Comparison of public transport capacities to aid understanding of the operational capacities of the NWRL, CSELR and other transport projects

Peter Egan – peteregan2001@gmail.com

14/26 Hampden Rd Artarmon 2064

Summary

Using measurements obtained from TfNSW and manufacturer websites, and by direct measure of vehicles, the area available for standing in buses, trams and trains has been calculated and vehicle capacity determined for a range of standing passenger densities.

Within a margin for error, the capacities correlate well with reported maximum capacities based on seats plus four passengers per square metre (4P/M^2) in standing areas (all space available to passengers not used for seating).

The operational experience of Sydney Trains and Sydney Buses has been applied to determine operational capacities of various trains, buses and trams.

A key finding is the operational capacity of trains and trams is seat plus 1.5P/M^2 of standing room – a figure which allows for comfort and social factors. The operational capacity of a 162-metre long driverless single-deck train with open ends between the carriages is between 800 and 830 depending on the number of seats and their layout. This just 60% of the capacity of a similarly equipped double-deck train (1350). A similarity equipped articulated train with alternating single- and double-deck segments that seeks to optimise dwell time, single-deck area and seat capacity has an operational capacity of 1210 – the same as the Waratah.

As similar comfort and social factors apply to trams, the new 67-metre Sydney trams will have an operational capacity of 240 passengers for a 0ne-hour capacity of 3,600. The highest peak-one hour public transport load factor is 111% of seat capacity on the Airport Line. An heroic 130% load factor for the CSELR gives it a one-hour capacity of 2,300, 153 per tram – one-third the nominal capacity.

That the 67-metre trams will operate at 15 services per hour across the day (7am to 7pm) says it's not a peak-hour service but one matched to demand between the peak periods

The licensed capacity of buses should be limited to seats plus 3P/M^2 for standing room, while operational capacity should be limited to seats plus 2P/M^2 for standing room which allows for comfort and social factors.

The crowding criteria for CityRail was changed on, or perhaps before, 1 July 2010 from "no more than 5% of AM peak period (6.30AM to 9.30AM) services should exceed 135% of passenger seating capacity", and "passengers should not stand for more than 20 minutes" to a limit of 4P/M^2 in standing areas. This was perhaps done to accommodate Labor's CBD Metro project. However, IPART continued to monitor the 135% criteria for at least a year, and mat still do so. There was no method to measure the 20 minute standing criteria.

'Greenfield' light rail and metro rail are poor value for money in Sydney's environment as their costs are similar to heavy rail on a per kilometre basis, while their capacities are well that of heavy rail. In an apple-apples comparison, Heavy rail has 1.6 times the seat capacity of metro rail and ten times the seat capacity of light rail.

Extending the Eastern Suburbs Rail Line in preference to the CSELR, will allow the removal of at least 80% of the 350 AM peak one-hour east and south-east Sydney buses from the Sydney CBD.

Sydney's rail network is cost efficient, but not service effective. It performs poorly on a passenger per carriage-kilometre basis when compared to 11 international networks. It is partly explained by New World urban sprawl. However, the radial nature of the Sydney Trains network, and a desire to minimise journey times between a few centres for new lines, reduces service effectiveness. 'Snaking' a commuter rail line through the Eastern Suburbs minimises journey times for far more people then do more direct routes. Using the NWRL to create a metropolitan orbital railway connecting Sydney's existing and new airports will create the opportunity for many more rail journeys – particularly to and from Sydney's West – and improve service effectiveness.

Trains

The long established operational capacity of a Waratah type train of 135% of seats is found, in Table 2, to correspond to seats plus 1.5P/M^2 in standing areas. This operational capacity reflects comfort factors such as availability of handholds and relative positions of seated and standing passengers. By observation, there is a strong passenger preference for separate seated and standing areas. Peak-hour train passengers are regularly observed to crowd in doorways at 2.5P/M^2 to avoid standing in spaces between seats – the aisles and wider spaces.

Average peak one-hour passenger loads for trains and Harbour Bridge buses and Eastern Distributor express buses is within a few percent of seat capacity (Table 4). The exception is the truncated Eastern Suburbs Rail Line which averages 60% of seat capacity.

Other Sydney CBD approach paths have average peak one-hour bus loads of 70% to 85% of seat capacity. In this context, while the proportion of doorway space to other standing space varies between vehicle types, seats plus 1.5P/M^2 in standing areas is a good measure of public transport vehicle capacity. The NWRL metro is being promoted with images of passenger densities of about 20% of seat capacity (see Appendix d) – A customer expectation is being built for a service with practically no standing passengers.

The operational capacity of a 162-metre long driverless single-deck train with wide openings between the carriages is between 800 and 830 depending on seat numbers and seat layout – 60% of the capacity of a similarly equipped double-deck train (1350).

A similar commuter train with Bombardier OMNEO features, including articulated carriage joints and alternating double and single deck carriages, has an operational capacity of 1210 – same as the double-deck Waratah which loses passenger cabin area due to its shorter length (156.6 metres), driver cabins and the unusable space between the carriages.

Side facing seating has a density of 2.0 seats per square metre when row-end protection is included. The high density seat layout of the Waratah upper and lower decks (row pitch 0.85 metres), where people can put their feet under the seat in front, results in a density of 2.5 seats per square metre – the same density as tolerated in doorways. Standing passenger density in seat aisles and other spaces between seats is very low in operation – perhaps 0.5 passengers per square metre.

Buses

Observed maximum capacity and licenced standing capacity in a 'standard' 12-metre bus is equivalent to 3 standing passengers per square metre of aisle and allowed rear doorway standing room (Table 3). The high-density four-abreast bus seating (row pitch 0.75 metres) has a density of 3 seats per metre squared.

Due to the generally very short time a bus is likely to experience maximum capacity, a licence to carry $3P/M^2$ standing is acceptable. However, operational capacity should be limited to $2P/M^2$ standing for the comfort of passengers.

It is notable that train doorway crowding matches that of the high-density seating compartments ($2.5P/M^2$), and that 'standard' bus aisle crowding matches that of the row seating ($3.0P/M^2$).

Articulated buses are closer trams and trains in their operation in that passengers prefer to avoid standing next to seated passengers and prefer not to stand on the articulated joint.

Passengers are not permitted to stand on the upper-deck of a double-deck bus due to the single-point of access and the greater risk of bus overturning. Standing on the lower-deck of the double-deck buses operated by Forest Coach Lines is limited to 20 passengers – similar to that of a 'standard' 12-metre bus. The double-deck bus seated capacity is 90 – two-thirds of the seats are upstairs.

Bus service frequencies are based on a minimum service requirements and greater frequencies where demand requires it. As with the trains, the peak one-hour demand can be matched with seats per hour, with standing room relied on cater for the peak of the peak one-hour.

Trams

Steel-tyred trams have more in common with their steel-tyred cousins (trains) and articulated buses than the standard rigid bodied bus. The train operational limit of $1.5P/M^2$ in standing areas is appropriate for trams. The operational capacity of the Alstom 67 metre tram chosen for Sydney is 240 passengers.

The nominal capacity of 466 passengers (based on $4P/M^2$ in standing areas) is nearly twice the operational capacity. Nominal capacity makes no allowance for passengers in wheelchairs and prams, and no allowance for baggage, bicycles, surfboards and other large objects passengers may have with them. It makes no allowance for the usability of 'standing' space, or the desirability of bringing men, women, girls and boys into such close proximity that they are in continual body contact with other passengers.

Operational capacity at 15 trams per hour is 3,600 passengers, of which 1770 can be seated. 16 seats in each tram can be folded up to create the standing area used in standing capacity calculations.

At the average passenger load of peak hour buses approaching the CBD (36 passengers), 15 trams per hour can replace 100 standard buses.

Presently, 60 express buses from the south-east suburbs bring an average of 52 passengers into the CBD via the Eastern Distributor – 3120 passengers. 15 trams can carry the average passenger load of 70 Eastern Distributor express services.

That the 67 metre trams will operate at 15 services per hour across the day (7am to 7pm) says capacity is matched to demand between the peak periods, not the peak one-hour (see Appendix A). Demand in excess of 3,600 passengers per hour must be diverted on buses.

The City Centre Access Strategy shows 20,340 people typically entered the CBD on buses and trains in the peak one-hour from the eastern and south-eastern suburbs in 2011. They could all be carried by the Eastern Suburbs Rail Line if the service frequency was raised to 23 trains per hour with an average load of seat capacity.

Randwick Council light rail brochure has Light Rail capacity at 12,000 per hour compare with 3,500 on buses (source Metro Transport via www.randwick.nsw.gov.au). 12,000 per hour equates to 26 trams, 67 metres long with $4P/M^2$ standing (466 per tram). However, at an operational capacity of 240 passengers ($1.5P/M^2$ standing) requires 50 trams per hour. 15 trams per hour will carry 3,600 passengers. At the average passenger load for south-east Sydney standard buses, 15 trams could replace 100 buses. However, the highest average peak-hour public transport service load is the Airport Line at 111% of seat capacity.

Achieving a peak-hour load factor of 130% of seat capacity (118 for the 67M tram) would be heroic. 15 services per hour would carry 2,300 passengers at this high relative load factor. 15 trams are likely to replace no more than 64 south-eastern Sydney bus services – one tram replaces 4.3 buses.

If the 2,300 passengers were diverted to Eastern Suburbs Rail Line for the journey to the city, maximum line load would lift from 49% of seat capacity to 64% of seat capacity.

If the light rail operational capacity of 3,600 was added to Eastern Suburbs Rail Line, its maximum line load would rise to just 72% of seat capacity.

Presently 175 buses head north on George St and 295 head north on Elizabeth St in the AM peak hour. At seat capacity (~45 seats), the capacities are respectively 7,900 and 13,300 respectively. When this is compared to the seat capacity of the trams (1770 seats), it is not surprising that Sydney did away with trams in the 1950s to replace them with buses.

Appendix E shows the technological convergence between articulated trams and buses. Electric buses with adequate battery capacity for typical bus operations are appearing in the market place. As are electric buses with supplementary power sources – fuel cells and internal combustion engines.

With barely perceptible differences in journey experience, steel-tyred trams and their very expensive railways and control systems, are poor value for service outcome compared to their rubber-tyred counterparts.

Origin of public transport capacity figures

The rail services contract TfNSW-RailCorp 1 July 2010 to 30 June 2015, Phase 1 (1 July 2010 – 30 June 2011) requirements, contains a crowding requirement of less than 4.0 standing passengers per square metre (see Appendix B).

Prior to that, the requirement was “no more than 5% of AM peak period (6.30AM to 9.30AM) services should exceed 135% of passenger seating capacity”, and “passengers should not stand for more than 20 minutes” (see IPART and Douglas Economics extracts in Appendix B).

RailCorp had an internal crowding limit of 1.9P/M^2 average for standing areas (Appendix B). This figure should not be used for operational capacity as it leaves the network at great risk of extended dwell times and lower service frequencies.

The impact of vehicle type on train service frequency has been analysed by Douglas Economics and Parsons Brinckerhoff, Cox, Hassell and Aecom (PB-CHA) – See Appendix C. The key finding is that metro style trains can alight and board passengers 10 seconds faster than double-deck style trains – i.e., the dwell time is 10 seconds less. Part of this is due the greater number of passengers per metre length of train in the double-deckers.

The MI09 double-deck Paris commuter train has sacrificed seat capacity for extra doors to offer a dwell times on a par with single-deck trains. A commuter version of the Bombardier OMNEO takes an approach that optimises seat capacity, door capacity and single deck area. It has six Waratah style double-deck compartments and 22 door-sets per side compared to 24 door-sets per side for the NWRL metro trains. As the large single-deck areas permit passengers to leave the double-deck compartments prior to the train arriving at the station, the dwell time difference between a commuter version of the OMNEO and a metro train is marginal.

Train acceleration and breaking is limited to ~1M/S^2 for passenger comfort reasons. Train control systems are applicable to all vehicle types. Platform access and concourse barrier capacity, rather than platform size, are the main station capacity issues at Wynyard, Town Hall and Central.

Value for money

Despite their differences, four projects and one current rail line illustrate that our rail planning is very poor, and why 'Heavy' is better than 'Metro' and 'Light' rail – see Table 1.

Table 1 – Comparison of light, metro and heavy rail costs and initial capacities

Line or project	Rail type	Cost $M	Cost/km $M	Initial peak capacity seats/hour	Comment
North Shore	Heavy	–	–	18,000	comparator
Epping-Chatswood	heavy	2,350	164	3,600	IPART 2009 costing
South West	heavy	1,800	140	900	TfNSW and Minister
North West	metro	5,500	240	5,500-6,000	**
South East	light	2,200	180	1,770	***

** 15 trains with 5,500 to 6,000 seats per hour - http://www.smh.com.au/nsw/gladys-berejiklian-northwest-rail-link-trains-to-run-every-four-minutes-98-per-cent-on-time-20140916-10hiza.html#ixzz3DS0hFfX8

*** Cost from Minister’s media release, capacity from Alstom website.

Based on NWRL costs, the Eastern Suburbs Rail Line and services could have been extended to Bondi Beach and Maroubra Junction for the same cost of the CSELR ($2.2 bn) and a capacity of 18,000 seats per hour (20 trains) provided – 10 times that for light rail. At least 250 buses in the peak hour would have been removed from CBD streets and local eastern suburbs bus services much improved.

TfNSW says tram services, and thus seat capacity, can be doubled as demand increases to 30 per hour despite the 100 second cycle time for traffic lights at many busy intersections.

Automation of the heavy rail lines will raise the heavy rail service frequency to within a few percent under metro rail frequency (30 services per hour), while more efficient train designs can lift heavy rail seat capacity to 160% of the seat capacity of metro trains.

A paper** by Chi-Hong (Patrick) Tsai and Professor Corinne Mulley, of Sydney University's Institute of Transport and Logistics Studies, demonstrates that Sydney Trains is cost efficient in a comparison with 12 international rail networks on a cost per carriage-kilometre basis, but is not service effective. It performs poorly on a passenger per carriage-kilometre basis. performance is partly explained by New World developed country urban sprawl. However, the radial nature of the Sydney Trains network, and a desire to minimise journey times between a few centres for new lines, reduces service effectiveness. 'Snaking' a commuter rail line through the Eastern Suburbs minimises journey times for far more people then do more direct routes. Using the NWRL to create a metropolitan orbital railway connecting Sydney's existing and new airports will create the opportunity for many more rail journeys – particularly to and from Sydney's West – and improve service effectiveness.

** How does the efficiency performance of Sydney CityRail compare with international urban rail systems, Chi-Hong (Patrick) Tsai[a], Corinne Mulley[b]
a,b Institute of Transport and Logistics Studies, Business School, The University of Sydney, 2006, Australia
a E-mail for correspondence: chi-hong.tsai@sydney.edu.au
Publication website: http://www.patrec.org/atrf.aspx 1

Table 2 – Comparison - Double- & single-deck trains with metro train features with the Waratah and light rail

Standing density	Train	Capacity seated	standing	total	% of driverless double-deck capacity
4P/M^2	Driverless double-deck	976	1005	1981	100%
	Waratah	894	838	1732***	87.4%
	Driverless Bombardier OMNEO	802	1082	1884	95.1%
	INSW driverless single-deck A	492	906	1398	70.6%
	Alstom Metropolis	464	952	1416	71.5%
	INSW driverless single-deck B	400	1057	1457	73.5%
3P/M^2	Driverless double-deck	976	754	1730	100%
	Waratah	894	629	1523	88.0%
	Driverless Bombardier OMNEO[5]	802	812	1614	93.3%
	INSW driverless single-deck A	492	680	1172	67.7%
	Alstom Metropolis	464	714	1178	68.1%
	INSW driverless single-deck B	400	793	1193	69.0%
2P/M^2	Driverless double-deck	976	503	1479	100%
	Waratah	894	419	1313	88.8%
	Driverless Bombardier OMNEO	802	541	1343	90.8%
	INSW driverless single-deck A	492	453	945	63.9%
	Alstom Metropolis	464	476	940	63.6%
	INSW driverless single-deck B	400	529	929	62.8%
1.5/M^2	Driverless double-deck	976	377	1353	100%
	Waratah	894	314	1208****	89.3%
	Driverless Bombardier OMNEO	802	406	1208	89.3%
	INSW driverless single-deck A	492	340	832	61.5%
	Alstom Metropolis	464	357	821	60.7%
	INSW driverless single-deck B	400	396	796	58.8%
1P/M^2	Driverless double-deck	976	251	1227	100%
	Waratah	894	210	1104	90.0%
	Driverless Bombardier OMNEO	802	270	1072	87.4%
	INSW driverless single-deck A	492	238	730	59.5%
	Alstom Metropolis	464	227	691	56.3%
	INSW driverless single-deck B	400	264	664	54.1%
4P/M^2	Alstom Citadis Casablanca 64.7M	102	336	438[7]	
3P/M^2	Alstom Citadis Casablanca 64.7M	102	252	354	
2P/M^2	Alstom Citadis Casablanca 64.7M	102	168	270	
1.5P/M^2	Alstom Citadis Casablanca 64.7M	102	126	228	
1P/M2	Alstom Citadis Casablanca 64.7M	102	84	186	
4P/M^2	Alstom Citadis 'Sydney 67M'	102	364	466[6, 8]	
3P/M^2	Alstom Citadis 'Sydney 67M'	102	273	375	
2P/M^2	Alstom Citadis 'Sydney 67M'	102	182	284	
1.5P/M^2	Alstom Citadis 'Sydney 67M'	102	137	239	
1P/M^2	Alstom Citadis 'Sydney 67M'	102	91	193	

Table notes: Except for the Waratah (existing train), the other trains have the following metro style features. Tram dimensions are over page. No allowance in the calculations for people with wheel chairs, prams or other bulky objects.

Trains

-- Driverless train** 162M long, 3.035M wide, with internal dimensions 160.0Mx2.89M = 462.4 M^2
Single-deck - less 7 carriage 'joints' that each occupy 2M^2 = 14M^2 cabin area = 462.4 – 14 = 448.4 M^2
Double-deck - add 8 upper-decks internally 9.05x2.89 x 8 = 209.2M^2 cabin area = 209.2 + 448.4 = 657.6 M^2
Bombardier OMNEO style 'articulated' 11-segment train with 6 'standard' upper decks =161.8+448.4 = 610.2 M^2
Alstom Metropolis style two-seat bench 0.99/2=0.495M x 0.823M=0.41M^2/seat = 2.44 seats/M^2
Side-facing seats – 1.0M from wall required to allow 0.3M for legs/feet. Allow for glass end wall and handrails at doors – allow 0.5M width per seat. Allow 0.5M^2 for each side facing seat = 2.0 seats/M^2
Single-deck assumed to have 24 door-sets per side, double-deck 16 per side, OMNEO 22 per side
Single-deck and double-deck have 16 bogies per train, OMNEO has 12 bogies per train

-- Driverless double-deck 816 @ 0.40 = 326.4M^2 plus 160 side @ 0.5= 80M^2 Seating uses 406.4M^2 leaving 251.2M^2 stand

-- Driverless OMNEO 'metro' has single-deck (~18M long) with 4 door-sets/ side alternating with double-deck (~9M long)
six double-decks including end-segments and five single-deck segments
612 seats @ 0.40 = 244.8M^2 plus 190 seats @ 0.5 = 95M^2 Seating uses 339.8M^2 leaving 270.4M^2 for standing

-- Alstom Metropolis - NWRL images imply 464 seats for an 8-car train – 240 forward facing, 224 side facing
240 x 0.41= 98.4M^2 plus 224 @ 0.5 = 112M^2 Seating uses 210.4M^2 leaving 238.0M^2 for standing

-- INSW metro A (492 seat) 268 x 0.41 = 109.9M^2 plus 224 @ 0.5 = 112M^2 Seating uses 221.9M^2 leaving 226.5M^2 stand
Equates to a six car capacity of 369 seats giving a 15 train/hour total of 5535 - complies with Minister Berejiklian's statement[1] to SMH that initial NWRL service will have 5500 to 6000 seats per peak hour

-- INSW metro B (400 seat[4]) 176 x 0.41 = 72.2M^2 plus 224 @ 0.5 = 112M^2 Seating uses 184.2M^2 leaving 264.2M^2 standing

-- NWRL website capacity 40,000[2] in 30 trains per hour = 1333/train – achieved in Alstom train with 3.65P/M^2 standing

-- Waratah seats 0.45M wide. Seat pitch 0.85M. But shared leg room of end seats gives average seat pitch 0.823M.
Movable seatback mechanisms 1.43M & 0.99M wide=2.42/5=0.484M/seat, 0.823x0.484=0.40M^2/seat, 2.5P/M^2
156.6M long with ~4M driver cabins, 1.5M car joints and 4 shorter upper decks – 657.6 - 78.9 = ~579M^2

776 seats @ 0.40 = 310.4M^2 + 118 side seats @ 0.5M^2 = 59M^2 Seating uses 369.4M^2 leaving 209.6M^2 standing
PB-CHA 'crush capacity' Waratah 2100 – 894 seats plus 1206 standing in 209.6M^2 = 5.75P/M^2 standing
*** 1732 at 4P/M^2 is 1% less than the Waratah maximum capacity for special events of 1750 - within margin of error. 1750 capacity source - Footnote 8
**** Waratah operational capacity, by experience, has been shown to be 135% of 894 seat capacity = 1207. The table shows this to be an average of 1.5 passengers/M^2 in standing areas.
1200 'nominal' capacity – 894 seats plus 306 standing in 209.6M^2 = 1.46P/M^2 standing, however, most of these passengers are standing in doorways at densities up to 2.5P/M^2
**Sydney Trains data[3]: Millenium, OSCAR, C-Set, K-Set all 163.1M long, Tangara 162.2M, S-Set161.8M, Waratah 156.6M
Train internal dimensions obtained by directly measuring Waratah internal spaces

Trams

102 seats requires 96 forward/rear seats x 0.43M^2*****= 41.3M^2 plus 6 'end' seats x 0.5M^2=3M^2 Total 44.3M^2
***** Bombardier Gold Coast tram measure by author.

Alstom Citadis Casablanca[7] tram 64.7Mx2.65M Standing room in two cabins = 2x62M^2 – 44.3M^2 = 79.7M^2
Internal cabin – 32.2M (overall) – 2.0M (drivers cabin), – ~0.6M (rear) = 29.6M (int) x 2.5M wide**= 74.0M^2
less ~8M^2 (4 flex joints), 3M^2 (4 fold-up 3-seat banks), 1M^2 (narrow rear of cabin) total 12M^2 62M^2
Alstom brochure capacity of 438 implies 336/4 = 84 M^2 – 4.3M^2 than calculated is available.
Increasing average internal width from 2.5M to 2.573M would provide the additional space

Alstom Citadis[6] 'Sydney' tram 67Mx2.65M Standing room in two cabins = 2x65 M^2 – 44.3 M^2 = 85.7M^2
Internal cabin – 33.4M (overall) – 2.0M (drivers cabin), – ~0.6M (rear) = 30.8M (int) x 2.5M wide**= 77.0M^2
less ~8M^2 (4 flex joints), 3M^2 (4 fold-up 3-seat banks), 1M^2 (narrow rear of cabin) total 12M^2 65M^2
Alstom brochure capacity of 2x233 implies 364/4 = 91 M^2 standing – 5.3M^2 than calculated is available.
Increasing average internal width from 2.5M to 2.586M would provide the additional space.

-- Bombardier Gold Coast tram seats in bogie car measure 0.475M wide with average 0.43M^2 per seat = 2.33 seats/M^2
Internal width at front/back facing seats = 2.5 metres

Table 1 footnotes:

1 Ministerial statement -15 trains with 5,500 to 6,000 seats per hour - http://www.smh.com.au/nsw/gladys-berejiklian-northwest-rail-link-trains-to-run-every-four-minutes-98-per-cent-on-time-20140916-10hiza.html#ixzz3DS0hFfX8.

2 http://nwrail.transport.nsw.gov.au/The-Project/Trains#2
"At the start of operations, the North West Rail Link will use six-carriage trains. However more carriages and trains can be added as demand increases, with the platforms to be built long enough for eight-carriage trains. When the Sydney Rapid Transit network is extended from the end of the North West Rail Link at Chatswood, under Sydney Harbour and through the CBD to Bankstown, it will have the capacity to run up to 30 trains per hour in each direction through the city."
"Sydney's rapid transit target capacity of about 40,000 customers per hour is comparable to the average hourly capacity of rapid transit trains worldwide. Sydney's current suburban trains can reliably carry 24,000 people an hour per line."

3 http://www.sydneytrains.info/about/fleet/a_sets

4 http://www.infrastructure.nsw.gov.au/media/16985/sis_report_section8.0_print.pdf
Compare with INSW SIS Table 8.5 Indicative passenger capacity of double deck and single deck train systems

	Train capacity(1)	Seats per train	Trains/hour	Total passengers/hour
Double deck	1,200	890	20	24,000
Single deck – comfortable(1)	1,200	600	30	36,000
Single deck metro – max(2)	2,000	400	30	60,000

(1) Double deck assumes a nominal capacity of 1200 people with seating in line with Waratah train specifications. Planned frequency of 20 tph across the harbour bridge from Sydney's Rail Future. Single deck 'high seating' capacity could have 500-600 seats (Source: Halcrow 2011), single deck would be based on standard international design with 3 doors per side.
(2) Source: MTR for Transport for NSW.

5 http://www.bombardier.com/en/transportation/products-services/rail-vehicles/commuter-and-regional-trains/double-deck-electric-multiple-units.html

6 http://www.alstom.com/products-services/product-catalogue/rail-systems/trains/products/citadis/
http://www.alstom.com/Global/Transport/Resources/Documents/brochure2014/Citadis%20-%20Sales%20brochure%20-%20Eng%20-%20Sept%202014%20-%20LD.pdf?epslanguage=en-GB Page 6

7 http://www.alstom.com/Global/Transport/Resources/Documents/brochure2014/Casablanca%20-%20Morocco%20Tramway%20-%20Case%20Study%20-%20EN%20-%20LD.pdf?epslanguage=en-GB P2

8 http://images.smh.com.au/file/2013/09/23/4770519/trains.pdf
Modelling Train & Passenger Capacity - Report to Transport for NSW By DOUGLAS Economics July 2012
Neil Douglas, DOUGLAS Economics www.douglaseconomics.co.nz

3.3 Single Deck Rolling Stock PB-CHA operation simulation evaluated a hypothetical single deck with nominal capacity of 900 based on 400 seats and 500 standing, Table 3.3. This compares with a nominal capacity of 900 seats and 300 standing for a Waratah double deck train.

Table 3.3: Rolling Stock Capacity

Capacity	**Waratah**	**Single-deck**	**Comment**
Seated	900	400	Rounded figures (Waratah has 896 seats)
Nominal	1200	900	Standing in double deck vestibules (19/vestibule) only approximately 2P/M^2 for single deck
Peak	1400	1120	Double deck maximum load observed on Western Line Standing at 3P/M^2 for single deck
Maximum	1750	1350	Only observed at special events Standing at 4P/M^2 for single deck.

Source: Parsons Brinckerhoff, Cox, Hassell and Aecom (PB-CHA) (2011)

Table 3 Bus capacities

Standing passengers in available standing area (based on Sydney Buses fleet)

Standing density	**~10.7M***	**~11.0M***	**~12.0M***	**~14.0M***	**~17.5M***
$4P/M^2$	21	22	24	29	58
$3P/M^2$	16	17	18	22	43
$2P/M^2$	11	11	12	15	29
$1.5P/M^2$	8	8	9	11	22
$1P/M^2$	5	5	6	7	14
Licenced standing passengers	**??**	**??**	**18**	**30**	**63**

Licenced bus capacities – observation at Wynyard Nov 2014

	Seats	**Standing**	**Total**
Sydney Buses articulated bus	52	<u>63</u>	115
Forrest Lines double-deck bus	96	20	116
Rigid single-deck dual axle	61	34	95
Rigid single-deck	44	<u>18</u>	62
Rigid single-deck	47	<u>18</u>	65
Rigid single-deck	47	22	69
Rigid single-deck dual rear axle	56	<u>30</u>	86

Table notes

<u>Measure of rear section late model 'standard' bus</u>

Internal width 2.35M. Seat frames 0.80M wide. Wall to double-seat edge 0.875M. Aisle 0.60 metres wide. Seat pitch 0.75M. Average area per seat = $0.33M^2$. <u>3.0 seats/M^2 average</u>.

* A measure of bus lengths at Mona Vale, Brookvale, Neutral Bay, Randwick and Botany bus depots via Google Earth (with a control measure of 40 foot (12.19M) containers), reveals Sydney Buses have exterior cabin roof lengths of:

~10.7M, ~11.0M ~12.0M ~14.0M ~17.5M

Allow 3.0M of bus length for driver and luggage areas, sloping front of buses, and rear panel of bus. The buses have passenger areas of:

$18.1M^2$ $18.8M^2$ $21.2M^2$ $25.9M^2$ $34.1M^2$

Assume the aisle is 0.6M wide, and ends 1M from rear wall

$4.0M^2$ $4.2M^2$ $4.8M^2$ $6.0M^2$ $8.7M^2$

Seats, rear door area (space of 4 seats) and articulated bus flexible joint occupy

$14.1M^2$ $14.6M^2$ $16.4M^2$ $19.9M^2$ $25.4M^2$

Seat capacity (@$3/M^2$ reduced by 4 seats for rear door-set rigid bus, & 16 for articulated bus joint & 2nd rear door)

38 39 45 56 60

Articulated bus has 52 seats – thus pace for 8 seats ($2.7M^2$) devoted to standing room at rear.

<u>Space available for standing passengers</u> – Aisle + $0.7M^2$ in front of seating area + $0.6M^2$ at rear door. For articulated bus, also add $1.4M^2$ at flexible joint, $0.3M^2$ at second rear door and 2.7M2 for 8 seat reduction

<u>Area available for standing</u>

$5.3M^2$ $5.5M^2$ $6.1M^2$ $7.3M^2$ $14.4M^2$

The intent of this table is a comparison. There is considerable variation in bus layouts to be found in Sydney and thus in the size and quality of standing areas. The table does indicate that the licenced standing capacity of 63 for the articulated buses is grossly excessive.

Table 4 Public transport vehicles and their passengers entering the City Centre between 8AM and 9AM weekdays

CBD entry direction	passengers 2001/02	passengers 2011/12	vehicles 2011	average per vehicle 2011	vehicles post changes	ave
Buses						
Harbour Bridge		14,484	379 (-55)	38.2	324	44.7
(60 buses to be diverted to Cahill Expressway – in peak hour?)						
(160 buses to be replaced by NWRL)						
Anzac Bridge		2,788	113 (-28)	24.7	85	32.8
William St		1,194	45 (-7)	26.5	38	31.4
Broadway*		5,378	175 (-33)	30.7	142	37.9
Eastern Distributor		3,116	56 (+4)	55.6	60	51.9
Total of above		***26,960***	***768 (-119)***	***35.1***	***649***	***41.6***
* At Goubburn St 5,900 bus passengers with 900 people in 720 cars (Access strategy)						
Elizabeth/Chalmers Sts		3,025	85 (-49)	35.6	36	36
Albion/Forveaux Sts		2,095	56 (-32)	37.4	24	36
Oxford St		3,535	99 (-27)	35.7	72	36
Total above 3		***8,655***	***240 (-108)***	***36.0***	***132***	
Total		***35,615***	***(1008 -227 = 781)***			
Light Rail						
Wentworth Park		473 (this is before the Dulwich Hill extension)				
Ferries						
Circular Quay		4,000				
Trains						
Harbour Bridge NS/Nor		16,257	18 (Northern 4 via Chats)		903	
Eastern Suburbs Line		7,375	17		434	
Airport Line		7,959	8 (via M)		995	
Redfern (west and south)		65,521	69		950	
Illawarra			19 (2 to CT)			
Bankstown			6 (4 TH, 2 M)			
IW/South			12 (via TH, 6 South)			
EH			4 (via M)			
Northern			8 (4 via Strat, 4 CT)			
Western			20 (Rich 2, Scho 4, EP 2, Penrith 5, St Marys 1, Black 2, EP-CT 4)			
HB, Air, Red		***89,737***	***95***		***945***	
HB, ES, Air, Red		***97112***	***109***		***891***	

14 trains city circle CQ to W. W to CQ 17

Carlingford 1 to CT (arrive 7.45)

Data source: City centre access strategy for passenger and bus numbers. Sydney Trains timetable for train numbers.

Appendix A – December 2014 Light Rail service frequencies

Table 3.2 Comparison of LRV service headway (in minutes) for the approved project and proposed modified design

Time of day	CBD/Surry Hills/ Moore Park		Kensington/Kingsford		Randwick	
	Opening	Future	Opening	Future	Opening	Future
LRV service frequency in minutes (approved project)						
10.00 pm to 7.30 am[1]	10	10	20	20	20	20
7.30 am to 9.30 am	3	2.5	6	5	6	5
9.30 am to 5.00 pm	4	3	8	6	8	6
5.00 pm to 7.00 pm	3	2.5	6	5	6	5
7.00 pm to 10.00 pm	5	5	10	10	10	10
LRV service frequency in minutes (proposed modification)[2]						
5.00 am to 7.00 am[1]	6	5	12	10	12	10
7.00 am to 7.00 pm	4	3.25	8	6.5	8	6.5
7.00 pm to 10.00 pm	5	5	10	10	10	10
10.00 pm to 1.00 am[2]	6	6	12	12	12	12

Note: Table above is for regular services only

Note 1: Operating hours for regular services do not include 1.00 am and 5.00 am. Special event services may occur during these times.

Note 2: With respect to slight increases between the approved and proposed headways in the early morning and late evening (such as the 10.00 pm to 1.00 am period), off-peak service were reviewed by Transport for NSW as part of the ongoing development of the proposed operation of the project and it was determined that 20 minute headways on the branch lines during the early morning and late evening were not consistent with Transport for NSW customer service obligations. As such, frequencies during this time have been increased slightly as part of the proposed modification.

Note 3: While this table shows proposed opening service frequency, more frequent services may be operated in the future where necessary. The modification has assessed the worst case from a noise impact perspective of 3.25 minutes in the peak. Future operation will be 10 or more years after opening).

Appendix B – Changes in TfNSW crowding requirements

The rail services contract TfNSW-RailCorp 1 July 2010 to 30 June 2015, Phase 1 (1 July 2010 – 30 June 2011) requirement contains a crowding requirement of less than 4.0 standing passengers per square metre (see extract below).

Prior to that, the requirement was "no more than 5% of AM peak period (6.30AM to 9.30AM) services should exceed 135% of passenger seating capacity", and "passengers should not stand for more than 20 minutes" – see IPART and Douglas Economics extracts below.

Passenger Services			
Crowding / Comfort	Satisfaction with punctuality (continuous improvement above 2009 levels)	73% (2009), 79% (2010)	Annual (ITSR Survey)
	Passengers standing per square metre	<4.0 per square metre	Half-Yearly (Peak Load Survey)
	Improve journey comfort (air-conditioned carriages, improved hand holds)	100% delivery of planned sets	
	Percentage of trains air-conditioned	> 70%	Monthly
	Operating Fleet < 10 years old	>16%	Quarterly

IPART 4 The quantity and quality of CityRail's services 4.4 Crowding on trains[1]

Prior to CityRail's services contract its performance targets were set under the Rail Performance Agreement[32] which stated that no more than 5% of AM peak period services should exceed 135% of passenger seating capacity. Although this is not the official loading target for CityRail it is still a good measure of crowding on the network.

In the past 4 years, CityRail has improved its performance against this measure, but still did not meet its target in some hours of the peak periods.

During the hours 7am to 10am, services exceeding 135% seating capacity fell from 16% in March 2008 to 11% in March 2012.

The highest levels of overcrowding occurred between 8am and 9am. In September 2011, the latest period for which we have hourly data, 12% of services exceeded 135% of seating capacity during this hour.

During the hours 4pm to 7pm, services exceeding 135% seating capacity fell from 9% in March 2008 to 5% in March 2012, with the highest levels of overcrowding between 5pm and 6pm. In September 2011, 6% of services exceeded 135% of seating capacity during this hour.

32 Until 31 December 2008, RailCorp was a state owned corporation with benchmarks and targets set in a Statement of Corporate Intent and in the Rail Performance Agreement which was agreed to by the board and the portfolio Minister. On 1 January 2009 RailCorp became a statutory authority subject to the direction and control of the Minister for Transport. From 1 July 2009 the Statement of Business Intent and Rail Services contract are the relevant agreements with Treasury and Transport NSW.

1 https://www.google.com.au/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=quantity%2Band%2Bquality%2Bof%2BCityRail%2Bs%2Bservices Original source - www.ipart.nsw.gov.au/

2012 Douglas Economics – modelling train line passenger capacity – 4.2 Train Capacity

CityRail surveys passenger loads on trains during the AM and PM peak periods twice a year. The survey results are used to assess average passenger density, train load versus seat capacity and length of stand. Three capacity standards are referenced in the NSW Auditor General's report.

Average Passenger density: measures the number of passengers per square metre (PSM) of standing space for the peak hour. The observed densities are compared against an international benchmark of 4 PSM and an internal RailCorp threshold of 1.9 PSM. Between 2007 and 2011 (Figure 4.2.1), CityRail comfortably met both targets with a peak hour passenger density of 1 PSM in four five years only approaching the internal threshold in 2008 with a density of 1.8.

Individual Train Loads: The Rail Service Contract drawn up by the Minister of Transport sets a standard that no more than 5% of AM peak hour suburban trains (trains arriving Central 8-9am excluding intercity) exceeding passenger loads of 135% of seat capacity.6 In fact, since September 2005 the target has been met only once in September 2011.7

Length of Stand: The third crowding standard is that passengers should not stand for more than 20 minutes. Definitive assessments would require monitoring of individual passengers although indicative assessments have been made from the loading surveys. For instance, the September 2011 Auditor General's report gave a figure of 47 morning trains with passengers standing for longer than 20 minutes.

Reviewing the three targets, the 135% train load implies a lower carrying capacity than the 1.9 PSM target whilst length of stand is the most difficult to measure. All three targets will depend on where the observations are taken.

Footnotes:
6 The 135% target is an average for a train and does not allow for load variations between cars.
7 The percentage has generally declined since March 2005 and reached a maximum in March 2007 with 16% of AM peak hour suburban trains exceeding passenger loads of 135%.

Appendix C Douglas Economics Rolling Stock capacity comparison

Douglas Economics http://images.smh.com.au/file/2013/09/23/4770519/trains.pdf

3.3 Single Deck Rolling Stock

PB-CHA operation simulation evaluated a hypothetical single deck with nominal capacity of 900 based on 400 seats and 500 standing, Table 3.3. This compares with a nominal capacity of 900 seats and 300 standing for a Waratah double deck train.

Table 3.3: Rolling Stock Capacity

Capacity	Waratah	Single Deck	Comment
Seated Capacity	900	400	Rounded figures (Waratah has 896 seats)
Nominal Capacity	1200	900	Standing in double deck vestibules (19/vestibule) only and at approximately $2P/M^2$ for single deck
Peak Capacity	1400	1120	Double deck maximum load observed on Western Line; Standing at $3P/M^2$ for single deck
Max Capacity	1750	1350	Only observed at special events Standing at $4P/M^2$ for single-deck

Source: PB-CHA (2011) via Douglas Economics

(Note by author - 19/double-deck vestibule is equivalent to $2.5P/M^2$ in the vestibule)

PB-CHA assumed that the train would have three doors per side per car: the extra set of doors per car offering the potential to speed up boarding and alighting, reduce dwell times and allow more trains per hour. PB-CHA considered that the capacity of existing stations would limit the reduction in dwell time.

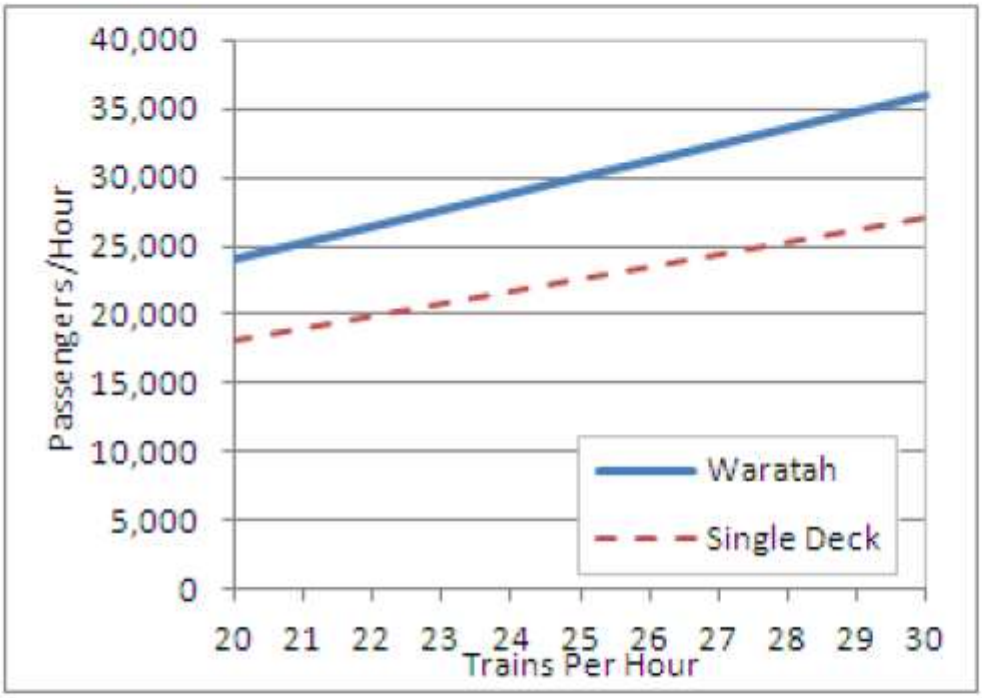
(Train frequency comparison)

For Town Hall, the critical station, PB-CHA assumed a 10 second reduction in dwell time**. Dwell times were assumed to reduce from 70 seconds with double deck trains to 60 seconds with single deck trains.

(** For single-deck trains compared to double-deck trains due to the lower number of people per train)

The small reduction in dwell time would be offset by a reduction in carrying capacity however. With the passenger assumptions in Table 3.3, the 25% lower single deck capacity would require 28 trains per hour to match the current capacity provided by 20 double deck trains per hour as shown in Figure 3.3.

Figure 3.3: Nominal Train Line Passenger Capacity



Neil Douglas CILT Talk 9/4/2014

Assessment of Train Type & Signalling Control

Passenger Capacity (Pax/hr) Alternative train types

(Existing Signalling)

Double-deck	20tph	Normal load	24,000
		Peak load	28,000
Single-deck	22tph	Normal load	19,800
	22tph	Peak load	25,000

Passenger Capacity (Pax/hr) with enhanced Signalling

(ETCS Level 2)

Double-deck	24tph	Normal load	28,800
Double deck		Peak load	33,600
Single-deck	26tph	Normal load	23,400
	26tph	Peak load	29,200

Passenger train capacity is the maximum number of passengers able to be carried per train (seated plus standing). For example, the "commonly accepted" capacity for an eight car double-deck train (e.g. Tangara or Waratah) for design purposes is 1,200 passengers (PB-CHA, 2011).[1]

Train line capacity is determined by the minimum headway between services. In Sydney, the planned headway is three minutes which is based on a signalling clearance time of two minutes plus a station dwell time of one minute.[2] This gives a figure of 20 trains per hour as the train line capacity.

1 The crush laden capacity is around 2,100 passengers, which represents a theoretical maximum occupancy**. The maximum practical load is around 1750 passengers. This occupancy value was derived from real loading tests undertaken by RailCorp in 2007, representing how many people can actually fit into the train and is commonly used in evacuation analysis. At this occupancy movement within the carriage is almost impossible, the only time actual services would be laden to this level without impact would be for terminating services at Olympic Park, where the whole train load alights (PB-CHA, 2011). BY way of comparison, TMG adopted a lower figure of 1,050 passengers for a standard 8 car train with 956 seats as a practical carrying capacity, (TMG International, 2004).
((** Equates to about 5.75 passengers per square metre standing in a Waratah – see Table 2 notes))

2 Wardrop derived a different figure based on observations of the North Shore. He estimated an intrinsic signalling clearance time of 100 seconds and a station dwell time of 80 seconds.

TMG has suggested a practical maximum of 8,400 passengers per hour per platform for Sydney CBD stations. This was based on a theoretical maximum of 12,000 which was then factored down by 0.7 to 8,400 to allow for that *"passengers do not distribute themselves evenly down the lengths of platforms, nor do they depart in equal numbers on successive Trains"*

PB-CHA (Parsons Brinckerhoff, Cox, Hassell and Aecom (PB-CHA) considered that 20 trains per hour was the "practical train capacity". They calculated a higher "theoretical" capacity of 22 trains per hour which implies a minimum headway of 2 mins 43 secs. In their simulations, running 22 trains per hour 'passed' their simulation tests.

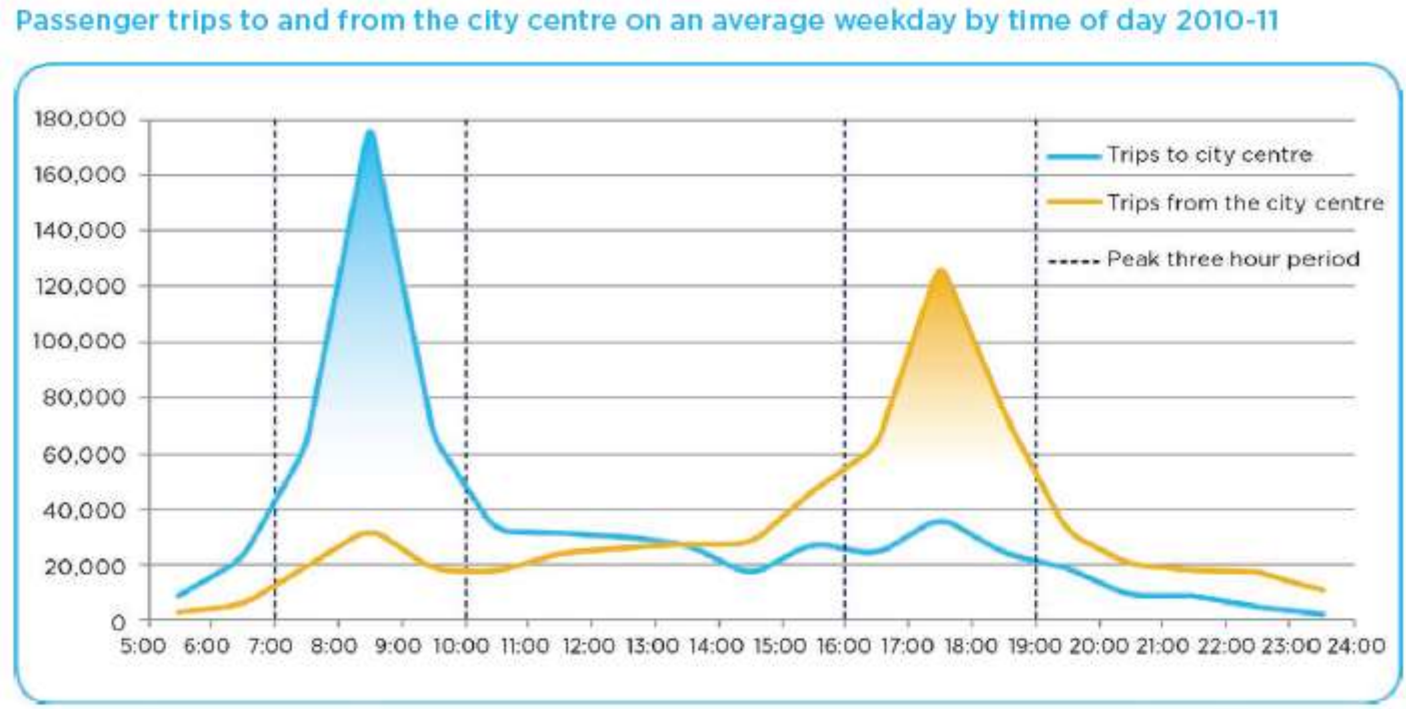
Dividing 20 by 22 trains (practical/theoretical) gives an 'utilisation rate' of 91%. PB-CHA noted that at 91%, the utilisation rate was above the recommended figure of 85% given in UIC 406 guidelines for peak hour suburban train operations (UIC, 2004).3 In fact, practical train capacity would need to reduce to 19 trains per hour if limited to an 85% utilisation rate.

Douglas Economics findings

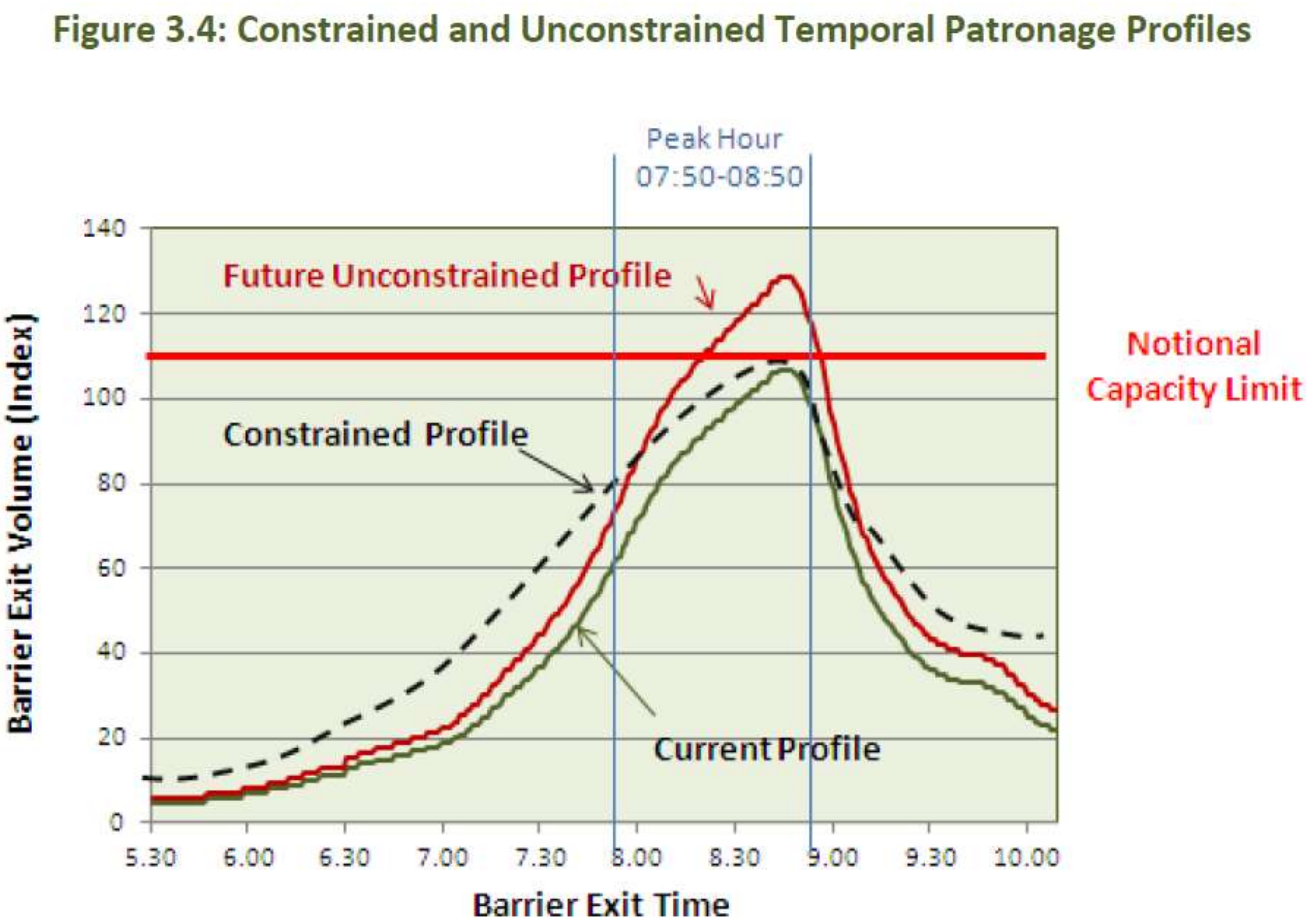
Douglas Economics, Neil Douglas (a New Zealand based UK expert in transport economics), "was engaged by Transport for New South Wales (TfNSW) in October 2011 to (i) assist in specifyingTfNSW engaged Douglas Economics, to assist in specifying a model to assess the interaction of rail passenger demand and train and station capacity for the Redfern to Chatswood rail corridor and (ii) review available computational packages worldwide to determine the degree to which they fit TfNSW's requirements." His report 'Modwelling Train & Passenger Capacity was sent to TfNSW in July 2012. It was published by Fairfax Media in 2013*. Douglas Economics drew on expertise from TfNSW and other consultants in preparation of the report.

The report notes "The CBD Rail Capacity Program is supporting the LTRP (Long Term Rail Plan) by identifying engineering works at key stations, and upgrades to rail systems. One of the key constraints is the dwell time at each of the main stations. Whilst capacity modelling has been done for individual stations, the interaction of the stations when combined with line/train capacity has not been fully understood at a network level. The cumulative impacts of how delays on the network, including how interchanging passengers impact station/operational capacity, needs to be understood in more detail. Such an understanding of capacity limitations will assist with the development of infrastructure upgrades for the CBD stations and lines.

"It has been identified so far that RailCorp and TfNSW have information on:
- Operational modelling for the North Shore
- Dwell time measurements on the North Shore and CBD stations.
- Pedestrian modelling
- Architectural and operational station capacity studies, in particular for Town Hall, Wynyard and Central
- Fire & life safety studies for the main stations
- Passenger Allocation models for the CBD stations."



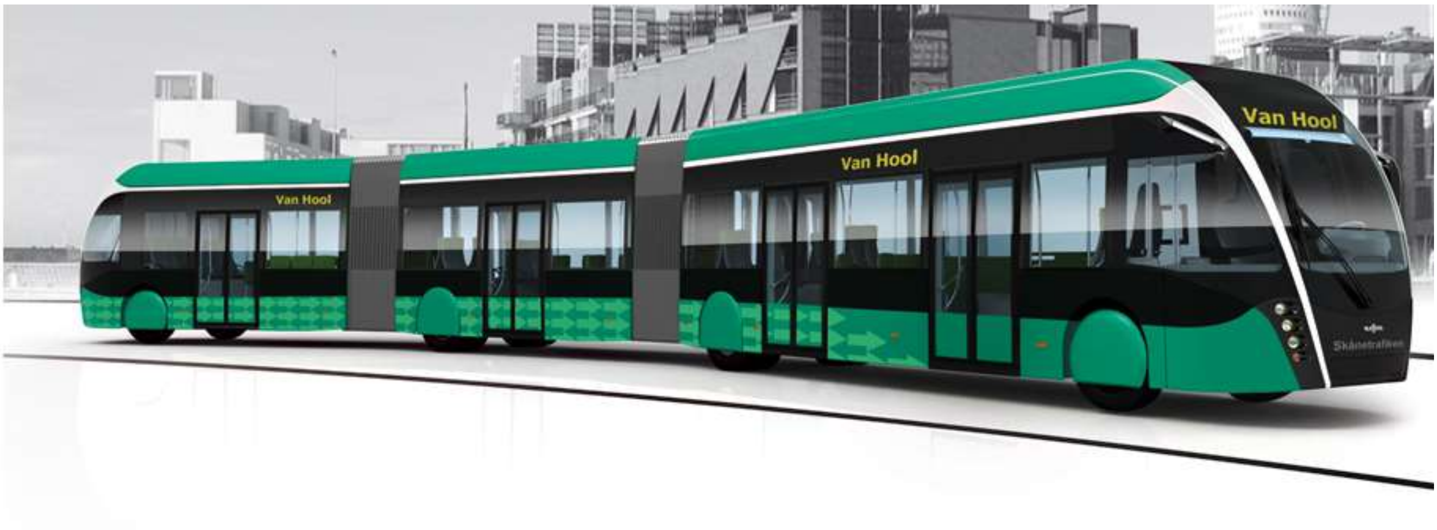
City Centre Access Strategy – travel demand profile



APPENDIX D NWRL website images with the number of passengers barely worthy of a bus

APPENDIX E – Comparison of a modern 43 metre tram with a bi-articulated 25 metre hybrid bus

Figure E1 – Bombardier Flexity 2 conventional tram – same model as Gold Coast tram



15 CNG-fueled, 78-foot ExquiCity 24 hybrid buses by Belgiumâs Van Hool for BRT service in Malmo, Sweden will have new Euro6 MAN engines, series hybrid electric drivelines by Siemens, and Type III carbon fiber-on-aluminum fuel cylinders by Luxfer-Dynetek.

Figure E2 – Van Hool hybrid bus for Malmo Sweden

Appendix F – CBD access strategy - people entering the CBD by vehicle between 8AM and 9AM