in that city is metropolitan bus network reform. Melbourne's bus network is extensive, yet service delivery is notoriously ineffective: many routes are slow, tortuous and infrequent, service spans are short, timetables are poorly aligned with trains and trams, resulting in poor network connectivity overall. Budgets for bus planning are constrained, meaning there has been scant work by government planners to re-imagine the network in the vein promoted by advocates. The Victorian Government's Bus Plan (DOT, 2021) acknowledges the issues with the network, but has little concrete in the way of targets or ways of achieving them.

In this paper, we draw on network planning principles for multimodal public transport and some of the bus reform proposals of Melbourne's foremost advocates to create scenarios to increase the overall network coverage from its current level of 51% to 70% of residents and jobs by 2036. Using network scenarios derived from government plans for rail and projections for population growth and distribution, we deploy the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) to assess the effects significant bus service reform would have on these plans. We find that while significant increases in network accessibility could be achieved, there would also be significant stresses placed on the rail system, even with the envisaged upgrades and extensions, allied with a reduction in the role of Melbourne's trams. These results indicate that bus network improvements, while critically important, need to be embedded in strategies that also give serious attention to capacity and performance deficits of the rail and tram systems in order to disperse demand within a more resilient network overall.

1. Introduction

Melbourne's bus system has long been treated as a 'poor cousin' to the iconic and prominent tram and rail systems that also serve its metropolitan area of nearly five million inhabitants. Over 7,000km in route length, yet accounting for only just over 20% of total metropolitan public transport patronage in the financial year preceding the COVID-19 crisis (DTF, 2019), the bus network has largely grown organically as the urbanised area expanded. Typical levels of service (low frequencies, limited operating hours, slow travel speeds) struggle to provide a viable travel alternative to users who have access to a private vehicle (Parker, 2011; 2021). Simultaneously, the generally higher standards of service offered on the rail and tram systems are only accessible within walking distance to about 30% of metropolitan Melbourne residents (in 2016, see Scheurer and Woodcock, 2017) using the common definition of 800 metres for the walkable catchment of rail stations and 400 metres for tram and bus stops

(Guerra et al, 2012). Buses are the only form of public transport available within walking distance of the homes of the majority of Melburnians. There have been a number of initiatives to improve Melbourne's bus service performance, including greater legibility and useability. In the late 2000s, a nine-route SmartBus network was rolled out, consolidating and simplifying a suite of cross-suburban and radial routes into a legible product, with some light traffic priority measures and improvements to stop facilities including real-time travel information (Currie and Delbosc, 2014). The SmartBus network is operated at consistent minimum service frequencies during the day and week (15 minutes on weekdays, 30 minutes evenings and weekends). This constitutes a vast improvement over the half-hourly or hourly frequencies with limited or no evening and weekend service that prevail over most of Melbourne's bus system, yet remains a modest standard when compared internationally or to Melbourne's tram routes (Parker, 2011; Currie and Delbosc, 2014; Pemberton, 2020).

Other bus network reforms to create more legible and reliably operated routes were applied locally during the 2010s, primarily in the LGAs of Wyndham, Brimbank, Whittlesea and parts of Casey. As with the earlier SmartBus routes, these efforts led to local patronage increases in the order of 25% (Currie and Delbosc, 2014; DOT, 2021) but at a metropolitan scale, they remain geographically patchy. As of 2016, Melbourne's bus routes performing to a SmartBus or SmartBus-equivalent standard (every 20 minutes on weekdays, 30 minutes on weekends) expanded the multimodal coverage, but still leave 57% of metropolitan residents, and 49% of residents and jobs combined, at the mercy of low-frequency bus services, or none at all (Curtis and Scheurer, 2016).

This paper builds a suite of scenarios aimed to increase the 2016 coverage of 51% of metropolitan residents and jobs to 70% by 2036. These scenarios consider various elements: committed rail and tram infrastructure and network reform projects (PTV, 2012); the Principal Public Transport Network (PPTN) included in Melbourne's current metropolitan strategy as a blueprint for the provision of bus services at the SmartBus standard in the future (DELWP, 2017); and the suite of proposals from the Melbourne on Transit blog (Parker, 2021) for cost-effective local bus improvements aimed to create a metropolitan-wide Useful Bus Network (UBN). Urban intensification and growth trends as identified in government forecasts (DELWP, 2019) have been used to project the distribution and concentration of land uses in 2036; for this purpose, fine-grained 2016 census data for residents and jobs were extrapolated by applying the forecast growth rate in each of the larger Victoria in Future spatial units with some adjustments for employment in central Melbourne and residential population in Greenfield growth areas.

Using some of the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) methodology, we explore what effects such an expansion of geographical coverage through a better performing, more user-friendly bus network has on the public transport system as a whole. The public transport system functions multimodally through the integration and coordination of fares, timetables, interchange facilities and network configuration (though it is acknowledged that many of these qualities remain underdeveloped in Melbourne). Thus improvements to one component of the system can be expected to have repercussions on other components. These are likely to be most prominent in the division of tasks between transport modes, entailing effects on the resilience of operations and the ability of the system to absorb the increased share of the travel market sought in public policy settings (DELWP, 2017)

2. Scenario Methodology

To build a base scenario for 2036, we assume that Melbourne's rail network will have been extended and service levels upgraded to Stage 4 of the 2012 Rail Network Development Plan

(PTV, 2012). This stage includes: the Melbourne Metro 1 tunnel, with western branch lines to Sunbury, Melton and the airport; the Melbourne Metro 2 tunnel linking the Mernda and Werribee lines between Clifton Hill and Newport; minimum 10-minute daytime frequencies on most rail and all tram routes in Melbourne; the first stage of the Suburban Rail Loop (SRL) between Cheltenham-Southland and Box Hill becoming operational by 2036 at 5-minute daytime frequencies; along the Principal Public Transport Network (PPTN), 56 bus routes will operate at least every 20 minutes (many every 10 minutes) all day.

This base scenario reflects the likely state of Melbourne's land use-transport system after implementation of all currently committed short and medium-term upgrades to public transport infrastructure and service levels, in combination with the expected level and spatial distribution of urban growth during the same time frame.

We acknowledge that 2019 government population projections will be affected by the unanticipated impacts of the COVID-19 pandemic; the time horizon used in these scenarios should thus be regarded flexibly as a certain future stage in Melbourne's urban growth trajectory (approximately 6.4 million residents) that may eventuate some time other than 2036.

The base scenario is compared with two further scenarios including a metropolitan-wide suite of incremental suggestions for bus network reforms that have been successively compiled by Parker (2021) in his Melbourne on Transit blog and labelled the 'Useful Bus Network' (UBN). These proposals supersede the PPTN network already included in the base scenario but with minor exceptions, provide service at an equivalent or better standard along all PPTN routes: they mostly rely on sensible redistributions of operational resources from ineffective or duplicate routings towards more legible solutions at improved service frequencies rather than on a net expansion of operational input.

Hence, the majority of the resulting total of 123 bus routes still only just meet the SNAMUTS minimum frequency standard of 20 minutes during weekdays and 30 minutes on weekends. Figures 1 and 2 illustrate the comparative extent of the PPTN network (base scenario) and the UBN network in the two subsequent scenarios.

The UBN generally conforms to the principles of good network planning promoted and documented by authors such as Nielsen et al (2005), Vuchic (2005), Mees (2010), Dodson et al (2011), Walker (2012), McLeod et al (2017) and Scheurer (2020). These principles are:

- a pronounced hierarchy of task-sharing between transport modes according to their performance characteristics (especially speed and capacity);
- a maximisation of the network structure's simplicity to enhance its legibility to users and to avoid duplication of operational resources;
- a focus on the quality and placement of interchanges to facilitate easy transfers between routes and modes in high-amenity locations (ideally within land use clusters that are significant destinations in their own right);
- a multi-directional layout of the network to allow for movement to occur as close as possible to geographical desire lines and to provide a diversity of journey paths between origins and destinations.
- The UBN will place about 70% of Melbourne's residents and jobs within walking distance of a public transport service of this standard or better, up from just over 56% in the base scenario for 2036 (and up from 51% in 2016). It can be expected that this expanded patronage catchment will add significant pressure on the public transport system as a whole, including the rail, tram and PPTN bus lines already included in the base scenario. The effects of the UBN will thus be assessed in two scenarios: one keeping service levels on the remainder of the network constant over the base scenario (UBN 1), and one including an additional boost to rail service frequencies (to every 5 minutes during the day on most inner sections and 10

minutes on most outer sections) where these are required to maintain an overall level of network resilience comparable to the base scenario (UBN 2).

Figures 1, 2: Vignettes for Melbourne's public transport network in 2036 as used in the base and UBN scenarios (NOTE: If greater detail is required than visible by enlarging this document by 500%, please use this link for further magnification: FIGS 1 & 2 Melbourne 2036 Scenarios)

3. SNAMUTS Methodology and Results

The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) methodology has been developed since 2008 at RMIT University and Curtin University by Dr Jan Scheurer and Prof Carey Curtis as a planning and decision-making support tool to assess accessibility and network performance in public transport systems (Curtis and Scheurer, 2016; 2021). The analysis includes a set of tasks and measurements that highlight the contribution of public transport network and service development from a range of perspectives. In this paper, we will use five SNAMUTS indicators (service intensity, 30-minute contour catchments, network coverage, betweenness centrality and network resilience). Full descriptions of each indicator including source data and calculation formulas can be found in Curtin and Scheurer (2016) or online at www.snamuts.com.

Service intensity

The service intensity index describes the number of vehicles or train sets on each mode that need to be in simultaneous revenue operation during the weekday interpeak period to deliver the service along those components of the public transport network that meet or exceed the SNAMUTS minimum service standard. This standard sets minimum frequencies of 20 minutes during the day on weekdays and 30 minutes on weekends for surface routes (buses and trams), and 30 minutes in combination with 7-days-a-week operation for rail lines. These figures are expressed on their own and in relation to metropolitan population to arrive at a comparative measure (over time, between scenarios and between cities) for the operational input provided into the public transport system.

In the 2036 base scenario, the overall service intensity (14.5 vehicles per 100,000 inhabitants) is only slightly higher than in the 2016 status quo (13.4 – Curtis and Scheurer, 2021), meaning that network expansion and service frequency improvements are expected to only just outpace the rate of population growth. In the UBN 1 scenario, bus numbers required to operate the (larger) network increase by about two thirds. However, this figure overstates the margin of change, as many of the additional UBN routes are already operated at lower frequencies in the current and 2036 base networks but not counted there due to the SNAMUTS minimum standard cut-off. In the UBN 2 scenario, train numbers grow by about 30% above the previous two scenarios due to the profligate frequency increases, which also affect some key bus feeder routes in the outer west and south-east.

Relative to population, the service intensity figure rises markedly compared to the base case in both UBN scenarios though it should be noted that such levels are by no means extravagant in a comparison beyond Melbourne. For example, Adelaide had already reached a service intensity level of 18.4 per 100,000 inhabitants in 2016 (Curtin and Scheurer, 2021) while in European cities, figures around the 25 mark are not uncommon (Curtis and Scheurer, 2016).

Table 1: Service intensity in the Base and the UBN scenarios, 2036

SNAMUTS *23R* Melbourne 2036	Base Scenario	Scenario UBN 1	Scenario UBN 2
Service Intensity (total per 100,000 inh)	**14.5**	**18.8**	**19.7**
Service Intensity (rail/tram/bus)	165/344/413	165/344/689	215/344/698

Geographical network coverage and 30-minute contour catchments

As elaborated above, the UBN scenarios were devised to increase the share of Melbourne's population and jobs with walking-distance access to public transport at the SNAMUTS minimum standard from 51% to 70%. This goal may appear modest, since it still leaves 30% of the metropolitan area without public transport at a 'useful' standard. However, a network coverage figure of 70% would be unprecedented among New World cities in the global SNAMUTS sample (the highest comparative scores on record are Vancouver in 2012 at 61.4%, and Sydney and Adelaide in 2016 at 56.0% and 54.0% respectively; Curtis and Scheurer, 2016; 2021). This can primarily be attributed to the highly dispersed settlement patterns particularly in outer metropolitan Melbourne which includes peri-urban and semi-rural municipalities such as Yarra Ranges and Mornington Peninsula, where even in the UBN scenario public transport service at the minimum standard is constrained to a small number of major corridors. In more contiguously built-up middle and outer suburban areas, the orthogonal bus network created in the UBN scenarios often leaves mid-block coverage gaps as the grid generally tends to be wider than the 800 metres suggested to allow for universal access within 400 metres. Lastly, the UBN proposals only partially cover emerging Greenfield growth areas; this is inevitable as the extent and locations of Greenfield growth by 2036 cannot be predicted with certainty, but also indicative of common Melbourne practice to build up public transport service levels to such areas gradually and without much initial concern for network coherence (Kroen, 2019).

The 30-minute contour catchment measures the number of residents and jobs within the walkable catchments of nodes that can be reached from the reference node within half an hour on public transport (not including walking or waiting time except during transfers), expressed as a percentage of all metropolitan residents and jobs. The modest increase in the average figure in the two UBN scenarios over the base scenario can be associated to a denser bus network that creates more opportunities for users to travel along geographical desire lines and thus avoid time-consuming detours. This is an essential characteristic of public transport networks approaching the navigational ease of private transport (Nielsen, 2005; Walker, 2012).

Table 2: Average 30-minute contour catchments and geographical network coverage in the Base and the UBN scenarios, 2036

SNAMUTS 23*R* Melbourne 2036	Base Scenario	Scenario UBN 1	Scenario UBN 2
30-min Contour Catchment (average)	**11.9%**	**12.4%**	**12.6%**
Geographical network coverage	56.3%	70.1%	70.1%

Betweenness centrality

Betweenness centrality measures the relative importance of an activity node or route segment for facilitating public transport movement across the city. It is calculated from the concentration of activities at either end of each journey, and the ease of movement (travel impediment derived from travel times and service frequencies) along that journey. Higher values indicate that a reference node is located at the 'crossroads' of movement. A higher global betweenness figure indicates a general increase in the penetration of the metropolitan area with public transport movement opportunities; however, local figures spiking in particular activity nodes or route segments can be associated with congestion or the risk thereof.

The methodology for calculating this index has been slightly modified from the template used in earlier SNAMUTS publications (Curtin and Scheurer, 2016) in that journey paths along congested route segments (with a resilience value less than -30, see below) are only considered up to the capacity limit (depending on the frequency, mode and length of vehicle used) of each segment they traverse, and journeys in excess of that capacity limit are discarded from the overall count. This is done to provide a picture more closely aligned with the actual journey-making capability of users, though it is acknowledged that the betweenness figures cannot capture whether a user is turned away from a particular service due to real-world overcrowding or for other reasons, such as poor legibility of the service (due to insufficient information or lack of conspicuous presence in the urban realm), or a perception of travel alternatives (driving, walking or cycling) as more attractive than public transport, even considering possible adverse implications (traffic congestion, parking cost and availability).

As shown in Table 3, global and average nodal betweenness figures go up from the base scenario to Scenario UBN 1, and then again to Scenario UBN 2, as would be expected when adding both more users (greater geographical coverage) and more travel opportunities (more routes in Scenario UBN 1 and more rail frequency in Scenario UBN 2). But it is remarkable that the addition of nearly 70 bus routes in Scenario UBN 1 with unchanged rail and tram service levels only adds moderately to the share of travel opportunities captured by the bus system (from 10.5% to 13.4%), and moreover, that this increase occurs entirely at the expense of the tram share while the rail share also goes up by a percentage point. The decrease in travel opportunities on the tram system mostly represents a relative drop, driven by the significant expansion of the network through additional minimum-service bus routes. But it to a smaller extent, it also represents an absolute drop in tram travel. This occurs through several effects: for example, a cross-suburban journeys may now be easier to make by a transfer trip between radial tram and orbital bus than by a more circuitous tram transfer trip through a central area (a notion supported by the tangible drop in travel opportunities channelled through the CBD where most tram lines meet); or an orbital bus route may provide a faster bus-rail transfer alternative to a radial trip to/from a middle suburban activity node along a lengthy and comparatively slow tram route.

Of concern, thus, is the increase in the share of travel opportunities captured by the rail system as the UBN 1 measures are introduced, as this represents both relative and absolute growth. It is commonsensical though: A better bus system vastly expands the catchment of the rail network, which acts as the dominant spine for public transport movement in Melbourne, through greater availability of feeder services that increase the number of travel opportunities channelled along the rail system (see also Currie and Loader, 2010). While the more multi-directional bus network might also pull some orbital journey paths away from the radial rail lines, this effect is more limited than in relation to the tram system because the higher speed of rail retains the travel time advantage over orbital buses for a greater number of transfer journeys through central areas despite the geographical detour incurred (see also Scheurer et al, 2016).

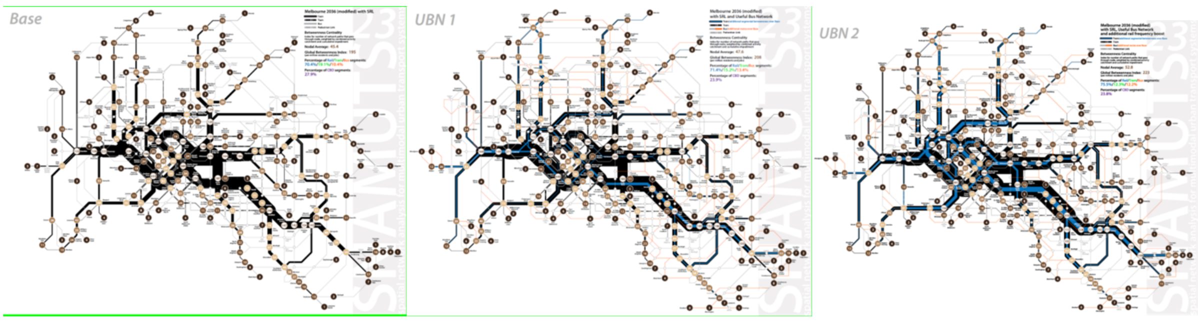
Table 3: Betweenness centrality measures in the Base and the UBN scenarios, 2036

SNAMUTS *23R* Melbourne 2036	Base Scenario	Scenario UBN 1	Scenario UBN 2
Global Betweenness	**195**	**208**	**223**
Nodal Betweenness (average)	**45.4**	**47.6**	**52.8**
Segmental Betweenness (rail/tram/bus)	70.4%/19.1%/ 10.5%	71.4%/15.2%/ 13.4%	75.5%/12.3%/ 12.2%
Segmental Betweenness (CBD)	27.9%	23.9%	23.8%

Does the expanded bus system thus result in removing stress from the tram system while adding stress to the rail system? In Scenario UBN 2, this tendency appears to consolidate with another significant jump in the share of travel opportunities captured by rail (an expected outcome as a consequence of the significant frequency improvements) accompanied by a greater relative drop in the tram figures than in the bus figures.

Figures 3-5 show the betweenness results for the three scenarios in geographical detail and illustrate some of these effects across Melbourne's network.

Figures 3, 4, 5: Betweenness centrality maps for the Base, UBN 1 and UBN 2 scenarios, Melbourne 2036 (NOTE: If greater detail is required than visible by enlarging this document by 500%, please use this link for more magnification: [FIG 3 (BASE), FIG 4 (UBN 1), FIG 5 (UBN 3))



An increase in travel opportunities due to the support of additional feeder buses can be observed on all radial rail lines, but most pronouncedly on those passing through Sunshine and Footscray in the west, and Dandenong and Caulfield in the south-east, where the UBN feeder routes access significant areas away from the rail lines in the municipalities of Wyndham, Melton, Brimbank, Monash, Greater Dandenong, Casey and Cardinia. Instances of travel opportunities being redistributed from trams to bus-rail combinations can be observed in the inner north (Lygon, Nicholson and Brunswick Street), the inner east (Victoria Street, Bridge Road and Swan Street/Riversdale Road) and along St Kilda Road.

Network resilience

Resilience acts as a proxy indicator for potential public transport congestion or for unmet, latent demand on public transport. It is calculated by drawing a ratio between the betweenness score and the public transport capacity provided on the journey path in question, on an open-ended downward scale from +30. Positive values indicate a good match between betweenness and capacity, negative values down to -30 are a cause for concern while negative values below -30 can be understood as exceeding the capacity limit, though the resilience figures continue to be calculated without the capacity cap introduced to the betweenness figures (see above).

The resilient network coverage figure captures the percentage of route segments across Melbourne's public transport system that return a positive resilience value, weighted by the concentration of travel opportunities they attract (segmental betweenness.

Average resilience across Melbourne's network drops quite dramatically (by a nodal average of 8.4 points, accompanied by a no less drastic contraction of resilient network coverage) as the UBN routes are introduced to otherwise unchanged service levels from the base scenario (Table 4). This effect makes itself felt most acutely on the rail system (where the drop amounts to 9.7 points). In other words, the addition of substantial new or improved feeder bus catchments piles pressure on the rail lines, to the point where some may reach their capacity limit despite the already quite significant network and frequency improvements over the 2016 status quo included in the 2036 base scenario. The further rail frequency improvements included in Scenario UBN 2 almost restore the resilience levels of the base scenario when counted as a nodal average or in terms of resilient network coverage, but they only partly restore them for the rail system. Instead, they appear to lead to tangible relief from pressure for the tram system.

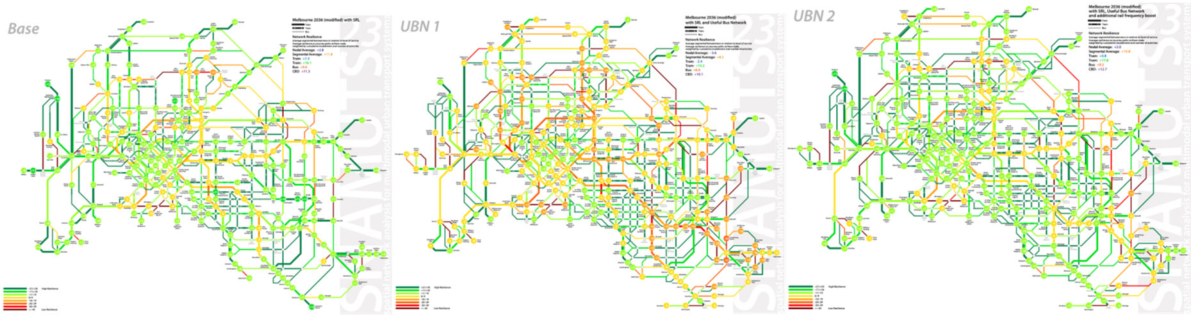
Table 4: Network resilience measures in the Base and the UBN scenarios, 2036

SNAMUTS *23R* Melbourne 2036	Base Scenario	Scenario UBN 1	Scenario UBN 2
Nodal Resilience (average)	**+2.8**	**-5.6**	**+2.0**
Segmental resilience (rail/tram/bus)	+7.3/+16.1/+9.6	-2.4/+15.2/+6.9	+3.8/+17.8/+9.2
Segmental resilience (CBD)	+11.5	+10.1	+12.7
Resilient network coverage	62.6%	35.5%	61.7%

Maps 6-8 illustrate these patterns in geographical detail. In the base scenario, significant resilience weakness is confined to the approaches of some radial rail lines to central area transfer points, notably on the Craigieburn to Frankston (split-loop), Werribee to Mernda (Melbourne Metro 2), Ringwood and Sandringham lines (all operated every 10 minutes during the weekday interpeak period in the Base and UBN 1 scenarios). On the bus network, resilience shortfalls are apparent on some feeder services particularly in the Melton, Brimbank and Casey areas, as well as on the inner orbital bus routes 401 (Parkville to

Victoria Park) and 602 (Sandridge to Anzac-Domain) and sections of middle-outer orbital bus routes 901 (Knox City to Rowville), 902 (Nunawading to Springvale) and 903 (West Coburg to Box Hill). These weak spots are where buses are unlikely to be able to accommodate all travel opportunities assigned to them by the land use-transport system.

Figures 6, 7, 8: Network resilience maps for the Base, UBN 1 and UBN 2 scenarios, Melbourne 2036 (NOTE: If greater detail is required than visible by enlarging this document by 500%, please use these links for more magnification: [FIG 6 (BASE)], [FIG 7 (UBN 1)], [FIG 8 (UB 2)])



In the UBN 1 scenario, poor resilience scores that suggest a capacity limit is being reached emerge on some of the aforementioned rail segments as well as along the Springvale to Oakleigh section on the Dandenong line. No substantial relief occurs on any of the bus route segments already identified in a critically poor resilience category in the base scenario (see above) – instead these strained services are joined by other radial feeder lines in multiple locations (for example, Werribee Plaza, Melton Centre, Craigieburn Junction, Forest Hill Chase, Keysborough and Mornington) as well as several new orbitals that assume a prominent network function illustrating crucial connectivity gaps or service deficiencies in the base network. Examples include routes 550 (Yarra Flats-Camberwell-Caulfield), 560 (Northland-Fairfield) and 902 (Keon Park-Doncaster). Some tram segments experience resilience improvements, though in most cases this affects segments whose resilience scores are already quite high in the base scenario.

The UBN 2 scenario vastly improves the resilience performance on most of the rail network, largely by doubling daytime service frequencies from 10 to 5 minutes along the problematic inner sections of the Split Loop (Essendon to Cheltenham) and Viaduct lines (Coburg to Elsternwick), as well as Melbourne Metro 2 (Preston to Laverton), and by introducing 10-minute frequencies on the remaining four outer branches of Melbourne Metro 1 (Sydenham, Melton, Pakenham and Cranbourne). The resilience analysis shows, however, that this may still be insufficient on both CBD approaches of Melbourne Metro 2 and the southern one of Melbourne Metro 1. There is little relief for the bus segments already identified as poorly resilient in the previous steps. Simultaneously, there is a continued trend for tram segments to increase in resilience even though they already perform well on this index. In a comparison of the Base and UBN 2 scenarios, whose average resilience performance is similar, there is a general geographical tendency for problematic nodal resilience performance (below zero) to find relief in inner and CBD fringe locations (Carlton, Fitzroy, South Yarra, Prahran) and instead emerge in outer suburban areas particularly in Dandenong and Casey.

4. Discussion and Conclusion

The SNAMUTS analysis of the three 2036 scenarios for Melbourne's public transport-land use system has shown the following:

- The introduction of a Useful Bus Network (UBN) in addition to the PPTN bus lines already slated for SmartBus-style service standards in 2036 significantly expands the geographical coverage of walking-distance access to public transport, both at a minimum service level (20-minute frequencies or better) and at an advanced service level (facilitating reliance on public transport for most daily movement needs).
- An expanded UBN interacts extensively with the rail system by facilitating bus-rail transfer journeys. Without corresponding increases in rail frequencies over and beyond those already planned to occur by 2036, it is likely that these additional journeys will lead to passenger capacity limits being exceeded on some of Melbourne's most critical rail lines.
- Simultaneously, the interplay of bus and rail service improvements leads to a relative and absolute decrease in importance, and likely in crowding levels, of Melbourne's tram system.

There are several implications to these findings. First, as a greater number of Melburnians live or work in public transport 'accessibility hotspots', we can expect public transport usage rates to increase not just in proportion to the growing metropolitan population, but to the faster rate of growth in these high-accessibility areas. In other words, travel patterns reliant on public transport for daily movement needs (as known from large European or Asian cities) are likely to also become more widespread among Melbourne's residents and workers. This trend, described by Walker (2012) in the context of suburban areas gradually intensifying towards greater transit orientation, will add further pressure on the public transport network.

Conversely, it could be argued that the severe increase in potential overcrowding on the rail system shown by the SNAMUTS analysis may include an element of methodological exaggeration. Of the residents and employees outside the walkable catchments of minimum-standard bus services in the base scenario (44% of the metropolitan total), it is likely that some still manage to perform rail journeys by accessing stations either by car (park-and-ride, kiss-and-ride, ride sharing, taxi), bicycle, walks longer than 800 metres, or by using the lower-frequency feeder buses that currently ply many of the UBN routes. These potential users are not specifically accounted for in the SNAMUTS analysis – but nor are those who still remain outside the walkable catchments of the enlarged UBN network (30% of the metropolitan total) and may also resort to such alternative rail access methods.

Further, the COVID crisis and its impact on the acceptance of work-from-home arrangements may permanently redefine the nature of job commuting in some industries and result in a reduction of average trip-making rates between residence and workplace, and potentially also of secondary journeys to and from one of these locations (for example through more online shopping or by substituting video conferencing for face-to-face business meetings even between office settings). It is conceivable that such reductions in travel may counteract the extent of public transport overcrowding (as well as road congestion) in the future, though examining or modelling such patterns remains outside the scope of this paper.

Second, the dependence of a geographically expanded bus network on an extremely high standard of performance on the rail system (5-minute frequencies) translates into a need for additional public investment in substantial rail upgrades. The base scenario described in this paper already includes some capacity-enhancing major infrastructure measures whose implementation, and by 2036 at that, remains far from certain (such as the Split Loop line or Melbourne Metro 2). The UBN 2 scenario further adds to this list: it is likely that all-day five-minute frequencies on the affected lines would necessitate the removal or closure of all remaining level crossings (even those with minor streets such as Kensington, Ripponlea or Merri) as well as the grade separation of rail junctions (such as Sunshine or Dandenong).

Simultaneously, it is hard to conceive that this pathway towards a high-frequency rail network supported by a geographically expanded useful bus network really had a viable alternative. In metropolitan areas of comparable population size to Melbourne in 2036 in Asia and Europe (Hong Kong, Singapore, Barcelona, Madrid) and even some smaller ones (Vienna, Hamburg), all-day five-minute services (or better) on the core rail and metro network are a common standard, not as an act of generosity to the public, but as a critical requirement for keeping the public transport networks functional. It is plausible to assume that this condition would also apply to a larger, more public transport-oriented Melbourne in the future. Conversely, continuing to suppress easier access to the rail system by, incidentally or deliberately, failing to roll out a UBN to Melbourne's underserviced areas away from the rail corridors would not only sabotage policy goals to achieve a greater role for public transport in the interest of climate change mitigation and adaptation, but also further entrench an already existing socio-economic divide between the 'haves' and the 'have-nots' concerning public transport accessibility in Melbourne (see also Scheurer and Curtis, 2019; Lagura et al, 2011).

Third, this dilemma also extends to the role of the tram system in the future of Melbourne's mobility mix, which the scenarios handled in this paper show as declining in relative importance and improving in resilience while the bus and rail systems are subject to a mounting capacity crisis. In other words, will inner Melburnians enjoy the privilege of access to a relatively uncrowded, iconic transport system exclusively serving their (increasingly gentrified) neighbourhoods while those from outer areas will have to resort to travelling like sardines in the dominant system composed of a limited spinal rail network and its bus feeders, bursting at the seams?

Thus helping the tram system (or medium-capacity modes in general) maintain and expand their tasks within the public transport system of a fast-growing Melbourne becomes a third, critical element on the path to future-proofing the city's land use-transport system besides rail upgrades and a UBN. In inner areas, this can be achieved by significantly speeding up the existing tram system through priority measures and physical separation from traffic in order to reduce the travel time gap between tram journeys and equivalent bus-rail journeys (with the latter having become faster in the scenarios described above through frequency improvements and greater network density). Bus routes with poor resilience, particularly orbital ones, should be considered for both performance upgrades (higher speeds through priority measures and right-of-way) and capacity upgrades (conversion to medium-capacity modes such as bus rapid transit, trackless trams, street-level or elevated light rail), This helps to divert transport tasks away from the radial rail lines (Stone and Woodcock, 2017; RFI, 2019).

References

Currie G, Delbosc A (2014) Assessing Bus Rapid Transit system performance in Australasia. *Research in Transportation Economics,* Vol 48, pp 142-151

Currie G, Loader C (2010) Bus network planning for transfers and the network effect in Melbourne, Australia. *Transportation Research Record: Journal of the Transportation Research Board,* No 2145, pp 8-17

Curtis C, Scheurer J (2016) *Planning for Public Transport Accessibility. An International Sourcebook.* Routledge, Oxon, UK

Curtis C, Scheurer J (2021) *Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS)* website, available online at www.snamuts.com

[DELWP] Department of Environment, Land, Water and Planning (2017) *Plan Melbourne 2017-2050.* Available online at www.planmelbourne.vic.gov.au

[DELWP] Department of Environment, Land, Water and Planning (2019) *Victoria in Future 2019. Population Projections 2016 to 2056.* Available online at https://www.planning.vic.gov.au/land-use-and-population-research/victoria-in-future

[DOT] Department of Transport (2021) *Victoria's Bus Plan.* Available online at https://transport.vic.gov.au/getting-around/public-transport/buses#busplan

[DTF] Department of Treasury and Finance (2019) *Delivering for all Victorians: Victorian Budget 19/20, Service Delivery.* Available online at https://www.dtf.vic.gov.au/2019-20-state-budget/2019-20-service-delivery

Dodson J, Mees P, Stone J, Burke M (2011) *The Principles of Public Transport Network Planning: A review of the emerging literature with select examples.* Griffith University, Brisbane (QLD), Australia

Guerra E, Cervero R, Tischler D (2012) Half-Mile Circle. Does it best represent transit station catchments? *Transportation Research Record: Journal of the Transportation Research Board,* No 2276, pp 101-109

Kroen A (2019) *Transport Goals in the Precinct Structure Planning Guidelines.* Briefing Paper, RMIT University

Lagura E, Norman P, Richmond M, Watling R (2011) The public transport usage of two Melbournes. *34th Australasian Transport Research Form (ATRF),* Adelaide, September 2011

McLeod S, Scheurer J, Curtis C (2017) Urban Public Transport: Planning Principles and Emerging Practice. *Journal for Planning Literature,* Vol 32, No 2, pp 223-239

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

Nielsen G, Nelson J D, Mulley C, Tegnér G, Lind G, Lange T (2005) *Public Transport – Planning the Networks. HiTrans Best Practice Guide 2,* Civitas Consultants, Oslo, Norway

Parker P (2011) Bus service reform in Melbourne – the last 5 years. *34th Australasian Transport Research Form (ATRF),* Adelaide, September 2011

Parker P (2021) *Melbourne on Transit.* Blog available online at melbourneontransit.blogspot.com

Pemberton S (2020) Optimising Melbourne's bus routes for real-life travel patterns. *Case Studies in Transport Policy,* Vol 8, pp 1038-1052

[PTV] Public Transport Victoria (2012) *Rail Network Development Plan.* Available online at http://ptv.vic.gov.au/about-ptv/ptv-data-and-reports/network-development-plan-metropolitan-rail

[RFI] Rail Futures Institute Inc (2019) *The Melbourne Rail Plan 2020-2050: Public transport for a city of 8 Million.* Rail Futures Institute Inc, Carlton (VIC)

Scheurer J (2020) Public Transport Network Planning. Chapter 15 in Curtis C (ed) *Handbook of Sustainable Transport.* Edward Elgar Publishing, Cheltenham, UK, pp 139-149

Scheurer J, Curtis C (2019) Reducing social-spatial inequity with public transport in Melbourne, Australia. Chapter 3 in Hickman R, Mella Lira B, Givoni M, Geurs K (eds) *A Companion to Transport, Space and Equity.* Edward Elgar Publishing, Cheltenham, UK, pp 25-38

Scheurer J, Curtis C, McLeod S (2016) Making Melbourne's public transport network multi-directional: Can the associated accessibility boost mobilise latent potential for ridership and city-building? *38th Australasian Transport Research Forum (ATRF),* Melbourne (VIC), November 2016

Scheurer J, Woodcock I (2017) Trams and Politics in Melbourne: Managing complex adaptations. *8th State of Australian Cities Conference,* Adelaide (SA), November 2017

Stone J, Woodcock I (2018) *Transport Strategy Refresh - Background Paper.* City of Melbourne, Melbourne (VIC)

Vuchic V R (2005) *Urban Transit: Operation, Planning and Economics.* Wiley, Hoboken (NJ), USA

Walker J (2012) *Human Transit. How Clearer Thinking about Transit Can Enrich our Communities and our Lives.* Island Press, Washington (DC), USA