# SYDNEY CBD SOUTH EAST LIGHT RAIL (CSELR)

## Response to the

# ENVIRONMENTAL IMPACT STATEMENT

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**Introduction**

In general the EIS is excellent. Replacing large numbers of buses with a greatly reduced number of light rail vehicles would do much for the air quality (reduction of smoke and particulates from diesel engines) and noise amelioration of Sydney's CBD streets, while the improved ride quality would be welcomed by passengers.

This submission on the Sydney CSELR EIS addresses problems caused by the particular design elements of the CSELR as currently proposed, and operational and user issues resulting there from. In doing so, it covers issues such as the fundamental issue of capacity, and that the proposed system is not operationally robust. Accordingly, recommendations are made which will improve system design and operation, leading to an improved environmental result

There are some serious problems with the draft proposal which, if not rectified, can cause reduced public acceptance of the new service, and a greater desire to use cars to access the CBD. Non-rectification of these would be undesirable from an environmental view.

**Contents**



**CBD Terminal capacity.**

The system as proposed does not provide capacity for the much needed tramway from the CBD to the University of Sydney and beyond. It should be noted that Melbourne had two CBD termini with capacity problems, Bourke Street at Spencer Street, and Elizabeth Street at

Flinders Street. The problem at Bourke/Spencer was solved when the line was continued north and south to termini elsewhere. At Elizabeth/Flinders there have been numerous changes in layout over the years, and now it is proposed that there will be a third stub terminal track, similar to the one proposed at Circular Quay. Elizabeth Street is reported to allow 38 trams to terminate in the hour but this requires the use of a scissors crossover and a second crossover further along Elizabeth Street. Even so there is often a queue of trams waiting to reverse, some being held up at the Collins Street stop.

However, at Circular Quay, while the proposed three track terminus should be just adequate for terminating LRVs on a two-minute headway, it will be totally inadequate when the proposed Parramatta Road Light Rail line (PRLR) from the University of Sydney and further west is added to the system, and will need a complete rebuild. The combined headway for the SCELR and the PRLR will be one minute or less. This is totally impractical for a three track stub end terminus. It would be easily possible for a looped terminus. <u>As such the proposed 3 track stub end terminus is undesirable on financial and environmental grounds.</u>

An example of the density of services made possible by a loop terminus is provided by the London County Council services operated on the Victoria Embankment. Routes 4, 4A, 14, 18, 24, 26, 31, 33, 35, 36, 40, 56, 62, 72 and 84 operated on the loop, a total of 15 services in each peak hour outbound via Westminster Bridge (map in "*London County Council Tramways", Vol.2 North London*, E.R. Oakley, 1991, London Tramways History Group.). If each service operated at 6 minute headways - 10 per hour, this meant that about 150 trams operated over this stretch of track in one hour, a tram every 24 seconds.

Stub end terminal capacity would be adequate at Randwick and Kingsford, but there are other reasons for preferring looped termini there.

**Seating capacity provision**

Passengers have, and should have, a reasonable expectation of getting a seat. Examination of the timetables of the bus routes that the trams will replace shows that there are about 82 buses which will pass the timing point at Anzac Parade/Cleveland Street during the morning peak period. Note this does not include the express, limited stop or metrobuses in this calculation, and the time used for the peak period may differ from that used in Technical Paper 1. It is understood that the new articulated buses are mostly used on metrobus and long express or limited stop services, so the buses to be replaced in the CSELR area will be mostly rigid buses with a seating capacity of 43, or 39 if wheelchair accessible. Using the figure of 43 seats per bus, 3526 seats are provided at that timing point. With the reported average load of 35 persons per bus, this gives a patronage of 2780, so at present every passenger on thse buses should have a fair chance o getting a seat. Using the suggested best headways of 2 minutes, and 80 seats per LRV gives a figure of only 2400 seats, a reduction to 68% of that currently provided and only 86% of average demand. This is unsatisfactory, to say the least. If the LRVs are to replace some of the L, M and X services, the situation will be even worse. If the peak headways are only 2.5 to 3 minutes, the situation will be “appalling”.

Reduction of seating capacity will mean less public acceptance, and thus a greater propensity to use private cars for travel to the CBD. <u>This would be environmentally unreasonable, and the situation must be corrected.</u>

“patronage is predicted to peak at more than 5,300 passengers per hour in the 2021 morning peak on the approach to Central Railway Station (page 9-13)

This means that for every 10 seats provided, there are 12 people standing, which is not a good ratio for a passenger service. Not conducive to passenger comfort or passenger acceptance. There is no justification in the EIS for using such short LRVs in a major city, with such high passenger demand.

The situation can be improved by two methods. One is to increase the length of the LRVs to around 60 m. For example, a six-section version of the Skoda 15T “For City” (60.2 metres) would provide 115 seats, while replacing the numerous single seats by double seats would enable 147 seats to be provided. This would enable 83% of the 5300 people to be seated.

The second method is to use single ended LRVs, which are desirable on many operational grounds. With doors only on one side, the space on the other side provided for each door can be used for an additional four seats. With more seats, there is less desire for passengers to cluster near the doors. On the grounds that encouraging patronage is a plus for the environment, it is considered that single ended operation is essential, whether or not the short 43-45 m LRVs are used or longer 60m LRVs.

“in the 2021 morning peak hour, over 2,000 passengers are forecast to transfer from buses to light rail at the Kingsford stop and over 1,600 passengers at the Randwick stop” (page 9-13)

With only 80 seats per LRV and a headway of four minutes on each branch, there will be only 1200 seats per hour available. So the lucky first (pushiest?) 1200 grab a seat and the other 800 or 400 respectively have to stand almost all the way. During the morning peak hour it is probable that almost all will wish to go to the CBD, and only from Central onwards will people be getting off, making seats available for those who have stood from Kingsford or Randwick. With 147 seats per LRV, there would be 2205 seats available at each of the termini, so all those transferring (apart from peaks due to uneven bus arrivals) would have a seat. This would greatly reduce the angst due to having to transfer vehicles.

It is preferable that both single ended and longer LRVs are used, as with the above example of the six-section Skoda 15T.

Note that with single ended operation, as the doors are only on the left side, in general all platforms must be to the side of the tracks. This is further considered in the section dealing with details of each stop.

**Loop Termini for Single Ended Operation**

Single ended operation means no stub ended termini, and no intermediate crossovers for short workings, but loops at each end and where short workings are to be operated. This will actually improve the environment at each of the termini.

At **Circular Quay**, the LRVs would turn into Alfred Street from George Street, to a stop alongside the northern kerb. Passengers would alight at this stop. The tracks would then split, one line remaining against the kerb and the other to a parallel platform. LRVs would then proceed to either of the two stops, depending on eventual destination. The tracks would then turn into Loftus Street, then into Bridge Street, and back into George St.

At **Randwick**, instead of entering High Cross Park, the LRVs should loop from High Street into Belmore Road, then into Cuthill Street, thence Avoca Street, and back into High Street. The terminal stops should be in High Street, east of Clara Street. If possible, the westbound LRV stop should be against the kerb, while the buses would stop between the rear of the LRV stop and Avoca Street. Buses (routes 372, 373, 374, 376, 377) would loop via Clara Street, Arthur Street and Belmore Road to return to their outer termini. The 'eastbound' stop – ie, that before the loop, would use a Vienna Stop (see later).

**Kingsford**
If it is decided that Kingsford should in fact be the terminus, the line should be looped via Sturt Street East and Botany Street. Bunnerong Road buses (routes 391, 392) would turn right into Sturt Street West thence left into Anzac Parade to the LRV interchange stop between Sturt Street and the Gardeners Road roundabout, and turn left at the roundabout to return south.

Consideration of the **Kingsford terminus** must be made in the light of the following paragraph in the Sydney Bus Futures paper just released [emphasis added].

> "Bus Rapid Transit and light rail
>
> Bus Rapid Transit (BRT) is a package of infrastructure, service, operations and bus improvements that together provide a higher level of bus service. A staged approach will be taken to introducing BRT on targeted Rapid service routes. In the long term, it may be possible to convert Rapid routes to light rail in areas with high growth and density. Key high growth corridors we will investigate for BRT or light rail include:
> • **Parramatta Road**
> • Victoria Road
> • **Anzac Parade between Kingsford and Maroubra or Malabar**
> • Northern Beaches
> • Proposed Western Sydney Light Rail Network."

A suitable design for the Kingsford stop has not emerged, in view of the three designs shown in the EIS. It is suggested that the short extension to Maroubra Junction (approx 2.15 km) be investigated now, for inclusion in the CSELR.

**Intermediate and other loop termini**

Given the very high numbers of passengers from Central to UNSW and vice versa, consideration should be given to providing intermediate loop termini at those places. At UNSW, LRVs could loop via Day Avenue, Houston Road and Barker Street. This would be very desirable if the line were extended to Maroubra Junction or further, but less so if the line only goes to Kingsford. At Central, the logical loop is from Eddy Avenue via Pitt Street, Hay Street and Elizabeth Street, to the stop outside the Devonshire Street subway.

Because of the occasional blockages of George Street and Circular Quay for processions or celebrations, it would be desirable for the Millers Point tram route to be restored, with appropriate service during normal days, but all LRVs diverted when Alfred Street is closed. A loop around the Queen Victoria Building will be desirable for situations when the northern part only of George Street is closed.

**Details and Locations of stops**

*Side platforms*
These provide a safe refuge for passengers boarding and alighting, and are easily accessed from the footpaths on either side of the street. Light rail systems and tramways are naturally access oriented to the footpaths where passenger activity is located. Island platforms are heavy rail practice, saving costs of duplicated stairs, escalators, lifts and waiting rooms. Generally there is little width restraint on heavy rail systems, so island platforms can be wide, giving plenty of space for passenger waiting areas (needed with infrequent services). Light rail systems are constrained within the road boundaries and traffic lanes either side, (other than in reserved tracks such as parklands – where there is no restriction on width) but due to frequency of services side platforms need not be wide. Indeed, a side platform need be no wider than the width needed for canopy supports, the space for two motorized wheelchairs or mobility scooters to safely pass, and for benches (which may be fold up to allow scooters to pass).

A LRV section 9.6 m long and 2.65 m wide could seat 24 people and have room for 31 people standing at 4 per square metre, total 55. These would, standing on the platform at the same 4 per square metre density, take up a width of 1.43 metres, which should be regarded as the absolute minimum width of platform. Supports for canopies should take up little room, so it may be envisaged that a normal minimum width of a side platform would be 2.0 metres. In the pedestrian section from Bathurst Street to Hunter Street – where the maximum passenger demand would be expected, there is no limit to platform width imposed by adjoining traffic lanes.

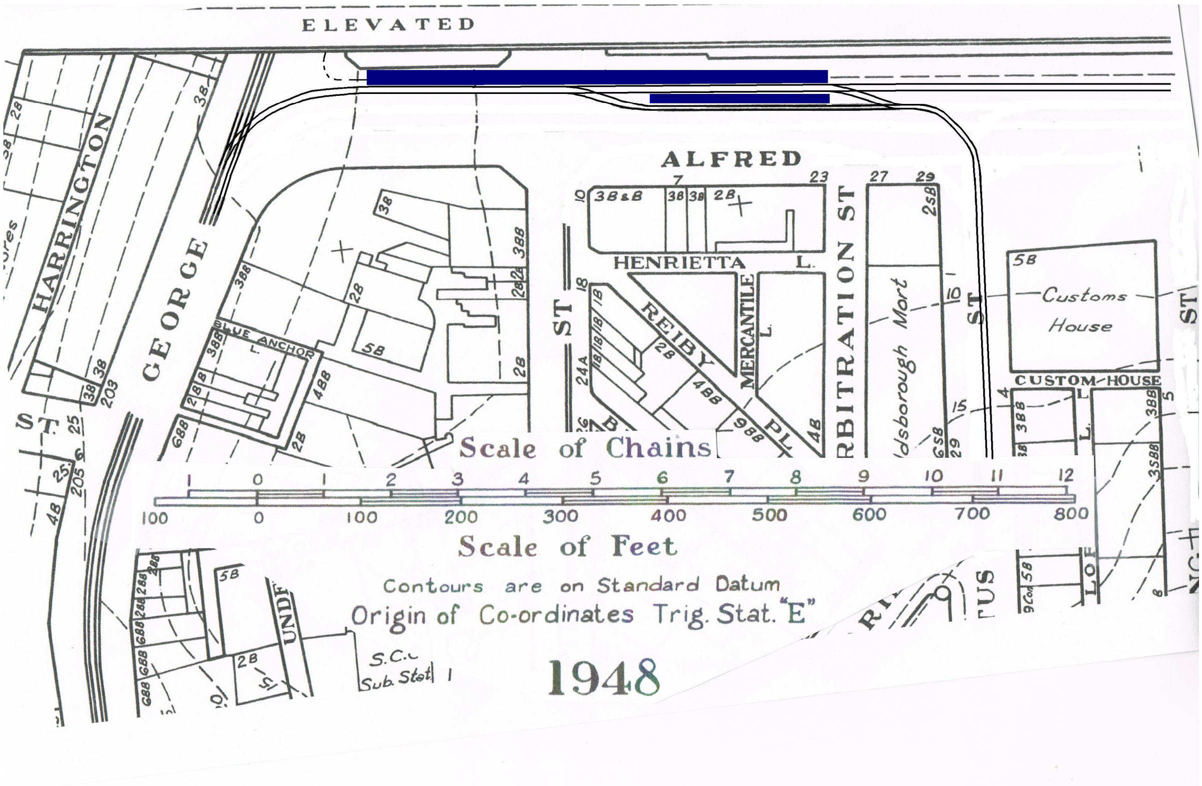
The draft EIS gives several widths for island platforms, some at 6, one at 5.2, several at 4.4 and one at 4.2 metres wide. It is clear that the alternative of side platforms at 2.1 or 2.2 metres wide would be completely acceptable. Further, if there are still constraints, it is reasonable to narrow the adjoining traffic lanes to the minimum permissible in NSW, or to use a ‘split platform’ stop, where the tracks are shifted left, with a side platform to the right, and then the tracks are shifted right with a side platform on the left. This is especially acceptable at a signalized intersection with far-side stops, where absolute LRV signal priority is used.

A platform does not have to be as long as the LRV it serves. For example, the Skoda 15T LRV has the front edge of the front door approximately 3.8 m from the front of the car, with a similar distance at the rear. Hence the 60.2 m version would only need a platform 52.6 m long at the full height, with the usual ramps to road level at each end.

Canopies should be provided for the full length of every stop in the CBD and if possible at all stops. Canopies should be simple, but they should extend a short distance over the roofs of the LRVs so there is no gap for drenching rain to reach passengers while boarding or alighting.

*Circular Quay*
As stated above, the Circular Quay stop should have three platforms, one for all LRVs for alighting passengers, followed by two parallel platforms for the two outer destinations, see diagram below. This will assist the longer distance passengers to gain the desired LRV, and with suitable signage, other passengers will be directed to the next departure for passengers to destinations on the common section of route. A siding for a ‘spare’ LRV (to be able to

provide a service should there be an excessive delay) should be provided either as a continuation of the two platform tracks or in Loftus Street.




*Grosvenor Street.*
With the terminal loop, it is suggested that a preferred southbound (outbound) stop should be in Bridge Street immediately before the George Street intersection. This should be a Vienna Stop. The northbound (inbound) stop should be immediately north of Grosvenor Street. This would allow provision of a possible future link via Grosvenor Street to the eastern lanes of the Sydney Harbour Bridge reclaiming them for public transit use. While unlikely in the immediate future, the possibility exists and should be allowed for.

*Wynyard*
This stop must be as close as possible to the entrance to Wynyard Station. No problems.

*Queen Victoria Building (QVB)*
This stop is situated rather closer to the Town Hall stop than to the Wynyard stop. It is suggested that it be relocated north of Market Street, so as to provide better coverage of the area. Further, locating it away from the QVB allows better views of the QVB, as they would be less obstructed by the LRV stop with its platform canopies. <u>Relocation of the stop would be a win on environmental grounds.</u>

*Town Hall*
This is at a large open space, so views of the Town Hall and St Andrew's Church would be not compromised by the canopies of the stop. Further, being located on top of Town Hall station there is the possibility of escalator connexions direct to the mezzanine of Town Hall station, with the obvious convenience of interchange.

*World Square*
The logic of locating this stop north of Liverpool Street is not clear. Note that the actual World Square building is in the SE quadrant of the Liverpool/George Street intersection. South of the intersection George Street is currently six lanes wide, so there is ample opportunity for a stop with two side platforms there.

*Chinatown*
This stop is closer to World Square than desired, especially if World Square stop is relocated to the south of Liverpool St, but this has the advantage that passenger loadings on these two stops would be lower than average, so that the side platforms could be narrower. If Campbell Street were "left in left out only" the stop could be sited in the wide section of George Street, with the southern end of the stop immediately at the junction with the Hay Street Inner West Rail Line (IWRL) and its northern end slightly overlapping the Campbell Street intersection. This would provide best possible interchange with the IWRL and so is desired on environmental grounds.

*Rawson Place*
This is an unsatisfactory site for the interchange as it will not be possible to accommodate all interchange movements between bus and LRV. It should be deleted in favour or an interchange in Eddy Avenue.

*Eddy Avenue*
There is need for an interchange as convenient as possible between all three modes, bus, LRV and train. This can only be satisfied by a purpose designed interchange on the southern side of Eddy Avenue, immediately adjacent to the station.

The interchange is designed to give cross platform interchange between LRVs going to Circular Quay and buses coming from George Street West and the Parramatta Road, with similar cross platform interchange between LRVs and buses in the reverse direction. For this to occur both left sides must be against a common platform.

Buses would enter from Pitt Street via the southern arch of the western IWRL ramp and go straight to a bus only roadway between two island platforms. On departure they would leave the bus roadway and go to the centre arch of the eastern IWRL ramp and exit with the other vehicles.

As traffic movements from Pitt Street (buses) and Rawson Place (LRVs) would occur on different phases there would be no problems with buses conflicting with the LRVs west of the stop. T the east of the stop the buses would cross only the arriving LRVs from Chalmers Street, with little conflict.

LRVs would enter from Rawson Place via the southern arch of the western IWRL ramp and thence a cross over so that eastbound LRVs would be on the southern side of the southern island platform, while the westbound LRVs would be on the northern side of the northern platform. This gives ideal cross-platform interchange for passengers from arriving buses to the departing LRVs for a straight forward continuation of their journeys. As the number of buses is several per minute (see Parramatta Road bus timetables) and the LRV headway is about 2 minutes in each direction it is easier for the LRVs to change to right hand running for the Eddy Avenue stop than it would be for the buses. On departing the LRVs would use the southern arch of the tram and rail bridges, still right hand running till the Devonshire Street

Subway (Chalmers Street) stop is reached. A return to left hand running could be made immediately before that stop. As the Eddy Avenue stop could not accommodate a coupled pair of 60 m LRVs these would, if used, uncouple and couple at the Chalmers Street stop unless the practice were adopted of coupled sets picking up and depositing passengers only at the Chalmers Street stop, and running through the Eddy Avenue, Pitt Street, Hay Street, Elizabeth Street loop without stopping for passengers..

*Central Station aka Chalmers Street aka Devonshire Street Subway*
This stop would be as close to the Devonshire Street subway as possible for interchange with passengers on the suburban platforms. As suggested above, it would be desirable for this stop to be the place for resumption of left hand running, but also if possible there would be two 120 m long platforms for the special services.

*Surry Hills*
The suggested location of the stop appears to conflict with Riley Street. It is suggested that consideration be given to locating the stop further east, with its eastern end at Crown Street, where there would be easy interchange with the buses in Crown Street. An island stop is not feasible. Westbound LRVs should have a side platform on the southern kerb, while the eastbound LRVs would use a Vienna platform.

From City of Sydney maps it appears that the gradient immediately west of Crown Street would be less than at the more westerly location. It is suggested that High Holborn north of Miles Street be one way southbound or “left in left out”, and the stub of Marlborough Street north of Devonshire Street be “left in left out” only.

*Entrance to the Moore Park cut and cover tunnel.*
A very short ramp is shown on the pictorial representation. It would be normal for the gradient to be no more than 10%. The minimum height for the contact wire in the tunnel would be about 3.8 m (figure for Skoda 15T) which means that allowing for fixing and insulation the clearance in the tunnel must be about 4 m above rail level. Allowing for the structure for the tunnel roof and the layer of earth/grass on top, the rail level must be at least 5 m below ground. This means a ramp of at least 50 m, plus an allowance for the vertical crest and dip curves. For low floor cars these are in the range of 300 to 350 m radius, which would make the ramp considerable longer than shown.

*Moore Park Stop(s)*
The suggested location is unsuited for both the school children and the Moore Park entertainment area sites. It requires the children to have a long walk including crossing Anzac Parade. Two separate stops would be preferred on safety grounds. From the entrance to the cut and cover tunnel the line should head for a stop at the north corner of the Sydney Boys High School. Referring to the diagram at 9.34 (Figure 9.6 Moore Park Precinct integrated event transport plan) the tunnel would run through the centre of the eastern circular playing field, then turn north of east to the ***High Schools stop***. This would have two side platforms, with a barrier between the tracks to prevent the children crossing the tracks. Each platform would have a set of stairs and a long ramp for those not capable of using the stairs. No lifts or escalators would be needed. This, being immediately adjacent to the Boys High School property, would provide a safe and short walk to the relevant school buildings, with no crossing the road required.

It is believed that the most economical method of constructing the tunnel under Anzac Parade, rather than using a "mining technique" would be to place a temporary steel bridge (an "umbrella") over the northbound lanes, excavate the soil under the bridge, using the equipment and the soil removal methods for the cut and cover section across the park, create the tunnel structure, and backfill any voids, replace the road surface, then transfer the temporary bridge to the southbound lanes and repeat the process. This means minimal interruption of traffic on Anzac Parade and avoids the need for temporary road diversions which could make it difficult to do the operation as one continuing project. It is suggested that separate cycle and foot paths are constructed to the side of the LRV tunnel – removing the need for a pedestrian footbridge in this area. The pedestrian crossing would be a modification of the route shown on Figure 9.6, and would give easy access from the schools to the AFL training oval.

From the ***High Schools stop*** the tunnel would cross under Anzac Parade at approximately right angles, and ramp up to head for a position surfacing rather north of the edge of the AFL training oval. Note that the proposed solution with a curve at the bottom of a down ramp is generally unacceptable on safety grounds, and should NOT be used unless there is no feasible alternative. The line would then curve around to a stop outside the Sydney Cricket Ground. The ***Sydney Cricket Ground stop*** would have a 120 m platform on the southbound side, but only a 60 m platform on the northbound side. South of the stop the line would run parallel to Driver Avenue clear of the football pitches, then curve around to cross Lang Road west of the tennis courts, to enter the existing busway. The creation of a "station" with stairs and lifts as shown is financially undesirable, unnecessary, and would be an environmental 'eyesore'.

*Busway*
As the CSELR is intended to replace a very large proportion of the buses using the busway there are no grounds for creating a separate route for light rail vehicles. Construction of the light rail tracks could be arranged so that only short sections (such as 200 m) are worked on at any time, buses using single lane working to by-pass these sections, and running of the light rail tracks as soon as they are completed. This means minimal delay to the buses. Creation of a separate route for LRVs should be opposed as environmentally undesirable.

For special event traffic, after leaving the 120 m southbound platform, a single track would diverge from the southbound track to curve around clear of the football pitches to join the northbound track, either just before or just after the northbound platform. This would enable 120 m LRVs to load conveniently from their left side at the SCG stop, and then turn to run back to Central.

*Alison Road Junction*
Anzac Parade north of Abbotsford Street is wide enough for six traffic lanes, being two in each direction for general traffic and one bus lane each side. If the bus lanes revert to being general traffic lanes there is room for a fully segregated median from Alison Road Junction southwards. For LRVs to cross the Anzac Parade/Alison Road intersection on the level is environmentally unsound. It adds delay to all other vehicles and will inevitably delay the LRVs, as it would not be possible to ensure absolute signal priority at this intersection.

A more environmentally sound arrangement is that the median tracks at some point north of Boronia Street are ramped up to then turn eastwards just north of Tay Street on a bridge over the southbound Anzac Parade lanes. The bridge would then continue across Alison Road and then turn north to separate ramps either side of the LRV tracks in Alison Road busway. One branch, however, would turn SE from the northbound bridge track to connect to the eastbound track in Alison Road (more details on this below). This means no delay at all to the LRVs, and northbound and southbound LRVs do not conflict at a flat junction. The LRVs will not interfere with the general traffic at this junction, meaning less fuel wasted while waiting for an LRV or two to cross the intersection. An environmentally sound arrangement.

***Randwick Route***

The Alison Road tracks should stay on the old tram (bus) reserve to Darley Road Junction with a stop immediately west of Darley Road. LRVs should cross to the south side of Alison Road under the protection of the traffic lights there, and remain on the south side till Wansey road as currently proposed. With single ended vehicles the turnback siding is not possible. A better arrangement to serve Randwick Racecourse is given later.

*Wansey Road*

Consideration may be given to locating at least one (the north bound) platform in Alison Road before the turn, and it may be possible to add the southbound platform there, to avoid disturbing (as far as possible) the majestic trees at the north end of Wansey Road. Undoubtedly they would need judicious pruning back to allow the passage of the LRVs, but this should not be too much as the road is currently used by buses. It would be best for the LRV tracks to be in the centre of Wansey Road (with no car parking) at least till opposite No 3 Wansey Road, after which they could shift to the side of the road as currently proposed. This would minimize the effect on the trees. Careful examination would need to be made of the overhead branches to ensure that there are no weak branches which could fall on the tracks or overhead. On environmental grounds no trees should, if possible, be removed, though judicious pruning is acceptable.

*High Street (West)*

This stop should be in High Street itself, either using a Vienna Stop arrangement in both directions or, preferably, using a kerb stop for the inbound LRVs. This would give maximum possible accessibility to and from the UNSW while not hindering other traffic. The stop in Wansey Road is farther than necessary, and means virtually all passengers have to cross High Street to get to the University. With a kerb stop for inbound LRVs there is almost no crossing of High Street needed.

*High Street (East)*

As previously mentioned, the westbound LRV stop should be against the kerb, with the 'eastbound' stop – ie, that before the loop, using a Vienna Stop. This would give maximum possible accessibility to the Prince of Wales Hospital and the eastern end of UNSW while not hindering other traffic. The EIS mentions traffic turning right into Avoca Street being on the LRV track. This is undesirable, as it could result in substantial delays. It would be better to prohibit right turns there, traffic should follow the Belmore Road, Cuthill Road route around High Cross Park, as should the LRVs. Consideration should be given to each of the three roads bordering the park to become a one way street.

***Kingsford Route***

From Boronia Street south to the terminus to Kingsford terminus Anzac Parade has six traffic lanes, two in each direction for general traffic, and one each side as a bus lane. The median strip is of varying width. The bus lanes should revert to general traffic, and one traffic lane should be added to the median to provide a fully segregated route for the LRVs (except for the intersections).

*Carlton Street*
There are seven traffic lanes in Anzac Parade north and south of Carlton Street. These are two through general traffic lanes in each direction, one bus lane in each direction, and a turning lane in a 'median'. With the bus lanes reverted to general traffic lanes, two centre lanes can provide room for the LRV tracks, and there is room for a side island arranged as a split stop, with the northbound platform north of Carlton Street, and the southbound platform south of the street. In this area traffic bound for residences or commercial buildings on the east of Anzac Parade should be encouraged to use Doncaster Avenue for access. Other than Abbotsford and Ascot Streets and Todman Avenue, intersections should be "left in left out" only.

*Todman Avenue*
This stop should have two side platforms. There is a very wide median strip here, and with the existing bus lanes reverting to general traffic lanes there is no need for an island platform.

*UNSW*
The tracks should swing over so that the southbound platform is on the alignment, or east of it, of the existing footpath. There should be no island platform, but a side platform for the northbound track. LRVs would be protected, if need be, by traffic lights for the southbound traffic in Anzac Parade.

*Strachan Street*
At Strachan Street Anzac Parade has 7 traffic lanes, similar to Carlton Street. Here a split stop, with far-side platforms, similar to the arrangement at Carlton Street, is recommended.

*Kingsford Terminus*
See above under Loop Termini for details re the Kingsford terminus. See below re "Possible Extensions" for the preferred extension to Maroubra Junction.

**Randwick Stabling Facility**

This is shown in Figure 5.50. It uses a double track entry and exit in both directions from Alison Road. Entering LRVs travel (two tracks with crossovers) nearly the full length of the site, then do a U turn to enter one of the 13 stabling tracks, with provision for 38 LRVs + 2 at the far end of the entry tracks. There is a two storey "Staff facilities and control centre building", a light maintenance building, a sub-station, a sand plant and a wash area. Much of the area is taken up with a large car park, for about 94 car spaces, with associated access road.

This can be improved. The access road comes off Abbotsford Road, and this can be used for LRV entry as well, turning from north and south off Anzac Parade. With single ended LRVs it is desirable that all should face the same direction, so the U turn track is not needed. Instead, the two entry tracks should be continued further, and the fan set as far south as is possible on the site. By doing this it is plausible that the capacity of the facility could be increased to 60 LRVs. Single ended LRVs can be driven from the rear when needed, so all would proceed to the far end then be driven from the rear into the relevant stabling track.

The car park should be raised above the stabling tracks, as should the facilities building and control centre.

LRVs should exit into Ascot Street, double track, with one turning north and one south into Anzac Parade. With entry and exit off Anzac Parade, it is not necessary that the Alison Road tracks cross Alison Road in this vicinity; instead, as suggested earlier, they do not cross till the Darley Road intersection.

To access Alison Road an exiting LRV would turn north in Anzac Parade, then use the overpass previously mentioned at the Alison Road Junction, and use the east turning single track to access the Alison road line bound for Randwick. Returning LRVs would cross Alison Road, but this would normally only be in off peak hours when a crossing could reasonably made without great disturbance to other traffic.

**Racecourse Traffic.**

As one of the Stabling Facility tracks parallels the border of the Racecourse, it is proposed that a 120 metre platform be provided for that track. LRVs would arrive off Anzac Parade via Abbotsford Road, go to the platform track to alight or board passengers, and then depart via Ascot Street, returning to Chalmers Street/Central.

**Possible extensions**

*Maroubra Junction*
Mention has already been made of the desirability of extending the line to Maroubra Junction. The extension would be just over 2 km long, and would be in the wide median all the way. At Maroubra Junction the possibility exists of looping from Anzac Parade via Boyce Road and Maroubra Road back to Anzac Parade, with the interchange in Anzac Parade. The loop would operate anticlockwise in the morning peak, and clockwise in the afternoon peak so that the vehicles to which the majority of passengers had transferred would depart in the appropriate direction.

From Alison Road to Kingsford, the timetables show 38 buses in the am peak hour, of which 27 came from Maroubra Junction. The other 11 (routes 391, 392) arrived from Bunnerong Road, so there is good reason to replace the 27 buses on Anzac Parade as far as Maroubra Junction (routes 393 to 397 and 399).

*Coogee*
Extending to Coogee would approximately halve the interchange requirement at Randwick. 32 buses in the peak hour arrive from the outer termini, being six on route 374, 11 on routes 376 and 377, and 15, nearly half the total, on routes 372 and 373 via St Pauls Street, Carr Street, and Havelock Avenue. This would be greatly beneficial to passengers in not having to change vehicles. Part of Carr Street is steep; however buses ascend and descend with no difficulty. While it is sometimes suggested that LRVs cannot ascend steep hills, this is not so, and gradients of up to 12% are known to have existed in the United States, and 11% and 10% in the United Kingdom. A steep hill means that the speed is lower on the way up, while on the way down the multiple braking systems of light rail vehicles promote safety. A table on page 152 of "*PCC – the car that fought back*" (Carlson and Schneider, Interurban Press, 1980) gives a balancing speed on level ground of 40 mph for a fully laden car, which drops to

17 mph with a 12% gradient. A loop terminus previously existed at Coogee, now partly occupied by a car park. This could be reused or a loop provided nearby.

**Alternative route to CBD (additional)**

A diagram of the bus route densities from Bunnerong/Matraville, La Perouse, Little Bay, Maroubra Beach and South Maroubra, Coogee and Clovelly show that from Cleveland Street in, during the peak hour 23 went via Cleveland Street (and on to Railway Square), 31 used Foveaux Street and 28 continued via Oxford and Liverpool Streets, both groups to termini in the Circular Quay area.

The Devonshire Street route would largely satisfy the local traffic from Cleveland Street and Foveaux Street, but it is suggested that bus 339 from Clovelly remain as bus, being diverted via Cleveland Street. This route is also operated by bus M50 and, in part, by bus 355.

The Foveaux/Albion couplet is not far from Crown and Campbell Streets to the east and north, and not far from Chalmers Street and Central to the west.

Consideration must be given to the needs of the numerous passengers desirous of destinations in the Oxford and Liverpool Streets area. Careful consideration needs to be given to the most appropriate methods of serving these passengers.

It is suggested that from the Sydney Cricket Ground stop the light rail route runs alongside Driver Avenue, and then alongside the pedestrian route shown on Figure 9.6 to Moore Park Road, which it would cross at right angles into Greens Road, thence into Oxford Street and Liverpool Street to join the existing route at the Liverpool Street/George Street intersection. The crossing of Moore Park Road would be immediately west of the open air ramp of the vehicular tunnel, and it would be necessary to strengthen this portion of roof.

In Oxford Street the existing bus only lanes would be converted to general traffic lanes, being replaced by segregated median strip lanes for buses and light rail vehicles. All buses in Oxford Street use Prepay from 7 am to 7 pm so there should be no problem with delays to the LRVs from buses, provided that all doors are used on the buses for passengers to board or alight, and the prepay system be 24 hour on this route. Given the non-stop section from the Sydney Cricket Ground stop to Greens Road, and the shorter route to George Street, compared to the Devonshire Street route with its speed restriction and more and lengthier stops it is plausible that there would be a considerable saving of time for passengers bound for destinations north of Liverpool Street. Any stop in Liverpool Street, the street being four lanes wide, would be a Vienna Stop

**Wire-free operation.**

At the request of Sydney City Council it has been agreed that there will be wire free operation within the pedestrian mall from Bathurst Street to Hunter Street. No details of the proposed system are given. However, the system will apparently require recharging erections at each stop within the pedestrian zone. These heavy gauge erections will be far more unsightly than the narrow diameter wires used for the overhead.

Several wire-free systems are possible. These are basically on board power – using batteries or supercapacitors, or on-road power, such as APS, Primove or conduit.

*Batteries* are heavy, and so the addition of these to LRVs means a substantial additional mass to carry around, meaning greater energy expenditure in accelerating (some of which should be recovered on braking). Depending on the type of battery used, life of batteries is usually short, and replacement frequently means cost and environmental problems in either separating parts for re-use or consigning to waste. Use of batteries for more than an emergency assist should be considered environmentally unsound.

*Supercapacitors* are heavy, and perform better than batteries in the rate at which a charge can be accepted and discharged. While they have been used successfully in transit applications, it appears that the better use for them is as 'shore-side' acceptors of regenerated energy, and boosters for supplying power in acceleration. This means that peak power demand is reduced, with a saving in energy charges. Environmentally acceptable as off-vehicle power demand regulators but, owing to their mass, environmentally undesirable for on-board use.

*APS – Alimentation Par Sol* – is a proprietary third rail in the street. Signals from the LRV switch sections on and off as the LRV moves over them. After initial problems the system appears to be working well, and is used in Bordeaux, Angers and Reims. It is intended to be used at Orléans and Dubai. Reports indicate that the on-board equipment adds about 100 000 Euros to the cost of the LRV and the in –street equipment is about three times the cost of overhead wires. (http://en.wikipedia.org/wiki/Ground-level_power_supply#In_other_cities) Undesirable due to the excessive costs.

*Primove* uses induction from coils buried in the road to provide power to vehicles over the coils. Originally it appeared that the coils were to be continuous but recently a high power recharging station has been used. This is still in the early stages.

*Conduit* was used for many tramway systems, but few other than New York, Washington and London survived many years. It had many problems, cost of construction, maintenance and the possibility of 'dead' sections amongst them. However, an attempt has been made to examine the problems and find a means of overcoming them. Attached is a paper on "*Modern Conduit*". If successful, it could provide a better system than APS, and would eliminate the necessity for unsightly charging stations.

**Speed in the pedestrian area.**

A speed restriction of 20 km/h in the pedestrianized area is unreasonable and environmentally unsound. At present, buses are permitted to travel at 40 km/h in George Street in close proximity to crowded footpaths. There is no logical reason why LRVs should be restricted to 20 km/h given that they will operate in the middle of the road, their path will be constrained by their tracks, the tracks will be distinctively marked – possibly including a 150 mm raised trambaan. Most pedestrians will be likely to spread out from the footpaths a bit, but are only likely to encroach on the LRV right of way when actually wishing to cross the road.

As such, an excessive reduction of speed will not increase safety – given the 20 km/h slow speed of the trams it is more likely that pedestrians would take less notice of them. It is at least plausible that an allowed speed of 50 km/h would be safer as pedestrians would be more likely to take notice of the generally higher speed vehicles.

This excessive reduction of speed will slow journeys down and not be appreciated by passengers who are looking for a reasonable fast journey. It is environmentally unsound.

**Vienna Stop**

This design of stop is for use in streets with Light Rail tracks where four lanes of traffic exist. To enable level access boarding the kerbside traffic lanes are gently ramped up the necessary 300 mm (approx) which is continued for the full length of the platform, and then ramped down again at the exit end. Depending on the road and traffic conditions, vehicles can always use the kerbside lanes, but may or may not be permitted to use the LRV centre lanes. In normal conditions, cars would use either kerbside or centre lanes, heavy goods vehicles (other than such as garbage collection trucks) would use the centre lanes, and cyclists would use the kerbside lanes. Other vehicles have to comply with the Australian Road Rules and stop when the LRV stops, continuing either via kerbside or centre lanes as soon as the LRV has commenced moving.

Dudley Horscroft
18 Daintree Close
BANORA POINT
NSW 2486

**Attachment**

# Modern Conduit

Overhead current collection has had a tried and proven record for over one hundred and twenty years, both for tramways and railways[1]. There are, however, situations where an alternative is required. This is the case in Sydney, where the City Council has requested "wire-free" operation in part of the CBD.

The advantages claimed for using conduit current collection were:

1. No unsightly overhead wires or posts.
2. No obstruction to fire appliances.
3. No danger from falling wires.
4. All-insulated system guarded against electrolysis (in later years).
5. Durability.

However, against these advantages the New York, Washington and London deep conduit systems had substantial disadvantages.

1. Excessive construction cost, of the order of 50% greater than the conventional overhead system.
2. Greater time to construct, due to the need to dig deeper, and the greater need to relocate other utilities.
3. Dead sections at junctions, which could exceed 3 metres, leading to stalled trams/streetcars if they had to stop on a dead section.
4. Maintenance was high and costly, in particular wear on ploughs was excessive and they did not last long.
5. Freezing rain could create problems when ice blocked the slots, leading to very expensive measures to free frozen-in ploughs (Washington in particular). Conversely, extreme heat caused the slot rails to expand, narrowing the slot and causing ploughs to jam and break.
6. Relaying of track had to be done rail by rail at night between last and first trams, as recourse to shoo-flies was not possible[2] [3].

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1 The first use of overhead current collection is believed to have been that at the Toronto Exhibition in 1885. The De Poele system was used – see Chapter 9 of "Pioneers of Electric Railroading", ed John R Stevens, "Headlights Vol 51 & 52, ERA, New York, 1991. The first street railway operation using underrunning trolley poles was at Montgomery, Alabama, where "Full electric operation commenced on June 22, 1887 …".

2 However, when the Dupont Circle subway was constructed in Washington, a shoo-fly was provided, at appalling cost. The shoo-fly cost $225 000, while the total cost to Capital Transit was $600 000. These figures are given in King, LeRoy O. Jnr, "*100 years of Capital Traction*", p 170. Total cost of the subway not stated.

3 I am indebted to Tom Fairbairn, who has advised that Washington did in fact replace rails during normal service between the passage of trams. He writes: "On several trips on DC Transit, I watched as girder rails were replaced in 10-foot sections (spanning three yokes) between regularly scheduled trams in daylight hours. This was on the track shared by the Wisconsin Avenue, Rosslyn, and Cabin John lines, so the time span between trams was not all that great at the point the works were in process. The jointing was done atop a yoke in every case, and the new rail was welded to the adjoining preceding one and fastened in place before the next tram arrived. It was quite a dance, but got the works accomplished in jig time and with no interruptions to service. The motorway main surface was unaffected, and the surfacing around the rails was only open for short stretches at a time. One crew in front of the plateslayers opened the surfacing, the plateslayers did their thing, and another crew restored the surfacing as soon as the plateslayers had completed that part of the way."

7. Changing from conduit to overhead and vice versa could be labour intensive and time consuming – at least one line in Washington was closed because the time to change the plough was greater than the headway in peak hours[4] [5].

The major problem with the conduit was its cost of construction. This is an inherent problem with deep level conduit containing both positive and negative power rails. They had to be separated a substantial distance (6 inches – approx 150 mm – in London) so that if the plough developed a fault and short circuited, the gap would be too great for an arc to be maintained. Similarly there had to be a sufficient depth beneath the power rails so that if the drains became blocked a downpour of rain could not collect to such a depth as to short circuit the rails. In London, the standard conduit yoke was 1' 11" from base to the surface on which the slot rails, 7" in height, would rest, requiring an excavation rather in excess of 2' 6" (concrete was poured around and under the yokes when the latter were correctly aligned.[6] It followed that the depth of excavation was high; the amount of material to be removed high and, in modern times, the excavation would require virtually all subsurface utilities to be moved, again at very high cost.

A second major problem was the existence of dead sections. As there was the possibility of one or other of the conductor rails becoming earthed, it was necessary to provide for either of the rails to be the positive while the other was the negative, with a voltage approximately earth. At junctions, one or other or both of the conductor rails had to be interrupted at diverging or merging points, and both had to be interrupted where tracks crossed, which could be "over a not inconsiderable length or for several shorter sections in quick succession."[7] "The longest break on any part of the [London] system … 12 feet."[8] Trams could easily become stuck on a dead section if halted by a policeman, or to avoid an accident. With the short headways in London, this was not a great problem in early years, as there would very soon be a following car to push the first off the dead, but in later years this became a great problem as at a major junction the stuck car would greatly impede cross traffic.

Maintenance of the conduit system was probably more expensive than for the overhead, as it was necessary to keep the drains in order, remove mud and other road detritus (especially horse manure in early days) from the conduit, and clean the insulators from time to time. At least children no longer play in the streets where once boys and girls rolled hoops along and were overjoyed at the fireworks display when the hoops fell into the slot and shorted out one of the conductor rails against the slot rails[9].

Snow and ice would not be a problem in Sydney, though it was in Washington and London. Wear and tear on the ploughs was high, as steel rubbing surfaces on the ploughs were continually in contact with the steel slot rails. "The writer was once told at Charlton Works that the average life of the metal plates was nine days!"[10] It is believed that London repaired the ploughs, whereas New York threw them away[11].

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4 "First, service to this fast growing area needed, in peak hours, headways of less than sixty seconds. Plow pit changes at 15th and H Street N.E ruled against this since they averaged sixty seconds." "100 Years of Capital Traction", LeRoy OP King, Jnr, Taylor Publishing Co. 1972., p 168 in reference to the Benning Line abandonment.

5 It is a pity that Washington never updated its plough change pit methods to that used in London, where changes resulted in delays of little more than 15 seconds when changing from overhead to conduit, and nil when changing from conduit to overhead.

6 Oakley, E.R. "*London County Council Tramways Vol 1, South London*", pp157-159.

7 G. E. Baddeley and E. R. Oakley, op cit, p 99.

8 Oakley, E.R. "*London County Council Tramways Vol 1, South London*", p 163.

9 Information from my Mother, who lived in Catford 1901-1914.

10 G. E. Baddeley and E. R. Oakley, *op cit*, p 100.

11 G. E. Baddeley and E. R. Oakley, *op cit*, p 81.

Because of the excessive cost of deep conduit, both Washington and London used change pits where the cars transferred from conduit to overhead or vice versa. Washington's system was complicated and slow. London simplified this by using bus bars and redesigned ploughs after the first change pits were installed (in 1908). A changeover switch eliminated the necessity to play with leads, and one man could happily handle a change pit. Delay to the tram was of the order of 10-15 seconds when going from overhead to conduit, none when going from conduit to overhead[12].

# Requirements for a new conduit system

The following are suggested:

1. Cost should be no more, or not much more, than the cost of using overhead power supply. It would be desirable that the cost should be less;
2. Construction should be easy, and take no longer, or little longer, than the time required to construct using overhead power supply;
3. There must be no dead sections, or they should be as short as possible, or they should be switched so as to be powered if necessary;
4. Maintenance must be minimal, and/or easy, and if possible all wearing parts must be easily accessible for regular checking and replacement.
5. The system must be able to cope with heavy rain, snow, ice and road authority's use of salt to clear snow (not relevant in Sydney!).
6. It must be easily possible to change from conduit to overhead current collection. This should be automatic, if possible, or controllable by the driver.

The following is an attempt to utilize modern materials and techniques to overcome these disadvantages, to put a modern conduit system on a level footing with overhead (or nearly so) in order that tramways may reasonably be constructed in cities or areas where the use of overhead wiring is banned or undesirable on aesthetic grounds.

**Cost of construction.**

The second generation systems used deep trenches to contain the conductor rails. Can the deep trenches be eliminated? Yes, but a pre-requisite is to abandon the all-insulated nature of the system. If only positive rails are used in the conduit they can be closer together as there is no problem with a flashover from one to the other, and the depth below them (approx 9" in Washington[13]) can be greatly reduced as there would be a minimal problem if, due to a blocked drain, water collected so as to cover the rails. (This requires, however, that all construction material, including drainage pipes, be insulated – as is normal with the use of plastic piping for drains – and where there is a connexion into a 'main drain' the connexion should be arranged so that electrically conducting water cannot directly form a conducting link to the main drain.)

At the same time, the use of a pair of positive conductors permits the simplification of the ploughs. Second generation ploughs (J. G. White system ploughs, as used in New York,

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12 Conduit to over head – while at a tram stop the conductor placed the trolley pole on the wire, and the driver operated the changeover switch. He then drove off after boarding was completed; the plough was shot out from under the car. When "Ploughing up" the tram was driven slowly alongside a section of conduit parallel to the track. The plough shift operator lifted a plough in readiness on the conduit, using a large fork which engaged with the tram's plough carrier. The conduit then curved under the tram, automatically transferring the plough to the carrier, and making contact with the bus bars. The conductor would then pull down the pole, and signal the driver to proceed.

13 Washington dimensions here and later are given in King, *op cit*, pp 302-3. I think that this dimension of 9" may be a typo on my part – perhaps the correct dimension should be 1' 9". Unfortunately I do not have access at present to my Washington book to be able to check this.

Washington and London) had, from one side to the other, a thin steel rubbing plate, a layer of insulating material, a copper ribbon to carry the current, a central layer of insulating material, a copper ribbon to carry the current of the opposite polarity, more insulating material, and finally the other thin steel rubbing plate. All this in no more than half an inch.[14]
With only the one polarity in the plough, it can be simplified to no more than a copper plate, insulating material and the rubbing plates. A further simplification can be made if the insulating material is transferred to the slot rail, which could be made of a smooth, nearly frictionless plastic, such as high density polyethylene similar to the hard plastic boxes used for take away foods – easily replaced if worn, while the plough shaft need be no more than a copper or copper alloy plate. This means rendering the plough live at all times when in contact with the conductor rails, but being always under the car it can never be a danger to people. The width of the plough then need be no more than sufficient to ensure sufficient strength and rigidity in use, perhaps 3 mm[15]. The width of the slot can then be further reduced (from the London standard of one inch, 25.4 mm, to perhaps 5 mm, or 4 mm if a 2mm thick plough can be used. This would reduce the ingress of rainwater by 80 - 85%. The possibility exists of adding a flexible material, such as a rubber flap, to cover the last few millimetres, virtually eliminating ingress of rainwater, street cleaning water, dirt and metallic objects thus reducing the need to clean the conduit.

Second generation conduits used deep, wide, trenches, (31½" = 800 mm deep by 52" = 1321 mm wide between yokes, and 37½" = 953 mm deep by 68" = 1727 mm wide at yokes in Washington. New York and London dimensions would have been similar. With the elimination of short circuit potential, and a major reduction in water ingress, a much shallower channel can be used. Modern track construction uses, in general, a substantial reinforced concrete track bed, on which are sited the rails, securely located to gauge by resilient fasteners embedded in the trackbed. As such, there is no need for the massive yokes employed on the second generation systems. The present proposal envisages a channel approximately 150 mm deep and 80 mm wide[16], in which the conduit is fitted. This means that the depth would be close to the height of the rails (CEN 49 E 2 rails have a height of 148 mm on a foot width of 125 mm, and 49.1 kg/m). Hence excavation costs are not increased.

# General description of a suggested modern conduit system

A modern conduit system should not be regarded as just an updated old-style conduit system but, as a miniaturized under-running protected third rail power supply, adapted to location between the running rails instead of outside them.

*The Conduit*
The walls and bottom of the conduit are made of PVC, which being a very good insulator, obviates the need for separate insulators. It also provides a very smooth surface which will not harbour dirt. Sections can be joined by standard PVC cement. Picture a semicircular base (similar to a water pipe sliced lengthwise), radius about 40 mm or less, attached to vertical walls. This can be manufactured in substantial lengths, and glued together as

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14 G. E. Baddeley and E. R. Oakley, *op cit*, p 100.

15 If the plough is a hard copper alloy, with reduced softness compared to pure copper, it may be possible to reduce this thickness to 2 mm, with increased length to give adequate current carrying capacity. Even, perhaps, a plough 2 mm thick, with stainless steel leading and trailing edges to give the necessary strength and a copper insert for current carrying capacity.

16 These dimensions could perhaps be reduced. Experiment is needed to assess what is (a) practical and (b) reliable in service.

necessary. The vertical walls have ledges moulded or glued-on part way up. On the ledges rest the vertical legs of angle bar conductor rails. The bottom edges of the angle bars are located securely by a ridge on the ledge. The angle bars are loosely clamped to each wall of the conduit by continuous 'Z' PVC strip, this being secured by plastic screws to the vertical sides of the conduit. Apart from securely locating the conductor rails, the strip prevents any water entering the slot from dropping onto the conductor rail, and also prevents metal objects, such as steel tape (inserted by the 'stupid'), contacting the conductor rail[17].

*Protection of the conduit, and drainage*

The width of the slot must be kept constant, within very narrow limits. The solution is to lay the conduit in a channel in precast concrete troughing, which would prevent tyre forces from road traffic affecting the conduit itself. The troughing would be laid in the centre of the track, aligned correctly, and then held in position by the concrete poured around it. The 'loose' fit of the conduit in the trough would make it easily possible to lift out sections as desired, should this become necessary.

The top of the conduit should be covered by pairs of bulb angle steel [18] or, where there is no heavy road traffic, fibreglass "cover plates". Steel cover plates are covered with neoprene, or a similar insulating material, highly resistant to wear and tear by traffic, bonded to the steel.[19] Fibreglass plates are plausibly cheaper, do not need a neoprene cover, and could have a variable coefficient of friction – high for the upper surface, low for the slot edge. Fibreglass plates would be amply strong enough for use in pedestrian areas. The plates are secured by bolts into the vertical walls of the concrete troughs. At the slot, high wear-resistant and very low friction plastic covers (high density polyethylene, as used on 'take away' food boxes) may perhaps clip over the neoprene, forming a protective edge to the neoprene. The gap between these clips forms the slot, designed to be 5 mm or less. The effect of the bulb is to raise the level of the slot edge and make it easy for the plastic covers to lock securely in place. The raised slot edge ensures that less water can enter the slot.

Reduction of the slot gap from 25.4 mm to 5 mm (or less) means that less rainwater will enter the slot. Protection from water running over the street surface is enhanced if the track is constructed using a trambaan (with the track and adjacent road surface raised above the general street level by from 100 to 150 mm). Further protection from water entry is afforded if the surface between the running rails is inclined at, say, 1 in 20 from the centre, where the slot is situated, to the rails. With the standard tram wheel back to back distance of 1380 mm, this means that the slot would be raised about 35 mm above the running rail level, an acceptable camber other than at intersections. However, there may be cases where torrential rain, or even heavy showers, could result in ponding of water over the tracks, submerging the slot. In such cases, it is suggested that close attention be paid to the normal street storm water drainage, to prevent water ponding, if possible. It is unlikely that such a case would occur between Bathurst St and Circular Quay.

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17 I am indebted to Dewi Williams for reminding me that it should not be possible for any metal object in a person's hand to enter the slot and accidentally contact the conductor rail. Nothing will stop the stupid, however.

18 One edge of the plate is thickened to form a bulb. This stiffens the edge of a plate forming part of a girder. However in this case the intention is to raise the slot edge and thus restrict ingress of water.

19 Steel is not suitable as a surface material in view of its very low friction with rubber when wet – hence a death trap to motorcyclists. The neoprene cover provides a surface with a higher coefficient of friction, apart from its insulating qualities. It is also suggested that a thin layer of insulating material be placed under the plates to supplement the insulation in the event of the neoprene cover being badly damaged.

*Conductor rails*
Standard grooved trolley wire has a cross sectional area of 0.125 square inches. The use of aluminium in place of copper may be considered on cost grounds. Pure copper has a specific conductivity of 59.6, International Annealed Copper Standard is 58, while aluminium has a specific conductivity of 37.8 (all times $10^6$ Siemens/metre). This means that the conductivity of aluminium is about 65% of that of IACS copper, so just over 1.5 times the cross sectional area (csa) of aluminium is required for the conductor to have the same resistance. Hence an aluminium conductor would need a csa of about 0.2 sq inches to have the same resistance as the trolley wire. An angle bar with exterior dimensions of 0.7 x 0.7 and 0.2 inches thick has a csa of 0.24 sq in and would suit. It is suggested that the conductor rails be aluminium angle bars with these, or similar dimensions (eg, 18 x 18 x 5 mm).

The conductor rails can be welded into suitable lengths on site, so as to form continuous lengths between breaks, depending on the need for allowance for expansion and contraction. They would be secured at mid length, and allowed to expand via suitable joints. At the expansion joints, the ends should be cut similar to tenon and mortice joints, with the edges chamfered and the tongues an easy fit so that expansion and contraction can be easily accommodated. Copper flexible bonds, secured to the back of the angle bars through the wall of the conduit will enable good conductivity from rail to rail, while further bonds, similarly placed, connect the two conductors in a conduit, and the two conduits in double track, together. Connecting the two angle bars together, and the conductors in double track, further reduces the resistance in the positive side of the circuit.

The undersides of the horizontal portion of the angle bars form the main rubbing surfaces. An aluminium alloy with a high wear resistance, or even with a very thin layer of stainless steel bonded to it, would be necessary to give a long life[20].

*The ploughs*
The ploughs are copper or copper alloy, or stainless steel plus copper, shaped like an inverted T. On the outer edges of the T cross piece are graphite collector blocks. The upper surface of the block is intended to be the main current collecting surface, with the outer surface to centralize, so far as possible, the plough, thus protecting the slot rail material from wear. Thickness of the plough shaft should be the minimum consistent with strength and rigidity in use. The fore and aft length is determined by the need for adequate conductivity for acceleration and braking currents. The fore-and-aft edges of the ploughs are raked so as to lift out any obstructions which may have lodged in the slot and, if it is considered desirable to add a flexible flap to completely cover the slot against water ingress, to lift the flap clear as the streetcar/tram moves along.

*'Change pits'*
Provision must be made for changeover to overhead current collection. This will occur in Sydney at Hunter Street and Bathurst Street. However, if modern conduit is used, it would be continued to Circular Quay, so that the only 'change pit' would be at Bathurst St.

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[20] Over-running aluminium conductor rails with a stainless steel rubbing surface have been used on the Southern Region of British Rail, with apparently good results in spite of being exposed to the weather and the use of the same collector shoes as used on the normal steel conductor rails. They are also used (as under-running and protected rails) on the Docklands Light Railway. However, in a completely protected situation, with graphite blocks used to contact the conductor rails, protection of the aluminium conductors from wear may not be necessary.

The London County Council devised an arrangement for easily removing and inserting the ploughs under the cars. An attendant placed the plough in a suitable position, so that as the tram moved it slid into place and the trolley was lowered. On the reverse direction, the trolley was raised, and the tram then departed, the plough 'shooting' out from under the car. This can be automated. Consider that the plough pick up point be at a stop, so that the tram is travelling slowly. If the plough when shot from a car travelling in the other direction is travelling fast enough, it could reach perhaps a height of two feet (speed must be at least 8.5 mph). When rolling back to the pick up track, it could be stopped at a point a foot above track level, by an escapement arrangement. As the tram approaches, the escapement is operated by a 'prong' projecting from under the car, such that one plough is released to roll down the slope quickly to a point very close to the track, just before the slot rails curve across the running rail. Here it is stopped by a gate. As the tram/streetcar moves past at very slow speed, the 'prong' meets the plough, pushes it past the gate, the slot rails guide it under the car onto the bearers which lift it to the working position with the carrying wheels just clear of the slot rails. Again, when the contacts on the plough complete the circuit between conductor rails and bus bars the pantograph is automatically lowered and the 'prong' retracted.

The most likely problem is interference by vandals. It may be possible to totally enclose the arrangement in a box between the tracks, covering all working parts. "Out of sight is out of mind". If vandalism is still considered a plausible problem, then operation of the plough shift by one man would probably be the preferable alternative.

At depot entrances, if there is no need for automatic change over from conduit to overhead, the London system can be used with depot staff providing the necessary attendant. A suitable run round track, if available, could be fitted with wear detectors for the collecting shoes.

*[Some further comments on automating plough changes are at the end following the table.]*

*Switches*

Switches have always been troublesome on conduit track. With the single polarity conduit suggested here, the problems are markedly reduced. At the junction, the angle bar conductor rails are reduced to flat horizontal bars, continuing the line of the horizontal bearing surface. One of these bars would follow each direction of the diverging, or merging, conduits, to maintain continuity of power to the tram. The vertical portion of the angle bars would be replaced by flexible strips, which would be moved as necessary to ensure that the plough entered into the correct slot.

*Crossings.*

At a crossing, where the slot crosses the running rails of another route, the running rails will have to be cut to enable the plough to pass through the intersection. A possibility is that the conduit be lowered on the approach to the crossing. The centre section of the bearers on which the plough is carried should be sprung so that on approach to the crossing the plough is pulled down by the conductor rails. This would require a lengthy shaft to the plough. Power may be maintained through the crossing, but it is suggested it would be preferable for there to be a short insulated section so that the plough is not live when close to the running rails. Power to the car to cross the other line and street could easily be provided by batteries, as is being done in Nice for a much greater distance (about 400 m in the historic centre). The crossing rails would only be cut for a gap of little more than the width of the slot, perhaps 5 - 6 mm, a distinct improvement on the one inch gap used in London, or the 7/8" gap used in Washington. In addition, the plough would be automatically isolated when it is lowered below the normal operating position. The plough would only be in contact with the car's bus bars when the plough is in the correct operating position. Either below or above, and there is no electrical contact. Alternatively, there is the possibility of retaining the conductors at normal depth, and massively strengthening the running rails to compensate for the removal of web and foot, with insulation preventing contact between running rail and plough. Naturally, flange running would be employed for the tracks in this area.

*Maintenance*
Reducing maintenance is important as this was a substantial cost area for early conduits, and killed many of the first generation conduit systems. There are two main cost areas for maintenance. These are keeping the conduit clean, and checking for wear and tear with replacement of worn parts.

*Keeping the conduit clean*
The conduit is designed so that a brush can be towed along the bottom, beneath the conductor rails. This could, perhaps, incorporate stiff bristles to loosen any adhering dirt, followed by a softer material completely filling the bottom of the conduit, which would move all loose dirt to the drain pits. High pressure water jets could be used to assist in washing dirt into the drains, and these, if directed to the conductor rails, would remove any adhering material there. In London, drain pits were sited at about 120 – 150 foot intervals, and it is suggested that this spacing would suffice. The drain pits "were connected together with 12 inch diameter pipes laid with a fall of 1 in 10 away from one track to the other. This fall continued through the width of the floor of the second track trap and through another pipe to a sump with a domed base which was about 5 ft. deep, 3 ft. long and 2 ft. wide on the inside and which was located outside the track margin. An outlet pipe about half way up the wall of the sump connected it with the nearest rainwater sewer, allowing mud and debris to be trapped in the bottom of the sump, so facilitating its removal."[21] This worked well in London, and can be expected to work well elsewhere. Frequency of brushing and water cleaning of the conduit would depend on the amount of dirt collected. With a deep enough pit, the entering water could be arranged at a level higher than the outlet to the normal street stormwater system, so that the fall of water would normally create an electrical discontinuity in the event of the water being contaminated.

London conduit had a gap of 25.4 mm, and was constructed when horse transport was still important. A very large amount of manure was deposited on the streets, and with the wide slot, much inevitably ended up in the conduit. This would not be the case now, with horse traffic virtually non-existent, and the potential to gather dirt will be substantially reduced with the much narrower conduit, as will be the amount of rainwater entering the slot.

*Wear and Tear*
The early conduit systems were 'rough' in that no consideration was apparently given of the importance of reducing wear to a minimum. Steel side plates on the ploughs rubbed against steel slot rails – no deliberate design to reduce friction and wear, though no doubt the rubbing tended to smooth the contact faces of the slot rails. In the modern conduit, it is essential that wear is minimized. The major areas of wear are the sliding of the plough collector shoes on the conductor rails, and contact between the shaft of the plough and the sides of the slot. The use of graphite collector shoes (lubricated with graphite grease from time to time) sliding on

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21 Oakley, E. R and C. E. Holland, "London Transport Tramways, 1933-1952", The London Tramways History Group, Bexleyheath, 1998, p 83.

a conductor rail designed for a minimum friction and high wear resistant surface, should ensure long lives for both the conductor rails and for the shoes. These should be at least as long as the life of the graphite inserts in trolley heads, and for trolley wire but, as the area of contact would be greatly increased, there should be every expectation of a far greater life. Inspection of the graphite shoes can easily be done in the running depots, where the ploughs can be pulled down from their housings and checked by eye, wear being measured if need be. Wear on the graphite shoes can also be automatically checked as they pass over detectors in the conduit. Wear on the surfaces of the conductor rails should be negligible, but may need checking from time to time.

The shafts of the ploughs are copper, copper alloy, or stainless steel/copper. This gives a very smooth surface. The conduit cover plates are covered by smooth, hard wearing and low friction plastic clips at the slot edges, and should not cause more than negligible wear on the plough shafts. At intervals, it may be necessary to replace the ploughs, but this interval is likely to be massively greater than the average nine day life of the steel protective sides of the first generation London ploughs. Wear is likely to be concentrated on the "slot edges". Wear could be determined by routine inspection, and the edges replaced as necessary. This would entail no more than loosening the bolts of the cover plates to enable them to be partially lifted, pulling off the worn slot edges, clipping on new edges and refastening the cover plates. Anecdotally, wear of the stainless steel surfaces should be no more than wear of a stainless steel cooking pot whose surface is cleaned by steel wool pads or proprietary cleansers!

# Conclusion

How does the 'modern conduit' fill the requirements given above?

**1.** Cost should be no more, or not much more, than the cost of using overhead power supply. It would be desirable that the cost should be less. **Construction costs would certainly be far less than traditional conduit as the excavation would be far smaller. While the cost of the conduit and its rails would be far higher than standard trolley wire, there is a major saving in the omission of the cost of the poles, excavation of their holes and possible shifting of utilities for them. Probably complies.**

**2.** Construction should be easy, and take no longer, or little longer, than the time required to construct using overhead power supply. **Conduit can be pre-prepared and installed at the same time as the rails are installed. Complies.**

**3.** There must be no dead sections, or they should be as short as possible, or they should be switched so as to be powered if necessary. **This design has no dead sections, unless in future it is proposed to install a crossing tramway. Complies.**

**4.** Maintenance must be minimal, and/or easy, and if possible all wearing parts must be easily accessible for regular checking and replacement. **Cleaning of the conduit easy by using brushes towed at the bottom of the conduit (hence the semicircular shape, and using high pressure water jets to push dirt to drains and sumps, as in standard London conduit. Wearing surfaces restricted to "slot edges", very easy to check and replace if**

**necessary, and graphite collector shoes on the ploughs, easy to check and replace, other surfaces stainless steel or plated to ensure very low wear. Possibly the ploughs might have a life approximating that of the car. Avoids the cost of restoring the overhead after a bad 'dewiring'. Complies.**

**5.** The system must be able to cope with heavy rain. **Problems with heavy rain reduced due to single polarity conductor rails and narrow slots. Complies.**

**6.** It must be easily possible to change from conduit to overhead current collection, and this should be if possible automatic. **Automatic changeover described. However, depending on the system, a manual changeover process at a stop may be preferred. Substantially complies.**

This shows that a modern conduit system could be constructed with little more cost (and possibly less) than an overhead system, and probably operated as satisfactorily. It may be desirable to build a short test track to test these arrangements for using modern conduit in appropriate areas. If the test fails, then there would be good reason to suppose that Washington should consider remove the ban on overhead wires for a new tram system[22].

Dudley Horscroft

*(Version dated 14 December 2013.)*

***Further comments on ploughs and plough changing.***
Ploughs are mounted on supports on the body permitting lateral and vertical movement of the plough as the body of the car pitches, sways, rolls or yaws, so the plough shaft will remain vertical, and sprung so the pressure on the conductor rails will be nearly constant. However, the supports must have sufficient vertical movement so that the plough can either operate in the normal position in the conduit, or be retracted into the body of the tram, with adequate clearance to the road surface. When retracted, the collector shoes should be protected from dirt which may be blown up by the passage of the tram in overhead wire areas. The ploughs would normally be mounted under the body in front of the leading bogie, as there would not be sufficient room under the low floor section of the body.

It may not be possible to design a sufficiently reliable automatic changeover arrangement. In this case changeover should be done at a stop. When the tram is at the stop, the conduit cover plates would be opened by the driver operating a control at a suitable height on a pillar outside the tram. The driver would then lower the plough while passengers are alighting and boarding. With the plough in the correct position the driver would release the control and the conduit cover plates would close, locking the plough in position. On moving off, with the plough making contact, the pantograph would be automatically lowered. In the reverse, as the plough was retracted, the pantograph would be automatically raised. With the plough fully retracted the driver would release the control and the conduit cover plates would close, restoring the road surface.

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22 It is understood that this ban has been overturned, or at least modified. However as at June 2012 construction is taking so long that the outcome of the ban removal is undecided.