Final Report

Inner Sydney Transport Strategy – Technical Support Services

Infrastructure New South Wales

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EXECUTIVE SUMMARY

The need for reform of the Sydney CBD public transport network has been strongly established. A number of studies are underway and various proposals including heavy rail and light rail elements have been suggested for consideration. It is apparent that a city the size and stature of Sydney needs a number of different modes of public transport in order to continue to operate successfully and to grow into the future.

The purpose of this piece of work is to support efforts undertaken by LEK Pty Ltd for INSW to examine aspects of a suggested possible CBD Bus Rapid Transit (BRT) facility. Although necessarily brief and high level, this examination has identified some potential benefits and suggests that a BRT option should be considered further as part of a rational and effective solution to Sydney's transport challenges.

The examination is based upon a reference project which suggests a BRT tunnel from the vicinity of the Sydney Harbour Bridge to an underground bus station at Wynyard Station, continuing to a second underground station in the vicinity of Town Hall with the tunnel surfacing somewhere south of Town Hall. It is noted that other variations or options may also have merit. One of the driving factors of such a project would be to reduce the number of buses which currently contribute to congestion on CBD surface streets (George Street in particular) and another is to improve travel time and reduce variability of bus travel in and through the CBD.

The development of a BRT or a light rail option in the future will clearly necessitate review and re-design of the bus network. In the case of BRT one reason for doing this is the need to maximise the number of buses that could potentially be displaced from George Street. It is also clear that there are potential benefits that could be derived by reforming the CBD bus network regardless of the development of any such project. The level of service for passengers should be a prime criteria in any considerations associated with future public transport options.

Initial "broad brush" analyses indicate that a BRT facility such as the reference project described might be capable of carrying of the order of 200 buses per direction in peak hours.

Based upon very broad comparison with other transport projects an underground BRT facility as described above might cost of the order of $750M to build. LEK have undertaken and reported further analysis on the basis of broadly estimated Capital and Operating costs.

Feasibility, cost, benefits and impacts of options examined in a high level concept sense here need to be investigated in further detail to further verify merits and to logically progress evaluation and planning.

This investigation was not intended to, and has not included:

- Consultation or discussion with any stakeholders or external parties
- Collection or review of comprehensive transport planning data
- Collection or review of traffic planning data
- Collection or review of survey, engineering data/information relating to existing or proposed infrastructure.
- Preparation of planning layouts for the facility and associated works.

Clearly, these matters would need to be dealt with at an appropriate level of detail and in the appropriate timeframes, as strategy development and option planning proceeds.

INTRODUCTION

1.1 Background and Purpose of this Report

INSW engaged LEK Consulting Pty Ltd (LEK) to develop a strategy for Inner Sydney transport, with a particular focus on improving travel times and supporting patronage growth on current bus corridors into the CBD.

The strategy is considering an underground CBD bus solution for the major bus corridors from the north and west (Harbour Bridge, Broadway and Anzac Bridge), which would free up surface street capacity for pedestrians and potentially light rail on George Street from Central/Anzac Parade.

A reference option may make use of the alignment of the old Wynyard tram tunnels and terminal, plus create a bus terminal under a new Town Hall plaza (with potential connection to the Cross City tunnel as well as the Wynyard terminal).

The LEK work focuses on high level analysis and communicating the logic for the strategy, clarifying objectives, and the extent to which different strategic options meet those objectives (including high level estimates of economic benefits, where feasible).

MRCagney Pty Ltd was commissioned by Infrastructure New South Wales (INSW) to provide supporting services to complement LEK's work by offering an operational perspective to infrastructure requirements for a CBD bus tunnel.

MRCagney was asked to test conceptual solutions for practicality, fitness for purpose and value-for-money and provide advice accordingly.

In order to do this MRCagney was asked to consider:

- High level principles for efficient bus operations through a new tunnel, having regard to level of demand, and with a focus on "through-running".
- For the assumed operating solution, identifying the broad infrastructure needs for an underground solution. e.g. How big does it need to be to work efficiently?
- Possible cost-effective design options to give surface bus routes appropriate access to underground sections.

LEK's draft report on a CBD access strategy makes broad comparisons of four alternative future options:

1. Surface Bus (Status Quo)
2. Light Rail
3. Underground Bus Rapid Transit (BRT)
4. Light Rail and BRT network

- Option 1 represents the status quo in terms of available PT modes.
- Option 2 is for a new light rail network with the following links:
  - Central Station to Anzac Pde
  - George St
  - Access created from Anzac Pde to George St

    - CBD to University of Sydney.
- Option 3 is for underground BRT facility, with north – south bus tunnel providing the following links:
    - Harbour Bridge to Town Hall (stations would be provided at Town Hall and Wynyard)
    - Possible link from the vicinity of Town Hall to the cross-city tunnel (to the west)
- Option 4 is a combination of Options 2 and 3, without the light rail link to the University of Sydney.

As noted above, MRCagney's focus was on the underground BRT scenario. This Option is outlined in greater detail in the following section.

1.2 Option 3 Underground BRT

The Option 3 concept is shown indicatively in figure 1 sourced from LEK's draft slides.

Figure 1: Underground BRT Concept

This concept includes an underground bus only tunnel system linking from the southern end of the Harbour Bridge to a location adjacent to Town Hall Station. The section from the Harbour Bridge to Wynyard Station coincides with existing tunnels that were built with the construction of the Sydney Harbour Bridge and carried two way tram traffic from 1932 to 1958.

A second east-west link from the vicinity of Town Hall Station to the Western Distributor (shaded) may be conceived via providing direct access into the cross city tunnel roadway although this link does not form part of the reference project examined. The concept includes two underground CBD bus stations one in the vicinity of Wynyard Railway Station (at the site of the former Wynyard underground Tram terminal) and one at Town Hall (in the vicinity of a possible new pedestrian plaza area centred on the George St frontage of the Town Hall).

MRCagney was also asked to support LEK's efforts by providing information and data on the characteristics of various relevant transport modes and insights into operation of public transport, and planning of public transport operations and infrastructure. A particular focus was requested by INSW on MRCagney input to examination of the underground BRT concept, accordingly this where most of MRCagney's efforts have been focussed.

The purpose of this report is to document the findings of the work undertaken by MRCagney. As such it is understood that elements of this report may be included in LEK's final report and/or the report may form an appendix to the LEK report.

1.3 Assumptions, Information Sources and Constraints

This piece of work requested of MRCagney was commissioned in late May 2012 and is necessarily a brief and high level review of issues. Available information included:

- a briefing on 22nd May 2012 by LEK Consultants & INSW staff
- draft copies of report material prepared by LEK
- site inspections of some key locations by MRCagney staff (22nd May and 27th May, 2012)
- publicly available information on current bus routes and timetables
- Sydney CBD Buses Study: Phase 1 Feasibility Report (RTA, 2010)
- Publicly available material on One City Wynyard development application

Very broad statistics and information on bus transport in the Sydney CBD have been reviewed and used as the basis for some of the analyses undertaken here. Where appropriate broad strategy level planning analyses have been undertaken.

Brief site inspections of some key locations were undertaken and where possible and relevant, appropriate standards and guidelines for operation and design of transport infrastructure have been referenced, however, due to the preliminary nature of the concept definition and planning, this can only be considered relevant for strategic level option definition and issue identification. Clearly considerable further investigations would be required to fully verify the appropriateness and detailed feasibility of any options.

The investigation was not intended to, and has not included:

- Consultation or discussion with any stakeholders or external parties
- Collection or review of comprehensive transport planning data
- Collection or review of traffic planning data
- Collection or review of survey, engineering data/information relating to existing or proposed infrastructure.

Clearly, these matters would need to be dealt with at an appropriate level of detail and in the appropriate timeframes, as strategy development and option planning proceeds.

2. LIGHT RAIL DATA

While the current Light Rail study is not yet released, it is understood that previous studies have proposed LRT headways of 2.5 minutes or less and stated that the only way to increase the resulting one-way peak hour capacity of 3,600 passengers would be double the length of the light rail cars (double sets). It is noted that there is some doubt as to the physical practicality of such a strategy because of the need to double the platform lengths.

As a comparison, operational experience with on-street tram service in Toronto, Canada suggests that even a 2.5 minute headway is impractical. Advice from staff of the Toronto Transit Commission is that based on their extensive experience, a headway of approximately 4 minutes is the maximum that can be operated if bunching and uneven service is to be avoided on congested central city streets even with signal priority and prepaid ticketing in place. Based upon a vehicle capacity of 250 passengers, the order of 3,750 passengers per hour would be the upper limit of such a line under reliable conditions.

The Melbourne tram system operates at higher frequencies, though does experience delays and bunching of vehicles in the CBD. It provides services at up to 2 minute headways within the CBD where multiple tram lines converge and use common stop platforms. The newest trams being deployed into service carry 240 passengers, suggesting a line capacity of 7,200 passengers per hour per direction.

A maximum line capacity of 12,000 passengers per hour per direction has been utilised in material provided to LEK. This is a theoretical maximum and is based on 1 minute headways, with a vehicle capacity of 200 passengers for a single vehicle unit. To achieve such a high frequency a number of measures would need to be taken that include:

- LRT operating in a segregated right of way with no mixed-traffic conditions;
- Signal priority at cross streets (although at peak 1 minute frequencies there will be limited opportunity for cross traffic);
- Passing Lanes at LRT stops;
- Potential for multiple vehicles to simultaneously use stops/stations;
- On-board and at station RTPI to reduce dwell times;
- Pre-paid ticketing on all vehicle at all stops; and
- Multi-door boarding and alighting.

Capex cost estimates have been based predominantly on research of comparable projects. Initial capex estimates for the infrastructure components of LRT projects ranged from as a low as $10 million per km to as much as $100 million per km. The adopted cost for the LRT infrastructure capex was $90Mper km. This was based on comparable projects which are currently under construction, including the Gold Coast LRT project and the Edinburgh Trams project. The first stage of the Gold Coast LRT project covers some 13.5km with a current cost estimate in the vicinity of $75M per km. The corridor will involve both dedicated right of ways and mixed traffic conditions. The Edinburgh Tram project was considered a comparable project due to its alignment through a CBD environment. Initial cost estimates for the Edinburgh Tram project were estimated to be as low as £375 million (AUD$595 million) however costs escalated and now estimates stand at £770M (AUD$1.2bn) for a 13km corridor, which equates to approximately $94M per km. A figure on $90M was considered appropriate due to the complexities of the Sydney CBD environment and similar costs associated with recent LRT projects both within Australia and abroad. For an **11.5km LRT corridor in central Sydney a capex in the vicinity of $1 billion** could well be realistic.

The opex costs have been based on MRCagney industry experience and research. For the purpose of the project, opex estimates are based on time costs for LRT and BRT. Time based costs have been utilised in order to quantify opex savings from time savings achieved through infrastructure improvements. The cost per hour to operate a bus is in the vicinity of $120 per hour, this is assumed to take into account all associated costs to operate a bus per hour including the capital cost of the purchase of a vehicle. Initially an opex cost of $400 per hour of service for an LRT vehicle was utilised, which was assumed to take into all costs associated to operate a LRT vehicle per hour including the capital cost of the purchase of the vehicle. The LRT figure was revised down to $235 per hour, although this figure does not include the capex cost of an LRT vehicle (at the request of the client). The vehicle capex costs are estimated to be in vicinity of $5 million per single vehicle unit, which is based on previous LRT projects.

3. BUS NETWORK

3.1 Existing Bus Network

The existing outbound STA CBD bus network is shown indicatively in Figure 2. Two key observations are:

1. There are eight key entry/exit points to the CBD for bus routes:
    a. North- Harbour Bridge
    b. East – Albion St, Oxford St, William St and Campbell St
    c. South – George St/Broadway and Elizabeth St
    d. West – Druitt St
2. Although complex, the existing bus network provides very wide coverage within the CBD such that the bus network provides the opportunity for intra-CBD travel.

Figure 2: Existing CBD Bus Network

Source: http://www.sydneybuses.info/network-interchange-maps

Examination of the STA timetables shows that the number of buses approaching and departing CBD each weekday are as shown in Table 3.1:.

Table 3.1: Current Weekday CBD Bus Movements (STA Services)

CBD Approach	AM Peak (8:00am - 9:00am)	PM Peak (5:00pm - 6:00pm)	All Day
North	554	184	2358
East	298	291	2997
South	453	149	1930
West	95	84	877
TOTAL	**1400**	**708**	**8162**

In addition to these services, there are a number of private operator services that also serve the CBD.

Examination of the STA bus network map indicates that the services that contribute to the congestion on George Street north of Town Hall are those that enter the city from the west via the M4, or from the south via Broadway. George Street is, quite simply, at its saturation point in terms of the number of buses it can serve in the peak periods.

It is noted that no bus route that crosses the Harbour Bridge terminates at Circular Quay. Whilst several STA routes terminate at Wynyard, most extend to either Town Hall or Central (or continue further and exit the CBD).

Consequently, for the proposed underground BRT to be effective in removing bus services off the surface of George St, north of Town Hall, the current network plan will need to be modified. This is an important observation and it highlights that one of the key benefits intended by the BRT scheme can be delivered in conjunction with a redesign of elements of the CBD bus network. Further, it confirms that the development of the infrastructure proposal needs to be lead by a proposed overall service plan.

The existing buses that do currently travel along the northern half of George Street use Circular Quay as a terminus. If the bus network were to remain substantially unchanged, in order to relocate these buses into the proposed underground BRT, a portal near its northern end would be required that would allow buses to then travel to Circular Quay. This would preferably occur north of Wynyard Station, allowing passengers to use this station in lieu of the existing nearby stops on George Street.

It is further noted that if the proposed University of NSW LRT project were to be implemented, it would reduce the number of buses that would enter the CBD from the south-east, which travel on Elizabeth Street and Castlereagh Street. This would in turn free up capacity on those streets, potentially creating an alternative travel path for other CBD buses.

Clearly, a comprehensive bus network review would be an essential element of planning for any significant new public transport infrastructure such as an underground BRT facility. A full study of the bus network is therefore recommended as a necessary planning step. This should include consideration of the fundamental principles of operation, (especially CBD operation), route structure, layover practices etc, with a view to improving efficiency and optimising service quality for customers in the future.

3.2 Challenges

As the number of different bus routes in a high volume bus corridor increases, average running speeds usually decline. It is much more difficult to schedule a smooth flow of buses in real time if a large number of different bus routes are involved. The tendency for bus bunching increases with the number of different routes and this inevitably creates delays. In addition, passenger boarding becomes more complicated and delays occur because different passengers are waiting for different buses at the same stop.

A further challenge that Sydney faces is the scarcity of space for bus layover in the vicinity of critical terminals such as Circular Quay. The fact that buses need to layover on-street in large numbers (effectively making some streets appear to "dominated" by buses) contributes to a perception that "buses" are a part of the city's problems. This situation is itself exacerbated by the large number of different routes in the network (and hence the need for many buses to layover in the same place at the same time).

3.3 Possible System Improvements

3.3.1 Network Review and Rationalisation

To address this situation the service plan needs to be the initial focus of any review of CBD operations. For example, can low frequency routes either be combined to create fewer more frequent routes or can they be turned into feeder routes to one or more high frequency services? In addition, are there opportunities to reschedule high frequency routes with articulated buses to further reduce the number buses?

As a guideline for a large metropolitan area like Sydney, routes that operate into the CBD should generally have a peak period headway of no more than 10 to 12 minutes with an absolute maximum of 15 minutes. As well as producing operational benefits, reducing the route headways will also make the services more attractive to passengers who can choose their mode of travel. Where such headways cannot be achieved through service redesign, the remaining low frequency routes should become feeder routes to high frequency services preferably scheduled with high-capacity buses.

In the AM peak when the primary movement is inbound, the resulting transfer is easy to make because it is from a low to high frequency service. In the PM peak, consideration should be given to increasing the frequency of the feeder service in the PM peak direction. This can usually be done at no net cost because of the savings on the former line haul section of the feeder service. **The use of high-capacity, low-floor three-door articulated buses wherever possible will speed up passenger boarding and reduce the number of buses in the corridor with a consequent improvement in service reliability.** Routes with headways of 8 minutes or less are candidates for articulated bus assignment.

3.3.2 Interlining and Through Routing

Experience suggests that the practices of through-routing or interlining is likely to produce net benefits in terms of the cost savings and the reduction in the number of CBD bus movements.

Through-routing is where a single bus route starts on one side of the city and ends on another, so the CBD is in the middle of the route rather than at one terminus. Interlining is where the same bus is used for two different routes in succession that have a common (in this case CBD) terminus point, so the bus terminates one inbound route then changes to another outbound route without laying over.

Terminating a large number of buses in the CBD creates problems in finding sufficient temporary storage for them and adds time and distance to the routes affected because of the need to turn the buses around and travel to and from the storage location. It also, as previously noted, adds to the perception that the buses are the problem. The advantage of terminating buses, however, is that it is easier to guarantee an on-time departure from the CBD, particularly in the PM peak.

In Ottawa, for example, interlining and through-routing was shown to produce vehicle savings in the order of 12% compared with the scheduling of individual routes. To gain full advantage of this practice, however, it needs to be possible to serve different trips in a route's timetable with buses that may pull out of different depots. Even with this requirement though, buses still return to their origin depot.

To further address the schedule adherence concern, a portion of the vehicle saving achieved through interlining and through routing can be assigned as extra service buses to be used on an as required basis to fill any serious gaps in service. In this regard it is noted that by eliminating low frequency services in the CBD, there will be fewer situations where an individually delayed bus will cause serious delays to waiting passengers.

A number of routes in Sydney are already through-routed through the CBD, including some of the Metrobus services. However, there is a logical limit to how many additional buses could be through-routed and still provide a measurable benefit. For example, in the AM peak hour buses that arrive from the south and currently terminate at Town Hall or Wynyard could be extended to travel north over the Harbour Bridge. But the benefit to passengers in doing this only exists if there is an unmet travel demand for such trips, especially considering the adjacent rail line which is likely to have spare capacity in the counter-peak direction.

Options for through-routing need to be assessed on a case by case basis and would best be addressed as part of an overall network review. A CBD bus network based upon greater use for a "metrobus" style high frequency services which are so frequent that a departure timetable is irrelevant to the customer is a desirable solution for a city of the size of Sydney where CBD layover space is expensive, problematic and already at a premium.

For buses that cannot be logically through-routed or interlined, an assessment needs to be made whether the vehicle should either:

- Enter a layover facility in the CBD until such time the bus is needed for an outbound service. Layover facilities have a cost to provide, either in an off-street facility which includes capital and operational costs, or in on-street layovers which result in both an aesthetic cost, and an opportunity cost for the utilisation of kerb space.
- Exit the CBD immediately to travel to a depot, or a suburban route commencement location. Such dead running is an expensive and undesirable inefficiency in bus operations, though is typically, to some extent, unavoidable when serving peak flow directions.

The approach can also vary based on the time of day. In the AM peak, buses that terminate in the CBD and have no interlining opportunities will usually return immediately to a depot. The PM peak is different, with the need to commence buses in the CBD creating some level of holding time in their operations, to allow the bus to be at its first stop, on time. To avoid congesting bus stops, this holding time is usually undertaken at a layover location close to the route commencement point.

Clearly, no layover would be permitted in the Underground BRT unless specifically designed to allow it, like the layover locations built into the busways in Brisbane.

3.3.3 Bus Type and Design

Passenger boarding time is affected by the design of the bus in terms of whether passengers must step up to board, the horizontal distance between kerb and the bus floor edge and the number and width of passenger boarding streams (doors). The use of low floor buses in combination with some form of precision docking, for example, has been shown to reduce per passenger boarding times by up to 20%. This can be achieved either through vehicle guidance, or tyre guidance.

Figure 3: Three Door Articulated Bus

Source: http://www.scania.com.au/about-scania/media/press-releases/Press-release-12.aspx

3.3.3.1 Vehicle Guidance

There are currently three different types of vehicle guidance providing precision docking that are either in service or in an advanced demonstration phase. They are mechanical guidance, optical guidance and magnetic guidance. A fourth guidance system that uses GPS technology is under development at the University of Minnesota but is currently only in its early development phase. Mechanical kerb guidance has by far the most operational experience and unlike the other systems it is non-propriety. The on-bus installation cost is much less than that of the optical and magnetic guidance systems. Mechanical guidance also can be provided using a guide rail buried in the road pavement as is the case for the Bombardier and Translohr rubber-tired trams but this technology is not readily adaptable to the operating conditions in Sydney CBD generally.

The first kerb guided bus system was successfully introduced in Essen, Germany in 1980. The same kerb guidance system was used on the Adelaide O-Bahn that went into service in 1986. Similar systems went into service in Leeds in 1995 and in Cambridgeshire in 2011. For guided busway or precision docking operations, buses are fitted with two 180 mm diameter solid rubber-tired guidewheels mounted behind the front wheels on solid forged arms linked directly to the steering mechanism of the bus as shown in Figure 4. The guidewheels project only a small distance beyond the width of the bus and are not retractable. The guidewheels run along the vertical face of the guideway kerbs. The arm connecting the guidewheel to the steering mechanism of the bus is designed to break off if subject to a much larger force than it encounters during its normal kerb guidance function so as to prevent damage to the steering mechanism. For precision docking at bus stops not on a guided busway, a guidance kerb is installed along the face of the bus stop platform. Cost estimates from the Leeds and Bradford operations suggest a per bus cost for the guidewheel installation of between $3000 to $8000 (2005 Figures) depending on the bus manufacturer and the production quantity.

Figure 4: Mechanical Bus Guidance

3.3.3.2 Tyre Guiding Kerbs

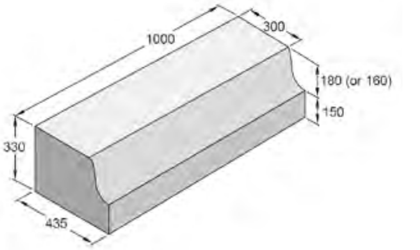
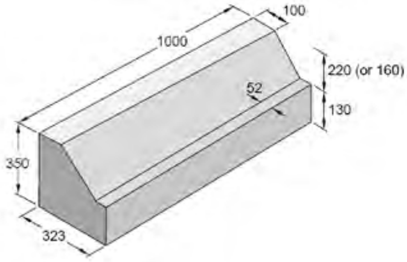
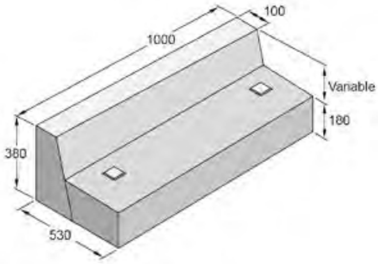
Whilst commonplace overseas, the use of tyre guiding kerbs is almost unknown in Australia.

These manufactured kerbs have a profile to help guide the bus along the kerb edge and into a position with a reduced horizontal gap between bus and the stop platform. Effectively, the bus driver eases the bus into the stop, intentionally making contact with the kerb (at a sufficiently low speed and angle). The profile of the kerb makes contact with the rubber tyre (but avoids the steel wheel hub) and guides the bus into position. These kerbs are more durable and less likely to be damaged by contact with bus tyres than a normal kerb. They are also made with materials that are better able to cope with bus tyre contact, without damage to the tyre.

As a preformed unit, the kerb section is also typically a few centimetres higher than a standard kerb, assisting with achieving level boarding.

The investigation of guided bus technology and/or tyre guiding kerbs is recommended for Sydney as part of any BRT system going forward as a possible means of assisting to reduce passenger boarding times and increasing levels of service and improvement bus station clearance times.

Table 3.2: Examples of Tyre Guiding Kerbs

Type	Heights available	Photo	Profile
Brett Landscaping 'Kassel' Kerb	180mm		
Camas (Charcon) Access Kerb	220mm or 160mm		
Marshalls Bus Stop Kerb	Up to 200mm		

Source: Accessible bus stop design guidance. Transport for London. 2006.

3.3.4 Fare System

The characteristics of the fare system that are the important determinants of passenger boarding time are the proportion of off-board fare payment and the use of multi-door boarding. The STA already utilise both of these at specific locations and times.

Off-board fare payment in the context of a BRT station would operate much like it does at a train station, with gated entry points requiring proof of payment to pass the gates. Effectively, every person waiting at the platform for the bus is a paid passenger, and no further checking or intervention is required with the exception of ensuring that a passenger has purchased a ticket covering enough zones or sections, when they disembark.

Multi-door boarding then takes advantage of this and allows passengers to board via all doors of the bus. This is of the greatest benefit for peak services where few or no passengers are disembarking, allowing unimpeded entry access. In instances where greater numbers of passengers are disembarking, their movement impedes boarding passengers, though this is usually tolerable.

The upcoming implementation of a smartcard ticketing system will improve the efficiency of passenger boarding, even if on-board fare collection is used (through touch-on smartcard readers). In Brisbane where smartcard ticketing has an uptake rate of over 90% in the CBD, boarding time has decreased to less than 2 seconds per passenger (though it would be faster again if prepaid platforms were to be created at busway stations).

In Ottawa, the improvement in boarding times due to the multiple-door boarding alone was sufficient to reduce by 10% the number of buses needed on the first articulated bus route introduced in 1981. This fare payment practice also means that over 200 buses per hour are serviced on 55m long platforms in the CBD. In Brisbane where platform lengths are also 55m, but multi-door boarding is not used, the estimated capacity of the platforms is estimated at around 140 buses per hour.

The use of pre-paid boarding in Sydney has been increasing in recent years. Details of this are presented on http://www.sydneybuses.info/prepay which states that:

> *The first trial to speed up boarding times was conducted in 2004 at the Watson Street bus stop on Military Road, Neutral Bay and saw a drop in on-board cash sales from 12% to 4% and average loading times were reduced from 50 seconds to 36 seconds. This involved the sale of single ride magnetic tickets off the bus by staff at State Transit's ticketing booth at Watson Street during the morning peak.*
>
> *The outbound Druitt Street bus stop was trialled as a PrePay Only bus stop between the hours of 3.30pm and 6.30pm. This initiative aimed to reduce passenger loading time at the stop and improve on-time service running for the trip.*
>
> *In 2006 the first PrePay-only bus, Route 333 was introduced on the busy Bondi to City corridor, to speed up boarding times. The high frequency service proved popular and so the concept was rolled out to other bus routes across Sydney.*
>
> *Since then, the number of ticket resellers across Sydney has been increased so that pre-purchasing tickets is now easier than ever.*

The current pre-paid boarding system (where used) in Sydney still requires on-board ticket validation (swiping). The establishment of a true “paid area” operation at the CBD BRT stations (where, as at major rail stations, tickets are validated at a barrier prior to the customer entering or leaving the station rather than the vehicle) would lead to the greatest station efficiency, through minimising boarding time hence vehicle dwell time and maximising throughput. Station passenger infrastructure should be planned to accommodate this style of operation.

3.4 Theoretical Capacity Requirements

In exclusive right of way operations, such as is proposed in this Underground BRT concept, busway capacity is governed by:

- Access and egress capacity (i.e. where the busway meets the street networks);
- Station Capacity; and
- Running-way capacity,

A further consideration, should it be relevant, would be any busway/busway intersections or other at-grade interactions (intersections with general traffic or pedestrian crossings).

Experience with busway systems in Brisbane and elsewhere indicates that station capacity and access capacity will likely constrain overall busway capacity long before the running-way capacity becomes an influential factor.

A typical busway station with platforms of standard 55m length (which is long enough to cater for two articulated plus one rigid bus) in the Brisbane busway context generally has capacity to service at least 130 buses per direction per hour. Combined measures such as simplified service structures, pre-paid platform areas, multiple door boarding, three door articulated buses and reliable real time passenger information have the potential to increase this to 180 buses per hour. Highly optimised system conditions such as those that have been previously reported from Ottawa can see this capacity rise to over 200 buses per hour. It is recommended that a CBD BRT system for Sydney should take advantage of as many capacity maximising features as possible so as to ensure the optimum efficiency, benefit and value.

It should be noted that there are in existence BRT systems such as Bogata's TransMilenio which can carry up to 45,000 passengers per hour per direction however this system comprises a running-way with at least two bus lanes in each direction and very long bus platforms. As such, the level of infrastructure provided is on a significantly greater scale than most other BRT systems world wide. This example does however indicate what can be achieved with bus based transport if infrastructure is dedicated on such a scale.

While the overall CBD BRT concept is still being developed and capacity governing factors such as the BRT entry/exit arrangements are still uncertain, it could be assumed that an efficient underground BRT might be capable of carrying the equivalent of up to 260 buses per hour per direction or somewhere in the vicinity of 30% of the current STA buses peak hour CBD buses. This could require dual platforms at each station (i.e. two pairs of platforms).

Preliminary examination of the BRT concept indicates that two in-line busway stations, one at Wynyard and one at Town Hall, would support the operation of a north-south underground BRT system. The Town Hall Station would however be potentially complicated if the connection of a western link (either directly from the cross city tunnel, or from a portal adjacent Town Hall) is required. It may be that due to the complex subterranean environment at Town Hall Station, grade separation of each pair of platforms would be required. One pair could be dedicated to buses travelling north-south through the CBD, the other pair to services travelling to/from the west. These platforms would ideally then be connected to each other for vertical passenger transfers (i.e. a "Metro" style of station), and also connected to rail platforms if station configuration allowed.

In summary, options to achieve high BRT capacity include:

Vehicles

- Larger doors
- More Doors
- Internal layouts (fewer seats)
- High Capacity Vehicles
- On-board RTPI (to minimise passenger confusion and passenger/driver interaction)

Infrastructure

- Segregated Right of Way
- Signal Priority

- Station passing lanes
- Increased platform length + depth
- Station Legibility
- RTPI at Stations (to minimise passenger confusion and passenger/driver interaction)
- Off-vehicle fare collection facilities

Operations

- Relatively Simple Bus Network Route Structure & Operating Plan
- All door boarding/alighting
- Pre-paid/Proof of payment ticketing
- Limit driver passenger interaction

3.5 Potential time saving (Underground vs Surface)

The average CBD operating speed for buses in Sydney is understood to be as low as 8km/h at the times and locations of greatest congestion. This correlates with published timetables for services running between the vicinity of Harbour Bridge (Lang Park at York St) and Railway Square and in George Street itself, with typical peak period (limited stops) bus running times of the order of 18 minutes for the 2.3km distance. The 800m distance between Town Hall and Wynyard stations is typically scheduled to take 5 minutes, a speed just under 10km/h.

Anecdotal evidence is that actual travel times for buses in the Sydney CBD and George Street in particular vary considerably, particularly in peaks, and it is not uncommon that actual bus travel times are significantly greater than the above averages. This consistent unreliability in bus travel times is also a major driver for consideration of an underground BRT facility.

The bus operating speeds that could be achieved in an underground BRT system are likely to average around 40km/h (based on the inner-city sections of the Brisbane busway), whilst average dwell time at each station would be up to 60 seconds. The estimated time to travel between Lang Park and Railway Square would reduce to Wynyard and Town Hall would reduce from 5 minutes to 2-3 minutes.

Time savings of 3-5 minutes north of Wynyard Station would also be achieved by bypassing the existing traffic signals between the station and the Harbour Bridge.

Further detailed surveys and study would be required to verify the precise quantum of time savings likely to be possible at different times of the day. Improved reliability would be an additional key benefit that would accrue.

4. BRT Alignment Elements

4.1 Overall Draft Concept

The overall BRT concept that was suggested in internal briefings is shown in Figure 5.

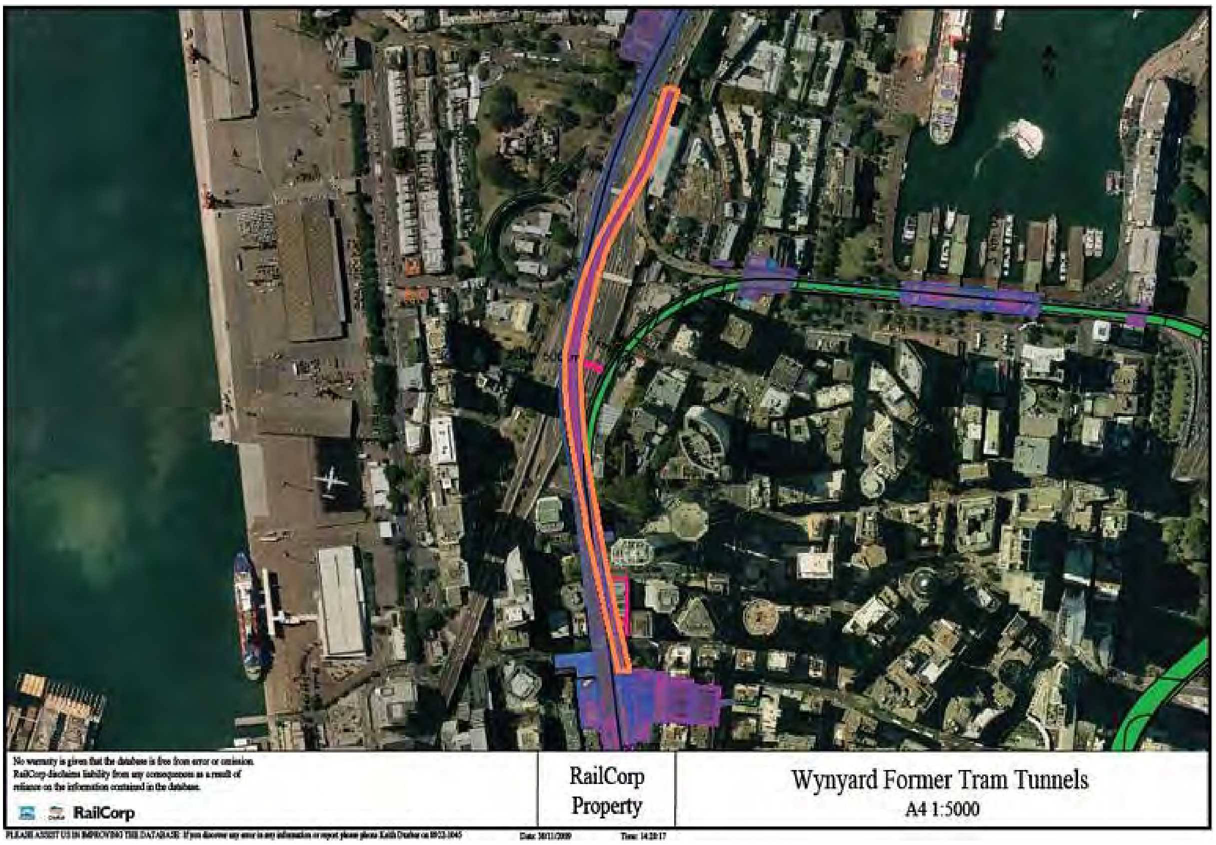
Figure 5: Indicative BRT Alignment

4.2 Wynyard Tram Tunnels

4.2.1 Location & Description

The location of the existing Wynyard Tram tunnels is shown in Figure 6.

Figure 6: Wynyard Tram Tunnels



(Source: http://www.heritage.nsw.gov.au/07_subnav_01_3.cfm?itemid=4800281&imageid=47282166)

A description of the tunnels sourced from http://www.heritage.nsw.gov.au/07_subnav_01_2.cfm?itemid=4800281 is as follows:

The Wynyard tram tunnels consist of two concrete lined arched tunnels heading north from Wynyard Station, reaching ground level on the south side of Argyle Street. Single line tunnels for the City Underground were built to be 4.6 metres wide and 3 metres high to the springline of the semi-circular arch, giving a centre height of 6.9 metres. The former track areas around the platform concourse have been filled and the tracks, signals, indicators and electrical infrastructure have been removed although some evidence remains in riveted steel I-beam columns and other associated features. The former concourse area has been utilised as a car parking station since 1964 and the eastern tunnel provides the main exit from the car park to Cumberland Street, where a transverse penetration was made from the tunnel to the street. The floor of the tunnel is asphalted and lighting has been installed along the tunnel. The western tunnel was reputedly utilised as a police pistol firing range for some time but is now used for storage.

A section of the existing tunnel currently used as part of the carpark exit is illustrated in Figure 7.

Figure 7: Former Wynyard Tram Tunnel

A more detailed discussion on the prerequisites for utilisation of the former tram tunnels for modern busway purposes consistent with contemporary Fire and Life Safety requirements is included here in Appendix A.

Based upon the limited information available to this study, it is concluded that:

- The original tunnel tubes (where un-modified) are individually large enough to physically permit a bus to pass through in one direction, however the tunnel dimensions are inadequate to allow buses to pass in the event of a breakdown, crash or a fire.
- The internal dimensions of each tunnel do not meet contemporary standards for busway operation
- The existing tunnel arrangements do not meet contemporary standards for emergency escape/egress.

The existing Wynyard tram tunnel passages would be best suited to guided electric light rail vehicles and trams which don't produce engine exhaust emissions. It may however also suit guided buses similar to those operated on the Adelaide O-Bahn and emerging future hybrid diesel buses can be operated through short tunnel sections by electric motor.

Hybrid propulsion systems combine an electric and a diesel engine with regenerative braking to charge batteries. Hybrid propulsion systems are increasingly being used in buses, fuel savings in the order of 30% are not uncommon over a traditional diesel engine. More cities around the world are adopting hybrid buses and their reliability has been improving and cost decreasing. Some hybrid vehicles allow the vehicle to operate purely on the electric motor for short periods of time. Such an arrangement would be beneficial in tunnels due to lack of at point source emissions, decreasing the ventilation requirements.

New York has the world's largest hybrid powered bus fleet, proving the viability of the technology when deployed on a wide scale. London's new Routemaster double decker bus, of which 600 will be delivered in the next three years, features a hybrid diesel-electric engine.

Trials of hybrid buses have been undertaken in Australia, although no agency or operator has yet committed to the technology.

Based on probable locations of buried structural steel members surrounding the Wynyard Tram Tunnel, it is unlikely that a tunnel roadheader or boring machine could be deployed to widen and/or combine its two vehicle passageways into a single two-way tunnel. An alternative potential reconstruction solution for small scale widening of the existing Wynyard tram tunnels without penetrating the tunnel water seal shell and which minimises disturbance to existing above tunnel utility services and building structures may be possible.

The solution could involve stripping off the interior wall linings from the outer structural columns and over and between the central columns from pavement level up to approximately 3.5m above pavement; casting in-situ tapered steel reinforced concrete barriers above and pinned to the pavement around and between all columns, and lining along the column faces above the cast barriers with a fire-rated high reflectance alpolic composite sheeting or similar. Cross passage emergency egress doors and fire hose cabinets would need to be built into the median barrier wall at intervals of 40 - 60m and door penetrations through the outer walls between columns for emergency egress PWD ramps and stairs to road surface level at intervals of around 180 – 200m. This arrangement would widen each tunnel passage by 600 – 700mm and permit unguided buses to travel at design speeds of around 50 - 60km/h, or higher if guided by rails.

Alternative solutions that could be investigated further would include using one vehicular tunnel for buses and devoting the other to an emergency passenger egress and services tunnel, or removing all the central columns and reinforcing the structure with additional new piles, headstocks and beams to create a single full width two-way tunnel.

Impacts of any reconstruction necessary and indeed the use of the tunnels for bus traffic, upon nearby above and below ground infrastructure and upon the existing heavy rail corridor which cross the tram tunnels in at least one location and over which the tram tunnels appear to be located should be investigated and may require mitigation.

It is suggested that the alignment of the Wynyard tram tunnels, if not the physical infrastructure, may well be useful as an underground corridor for BRT, so the feasibility of using the alignment of the tram tunnels to connect between Wynyard Station and the vicinity of the Harbour Bridge could be investigated in further detail.

4.2.2 Tunnels South of Wynyard

The connection of a BRT tunnel south of Wynyard Station will clearly require a new dedicated alignment. Detailed investigation of underground infrastructure and geotechnical conditions will be required to formally identify feasible (and most desirable) options. While deeper alignment options may avoid existing infrastructure and represent less disruption during construction, overall cost could be very substantial.

4.2.3 Link to Harbour Bridge

A quality link to the Harbour Bridge will likely be challenging to achieve partly due to public and possibly political views around potential impacts on the existing road network and bridge capacity. There are however several options that would appear to bear further investigation:

- "reinstatement" of former tram style access
- access via a central portal facilitated by southern Harbour Bridge approach rationalisation
- access via surface street network

The former tram access to the bridge pre-dated the construction of the Cahill Expressway and the two extra traffic lanes on the eastern side of the bridge, so the original tram access was by simply at grade ramp from the existing portals just south of Argyle St up to the bridge as shown in Figure 8. This arrangement is similar to the existing heavy rail access on the western side of the bridge.

Figure 8: Former Harbour Bridge Access Arrangements

Source: http://www.photosau.com.au/CosMaps/maps/pdf/AO1/AO014.pdf

The at grade alignment of the former tram ramp coincides with the support structure for the two added road lanes as shown in Figure 9.

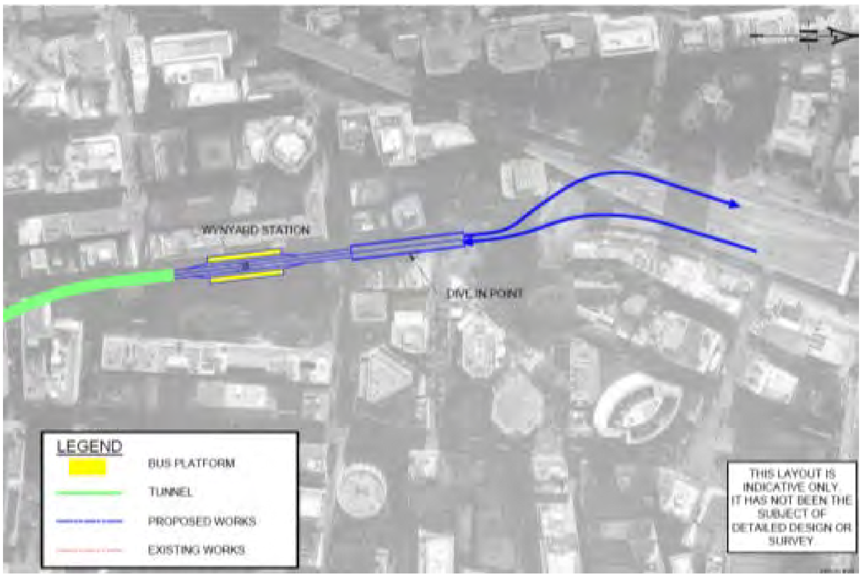
Figure 9: Former Tram Access to Harbour Bridge

Assuming that a two way BRT system is to be developed, if this former access arrangement were to be "reinstated" for BRT, the implications would appear to be loss to general traffic of two eastern most lanes across the Harbour Bridge. It is noted that one of these lanes is a peak (6a.m. – 10 a.m. & 3p.m. – 7 p.m. Weekdays) bus lane. Also due to the resultant "contra flow" of the northbound BRT lane, the two BRT lanes would need to be carried across the Harbour Bridge and a suitable entry/exit arrangement developed on the northern approach (i.e. the BRT lanes could not be "merged into general traffic lanes at some point on the bridge and part time bus lane status would not be practical).

It is understood that reconfiguration of the former toll plaza area at the southern end of the Bridge is contemplated. This might present an opportunity to free up space in the middle of the southern bridge approach that could be used to form a portal for "median" running BRT lanes across the Bridge. As these BRT lanes would be consistent with the direction of traffic lanes flowing across the Bridge rational lane merge options might be possible to develop. This option is therefore worthy of further consideration.

Another option that appears to be worthy of further investigation is to develop a portal to the surface street network (say on York St in the vicinity of Lang Park), shown indicatively in Figure 10. While not necessarily providing bus priority all of the way onto the Harbour Bridge, this option could also potentially provide for northbound bus access to Circular Quay and as such may more easily facilitate usage of the BRT facility by a wider range of bus routes.

Figure 10: Harbour Bridge Access Concept Option 3

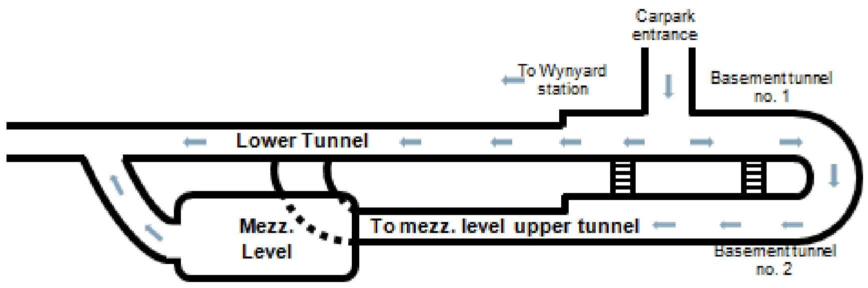


Any of these options may have impacts upon traffic capacity, Bridge capacity and potentially physical impacts upon other infrastructure. These impacts would need to be carefully investigated and considered in any decision relating to a preferred option for access to the Harbour Bridge. In this regard Option 3 may well prove to be the most flexible and least disruptive alternative.

4.2.4 Wynyard Station

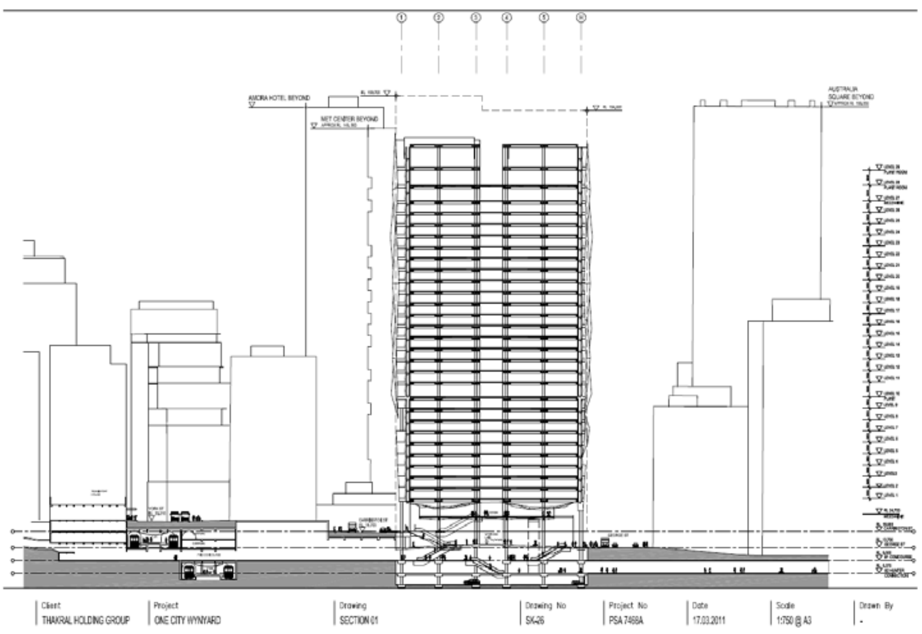
The former Wynyard tram terminal is now the site of the underground car park for the Menzies Hotel (refer to Figure 11). Initial inspection indicates that it is very unlikely to be possible to retro fit the current structure to function safely and efficiently as a modern busway station. However, the location adjacent to the Wynyard Railway station has considerable merit as a bus station under the BRT concept. It is considered that reconstruction of the station site will be required.

Figure 11: Menzies Hotel Car Park



A cross section from a current development application for the site (Figure 12) shows the location of where the station might be configured.

Figure 12: One City Wynyard Concept



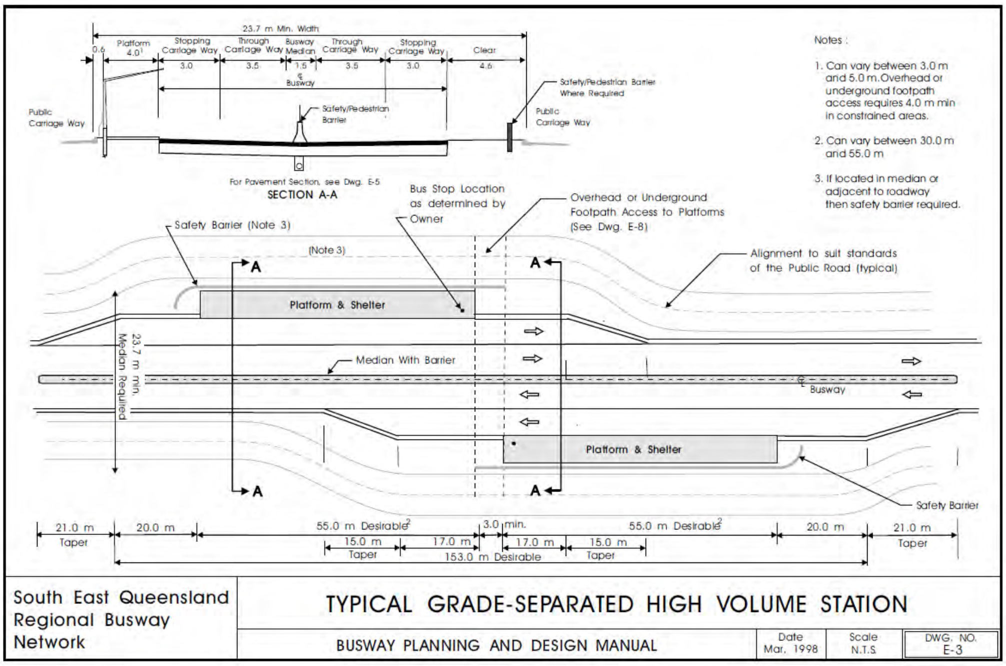
Hassell drawing SK-26 for Thakral Holding Group

Figure 13 indicates a typical layout for a standard 55m platform busway station, of the type referred to in Section 3.4. It is noted that in the Brisbane context the platforms are usually aligned directly opposite each other, reducing the overall length required for the station. As discussed in Section 3.4, detailed investigation and study may find that two sets of platforms (i.e. 4 platforms) may be desirable for a Wynyard BRT station.

Further detailed investigation is required to determine:

- the functional requirements for a Wynyard Station
- detailed feasibility for locating the station given surrounding existing and planned infrastructure and feasible tunnel approach options.

Figure 13: Typical High Volume Busway Station Layout



Source: 1999 South East Queensland Busway Planning & Design Manual

4.3 Town Hall Station

Proposals for the development of a public plaza at Town Hall provide an opportunity to consider the location of a BRT station in that location. A concept layout for the Plaza suggested by Gehl Architects is shown indicatively in Figure 14 and Figure 15. The option to construct an underground BRT Station with the development of the plaza is attractive and appears to make sense. The depth of such a station would be governed by a number of factors including:

- Existing railway lines and station
- Other existing underground infrastructure
- Feasible approach alignments for BRT tunnels
- Surrounding development and re-development plans

While further study is required to determine the functional requirements of a BRT station at this location, it appears to be reasonable to assume that a station similar to that described above for Wynyard would be appropriate viz: 4 x 55m platforms.

A further option that could be considered is the incorporation of a surface BRT station within the public plaza (perhaps along one edge) if tunnel options are not pursued at this location. A bus tunnel portal at one end of the plaza (not dissimilar to the Queen Street Bus Station portal at Redacliff Place in Brisbane) may be worth considering.

Figure 14: Town Hall Square Concept

Source: Gehl Architects – Public Space Public Life Sydney

Figure 15: Town Hall Square Concept Layout

Source: Gehl Architects – Public Space Public Life Sydney

4.4 Southern Portal Options

Options for southern BRT tunnel portals that have been suggested include:

- George Street at New Town Hall Plaza (1)
- Mid block in George St [2 options] (2)
- Pitt Street south of Hay Street (3)
- Via the Regent Street layover and disused railway corridor (4).

These locations are shown on Figure 16.

Figure 16: Southern Portal Options

George Street at Town Hall Plaza provides the northernmost opportunity and as such may result in the lowest overall cost but also the shortest length of BRT priority. As noted above, this might be able to be integrated with future plaza development and hence may have minimal disruption both in construction and operational phases.

Mid block options in George Street appear to represent mixed outcomes, providing slightly longer lengths of bus priority at additional tunnel cost, offset against likely greater disruption in construction and operational phases.

Pitt Street option appears to represent a potential for manageable disruption during construction although buses would need to be diverted off the current George Street approaches to access this location. Satisfactory traffic arrangements would need to be developed to facilitate this. The length of tunnel (and hence priority) would be greater than for the above options but the off-tracking would negate some of this benefit.

A further option conceived during the study is the possibility of utilising the Regent St bus layover and the adjacent disused railway tunnel portal. This option represents the longest tunnel length but potentially the least disruption during construction and, subject to satisfactory traffic access arrangements, possibly minimal operational phase disruption.

The detailed engineering feasibility and detailed operational benefits and dis-benefits of each of these portal options should be investigated further n conjunction with the investigation of the feasibility of the north-south tunnel components.

5. BRT COST RANGES

Based upon research and industry experience, strategic level, BRT capex and opex costs of the concept have been developed. The capex and opex costs provided are strategic level broad cost ranges. It is beyond the scope of the current study to attempt to cost, in any detail, the concepts that have been identified. In any case, there are still many significant unknowns in relation to existing conditions, and environment and the concepts themselves. General comparative costs based upon other past projects of a similar scale or nature are outlined below as a means of attempting to understand the possible scale of cost range relevant.

BRT capex estimates have been based on the corridor being in a driven tunnel. The numbers of BRT tunnel projects are limited, so recent road tunnel projects were considered for comparison purposes. Brisbane's Clem 7 tunnel has been recently completed is estimated to have cost approximately $441 million per km (twin tunnels). The Sydney Cross City Tunnel in 2005 had a cost estimate of approximately $323 million per km (also twin tunnels). Brisbane's Inner Northern Busway (INB) project between Queen Street Mall and Roma Street, despite being a cut and cover tunnel, is considered comparable in scale, The INB project stretched 1.25km including 500m of cut and cover tunnel. The project had an estimated cost of $266 million per km in 2008. Based upon this information, a figure of $300m was considered relevant for a driven BRT tunnel through the Sydney CBD. For a **2.5km driven BRT tunnel under the Sydney CBD a capex in the vicinity of $750million** is therefore considered relevant.

Vehicle capital expenditure figures are based predominantly on MRCagney industry experience. For the BRT component, the cost estimates have assumed standard 12.5m rigid buses will continue to be used. 12.5m buses in Australia cost in the vicinity of $450,000 each and have a combined sitting and standing capacity of 75 people. Based on recent project research and the 2007 Brisbane Mass Transit Investigation, the cost for a LRT single vehicle unit (SVU) is in the vicinity of $4 million with a carrying capacity of approximately 200 people (sitting and standing).

The opex of three different scenarios was investigated. The first was Option 1: Base Case – Status quo, this is assumed to include all bus services entering the Sydney CBD[1] that would use a BRT tunnel between the Harbour Bridge and the Queen Victoria building but currently use surface routes. Option 2 is the opex of an LRT route and is based on LRT services operating at peak capacity 6 hours per day and at 80% of capacity for a further 8 hours of the day[2]. Option 3 is the opex of the quantum of services in Option 1, although operating in a BRT tunnel allowing the opex savings associated with shorter travel of a BRT tunnel to be quantified[3]. The opex of the three options are as follows:

- **Option 1 is in the vicinity of $17.5 million per year**[4]
- **Option opex is estimated to be in the vicinity of $66 million per year**
- **Option 3 opex is estimated to be in the vicinity of $7.5 million per year**

Based on these opex estimates, a BRT tunnel would result in opex savings of $10million per year, which it is noted may not be a significant differentiating consideration in the context of the overall capital expenditure envisaged in these options.

[1] 2342 services per day would utilise a tunnel from The Sydney Harbour Bridge to Wynyard and 3536 services would utilise a tunnel between Wynyard and the Queen Victoria Building
[2] Estimated to be 700 services per day per direction
[3] Without a tunnel travel time from the Sydney Harbour Bridge to Wynyard assumed to be 6 minutes and with a tunnel 2.3 minutes. From Wynyard to the Queen Victoria Building without a tunnel the travel time is assumed to be 4 minutes and with a tunnel 2 minutes.
[4] Based on 312 days of operation per year

6. SUMMARY OF FINDINGS

This work is based upon a reference project which suggests a BRT tunnel from the vicinity of the Sydney Harbour Bridge to an underground bus station at Wynyard Station, continuing to a second underground station in the vicinity of Town Hall with the tunnel surfacing somewhere south of Town Hall.

Initial "broad brush" analyses indicate that a BRT facility such as the reference project described might be capable of carrying of the order of 200 buses per direction in peak hours.

A number of options for tunnel, portal and station arrangements have been considered from a strategic level concept perspective and further work has been identified that would need to be carried out to pursue these.

Based upon very broad comparison with other transport projects, an underground BRT facility as described above might cost of the order of $750M to build. LEK have undertaken and reported further analysis on the basis of broadly estimated Capital and Operating costs. Their work further enumerates the benefits and strategic drivers for pursuing such a facility.

The development of a BRT or a light rail option in the future will clearly necessitate review and re-design of the bus network. In the case of BRT, one reason for doing this is the need to maximise the number of buses that could potentially be displaced from George Street. It is also clear that there are potential benefits that could be derived by reforming the CBD bus network regardless of the development of any such project. The level of service for passengers should be a prime criteria in any considerations associated with future public transport options.

Feasibility, cost, benefits and impacts of options examined in a high level concept sense here need to be investigated in further detail to further verify merits and to logically progress evaluation and planning.

This investigation was not intended to, and has not included:

- Consultation or discussion with any stakeholders or external parties
- Collection or review of comprehensive transport planning data
- Collection or review of traffic planning data
- Collection or review of survey, engineering data/information relating to existing or proposed infrastructure.
- Preparation of planning layouts for the facility and associated works.

Clearly, these matters would need to be dealt with at an appropriate level of detail and in the appropriate timeframes, as strategy development and option planning proceeds.

Appendix A

Desktop Review of Fire and Life Safety for BRT Use of Wynyard Tram Tunnels

Wynyard Tunnel Fire and Life Safety Upgrades for Buses

A Wynyard Tram Tunnel As-Constructed Section

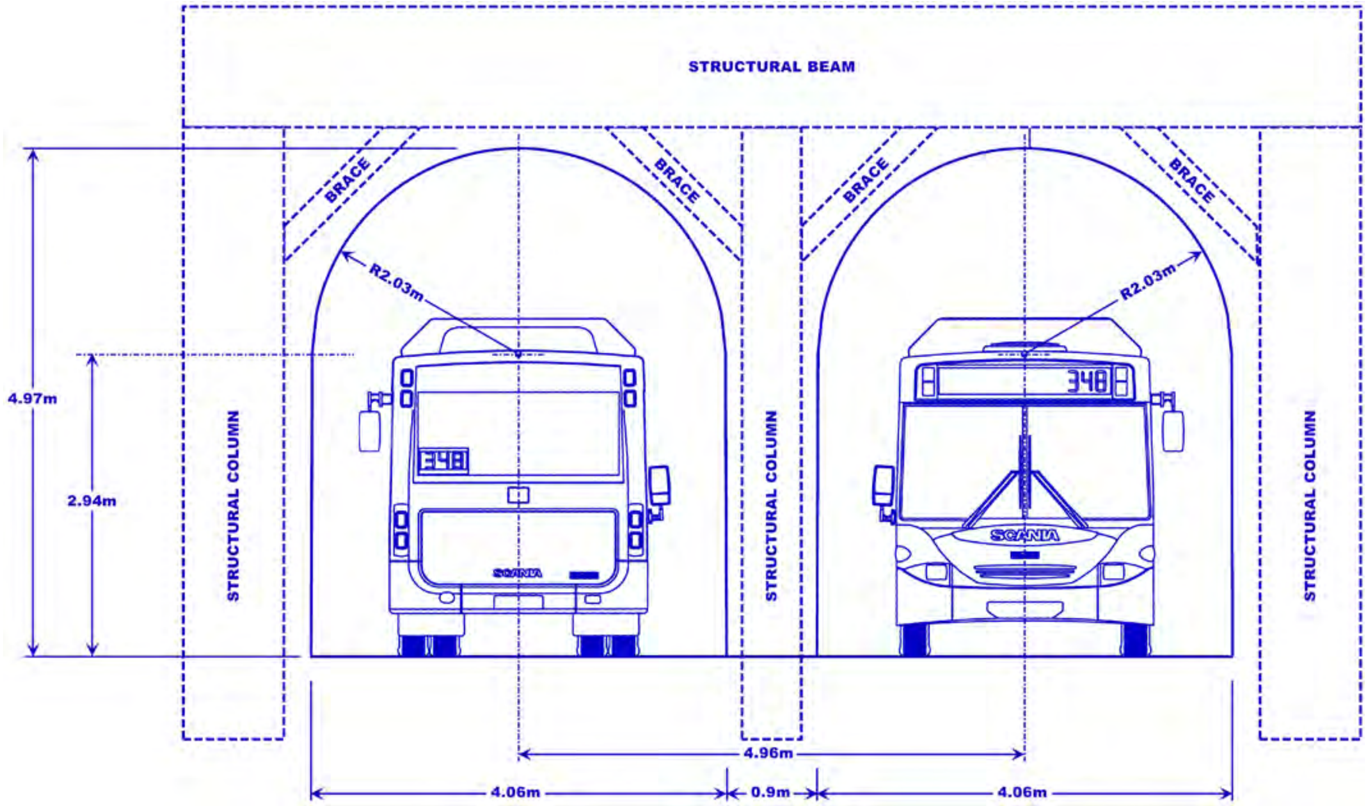


Figure 17: Wynyard Tram Tunnel As-Constructed Section

The Wynyard Tram Tunnel as-constructed section shown in Figure 17 is considered to be typical and has been derived from a review of 4 historical Sydney tramway photographs and typical NSW railway and tramway tunnel sections published in the *Report on Proposed Electric Railways for the City of Sydney, J.J.C.Bradfield, 1916, Dept of Public Works, Sydney, NSW*.

Likely positions and dimensions of structural frames surrounding the two adjacent tunnel passages have been illustrated in ghost outline on Figure 17. These assume the tunnels were originally constructed by cut and cover excavation and the structural frames finished over with formwork to create the concrete outer water seal shell and inner wall and soffit linings, both presumed to have been cast in-situ and bonded to the structural frames by a cage of steel rebar and mesh. The tunnel inner lining is likely to be around 300-400mm thick.

Buses of similar dimensions to those currently operated by the NSW State Transit Authority have also been overlayed on the two tunnel passages and have an approximate wall-to-wall clearance of 780mm each side of the bus body (excluding mirrors).

B Comparison of Wynyard Tram Tunnel and Brisbane Busway Tunnel Sections

The illustration at top on Figure 18 overleaf presents an overlay of the existing Wynyard Tram Tunnels (blue outline) on a typical Brisbane Busway Tunnel (red outline) cut and cover section. Key busway tunnel section dimensions are indicated on the tunnel section drawing (in black) appearing at the bottom of Figure 18. The section drawing shown is for a heavy omnibus design speed of 90km/h.

Two-way lanes in Brisbane busway tunnels are 3500mm wide with a 1400mm nominal shoulder, separated by a single unbroken centreline with no median barrier to segregate opposing traffic flows. Overtaking is however strictly forbidden in all busway tunnels and other two-way busway lanes.

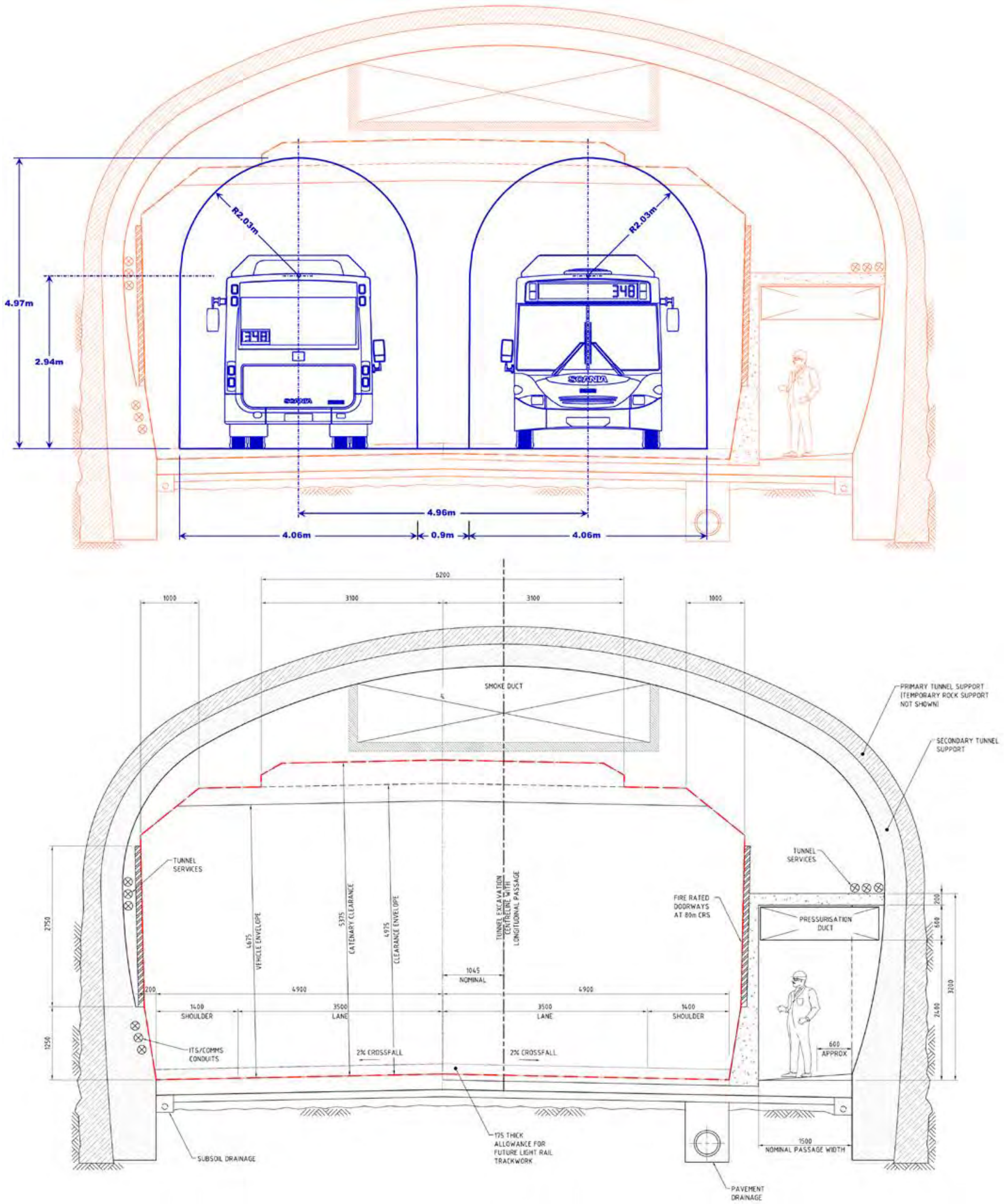


Figure 18: Comparison of Wynyard Tram Tunnel and Brisbane Busway Tunnel Sections

The red outline on the bottom drawing in Figure 18 shows the minimum 5375mm high envelope required for future light rail vehicle exclusive use and proposed interim shared light rail vehicle and bus utilisation of Brisbane busway tunnels. The bus only clearance envelope has been nominally set within this envelope at the lower height of 4625mm.

Busway tunnels over 200m in length typically include a pressurised PWD accessible emergency egress tunnel along one side for escape of bus passengers and drivers from a bus fire or collision incident, but busway tunnels have been built with PWD escape doors and ramps to street level from shallow tunnels similar to Wynyard Tram Tunnel constructed under public road alignments. Emergency egress doors are typically located along one side of the vehicular tunnel at intervals of 40 – 60m.

The longitudinal smoke extraction duct shown on the vehicle tunnel sections in Figure 18 have only been installed in Brisbane CBD busway tunnels where bus exhaust fumes have had to be exhausted vertically to towers. Engine fumes generated in most busway tunnels constructed in Brisbane outside the CBD are typically exhausted through the tunnel portals using tunnel soffit surface mounted jet fans.

C Potential for Minor Widening of Wynyard Tram Tunnel Passages

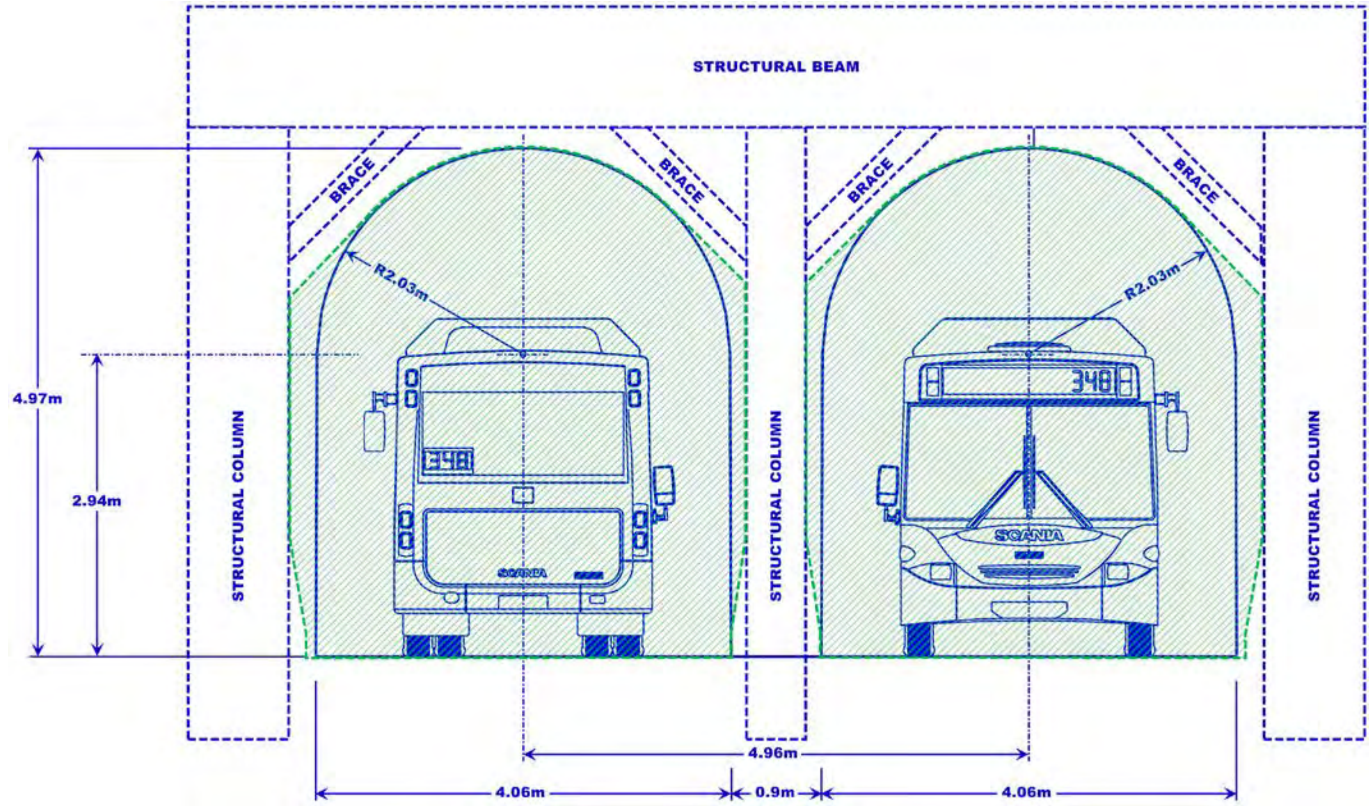


Figure 19: Potential Section Widening of Wynyard Tram Tunnels

The existing Wynyard tram tunnel passages would be best suited to guided electric light rail vehicles and trams which don't produce engine exhaust emissions. It may however also suit guided buses similar to those operated on the Adelaide O-Bahn and emerging future hybrid diesel buses can be operated through short tunnel sections by electric motor.

Based on probable locations of buried structural steel members surrounding the Wynyard Tram Tunnel, it is unlikely that a tunnel roadheader or boring machine could be deployed to widen and/or combine its two vehicle passageways into a single two-way tunnel. Figure 19 presents an alternative potential solution for small scale widening of the existing Wynyard tram tunnels without penetrating the tunnel water seal shell and which minimises disturbance to existing above tunnel utility services and building structures.

The solution involves stripping off the interior wall linings from the outer structural columns and over and between the central columns from pavement level up to approximately 3.5m above pavement; casting in-situ tapered steel reinforced concrete barriers above and pinned to the pavement around and between all columns, and lining along the column faces above the cast barriers with a fire-rated

high reflectance alpolic composite sheeting or similar. Cross passage emergency egress doors and fire hose cabinets would need to be built into the median barrier wall at intervals of 40 - 60m and door penetrations through the outer walls between columns for emergency egress PWD ramps and stairs to road surface level at intervals of around 180 – 200m. This arrangement would widen each tunnel passage by 600 – 700mm and permit unguided buses to travel at design speeds of around 50 - 60km/h, or higher if guided by rails.
Alternative solutions would include using one vehicular tunnel for buses and devoting the other to an emergency passenger egress and services tunnel, or removing all the central columns and reinforcing the structure with additional new piles, headstocks and beams to create a single full width two-way tunnel.

D Likely Fire and Life Safety Upgrades to Existing Wynyard Tram Tunnel

Table 6.1 lists the likely upgrades needed to the existing Wynyard Tram Tunnels to permit safe usage of diesel buses, passengers and drivers.

Table 6.1: Likely Fire and Life Safety Upgrades Required for Wynyard Tram Tunnel Diesel Bus Use

Facilities, Systems and Services	Fire and Life Safety Functions	Locations Where Facility, System or Service Would Typically be Installed	Relevant Standard
SCADA / PLC Tunnel Management System	Automatically Controls Tunnel Fire and Life Safety Systems. Provides Remote Monitoring of Tunnel Systems to Tunnel Management Centre Operator Terminals. Records and Reports System Fault Alarms to Operators, Breakdown Crews and System Maintainers	SCADA Server and Terminals in Tunnel Management Centre and at Maintainers' Workshops. PLCs Located in Tunnel Plant Rooms, Switchrooms, Pump Rooms, Egress Switchboards and Comms Rooms	
Air Quality Sensors	Gas Sensors Monitor Carbon Monoxide, Nitrogen Dioxide and Methane. Air Opacity Detectors and Wind Direction and Speed Anemometers Monitor Smoke Density and Prevailing Wind Direction. Prevailing Wind Anemometers are Required by the SCADA/PLC Tunnel Management System to Determine through Which Portal Jet Fans Should Purge Noxious Gases, but are Not Required for Ducted Vertical Exhaust Extraction Systems	Carbon Monoxide and Nitrogen Dioxide Sensors are Mounted on Tunnel Wall Linings above Barriers. Methane Sensors Mounted at Top of Soffit Arch. Opacity Meters Mounted on Central Tunnel Cabling Ladder. Wind Direction and Velocity Anemometers Mounted on Exterior Revetment Walls Leading into Both Tunnel Portals	US OSHA and British HSE Short Term Exposure Limits for CO and NO_2. Australian Standard LEL Limits for Methane Concentration in Confined Spaces. PIARC 1999 Recommendations for Minimum Visibility Smoke Levels
Stopped Vehicle Detection System	Vehicle Detector Loops and/or Stopped Vehicle and Video Surveillance Cameras Measure the Time Taken by Vehicles to Pass Adjacent Loops or Stopped Vehicle Cameras. Generated Loop and/or Camera Pass Through Timeout Alarms are Automatically Monitored by the SCADA/PLC Tunnel Management System	Vehicle Detector Loops are Cut into Both Lane Pavements at Around 200m Intervals. Stopped Vehicle Cameras are Erected on the Central Cabling Ladder every 40 - 60m Along the Vehicle Tunnel and Double as Video Surveillance Cameras. They are Often Positioned to Simultaneously Monitor Vehicle Traffic Lanes, Egress Doors and Fire Hose Reel	

		Cabinets	
Fire Incident Detection System	Fire is Detected by a Combination of Smoke Detectors, Flame Detectors, Stopped Vehicle and Video Surveillance Cameras, a Continuous Brullion Scatter Effect Optic Fibre Temperature Detection Loop, Manual Call Points and Fire Hose Reel Cabinet Door Switches. All Fire Detection Sensors are Monitored by the SCADA/PLC Tunnel Management System and Local Alarms at Fire Indicator Panels	Smoke Detectors and Cameras are Mounted Every 40 – 60m Along the Overhead Central Cabling Ladder. The Brullion Effect Optic Fibre Loop is Run the Full Length of Each Tunnel Arch Perimeter. Manual Call Points and Fire Hose Reel Cabinets are Mounted Adjacent to Every Egress Door at 40-60m Intervals	Fire Safety Guidelines for Road Tunnels (Australian Fire Authorities Council, 2001) and International Fire Engineering Guidelines (ABCG, 2005)
Stopped Vehicle Warning Lights	Wig-Wag Warning Signs, Portal Warning Lights and Lane Control Signs are Utilised to Stop Buses During Tunnel Emergencies. These Stopped Vehicle Warning Lights are Centrally Controlled by the Stopped Vehicle Detection System and/or Fire Detection System under SCADA Supervisory Control or May be Manually Activated on Demand by a Tunnel Management System Operator in an Emergency from his/her SCADA Terminal	Wig-Wag Warning Signs are Erected at Intersections Leading into Tunnel Portals where Buses Can be Diverted to Alternative Routes when the Tunnel is Closed. Portal Warning Lights are Mounted over Exterior Tunnel Portals to Block Approaching Bus Entries into the Tunnel. Flashing Overhead Lane Control Signs Stop Buses Already in Tunnel when Forward Passageways are Blocked by a Stopped Vehicle, Traffic Jam, Breakdown, Maintenance or Emergency Services Personnel	
Vehicle Tunnel Ventilation	Extracts Engine Exhaust Fumes and Smoke and Maintains Breathable Air Quality within the Vehicle Tunnel. Air Quality is Continuously Monitored by the Air Quality Sensors and Controlled by SCADA/PLC Tunnel Management System. Normal Tunnel Ventilation Fan and Damper Controls are Automatically and Selectively Controlled by the Fire Detection System within the SCADA Tunnel Management System	Surface Mounted Jets Fans are Erected in Soffit Arches or Continuous Exhaust Ducting is Erected in Soffit Arches to Axial Fan Extraction Towers Built at Road Surface Level	PIARC Technical Committee Reports for Road Tunnels
Emergency Egress Passage Pressurisation and Ventilation	Pressurises Egress Passages with Fresh Air to Prevent Smoke Entry when Egress Doors are Opened. Egress Door Openings are Continuously Monitored and Pressurisation Fans and Dampers Automatically Controlled by the SCADA/PLC Tunnel Management System. Fans and Damper Operations Time Out from Last Egress Door Opening But Continue to Operate when Overriden by the Fire Detection System under Supervisory Control within the SCADA Tunnel Management System	All Egress Doors are fitted with Reed Switches to Sense Door Openings. Pressurisation Fans and Dampers are Installed at the Portal End of Each Egress Passageway	BCA Part D – Access and Egress
Fire Deluge	Fire Deluge System Comprises of a	A Deluge System Water Storage	Handbook of

and Fire Hose Booster System	Zoned System of Solenoid Valve Controlled High Capacity Sprinklers which Selectively Dump Tens of Thousands of Litres of Water per Minute in Targeted Zones of Around 30m in Length. The Targeted Deluge Zone is Automatically Selected by the SCADA/PLC Tunnel Management System using the Fire Location Signal Received from the Brullion Scatter Effect Optic Fibre Temperature Detection Loop or May be Manually Activated from a SCADA Terminal by a Tunnel Management Centre Operator using Visual Fire Surveillance	Tank and Booster Pump Station Will Need to be Constructed at Surface Level. The Water Tank may Alternatively be Buried but Lost Water Head Increases Pump Motor and Distribution Pipe Sizes. Sprinkler Piping is Suspended Centrally over Each Tunnel Vehicle Lane and Controlled by Distributed Hydraulic Valve Chests Mounted in the Emergency Egress Passageways. Fire Control Panels with Inbuilt Red Warden Phones are Required for Fire and Rescue Services Use and are Located Near Each Exterior Tunnel Portal	Tunnel Fire Safety (Beard and Carvel, 2005), Fire Safety Guidelines for Road Tunnels (Australian Fire Authorities Council, 2001), AS2444, AS/NZS1221, AS2149 and AS2118.1
Tunnel Portal Transition Lighting	Prevents Short Term Driver Blindness when Looking at Bright Sunlit Tunnel Portals from within Dark Tunnels and when Driving into or out of Dark Tunnel Portals. Illuminance is Constantly Varied by Time of Day to Match Exterior Ambient Sun and Moon Natural Lighting Levels using External Photometers. Switched Portal Transition Light Banks are Automatically Controlled by the SCADA/PLC Tunnel Management System	Light Fittings are Installed on Lead-in Soffits and Walls at Sunlit and Bright Underground Station Tunnel Portals. Photometers are Installed on Poles Around 50 – 60m from and Facing into Both Exterior Tunnel Portals	PIARC CIE 61-1984 CIE 88-2004
Tunnel Interior Lighting	Illuminates Vehicle Tunnel Interior Walls and Pavement to Prevent Vehicle Collisions with Barriers at Design Speed. Illuminance is Constantly Varied by Time of Day to Match Exterior Natural Ambient Light Levels using Switched Interior Light Banks Automatically Controlled by the SCADA/PLC Tunnel Management System	Flame and Explosion Proof Light Fittings are Installed under the Suspended Central Overhead Cabling Ladder Above Each Lane	AS1158.5 CIE 88-2004 CIE 31-1976 (TC-46)
Tunnel Egress Passageway Interior Lighting	Illuminates Egress Passageways when Egress Doors are Opened and Then Times Off. Light Switching is Automatically Controlled by the SCADA/PLC Tunnel Management System During Stopped Vehicle and Fire Emergencies as Fire Crews Use Emergency Egresses to Access Burning Vehicles	Egress Light Fittings are Installed on Egress Passageway Walls and Ceilings, or if Neither is Suitable, under Suspended or Wall Mounted Cable Trays	AS1680
Emergency Egress Lights	Comprises Tunnel Emergency Lights, Egress Door Exit Lights and Smoke Piercing Flashing Zenon Emergency Exit Door Guidance Lights with Loud Hailers Used to Guide Passengers and Drivers to Egresses During Fires. They are	Tunnel Emergency Fluorescent Lights are Fitted in Tunnel Lining Panels Above Barriers every 40 - 60m. Exit Lights and Smoke Piercing Flashing Zenon Emergency Exit Door Lights are Fitted on the Vehicle Tunnel Side above All Emergency Egress Doors	AS/NZS 2293

	Activated by the Fire Detection System within the SCADA Tunnel Management System. All are Inbuilt Battery or Switchroom UPS Operated to Continue Working in the Event of a Blackout Due to Burnt Out Cabling within the Vehicle Tunnel		
Emergency Egress Lifts	Lifts are Required Where Emergency Egresses to Surface Level Can Not be Made PWD or Elderly Person Accessible by Short Ramps. Lift Access Doors at Tunnel Level Must be Permanently Accessible but Closed to Public Use at Surface Level Other than When Opened Locally by Emergency Services Keys or Remotely by Tunnel Management Centre Operators in an Emergency	All Passenger Emergency Egresses to Surface Level from the Vehicle Tunnels Which Can Not be Designed as PWD or Elderly Person Accessible	BCA, AS1428 and AS1735
Emergency Help Points	Emergency Help Points Communicate Directly and Hands Free by Voice with Tunnel Management Centre Operators	Emergency Help Points are Installed in Egress Passages opposite Every Egress Door and in Every Emergency Egress Lift	
Mobile Radio and Mobile Phone Repeaters	Lossy Coax and Discrete Antenna Radio Rebroadcast Repeaters are Needed to Maintain Communications between Buses and Bus Operator Depots and to Provide Emergency Services (Police, Ambulance, SES and Fire Rescue) Communications During Major Tunnel Incidents. Mobile Phone Repeaters are Primarily Used by Bus Passengers but Double as Emergency Service Backup Communications	Lossy Coax Antennas are Hung Under the Entire Length of the Suspended Central Cable Ladder above Each Bus Lane and Two Would be Required for Separated Tunnels. Discrete Antennas are Dropper Mounted off the Soffit at the Centre of Each Tunnel and Around 50m in from Both Exterior Portal. Rebroadcast Repeaters are Installed Centrally in Tunnel Comms Room but Require Surface Mounted Antennas to Transceive with Donor Base Stations. They May Alternatively be Connected over an Optic Fibre Link to a Remote Site Antenna and Rebroadcast Repeater	
Video Surveillance Cameras	Tunnel and Emergency Egress Video Camera Views are Received at Video Monitors located on Tunnel Management Centre Operator Workstations. Cameras Perform Multiple Functions Including Visual Surveillance, Operator and Device Triggered Pan, Tilt and Zoom to Preset Tunnel Views, and Incorporate Video Analytics Software to Automatically Detect Flames, Unauthorised Vehicle, Animal and Human Motion Detection, Security Threats such as Unattended Bags in Egresses and Stopped Vehicles in	Video Cameras are Selectively Positioned on the Central Cabling Ladder over Each Bus Lane or on Soffit Droppers at Tunnel Portals and Near Egress Doors and Fire Hose Reel Cabinets at 40 – 60m Intervals along the Vehicle Tunnel. They are Also Installed in Egress Lifts and in Egress Passages to Observe Egress Doors and Emergency Help Points	

	Tunnels		
Tunnel, Egress and Lift Public Address System	Comprises a Large Number of Fireproof Loudspeakers Distributed Throughout the Vehicle Tunnel, Egresses and Lifts for Tunnel Management Centre Operators to Instruct Bus Drivers and Passengers on How and Where to Proceed and Muster During a Tunnel Fire or Other Incident Evacuation. The Public Address System is Zoned to Broadcast Specific Messages to Different Locations within the Vehicle Tunnel, Egress and Lifts and Generally Includes SCADA Activated Pre-Recorded Voice Massages to Selected Zones	Loudspeakers are Distributed Throughout the Vehicle Tunnel and Egress on the Central Cable Ladders and Walls and in Lift Cars. PA Voice Messages are Relayed over Hearing Augmentation Loops Built into Lift Car Ceilings	
Tunnel Services Rooms	Comprise HV Electrical Switchrooms, Booster Pump Stations, Comms Rooms and Plant Rooms	HV Switchrooms and Their Associated UPSs and HV Transformers that Power the Tunnel, and Booster Pump Stations to Operate Fire Deluge and Hoses are Typically Located at Surface Level Near One or Both Exterior Portals. Comms and Plant Rooms are Typically Built into Tunnel Walls Not Used for Egress Passages	