

**Stream:** Infrastructure

**Transforming Melbourne through Transit Oriented Intensification: Implications for public transport network performance, accessibility and development densities**

**1. INTRODUCTION**

This paper investigates the implications of a transit-oriented intensification scenario for public transport and the distribution of potential development densities in Melbourne. Recent research has looked at two models of transit-oriented intensification aimed at minimising the use of Greenfield land on the metropolitan fringe – along existing road-based transit corridors (Adams 2009) and within activity centres, railway stations and tram corridors (Woodcock et al 2009, 2010). Both models share the same conceptual basis of tightly constraining the spatial distribution of projected population growth to the land directly associated with Melbourne's public transport system. Their virtues have been promoted as affecting only a very small proportion of the urbanised area, requiring only modest increases in heights, expanding areas of urban vitality and potentially accommodating significantly larger population growth than currently projected without further encroaching on Greenfield land at the urban fringe.

Questions have been raised, however, about the capacity of the public transport system to absorb the anticipated surge in usage that comes with transit-oriented urban intensification. To address these concerns, we will use the Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool (Scheurer 2009) to assess the likely impacts of the intensification scenarios on Melbourne's public transport at current levels of service, and the correlations between urban growth and patterns of stress on specific public transport nodes and corridors. Utilising a range of future visions for Melbourne's public transport, SNAMUTS will also demonstrate how urban density distribution and public transport network and service configuration can be optimised to maximum mutual benefit, and thus meet the broader planning and design aims of a low-carbon city.

In section 2, we will elaborate on the assumptions on patterns of urban intensification that form the basis of the accessibility assessment undertaken by the SNAMUTS tool. A new SNAMUTS indicator designed to quantify network stress will be introduced in section 3, before being utilised to analyse the impacts of land use intensification in conjunction with several scenarios for future public transport network and service configurations in 2030 (section 4). In conclusion, we will reflect on the findings, their implications for urban movement and place quality, and on the broader suitability of the SNAMUTS stress index for measuring these conditions accurately and meaningfully.

**2. URBAN INTENSIFICATION IN MELBOURNE**

The basis for modelling in this paper is the transit-oriented intensification scenario where all population growth between 2010 and 2030 projected in Melbourne 2030 and its update Melbourne @ 5 Million (approximately 600,000 dwellings) is contained within higher-order activity centres, rail station precincts, along tram routes and the 903 SmartBus corridor (see Woodcock et al 2010 for a detailed description of parcel selection and assumptions). This model is premised on current planning system constraints and was set up as a way of investigating a number of issues, including parameters for as-of-right planning overlays to facilitate high quality, low-rise higher-density development in very close proximity to good public transit, along with streetscape modelling to test resident perceptions and acceptance of the types of streetscapes that could result (Woodcock et al 2012). In line with other studies using a similar approach (Adams et al 2009), the land required for accommodating the projected population growth occupies a very small proportion of the built-up metropolitan area – in this instance, 7% - and crucially, excludes land covered by heritage overlays or any other planning controls that would complicate development processes or suggest that high levels of resident resistance would be aroused.

For the purposes of utilising the SNAMUTS tool, slight revisions to the residential density figures in this model have been made, such that the average net target density becomes 180 dwellings per hectare (including existing dwellings on the sites identified). This is well within the 100-300 DU/Ha range that our research found can be achieved on such sites within heights of 3-5 storeys (Woodcock et al 2010:98). Additionally, given the potential for SNAMUTS to take into account likely concentrations of higher-density development and market-related variations, we assumed that development take-up

rates would vary on the basis of SNAMUTS scores for activity nodes catchments in the Status Quo network with 2010 land use as follows: Where the composite score is 20 or above, the take-up rates would be 100% of properties (by land area) or density target; where the composite score is between 15 and 20, take-up rates would be 80%; where the composite score is between 10 and 15, take-up rates would be 60%; and where the composite score is below 10 (but higher than 0) take-up rates would be 40%. On land parcels currently zoned as railway land (PPZ4) regardless of SNAMUTS composite score, take-up rates would be 10%. The rationale for this distribution is twofold. Firstly, it optimises as far as possible the local relationships between land-use intensity and transit capacity; secondly, it acknowledges that while the largest proportion of land available for this type of development is on railway-zoned land, development at the kinds of intensity envisaged on more than 10% of the land would require significant state intervention to achieve the co-ordination necessary for comprehensive redevelopment in most places (see Woodcock et 2010:96-97 for detailed explanation).

### **Two scenarios for employment distribution – ‘prop’ and ‘trend’**

The original assumption of the latent intensification capacity modelling was that jobs would be distributed proportionally with intensification, an approach referred to here as ‘Scenarios Prop’. These scenarios imply employment growth between 2010 and 2030 (approximately 400,000 jobs in total) to be co-located proportionally with the residential growth identified above (approximately 4 new jobs per 10 new residents), leading to a CBD share of only 15,000 additional jobs. However, for this paper, we added another employment distribution possibility – ‘Scenario Trend’ – which implies employment growth between 2010 and 2030 being geographically distributed in line with the current trend, including 135,000 additional jobs in the CBD.

### **3. SPATIAL NETWORK ANALYSIS AND NETWORK STRESS**

The Spatial Network Analysis for Multimodal Urban Transport Systems (SNAMUTS) tool has been developed since 2006, initially in the context of several consultancy research collaborations on public transport accessibility and integrated land use-transport planning between RMIT University, Curtin University and public agencies in Perth and Melbourne (Curtin and Scheurer, 2010). Since 2008, further collaborations with researchers at the Technische Universität Hamburg-Harburg (Germany), Universidade do Porto (Portugal), Aalborg Universitet (Denmark) and Universiteit van Amsterdam (Netherlands) have enabled the application of SNAMUTS to various European cities. Since 2011, it forms the basis of an ARC Discovery grant aiming at strengthening and diversifying the tool by applying it to a suite of 25 cities across Australasia and worldwide.

SNAMUTS consists of a set of six core indicators, reflecting the significance of different angles on spatial accessibility to arrive at a comprehensive and valid understanding of the concept (Porta et al, 2006a, 2006b; Scheurer and Porta, 2006). The tool applies these indicators to the public transport network servicing a defined geographical entity and conforming to a minimum service standard (which in the Melbourne case is set at a 20-minute service frequency during the weekday interpeak period, and a 30-minute frequency during the day on Saturdays and Sundays). It is based on a matrix of activity nodes found across the network and representing spatial concentrations of urban activities (origins and destinations, measured in number of residents and jobs within a node’s local catchment). This list is derived from the activity centre hierarchy in strategic planning documents such as Melbourne 2030 (DOI, 2002) and Melbourne @ 5 million (DPCD, 2008) but in some cases also includes smaller activity nodes that have an important role as public transport hubs, or divides activity centres into several activity nodes where public transport access is provided in two or more separate locations. For example, Melbourne’s CBD (Hoddle Grid) contains 23 separate SNAMUTS activity nodes, reflecting the five City Loop rail stations and the dense grid structure of the tram and bus network in this area (Scheurer, 2009).

The six core SNAMUTS indicators are concerned with:

- the ease of movement across the network, expressed by a travel impediment measure consisting of travel time and service frequency (closeness centrality);
- the transfer intensity of the network (degree centrality);
- the percentage of metropolitan residents and jobs accessible within a fixed 30-minute travel time budget (contour catchment);
- the competitiveness of public transport with the car in terms of node-to-node travel times (speed ratio);
- the geographical distribution across network elements of travel opportunities, generated by the interplay of land use and public transport (betweenness centrality); and

- the ability of nodes to act as hubs and connectors for multi-directional movement (nodal connectivity).

SNAMUTS is a supply-side analytic tool; it is designed to provide quantitative accessibility measures as a discursive basis for promoting land use-transport integration in strategic planning (Curtis and Scheurer, 2010). As such, the tool does not attempt or pretend to represent current patronage levels or forecast future ones, nor to provide robust usage figures that could inform tactical decisions for possible capacity modifications along route segments or at transport interchanges. Rather, its utility is on a strategic level, querying the geographical configuration, route density, location and quality of transfer points, and interplay of transport modes with different characteristics across the network as a whole. Similarly, SNAMUTS can capture the effects on accessibility that derive from the concentration (or not) of land use activities, particularly residents and jobs, around public transport facilities. The tool thus highlights the coincidence of node and place functions at network hubs, the key constituent components of spatial accessibility (Bertolini, 2005) and responds to changes in this relationship over time.

The betweenness index in particular expresses this relationship: it shows how travel opportunities derived from land use activities in public transport catchment areas (the place function) are distributed across the network by tracing the travel paths users may prefer following ease of movement (travel times and service frequency) and transfer intensity. Betweenness centrality counts the number of preferred network paths that pass through each route segment, weighted by the importance of the path as determined by the size of the activity node catchments at either end, as well as the proximity of the nodes to each other. The indicator thus depicts the strategic significance of each route segment and node for the functioning of the network as a whole, in proportion to the strength of land uses influencing each trip relation and can provide some insights into how well the structure of the network responds to the movement tasks the urban structure generates. It also allows for reflections on the most significant weak spots, underutilised potential and whether future plans to modify the network are suitable to address these.

From this detailed supply-side assessment of network performance potential, a network stress indicator has recently been developed in the context of a SNAMUTS study informing the 2011 update of the City of Melbourne transport strategy (Scheurer, 2011). The purpose of applying this new index to a range of public transport network configurations is to identify which network elements (route segments) currently or in the future bear a greater, equivalent or lesser degree of strategic significance than their carrying capacity, defined as the number of passengers per hour per direction that can reasonably be moved over the route segment in question with the mode (or combination of modes) and service frequency offered during the weekday interpeak period.

As described above, the strategic significance for facilitating travel opportunities across the network is expressed by the betweenness centrality index. The stress index uses a segmental betweenness index, ie. it measures the concentration of travel opportunities along route segments (rather than through activity nodes as in the nodal betweenness measure used for calculating the SNAMUTS composite index). This procedure enables us to calculate a ratio of betweenness centrality to the actual number of passengers that the public transport service can carry along the segment. Carrying capacity depends on service frequency and on the mode offered. Trains (assumed at 600 passengers) have a greater carrying capacity than trams (100 passengers in 2010), which in turn have a greater carrying capacity than buses (50 passengers). Note that these assumptions represent full-length (six-car) train sets and average values for surface modes, especially trams which come in a range of different-sized vehicles in Melbourne and will be subject to change in the future as the fleet is renewed (and for which reason the average carrying capacity for a tram in 2030 is assumed to be 150 passengers). They also take into account that it is generally more acceptable and less uncomfortable to spend a certain portion of the journey standing when travelling on rail-based vehicles (trains and trams) than on road vehicles (buses).

Map 1 shows the segmental congestion index for Melbourne's inner region in the Status Quo (2010) network with the current density and distribution of residents and jobs. The scale for the stress figures on each route segment is arbitrary, but is kept constant through all stress maps in this paper for valid comparability. The segments are marked in traffic light colours, with red segments indicating high stress and green segments indicating low stress.

The highest-stress network segments in inner Melbourne, according to this index, can be found on the bus system, particularly on the central city approach of the Doncaster area SmartBus routes (905-908), route 246 along parts of Hoddle Street, route 216/219 between Footscray and Southbank/St Kilda Road, and routes 200-207 along Johnston Street and Studley Park Road. On the tram system,

the Elizabeth Street-Flemington Road-Mount Alexander Road corridor along route 59 stands out as the most stressed network element, followed by the Wellington Parade-Bridge Road corridor along routes 48 and 75, and parts of St Kilda Road. The train system generally displays lower relative levels of stress than the aforementioned tram and bus routes, but among the approach routes to central Melbourne, the Caulfield to Richmond corridor has the highest figures, followed by the Camberwell to Richmond and Footscray to North Melbourne corridors.

Relatively low levels of stress are present along much of the Werribee, Sydenham, Craigieburn, Upfield and Glen Waverley train lines, on trams along Latrobe Street, Chapel Street, in the Docklands area and around South Melbourne, and on bus routes 250-251 as well as route 246 between Richmond and St Kilda Junction.

**Map 1: Segmental congestion index on inner Melbourne's public transport network in the Status Quo (2010) with current land use patterns.**

$$SC_k = \frac{\sum (p_{ij}(k) \cdot (act_i \cdot act_j) / L_{ij})}{(100 \cdot f_k \cdot C_k)} \quad [1]$$

where:

$SC_k$  = Segmental congestion index of segment  $k$

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

$act_i$  = Number of residents and jobs in catchment area of node  $i$

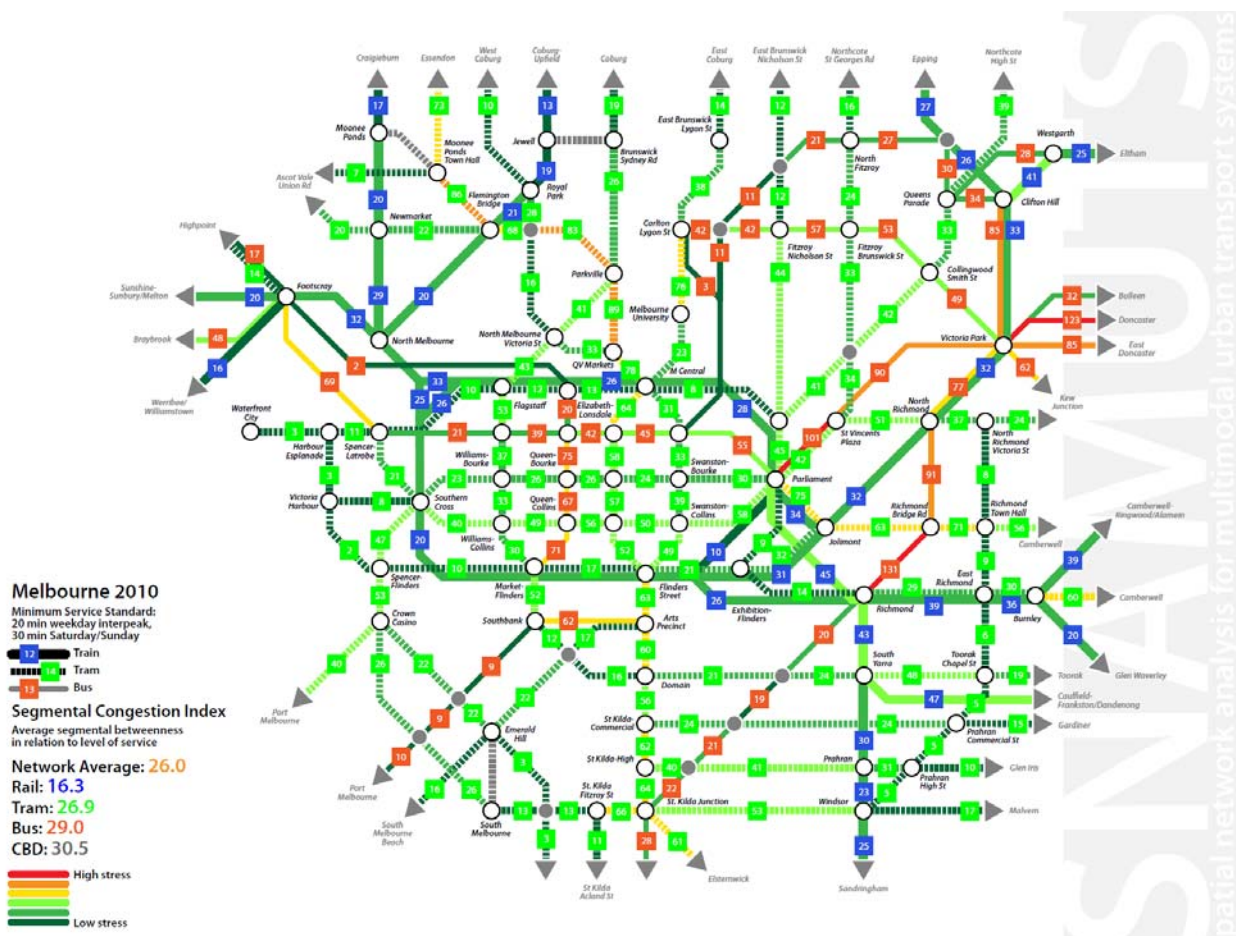
$act_j$  = Number of residents and jobs in catchment area of node  $j$

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

$f_k$  = Service frequency along route segment  $k$

$C_k$  = Modal coefficient for route segment  $k$  (train = 600, tram = 100 (2010), tram = 150 (2030), bus = 50)

$N$  = All activity nodes in the network



Segmental congestion is an index that derives its concept of stress from the number and geographical distribution of *travel opportunities* the transport system obtains from the land use system. For this reason, high stress levels on this indicator do not necessarily correspond with actually observed

instances of overcrowding along particular routes, or conversely, low stress levels need not always indicate ample spare capacity on the route segments in question. Beyond land use concentration and ease of movement on the public transport system (the variables that make up the betweenness index), actual usage of public transport is further influenced by factors such as the competitiveness of other transport modes (in terms of speed, availability and/or user cost), the legibility of the network (and thus the ability of passengers to easily pick the most effective journey path as suggested by the SNAMUTS analysis), and the propensity of users to respond to chronically overcrowded and hence possibly unreliable services by selecting alternative routes or transport modes that offer greater convenience.

Another critical characteristic of the stress index is its dynamic reference to public transport levels of service, in that travel impediment (travel times and service frequency) in itself determines the number of travel opportunities offered along a particular route or route segment. For this reason, route segments are not necessarily relieved from high stress on this index by simply increasing the service frequency, since the additional services also increase the travel opportunities in this area. Nor do routes segments with low stress necessarily develop a more balanced ratio between travel opportunities and service level if the latter is reduced. Instead, the segmental congestion index puts far greater emphasis on the way the network hangs together as a system, and how the role and interplay of different modes with different carrying capacities can be optimised to mutual benefit.

#### **4. NETWORK STRESS IN 2030**

This section examines how network stress evolves under the influence of a land use strategy that accommodates all residential growth over the next two decades in designated higher-order activity centres (with a minimum level of service as defined by SNAMUTS), rail station precincts and along public transport corridors with intensification potential (Woodcock et al, 2010), as elaborated in section 2. Three public transport network scenarios have been adapted from the background work associated with the City of Melbourne transport strategy (Scheurer, 2011) – referred to as Status Quo, Combination and Target. The Status Quo scenario assumes that network configuration and service levels will remain unchanged between 2010 and 2030; while this is not necessarily realistic (or even politically palatable), the function of this scenario is to investigate the effect on network performance and network stress of a ‘do-nothing’ base-case. The first of the remaining two scenarios – Combination - consists of a suite of measures aimed at generating standardised 10-minute (or better) service frequencies across most of the rail network, the entire tram network and many core bus routes (with many further bus routes operating every 20 minutes and thus meeting the SNAMUTS minimum service standard). The Combination scenario further assumes travel time reductions across the surface network of 15%, and of 25% on tram routes operating in mixed traffic, as well as physical interventions in 20 activity centres to improve the connectivity between trains, trams and buses where this is currently absent or sub-optimal. It further includes some infrastructure measures already under construction, such as the suburban rail extensions to Sunbury and South Morang.

The Target scenario includes all the measures from the Combination scenario, and additionally assumes the implementation of a major package of new public transport infrastructure. Among these are the north-south rail tunnel linking Footscray/Kensington and Caulfield along the Parkville-St Kilda Road corridor, suburban rail extensions to Wyndham Vale, Melton, Tullamarine Airport, Mernda and Rowville, as well as links between Victoria Park and Ringwood via Doncaster and Alamein and Caulfield via East Malvern and Chadstone. Five new orbital tram routes and a host of initiatives to optimise existing tram and bus routes are also included. For a detailed list of measures refer to the relevant sections in the City of Melbourne document (Scheurer, 2011).

This choice of scenarios is intended to answer the following questions: How do both network performance and network stress increase as more land uses are added to the existing public transport catchments? What is the impact of network and service upgrades in reinforcing or mitigating these effects? And are (less expensive) service, traffic and place management measures (Combination scenario) sufficient to achieve better network performance as well as reduced stress, or are (more expensive) major infrastructure upgrades (Target scenario) also required to cope with these impacts?

Maps 2 and 3 show the stress levels on inner Melbourne route segments under the assumption that the 2010 network configuration and service levels remain unchanged while urban intensification is added in activity centres, station precincts and along transit corridors as detailed in section 2. Map 2 depicts segmental congestion under the assumption that job growth follows the current spatial trend with a strong focus on the CBD and CBD fringe areas (Scenario Status Quo Trend), while Map 3 assumes decentralisation of future employment growth proportional to the distribution of residential

intensification in activity centres, rail station precincts and along transit corridors, but generally away from the CBD (Scenario Status Quo Prop).

The average measure for segmental congestion across the network more than doubles over the current value (26.0, see Map 1) in both 2030 scenarios. This is associated with a hike in the global betweenness index from a current value of 676 by a factor of 2.6 to 1,738 in the Status Quo Trend scenario, and by a factor of 2.1 to 1,430 in the Status Quo Prop scenario. While these figures suggest a shift by orders of magnitude in terms of both the significance of public transport for urban movement (global betweenness) and potential network congestion (stress index), they should also be seen in the context of and in relation to the shift anticipated within policy of overall public transport patronage and mode share. Victorian government policy has long advocated a 20% share of public transport among motorised trips in the year 2020 (DOI, 2002); taking into account population growth, this target requires total annual public transport journeys in metropolitan Melbourne to treble between 2000 and 2020 (Scheurer et al, 2005). By 2010, such journeys had grown by about 50% over 2000 levels, a pace of growth that will need to double during the 2010s to achieve the target; extrapolating this trend further into the future would require a three-fold increase in absolute public transport trips between 2010 and 2030.

Against this background, global betweenness factors growing by magnitudes of 2.1 or even 2.6 times fall short of serving the needs of a more public transport-oriented city. The implication is that the current public transport network configuration and service levels will be unable to serve a significant portion of the travel needs that a 2030 land use-transport system is expected to generate, even under the assumption made in this exercise that urban growth is restricted to highly transit-oriented areas, and that it will be unable to deliver on the mode share targets of current public policy. This could become manifest in a significant share of 'suppressed demand' on public transport, ie. journeys that have to be made by other modes that may be less convenient, equitable or affordable, or journeys that are limited to a smaller choice of destinations. Both effects result in poorer accessibility for users.

But do these scenarios also result in disproportionate congestion on the network? Both land use scenarios have quite similar metro-wide averages for network stress, but they differ across the modes and geographical areas. In the Status Quo Trend scenario, there is a much higher stress level across CBD segments than in the Status Quo Prop scenario, associated with a greater concentration of employment there; conversely, the Status Quo Prop scenario further exacerbates a trend already set in the Status Quo Trend scenario that sees the bus network experience by far the highest stress levels of all three modes. On the first count, it could be argued that decentralising employment alongside residential intensification in transit-oriented redevelopment sites (Status Quo Prop) distributes the increase in network stress more evenly across the inner area than maintaining the current focus of job growth in or near the CBD. But conversely, it could be argued that doing so in the absence of major boosts to public transport network structure and service levels will make itself felt most prominently on the mode that has the lowest capacity and is hence least prepared for taking on large-scale additional transport tasks.

**Map 2: Segmental congestion index on inner Melbourne's public transport network in the Status Quo Trend network with 2030 land use patterns (transit-oriented residential intensification and employment growth distribution according to current trend).**

**Map 3: Segmental congestion index on inner Melbourne's public transport network in the Status Quo Prop network with 2030 land use patterns (transit-oriented residential intensification and employment growth distribution proportional to residential growth).**

**Melbourne 2030**  
Residential intensification along transit corridors  
Job growth following spatial trend

Minimum Service Standard:  
20 min weekday interpeak,  
30 min Saturday/Sunday

172 Train  
106 Tram  
15 Bus

**Segmental Congestion Index**

Average segmental betweenness  
in relation to level of service

Network Average: 54.0

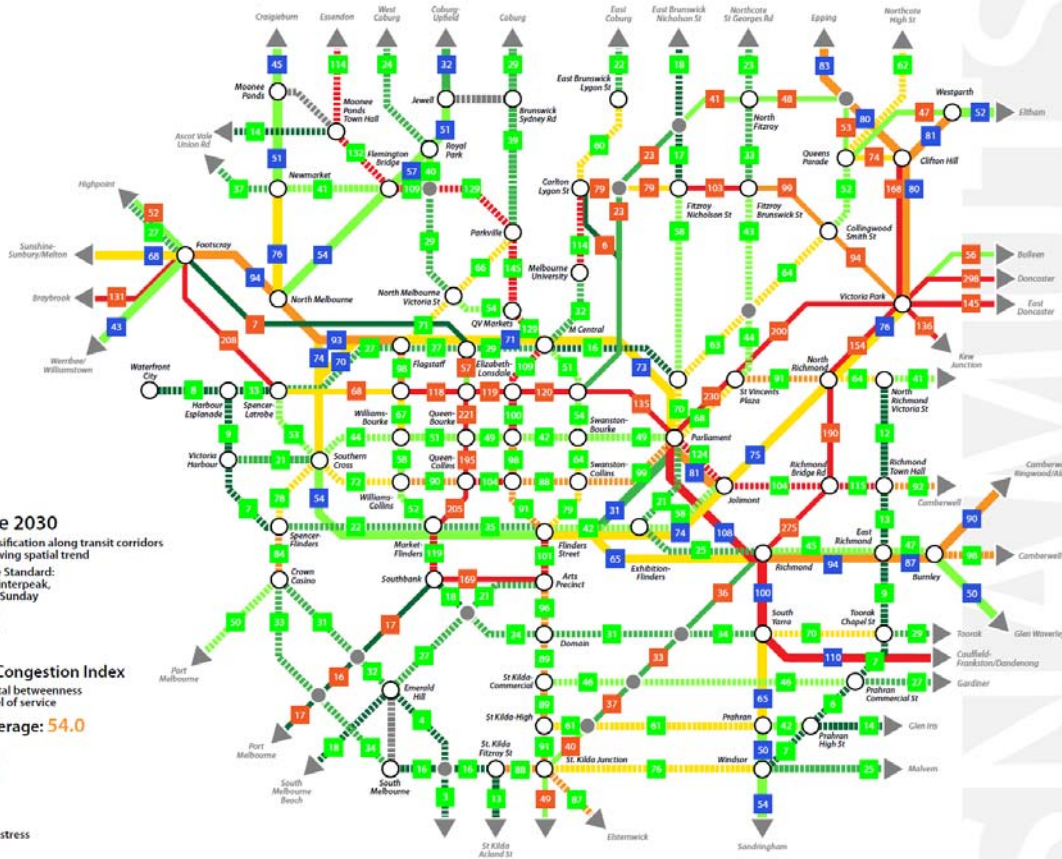
Rail: 40.6

Tram: 42.9

Bus: 67.4

CBD: 65.2

High stress  
Low stress



**Melbourne 2030**  
Residential and employment intensification  
along transit corridors

Minimum Service Standard:  
20 min weekday interpeak,  
30 min Saturday/Sunday

172 Train  
106 Tram  
15 Bus

**Segmental Congestion Index**

Average segmental betweenness  
in relation to level of service

Network Average: 55.7

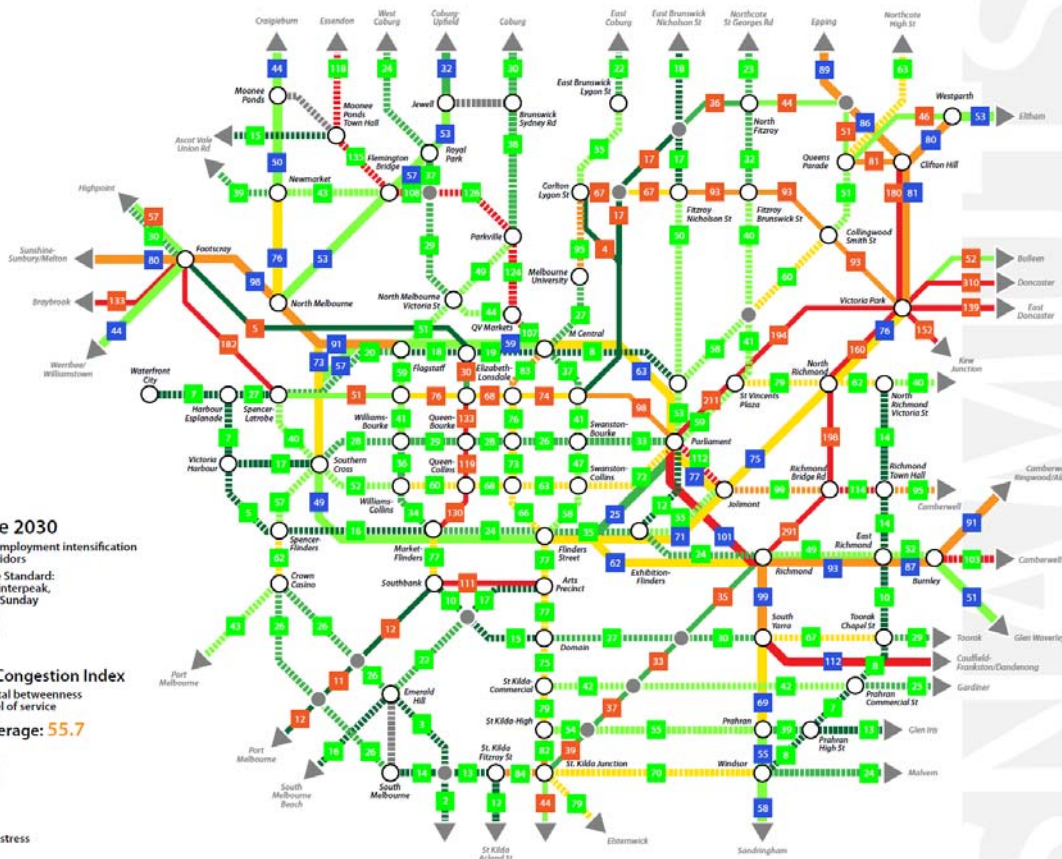
Rail: 41.6

Tram: 40.9

Bus: 72.0

CBD: 51.3

High stress  
Low stress



Spatial network analysis for multimodal urban transport systems

Large-scale transit-oriented urban intensification without changes to public transport network structure and service levels is thus likely to result in substantial congestion effects across major parts of the network, while not generating the accessibility gains required to meet even the relatively modest mode share target enshrined in policy. But can either shortfall be solved by improving the public transport supply?

Maps 4 and 5 show the segmental congestion levels across inner Melbourne in the Combination scenario, ie. following a package of improvements to public transport service frequency, tram and bus travel times and intermodal connectivity in key network hubs, but no large-scale expansion of public transport infrastructure. Again, two land use scenarios are considered, differing by the geographical distribution of future job growth (Combination Trend and Combination Prop). Similar to the previous comparison of the two Status Quo scenarios with 2030 land use, the Combination Trend scenario (at 2,510) achieves a higher global betweenness score than the Combination Prop scenario (at 2,164), or in other words a greater number of overall public transport travel opportunities generated by the transport-land use system. In both scenarios, however, this figure grows by an increment over the Status Quo with 2010 land use (676) that is greater than the envisioned three-fold growth factor in patronage until 2030. The much improved network in the Combination scenario is thus on track to meet the accessibility requirements implied by the 20/2020 mode share target and hence the anticipated, greatly expanded role for public transport in the mobility mix of Melbourne. However, what price can public transport users expect to pay for this privilege in terms of network stress?

It is remarkable that network-wide average stress levels drop only very slightly in the Combination scenarios over the Status Quo with 2030 land use scenarios, from 54.0 to 53.4 in the Trend case and from 55.7 to 53.8 in the Prop case. For trains and trams, stress levels go up quite markedly while buses experience some relief, though only in outer areas while segmental congestion in and around the CBD area increases across all modes. It appears as though the accessibility gains associated with frequency, travel time and connectivity improvements translate into an even greater gain in the number of travel opportunities offered by the network, which could perhaps be considered a positive synergistic outcome were it not associated with a looming capacity crisis on many central area approach routes (particularly along the Sydenham, Craigieburn, South Morang, Ringwood, Dandenong and Sandringham rail lines, as well as the Doncaster SmartBus routes, trams 59 and 112 and many other bus and tram routes within or near the CBD).

**Map 4: Segmental congestion index on inner Melbourne's public transport network in the Combination Trend network with 2030 land use patterns (transit-oriented residential intensification and employment growth distribution according to current trend).**

**Map 5: Segmental congestion index on inner Melbourne's public transport network in the Combination Prop network with 2030 land use patterns (transit-oriented residential intensification and employment growth distribution proportional to residential growth).**

### Melbourne 2030 Combination Scenario

Residential intensification along transit corridors  
Job growth following spatial trend

Minimum Service Standard:  
20 min weekday interpeak,  
30 min Saturday/Sunday

172 Train  
160 Tram  
15 Bus

#### Segmental Congestion Index

Average segmental betweenness  
in relation to level of service

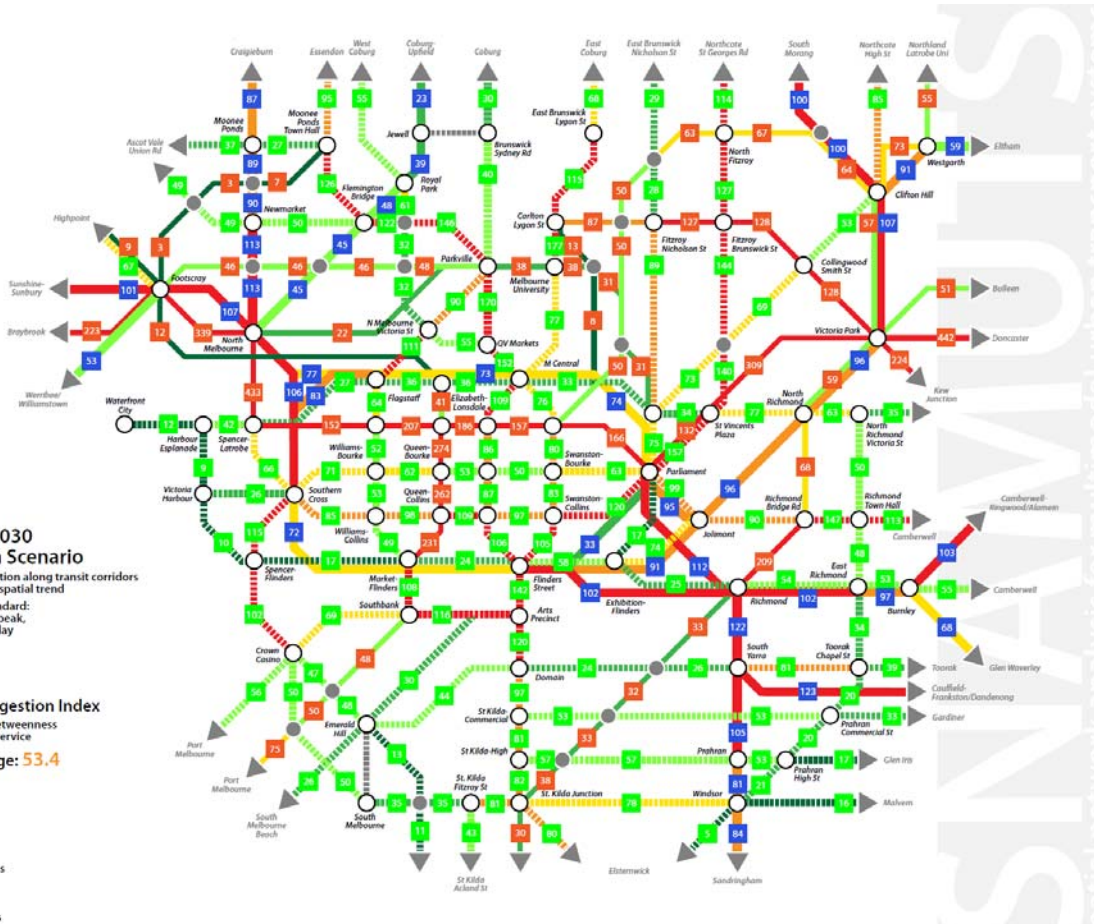
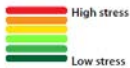
Network Average: 53.4

Rail: 52.5

Tram: 57.9

Bus: 52.1

CBD: 72.3



### Melbourne 2030 Combination Scenario

Residential and employment intensification  
along transit corridors

Minimum Service Standard:  
20 min weekday interpeak,  
30 min Saturday/Sunday

172 Train  
160 Tram  
15 Bus

#### Segmental Congestion Index

Average segmental betweenness  
in relation to level of service

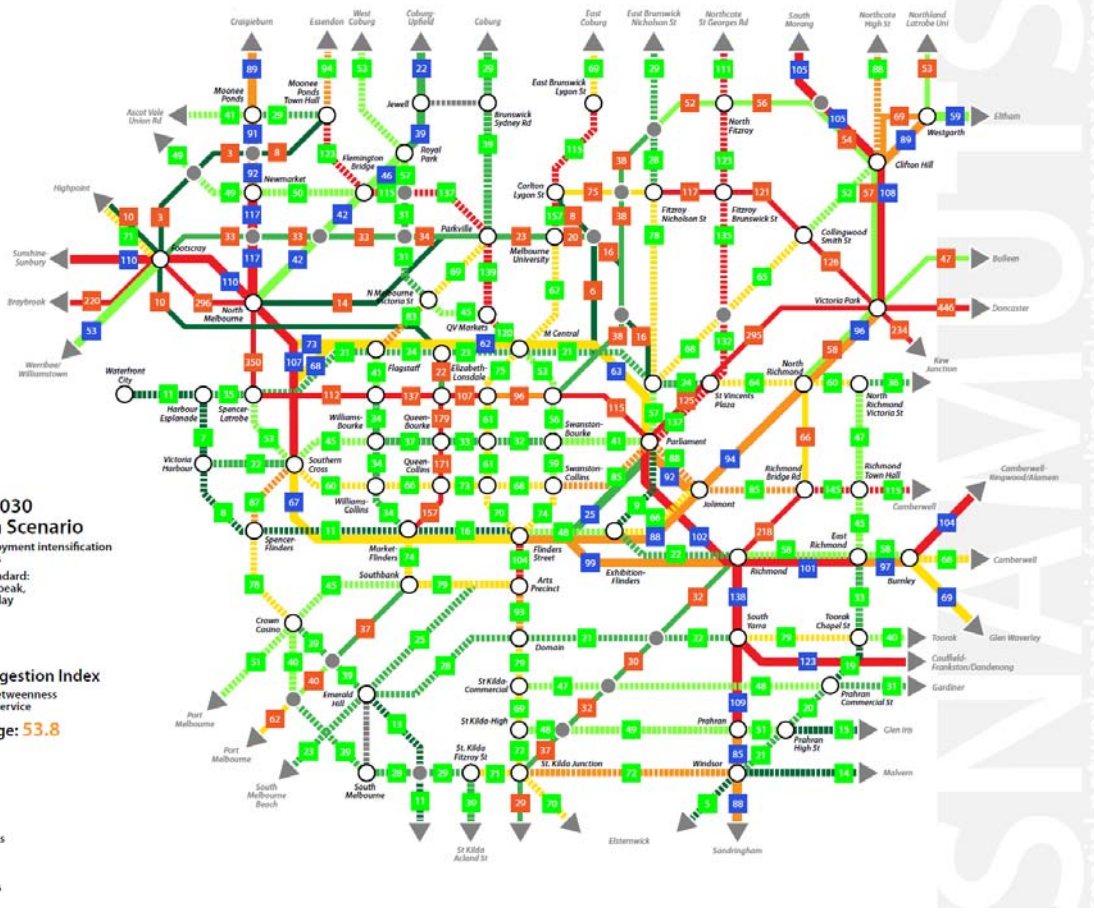
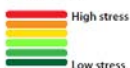
Network Average: 53.8

Rail: 52.4

Tram: 54.6

Bus: 53.7

CBD: 55.8



Spatial network analysis for multimodal urban transport systems

This situation suggests that while the Combination scenarios may provide a level of spatial accessibility that appears adequate for the vast majority of places with concentrations of additional land uses around public transport facilities, they do so by relying excessively on modes with insufficient carrying capacity for the associated transport tasks, and perhaps on too low a number of higher-capacity routes in locations that are vulnerable to congestion. All of these observations lead to an obvious question: can major additional infrastructure aimed at boosting public transport capacity by orders of magnitude provide some tangible relief here, bearing in mind that such measures will also generate additional travel opportunities that potentially add to network stress?

This question is investigated in Maps 6 and 7 that show the segmental congestion levels for inner Melbourne under the Target scenarios, again via differentiating the two land use cases of Target Trend and Target Prop according to the spatial distribution of new employment. Global betweenness scores, as a proxy for the total level of accessibility generated by the land use-transport system, is indeed higher than in the Combination scenarios but not by much; when considering the expansion of the network across a number of new, mostly outer suburban nodes, the average betweenness figures per node remain comparable in both land use cases (Table 1). There is, however, a tangible drop in network stress levels, across the board by about 10 points to a network average of 43.6 (Target Trend) and 43.9 (Target Prop) as well as across all three modes, most significantly the bus system which is relegated to the roles it can fulfil best following the conversion of several high-stress bus routes to rail or tram operation in this scenario.

This is not to say, of course, that the Target network was free of elements with critical stress levels. The new north-south rail tunnel, the Clifton Hill group of existing rail lines (with third branch from Doncaster added) as well as the new east-west tram route through the inner north linking Highpoint and Clifton Hill in particular stand out as attractors of travel opportunities whose number may well outstrip these routes' carrying capacity. On the one hand this circumstance confirms these network additions as highly worthwhile in a business sense; on the other hand it raises the question whether their capacity should not be increased further from the outset. This could be achieved by catering for larger vehicles (such as 9-car train sets in the north-south tunnel and dual traction trams on the Highpoint to Clifton Hill link), and by considering whether the Doncaster rail branch should be extended into the city on exclusive tracks in the long term.

**Map 6: Segmental congestion index on inner Melbourne's public transport network in the Target Trend network with 2030 land use patterns (transit-oriented residential intensification and employment growth distribution according to current trend).**

**Map 7: Segmental congestion index on inner Melbourne's public transport network in the Target Prop network with 2030 land use patterns (transit-oriented residential intensification and employment growth distribution proportional to residential growth).**

### Melbourne 2030 Target Scenario

Residential intensification along transit corridors  
Job growth following spatial trend

Minimum Service Standard:  
20 min weekday interpeak,  
30 min Saturday/Sunday

12 Train  
16 Tram  
19 Bus

#### Segmental Congestion Index

Average segmental betweenness  
in relation to level of service

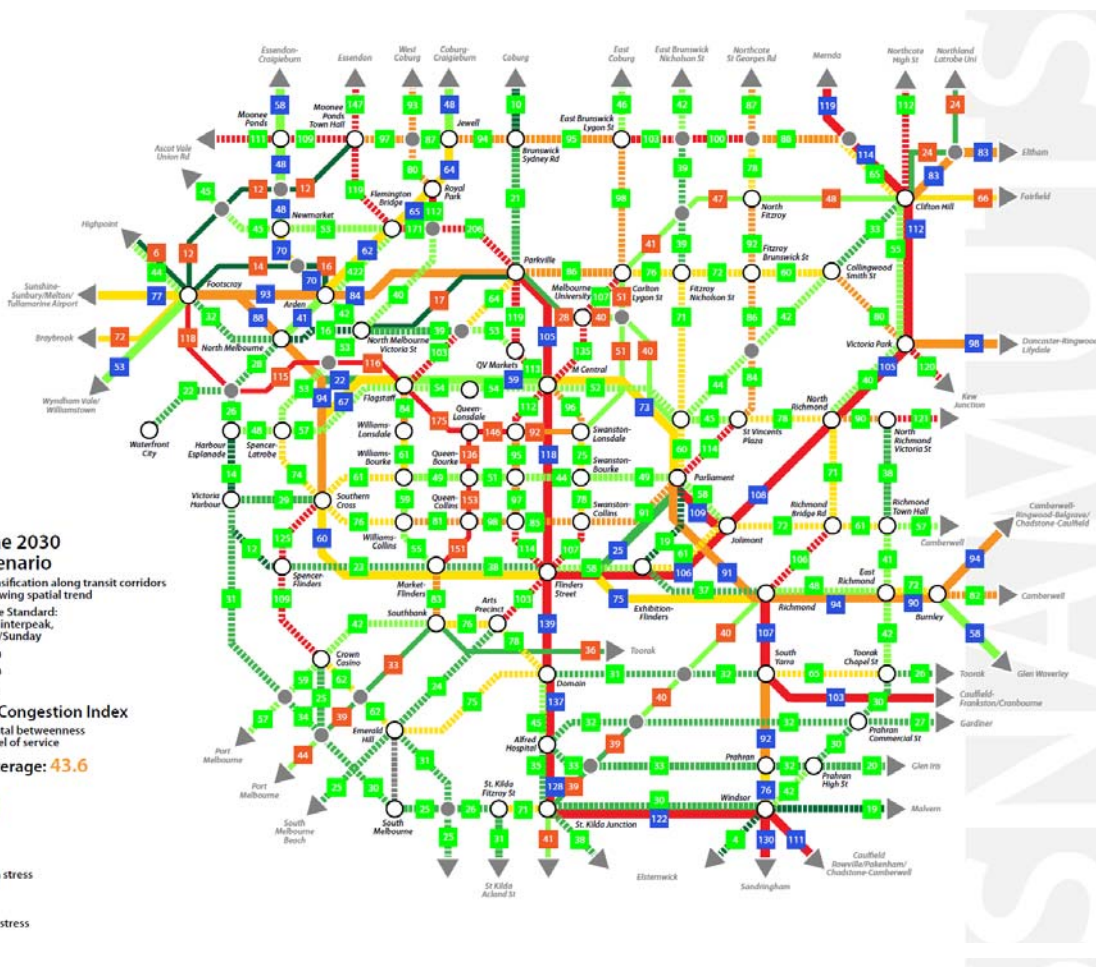
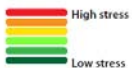
Network Average: 43.6

Rail: 47.6

Tram: 54.1

Bus: 38.4

CBD: 70.2



### Melbourne 2030 Target Scenario

Residential and employment intensification along transit corridors

Minimum Service Standard:  
20 min weekday interpeak,  
30 min Saturday/Sunday

12 Train  
16 Tram  
19 Bus

#### Segmental Congestion Index

Average segmental betweenness  
in relation to level of service

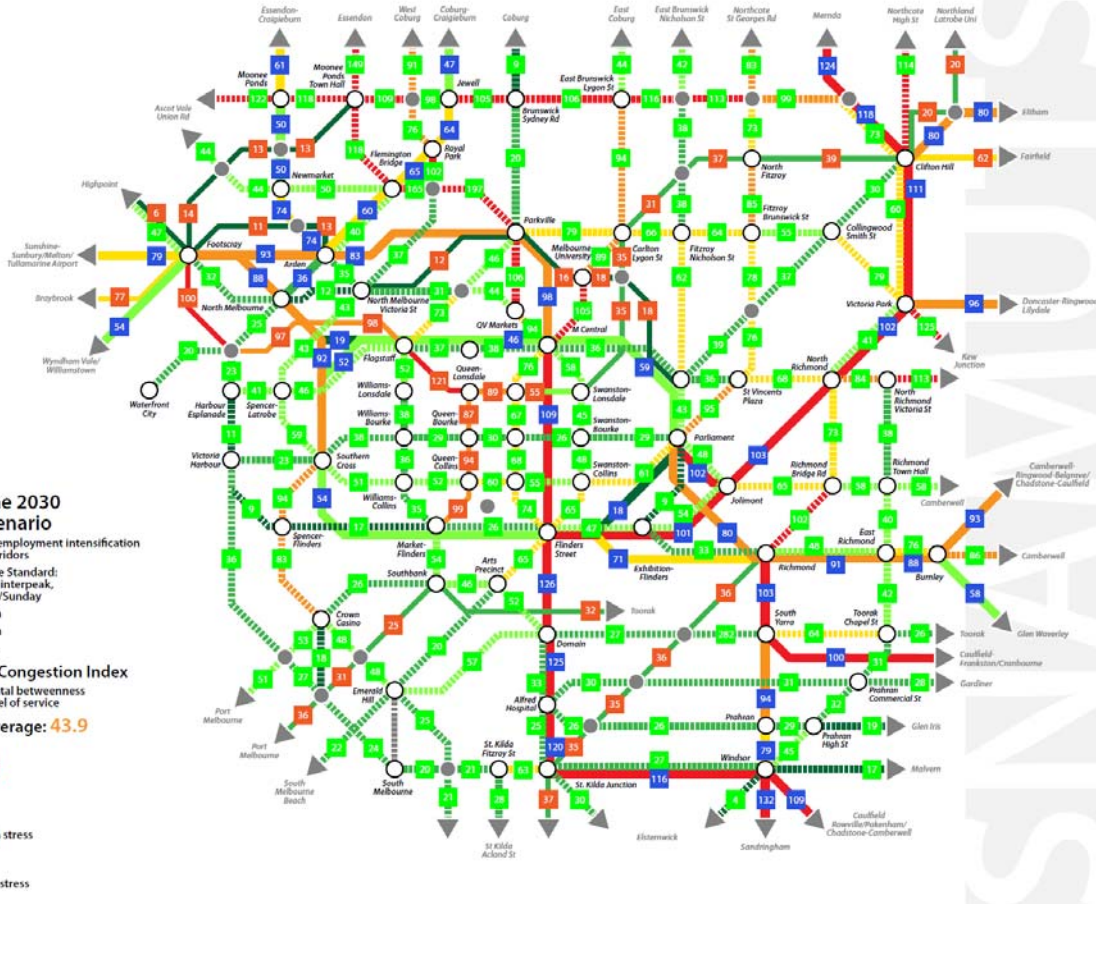
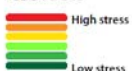
Network Average: 43.9

Rail: 46.6

Tram: 52.3

Bus: 39.9

CBD: 53.5



spatial network analysis for multimodal urban transport systems

**Table 1: Overview of SNAMUTS betweenness and stress index results in the Status Quo (2010) and six future scenarios.**

Indicator	2010 Status Quo	2030 Status Quo Trend	2030 Status Quo Prop	2030 Combination Trend	2030 Combination Prop	2030 Target Trend	2030 Target Prop
Global Betweenness	676	1,738	1,430	2,510	2,164	2,666	2,368
Nodal Betweenness, Average	23.3	57.5	52.2	77.7	71.7	77.8	72.9
Network Stress Index, Average	26.0	54.0	55.7	53.4	53.8	43.6	43.9
Network Stress Index, Train	16.3	40.6	41.6	52.5	52.4	47.6	46.6
Network Stress Index, Tram	26.9	42.7	40.9	57.9	54.6	54.1	52.3
Network Stress Index, Bus	29.0	67.3	72.0	52.1	53.7	38.4	39.9
Network Stress Index, CBD	30.5	65.2	51.3	72.3	55.8	70.2	53.3

## 5. CONCLUSIONS AND REFLECTIONS

The spatial analysis undertaken in this paper has at its core an ambitious assumption about the nature of future urban growth in metropolitan Melbourne. Residential growth, currently characterised by a coexistence of fringe area expansion and intensification of the existing urbanised area, is anticipated to abandon the first pathway entirely and focus exclusively on the second one, aided by a regulatory framework that concentrates all new development in public transport-oriented activity centres and corridors while leaving heritage precincts and open space intact.

Whether or not such a vision is achievable to its full extent in political, planning or commercial terms is not the object of this paper. Instead, we have tried to examine the degree to which the spatial accessibility needs generated by the intensified areas can be accommodated by Melbourne's public transport system while simultaneously delivering on the mode share targets enshrined in state government policy that aim at an increasing role for public transport in the mobility mix.

It has been shown that major improvements to the current public transport system are imperative to achieve these goals and to keep the network functional, ie. to avoid exposing trains, trams and buses to unmanageable levels of stress derived from the concentration of travel opportunities generated by the land use-transport interplay. Stress relief is most critically enabled by adding new infrastructure for higher-capacity modes (trains and trams) along carefully selected corridors, as well as increasing connectivity across the network by allowing for more multi-directional movement through additional orbital and diagonal links. A strategy to decentralise employment growth alongside the intensified residential areas will help to distribute network stress away from congested areas, especially the CBD, but this also reduces overall accessibility somewhat and can be expected to result in a lower mode share for public transport than if job growth was allowed to continue with a significant CBD component.

These findings are associated with some transformative implications for urban public space within the intensified precincts and corridors and beyond. The scale of the improvements to transit infrastructure and services required is of such magnitude as to necessitate a transformation in the character of the streets in which it happens - from noisy and vehicle-filled to quieter, cleaner and more pedestrian and bike-friendly to accommodate the additional transit services. 15/25% surface travel time reductions require significant traffic calming measures to be effective, traffic volume caps and in some cases, complete bans for motorised traffic alongside transit routes. The virtuous circle here is that this would make such streets more convivial environments for the kind of low-rise high-density residential and mixed-use buildings that such concentrated transit-oriented intensification scenarios rely upon, thus addressing a major concern of many regarding the potential quality of the urban environment in such a scenario. Certainly, there is a clear requirement for significant investment in transit to solve network

stress, but the benefits are multiple and go beyond the gains to transit itself. Furthermore, the significant number of connectivity improvements needed within most activity centres – bringing trains, trams and buses into co-located, pedestrian and cyclist-friendly interchanges - will be the very catalysts needed for achieving the place-making agendas at the heart of contemporary activity centre structure plans and place-management strategies.

Finally, the SNAMUTS segmental congestion or network stress index has been used here for the first time and while it can capture and compare relative stress levels along route segments over time or between concurrent scenarios, it still falls short of defining meaningful benchmarks for what constitutes acceptable or unacceptable levels of network stress. We simply have not yet collected enough evidence from enough scenarios to draw robust correlations between SNAMUTS stress values and observed phenomena in public transport operation or usage patterns. In this context, it is also highly probable that network stress can become manifest in various and not necessarily predictable forms: for instance, it may make itself felt directly through overcrowding of vehicles or stations, or indirectly in a tangible degree of latent demand by users who avoid a stressed public transport service in favour of alternative transport modes or alternative destinations even where these offer a lower standard of amenity. It is hoped that a broader empirical base can be established for this purpose as the SNAMUTS is expanded across a larger set of case study cities and urban intensification scenarios, and the stress index can be further tested, calibrated and refined towards a useable set of benchmarks in the future.

## ACKNOWLEDGEMENTS

SNAMUTS was developed with support from Australian Research Council Linkage Grant (LP0562422) 'The impacts of transit-led development in a new rail corridor' and Discovery Grant (DP110104884) 'Spatial Network Analysis for Multimodal Urban Transport Systems: a planning decision support tool'. Seed funding was further provided by the Global Cities Institute at RMIT University and the Curtin University Sustainability Policy Institute (CUSP). The authors are grateful for the contributions of Prof Carey Curtis (Curtin University), Dr Sergio Porta (University of Strathclyde), Dr Michelle Zeibots (UTS), Prof Petter Næss (Aalborg Universitet), Dr Cecilia Silva (Universidade do Porto), Prof Luca Bertolini, Dr Marco te Brömmelstroet and Thomas Straatemeier (Universiteit van Amsterdam), Sonja Loewa (TU Hamburg-Harburg) and Dr Paul Mees (RMIT University) in conceptual collaboration, Roger Mellor (Curtin University) and Kristen Bell (RMIT University) as PhD researchers, and Elizabeth Taylor and Sarah Taylor (RMIT University) as GIS assistants. The transit-oriented intensification capacity modelling work drew on research funded by a Linkage Grant (LP0669652) 'The character of urban intensification: protecting and creating place-identity in activity centres' from the Australian Research Council, the Victorian Department of Planning and Community Development and the cities of Melbourne, Moreland and Yarra. The authors are grateful for the contributions of Prof Kim Dovey (University of Melbourne), Prof Rob Adams (University of Melbourne), the GIS work of Simon Wollan (University of Melbourne) and research assistance of Ammon Beyerle (University of Melbourne).

## REFERENCES

- Adams, R (2009) *Transforming Australian Cities: for a more financially viable and sustainable future*, Melbourne: City of Melbourne
- Bertolini L (2005) Cities and Transport: Exploring the Need for New Planning Approaches. Chapter 5 in Albrechts L, Mandelbaum S J (2005, Eds) *The Network Society. A New Context for Planning*. Routledge, Oxford, UK
- Curtis C, Scheurer J (2010) Planning for Sustainable Accessibility: Developing Tools to Aid Discussion and Decision Making. *Progress in Planning*, Vol 74, No 2
- Department of Infrastructure (DOI, 2002) *Melbourne 2030. Planning for Sustainable Growth*. Melbourne (VIC)
- Department of Planning and Community Development (DPCD, 2008) *Melbourne 2030 – A Planning Update: Melbourne @ 5 Million*. Melbourne (VIC)
- Porta S, Crucitti P, Latora V (2006a) The Network Analysis of Urban Streets: A Dual Approach. *Physica A, Statistical Mechanics and its Applications*, Vol 369, No 2
- Porta S, Crucitti P, Latora V (2006b) The Network Analysis of Urban Streets: A Primal Approach. *Environment and Planning B: Planning and Design*, Vol 33
- Scheurer J (2009) Public Transport and Land Use Integration in Melbourne and Hamburg: Can Comparative Network Performance Provide a Sense of Future Direction? Proceedings of the *State of Australian Cities National Conference*, Perth, WA

- Scheurer J (2011) *Scenarios for Future Land Use and Transport Integration in the City of Melbourne (and beyond)*. A background report for the City of Melbourne, Melbourne (VIC)
- Scheurer J, Kenworthy J, Newman P (2005) *Most Liveable and Best Connected. The Economic Benefits of Investing in Public Transport in Melbourne*. Metropolitan Transport Forum (MTF), Melbourne (VIC)
- Scheurer J, Porta S (2006) Centrality and Connectivity in Public Transport Networks and their Significance for Transport Sustainability in Cities. *World Planning Schools Congress*, Mexico (DF), 13-16 July
- Woodcock I, Dovey K, Davison G (2012) Envisioning the compact city: resident responses to urban design imagery, *Australian Planner* (forthcoming).
- Woodcock I, Dovey K, Wollan S, Beyerle A (2010) Modelling the compact city: capacities and visions for Melbourne, *Australian Planner*, 47 (2) 94-104
- Woodcock I, Dovey K, Wollan S, Beyerle A (2009) Compact City Visions for Melbourne, Proceedings of the *State of Australian Cities National Conference*, Perth (WA)