# Buses and Trams and Traffic Modelling

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## 1 Introduction

Some 50 years ago, Sydney abandoned its trams system and knocked down its CBD tram sheds to build an opera house. Since then buses have assumed the servicing role of trams.

Sydney CBD has grown significantly over the decades and so has the transport task. Although parking in the CBD has grown to 30,000 off-street spaces and about 15,000 on-street spaces the travel mode share of the public transport system is still considered respectable on a world standard. Figure 1 indicates the transport task by train, bus and car for the CBD.

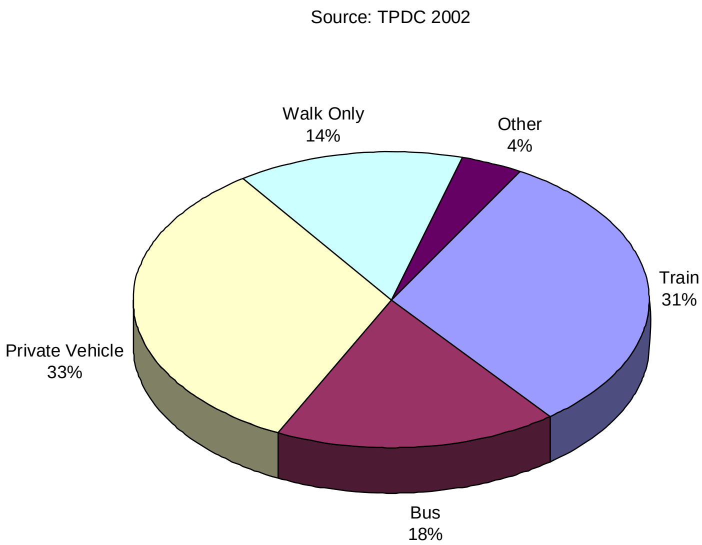


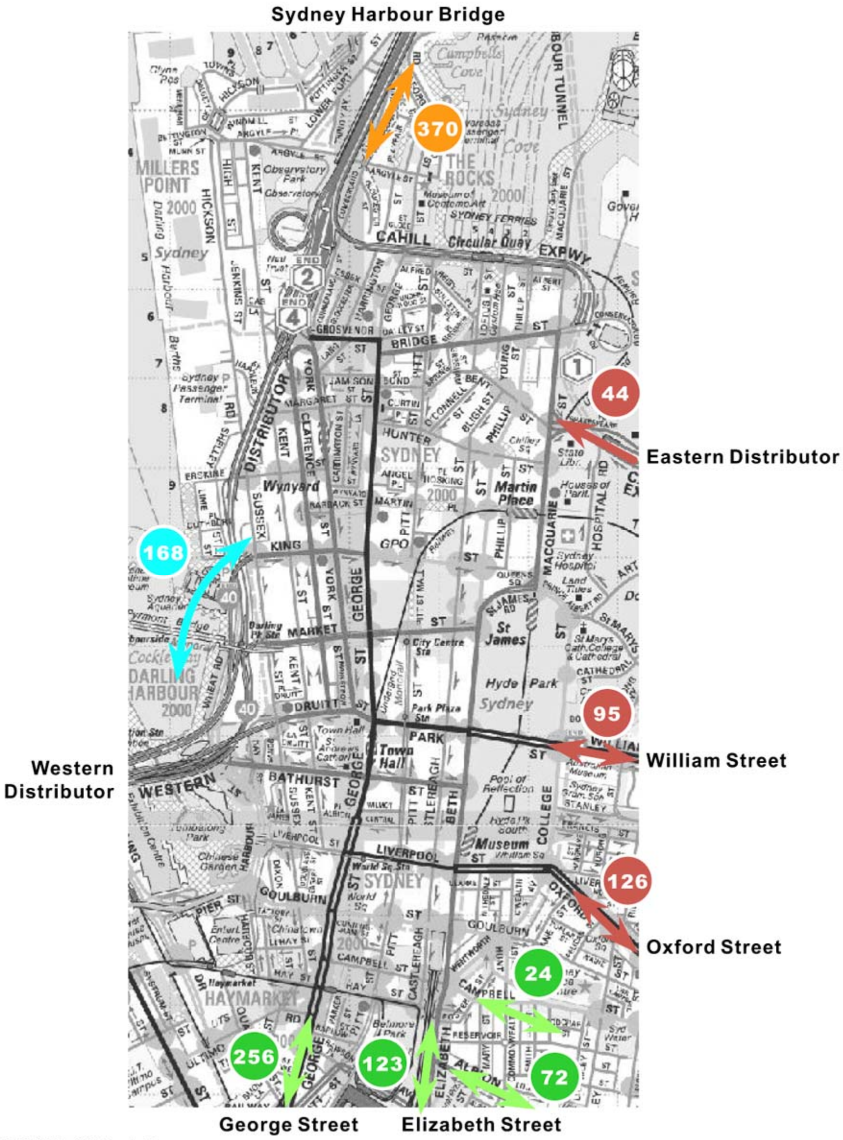

Figure 1 - Weekday Mode Share to Sydney CBD

Since the removal of trams, the bus system that has progressively increased to the state that now there are well over a thousand bus movements in the morning and afternoon peak periods as exhibited in Figure 2.

The message is clear that bus is still carrying a high proportion of person trips into and out of Sydney CBD.

However, with increasing levels of traffic congestion in the CBD and continued growth in private vehicle travel (in absolute terms) it is evident that bus servicing in its present form will become unsustainable. Unfortunately, there are now so many buses in the CBD as exhibited in Figure 2 that they now contribute significantly to the levels of traffic congestion in the city.

Over recent years there has been a push from certain sections of the community to reintroduce trams as a solution to the transport needs and smooth functioning of a large urban CBD. At the same time a number of proposals have been suggested for high levels of bus priority within the Sydney CBD to improve levels of service of the system.




Souce: STA 2003 AM Peak Survey

Figure 2 - Morning Peak Hour Bus Services to/from Sydney CBD

The imminent opening of the Cross City Tunnel (CCT) in August 2005 is now the catalyst for examining new options for improving road base public transport systems. Based on strategic model forecasting reported in the Environmental Impact Study, the CCT is expected to remove some 60,000 trips per day through traffic off the CBD street system thus presenting new opportunities for reclaiming road space for public transport.

But, regardless of whether trams or buses service the city, it is evident that it is not possible to take up to five lane kilometres of capacity out of the CBD like Sydney without incurring some form of disruption. It is abundantly clear that either transport mode would have to be complimented by an overall operational strategy for the CBD involving parking, rail linking as well as an on-street and off-street parking management systems.

To assess various operational strategy options for the CBD, it is first necessary to evaluate the probable impact of both tram and bus priority infrastructure in the CBD road network.

This paper explores an evaluation process for assessing the impacts of bus and tram operations not previously possible until the advent of micro simulation modelling techniques.

## 2 Stakeholders and the Evaluation Process

Unfortunately, there is no one overall body responsible for transport management planning for the Sydney CBD as this task is shared between a number of different ministries and agencies including the Roads and Traffic Authority of NSW (RTA) and the City of Sydney Council. Within these parties there are various levels of technical expertise with respect to understanding operational issues associated with the different forms of travel mode.

It was therefore necessary to set up an evaluation tool and process that was transparent as well as informative.

Further, such a system had to be set up so that each member could clearly see for operational characteristics of different options, why certain things would or would not work, and most importantly, why a favoured scheme had certain irrevocable drawbacks.

It was decided to utilise the RTA's newly developed micro simulation model for the CBD. This is a vehicle-by-vehicle simulation model that enables visualisation of expected traffic conditions. As such this allowed all parties to actually see the operation within the CBD, to see the interactions, to see congestion points and to see the probability of success or not of various proposals.

However, visualisation is simply not enough when evaluating such a complex system as Sydney CBD. Accordingly a number of tools were developed to help in the setting up of the model and the evaluation of options.

### 2.1 Interpreting Micro simulation Model Results

As indicated previously, the removal of up to 5 lane kilometres of capacity within the CBD is likely to have a significant impact on the performance of the CBD road network and therefore it was necessary to undertake a careful evaluation. Unfortunately, within simulation models with fixed matrices, and to a certain extent fixed destinations, it is always possible that generalised statistics can give a misleading picture. For example, within the model there are three types of trips, those trips that start and finish within the simulation temporal window, those that start but do not finish due to the fact of network congestion and lastly those that never start at all because congestion is such that they can never get on to the network.

Sometimes, as congestion is never temporally or spatially consistent, it is possible its effects can be inadvertently omitted from generalised statistics. For example, in a model where congestion occurs late in the simulation period, it is possible that trips which are heavily affected do not complete their journey or indeed do not enter the system at all. A system that only evaluates the performance of those vehicles that start and finish their journey would miss this severe congestion and would erroneously indicate the network was operating smoothly. It thus necessitated the writing of a special program to not only identify the costs of trips which had passed through the system but also those that have not completed their journey and those that have never actually got onto the system due to congestion in the vicinity of the entry to the network. This special program is known as “plugin” and utilises the Paramics API feature that allows users to add extra functionality.

The following briefly describes the Evaluation plugin.

### 2.1.1 Evaluation Plugin

Measured statistics can only be reported for completed trips or incomplete trips which load onto the network and are part completed by the end of the simulation period. Although the standard Paramics software produces an array of outputs it is often time consuming to amass all the data required and present summaries for any single model run.

The Evaluation plugin provides a means of measuring a scheme against its alternatives, taking into account incomplete trips and uncommenced trips.

The following standard Paramics outputs are used as inputs by the plugin:

- number of vehicles
- travel time
- travel distance
- vehicle speed
- free flow time; and
- number of stops.

Further options allow for aggregation of data by zones (external and internal zones) and by fixed routes (split into two classes, those under study, and others). The recorded data is grouped according to the specified “external zones” and “study routes”. This flexibility enables the user to specify how the results are summarised and aggregated for any model. It is therefore a relatively simple process to separate fixed route public transport vehicles from general traffic and provide summary statistics for each.

The plugin has been developed to estimate operational values (such as travel time, and travel distance) for uncommenced trips and to approximate how the incomplete trips would finish their journey.

As a vehicle is released by the model to enter the road network at an origin zone, logic in the plugin checks if there are any released vehicles already waiting to enter the network (queues) at its time of departure. If there are, the plugin then estimates the delay experienced by the vehicle at the origin zone based on the current size of uncommenced trip queue, the number of successfully released vehicles and the length of the measurement period. This origin zone delay is then added to the overall trip time and these times are used as measured values for travel time.

For incomplete and uncommenced trips, it is assumed that these will tend to use the same route as the completed trips, and the distance travelled will be the same. Also, it is assumed that vehicles will travel at an average speed not exceeding that of the average speed recorded for the incomplete trips (the most recent trips). The average travel time for incomplete and uncommenced trips is then calculated using these speeds and distances.

Figure 3 details the delay and travel time estimation for incomplete and uncommenced trips.

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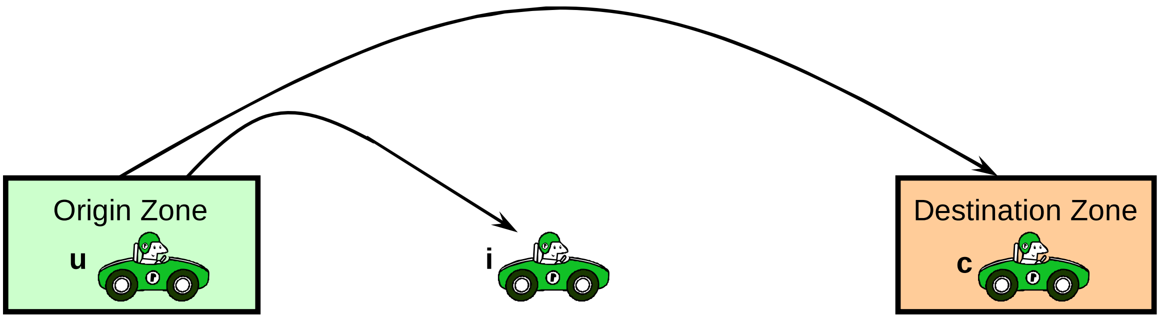


**State at the END of the Simulation Period**

**c** – *Completed trips* are trips that travel from the origin zone to the destination zone.
**i** – *Incomplete trips* are released from the origin zone but do not reach their destination zone.
**u** – *Uncommenced trips* are trips that cannot enter the network due to congestion but stored within the zone in the form of queues**.** This is a sub-category of Incomplete Trips.

Figure 3 Network Evaluation Plug-in

The network Evaluation Plug-in gathers travel time, average speed and distance statistics for both *complete* and *incomplete* trips so that estimates of *unreleased* trip travel times, speeds and distances can be made.

The following simple assumptions are made in order to produce a full set of reasonably valid statistics for both *incomplete* and *uncommenced* trips:

- Incomplete and uncommenced trips tend to use the same route as completed trips;
- Uncommenced trips travel at same speed as the recently completed trips (incomplete trips).

The calculation for incomplete trip travel time can be expressed as:

$$i_t = c_d / i_s$$

where,

$c_d$ = *completed trip* **distance**
$i_t$ = *incomplete trip* **time**
$i_s$ - *incomplete trip* **average speed**

and the *uncommenced trip* time is calculated from:

$$u_t = c_t + u_D$$

where,

$u_D$ = (*uncommenced trip* **delay**) the time difference between model release time and when the vehicle actually enters the network
$c_t$ = *completed trip* travel time
$u_t$ = *uncommenced trip* travel time

Note that the measured travel time includes origin zone delay time (if applicable) and measured speed is calculated from measured distance and measured time. This measured speed is then used to calculate the estimated travel time for incomplete and 'queued' vehicles. Therefore the estimated travel time will include origin zone delay time if there were uncommenced vehicles at time of departure.

## 2.2 Traffic Congestion and Gridlock

Modelling of some of the bus and tram proposals resulted in severe traffic congestion and, in some cases, gridlock. In reality the response to such events is that people would either divert to other routes, travel at another time, change modes or decide not to travel at all.

The nature of micro simulation modelling process is that it does not respond to such situations by suppressing or altering the travel demands. To overcome this it was considered not desirable to apply arbitrary adjustments to traffic demand as forecast by the strategic model as the results would be as much a representation of the modeller's perception of the impact as it would be to actuality. Further, the idiosyncratic nature of this process would not be helpful to an independent and bipartisan evaluation.

Notwithstanding, the study process did not provide sufficient time for revision of the strategic forecasts in light of congestion issues revealed at the micro simulation level.

Thus, in undertaking the study it was evident that if existing traffic was assigned to a network with considerably less road space then congestion would be a self fulfilling prophesy. All networks would be locked up and no useful information as to the probable impact or the comparative impact of different options would be available.

To overcome this situation, selected through trips (predominantly east-west) were then removed from the trip matrix on the basis that these trips had the greater probability of diverting to a less congested route, i.e. the new Cross City Tunnel.

While all through trips may not alter their routing or timing, the removal of these through trips allowed each of the modelled options to be compared without precipitating unrealistic network lockups.

Subsequent modelling of the bus and tram options involved the incremental reinstatement of the through trips in order to test the robustness of the road network. The general approach was thus a sensitivity analysis in the absence of knowing exactly how through trips would adjust to the bus and tram proposals.

Table 1 shows the total travel demand modelled and the trips removed.

Table 1 - Total Trips Modelled (Peak 2 Hours)

| | **AM** | **PM** |
|---|---|---|
| Base 2006 Total Trips | 85,225 | 89,621 |
| 2006 with Impacted Through Trips Removed | 79,563 | 81,165 |
| Base 2006 Through Trips | 50,344 | 56,148 |
| Total Trips Percentage Change | – 6.6% | – 9.4% |
| Through Trips Percentage Change | -11.2% | -15.1% |

It is apparent from Table 1 that during the AM peak there are 5,662 trips which are considered to be impacted through trips which increases to 8,456 trips during the PM peak because of the changes in traffic pattern.

When an initial assessment had been made of all the options with these reductions in through traffic, the trips were progressively added back in to see at which level the degrees of congestion became intolerable.

### 2.3 Random Nature of Micro Simulation

Micro simulation modelling is a stochastic process. Vehicles are randomly allocated to the system through a random number generator, or "seed" value, and accordingly the results of model runs vary with different seeds. It was therefore necessary to not only use a number of seeds but it was also necessary to normalise final results for correct comparison, i.e. compare all models with exactly the same numbers of vehicles.

In addition, to aid the evaluation a "congestion index" was developed to enable the stakeholders to understand the relative change in the road network performance from present day conditions to which all related.

The Congestion Index of present day conditions (drawn from the calibrated/validated 2001base models) was defined as 100 (or 100%). Congestion was a measure of average vehicle delay plus travel time and this was derived from the plugin outlined in Section 2.1.1. Further, conditions were measured as a percentage change to the 100 index. For example, a modelled bus/tram scenario with a Congestion Index of 103 meant travel time and delays were 3% worse than current day conditions.

A Congestion Index could be determined for both private vehicles and road based public transport, i.e. bus and/or tram.

## 3 Other Enhancements to the Modelling Processes

During the course of undertaking the study, about four different applications were required to be developed to augment the functionality of the Paramics model. These ranged from evaluation modules to vehicle behavioural modules. The complexities of the Sydney CBD model required plugins to better reflect traffic behaviour and provide realistic network results. These following provides a short description of some of the issues and the plugins to resolve them

### 3.1 Route Choice Plugin

Like most inner urban networks Sydney CBD has a large number of alternate routes between any given origin and destination (OD) pairs. Since drivers have imperfect knowledge about these alternate routes then it may become necessary to control the routing that the Paramics assigns to specific vehicle groups. Two problems which can occur in the CBD model are:

- Drivers leave the principal roads to rat-run through CBD lanes etc causing unrealistic congestion levels; and
- As perturbation is used then vehicles begin to alter their routes sometimes in illogical ways causing greater congestion than would be the case in reality.

This plugin was applied to the Sydney CBD model to better match known travel patterns and to avoid unnecessary detours within the CBD.

The Route Choice Plugin allows rules to be defined that control the route choices made by groups of vehicles in the Paramics model. This control is based on the exit taken by all vehicles in a defined group on any link in the network. The groups of vehicles can be defined at a high level in terms of per-trip filters: vehicle types and zones/sectors or a combination of these. A lower level per-link filter allows you to select vehicles based on the number of lanes currently open, for use with tidal flow schemes.

The difference with this Plugin and the Lane Choice Plugin described next is that the exit route from a link rather than the range of lanes on that link is defined.

### 3.2 Lane Choice Plugin

The Lane Choice Plugin allows the user to define rules that control the lane usage for groups of vehicles in the Paramics model with both the range of lanes used on a link and the next lane value being controlled. The groups of vehicles can be defined at a high level in terms of per-trip filters: types, origins, destinations or a combination of these. Vehicle types can be grouped together by restrictions. Origin or destination types can be grouped together by sectors. Lower level per-link filters select vehicles based on link specific attributes – the number of lanes currently open (tidal flow etc) or the lane currently used by the vehicle.

Using this plugin it was possible to reduce unnecessary lane changing and therefore flow disruption at critical locations. The other advantage of using this plugin within the CBD model (with its associated short blocks and multitude of car park accesses) was that it is able to reduce the impact of short links within Paramics by allowing vehicles to enter the correct lane well in advance of any critical intersection.

### 3.3 Obstruction Monitoring and Clearance (OMAC) Plugin

In any model road network where lock up congestion can occur, the lock up itself restricts traffic movement to other areas and thus can possibly mask deficiencies in other parts of the model. This means highly iterative process has to be undertaken stepping from one problem to another. Thus the OMAC plugin was developed which monitors the progress of all vehicles and removes vehicles which are stalled in their process beyond a specified period of time. When doing this, the plugin logs and displays each of the areas where vehicles have been removed showing the origin time, destination time, and other vehicle characteristics. This allows the modeller to immediately identify the problems whist the model keeps running.

This plugin is probably of less value in smaller models however in big models is inestimable.

### 3.4 Public Transport Scheduler Plugin

This plugin was developed to enable greater control and reporting on public transport vehicles. Its features included:

- Keeping a constant headway (frequency) between successive vehicles. For example, a loop tram system where vehicles run 10 minutes apart and remain 10 minutes apart for the entire route. The plugin allows users to code and control these systems.
- Scheduling. The user can specify target arrival times for any stop or layover and can include a minimum/maximum stop time. The plugin will seek to make up lost time by reducing stop time or even skip stops. Conversely stops are extended if a vehicle is ahead of schedule.
- Improved reporting. The plugin will report the impact on bus/tram stops and on waiting time, the number of passengers waiting at each stop, the number of passengers on each bus or tram. Additionally it will record waiting and stop time for buses and trams and compare against a target timetable if provided.

## 4 The Inner Sydney Public Transport Study

As previously stated, the opening of the CCT is anticipated to remove around 60,000 through trips a day from Sydney CBD surface streets with the principal relief on the east-west routes.

This relief will afford a unique opportunity to introduce some form of public transport improvement within the CBD. Two scenarios were considered for the operation of public transport on the surface streets of Sydney CBD. The first examined a number of tram options and the second considered new bus strategies for the CBD.

Because the options are still in development and assessment and in some cases route locations still confidential in nature, route descriptions in this paper are required to be non specific.

### 4.1 Tram Operation

The tram options considered a series of alternative routes running predominantly south-north between Central Station and Circular Quay utilising combinations of 2-way sections and/or one-way routes. These streets included:

George Street – north bound but one option considered two-way for some sections
Pitt Street – north bound
Castlereagh Street – south bound
Elizabeth Street – south bound

Conceptually, the options were grouped as 1) a wide spaced loop and, 2) a narrow spaced loop. One route in each of these groups is reported in this paper.

Each of these routes was evaluated in terms of their own performance as well as impacts on the existing road system performance. The network performance of each route was ranked based on the stratified results obtained for private vehicles, buses and tram vehicles.

Early in the tram study it was established that the CCT would not result in sufficient reductions in surface street traffic as forecast by the strategic models to accommodate any of the tram options. As discussed in Section 2.2, to simulate the required change in travel behaviour, selected through trips were removed (these concentrated on the CBD east-west movements).

Generally the impact of these tram alternatives on the operation of the existing system caused significant delays to other road users however the tram routes remain relatively independent of general network conditions, with little significant deterioration in service as traffic congestion increased.

### 4.2 Bus Strategy Operation

The first set of bus options evaluated simply mirrored the tram options. Buses were provided exclusive lanes. Because buses require much less capital investment compared to trams, the purpose of this evaluation was to establish additional benefits/disbenefits derived by the additional capital investment for trams.

The second set of options investigated a number of bus strategies that consolidated existing bus services within the CBD in order to maximise the advantages of the opening of the CCT while reducing traffic volumes on George Street. This post CCT Bus Strategy was intended to lock in a bus priority corridor following the opening of the CCT and can be considered as an interim option.

A number of traffic management measures combined with some operational changes were developed by the stakeholders. These measures complemented the consolidation of buses in York Street/Clarence Streets and George/Elizabeth Street corridors by moving Castlereagh Street buses to either George Street or Elizabeth Street.

To better facilitate these changes and to reduce congestion problems around the Queen Victoria Building (QVB) there was increased use of peripheral layovers and a new bus interchange was created at Park Street. Bus routes were also extended from the QVB to a new terminus at Hyde Park. The Druitt Street bus stop was also moved closer to George Street to better serve passenger desire lines.

The preliminary analysis indicated that the Bus Strategy Option would perform satisfactorily from a bus operation perspective. However, there would be a significant increase in the overall level of congestion in the CBD.

### 4.3 Modelled Options

Table 2 summarises the options that were evaluated. Again it is noted that due to the fact these routes are still in development and assessment and that some route locations remain confidential at the time of preparing this paper, the descriptions are nonspecific in nature.

The table also indicates an updated base network was used. During the course the study, enhancements become available in the micro simulation software, and given the passage of time of the study the decision was made to update the base network with the implementation of the new software. Accordingly a 2004 calibrated base model was prepared.

Table 2 – Summary of Modelled Options

| Option | Description |
|---|---|
| **2001 Base with Reduced Demand** (see Section 2.2) | Represents 2001 CBD road network with implementation of CCT including associated surface street treatments. Reduced demand is based on the assumption that selected private vehicle through trips divert to routes outside the modelled network due to increased congestion caused by the implementation of either tram or increased bus priority within the CBD. This diversion is additional to that predicted by the strategic models used to forecast the CCT effects. Note that the tram and bus route options are also subjected to this reduced demand. |
| **Tram Option 1** | Represents 2001 CBD road network with implementation of CCT including close spaced tram loop running from Central Station to Circular Quay with reduced demand. |
| **Tram Option 2** | Represents 2001 CBD road network with implementation of CCT including a wide spaced tram Loop running from Central Station to Circular Quay with reduced demand. |
| **Bus Option 1** | Similar to Tram Option 1 but the loop serviced by buses. |
| **Bus Option 2** | Similar to Tram Option 2 but the loop serviced by buses. |
| **Inner Sydney Bus Strategy on a base updated to 2004 conditions** | Represents 2004 CBD road network with implementation of CCT including associated surface street treatments and interim bus scheme that consolidates bus routes etc (see 4.2) |
| **Base Update 2004 unadjusted demand** | Represents 2004 CBD road network with implementation of CCT including associated surface street treatments with full traffic demand i.e. no private vehicle through trips removed. |
| **Inner Sydney Bus Strategy + Full Demand** | As "Inner Sydney Bus Strategy" with full traffic demand |

## 4.4 Study Results

The results from each of the individual option tests were presented to the stakeholder. This group included laypeople for whom it is vital that they understand the relative impacts of various options in an easily interpreted way.

Tables 3 and 4 provide examples of the level of detail that model statistics were reported. By keeping comparison statistics to just two key indicators, the layperson has a better opportunity of understanding model results across a range of option tests.

Table 3 – Network Performance – Private Vehicles

| Private Vehicles | | | | |
|---|---|---|---|---|
| | AM Peak (0730-0830) | | PM Peak (1630-1730) | |
| **Option Test** | **Ave. Speed** | **Relative Congestion Index** | **Ave. Speed** | **Relative Congestion Index** |
| 2001 Base with Reduced Demand | 33.9 | 100 | 31.5 | 100 |
| Tram Option 1 | 32.1 | 107 | 27.3 | 126 |
| Tram Option 2 | 29.3 | 116 | 27.0 | 137 |
| Bus Option 1 | 31.3 | 78 | 28.4 | 120 |
| Bus Option 2 | 24.5 | 110 | 24.9 | 116 |
| Inner Sydney Bus Strategy | 31.2 | 105 | 29.0 | 107 |
| Base 2004 Update + Full Demand | 26.1 | 139 | 24.4 | 142 |
| Inner Sydney Bus Strategy + Full Demand | 26.8 | 135 | 25.1 | 138 |

Table 4 – Network Performance – Transit Vehicles

| Bus Services Across Network | | | | |
|---|---|---|---|---|
| | AM Peak (0730-0830) | | PM Peak (1630-1730) | |
| **Option Test** | **No of Vehs.** | **Average Speed** | **No of Vehs.** | **Average Speed** |
| 2001 Base with Reduced Demand | 1063 | 13.0 | 945 | 10.2 |
| Tram Option 1 (5.1km route length) | 1152 | 12.4 | 975 | 9.9 |
| Tram Option 2 (5.9km route length) | 1093 | 12.3 | 964 | 10.3 |
| Bus Option 1 | 1167 | 12.3 | 997 | 9.6 |
| Bus Option 2 | 1107 | 12.1 | 971 | 10.0 |

The modelling outcomes suggest reductions in private vehicles through trips over and above that produced by the CCT opening equating to at least 5% in the AM peak and 7.5% in the PM peak are required for the Bus Strategy and significantly more is required for any of the tram options.

## 5 Conclusions

This paper has shown that in evaluating complex systems especially those involving large impacts on existing systems that “the devil is in the detail”, and that the more realistic the simulation then the better the decisions of the decision maker. In addition the authors have attempted to indicate that micro simulation modelling is an extremely complex task and to a large extent it is still the skills of the modeller rather than the software that are important and that without an open mind and a willingness to develop software to augment existing off the shelf software, good modelling cannot prevail.

On the study itself, it was clearly established that to accommodate any of the tram options, additional reductions in through traffic over that forecast for the CCT would have to take place through changes in private vehicle travel behaviour such as:

- Diverting to other routes outside the CBD core; and
- Undertaking the trip at times of less congestion

As exhibited by the Congestion Indices provided in Table 3, a significant change to future travel behaviour is required in the CBD to accommodate mass transit modes.

Whether this is achievable and/or desirable, is of course the subject of another debate.

Regardless, the exclusive use of public road space for any mass transit modes within Sydney CBD should consider:

- A comprehensive parking policy to suppress demand
- Out of hours servicing
- Road closures
- Diversion of some through trips in the peak periods
- Forced passenger interchange at periphery of the CBD to reduce bus movements

Finally, the purpose of this paper is not to advocate a particular public transport strategy or policy position, but to demonstrate the advances in analytical tools, modelling techniques and reporting that will enable more informed decisions to be made.