Evaluation of Bus Operations by microsimulation in a Sydney CBD corridor

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Abstract

More than 600 buses enter the Sydney CBD from the Harbour Bridge during the peak periods, causing severe congestion and long delays for passengers in the York Street – Clarence Street corridors and around the Wynyard and Queen Victoria bus terminals. The demand is expected to increase significantly in the next five years raising serious doubts whether the corridor can accommodate this growth.

The Transport Data Centre (TDC), in cooperation with AECOM, undertook a study to analyse the bus operations in the corridor and to evaluate various alternative operational and traffic management scenarios in order to accommodate the expected growth in bus numbers. The AIMSUN microsimulation software package was used as the most appropriate modelling platform, using data from the Sydney Strategic Travel Model (STM) and the SCATS traffic signal control system. This paper presents an overview of the study, focusing on the difficulties encountered in modelling such high levels of bus congestion, and the innovative solutions used to overcome those difficulties and to present the findings. The paper presents the conclusions of the study and the recommendations on how to accommodate the future growth while maximising the public transport performance and minimising the economic and environmental impacts.

Introduction

More than 600 buses enter the Sydney CBD from the Harbour Bridge during the morning peak and almost as many leave in the afternoon, causing severe congestion and long delays for passengers in the York Street – Clarence Street corridors and around the Wynyard and Queen Victoria bus terminals. The demand is expected to increase significantly in the next five years, raising serious doubts whether the corridor can accommodate this growth.

The Transport Data Centre (TDC), in cooperation with AECOM, undertook a study to analyse the bus operations in the corridor and to evaluate various alternative operational and traffic management scenarios in order to accommodate the expected growth in bus numbers (AECOM 2008). Separate models were developed and calibrated for the AM and PM peak periods in the base year (2007), using data from the Sydney Strategic Travel Model (STM) and the SCATS traffic signal control system. Several future management scenarios were simulated in the AIMSUN microsimulation software package and a comparative analysis was performed on the model results. The modelling of detailed bus operations under highly congested conditions presented unusual challenges to the modellers and to the software platform and has led to some innovative approaches in dealing with these.

This paper presents an overview of the study, focusing on the difficulties encountered in modelling such high levels of bus congestion, and the solutions used to overcome those difficulties and to present the findings. The paper is structured as follows. The next section outlines the model development process for the morning and evening peak periods, the calibration process and highlights some challenges to deal with the level of bus congestion in the simulation. The following section describes the process of developing future management alternatives and the scenarios selected for modelling. The next section presents a summary of the result for the modelled scenarios. The last section presents the conclusions of the study in terms of the recommended management alternatives as well as the lessons learnt in modelling such highly congested bus operations in a simulation platform.

Model Development

The geometric layout of the study area (Figure 1) was built in an earlier version of the AM Peak model based on the Sydney Strategic Travel Model (STM) in 2006. The PM Peak model was built in 2008 by modifying the tidal flow arrangements in the AM Peak model where required. Both the AM and PM models were then calibrated using data from 2007.

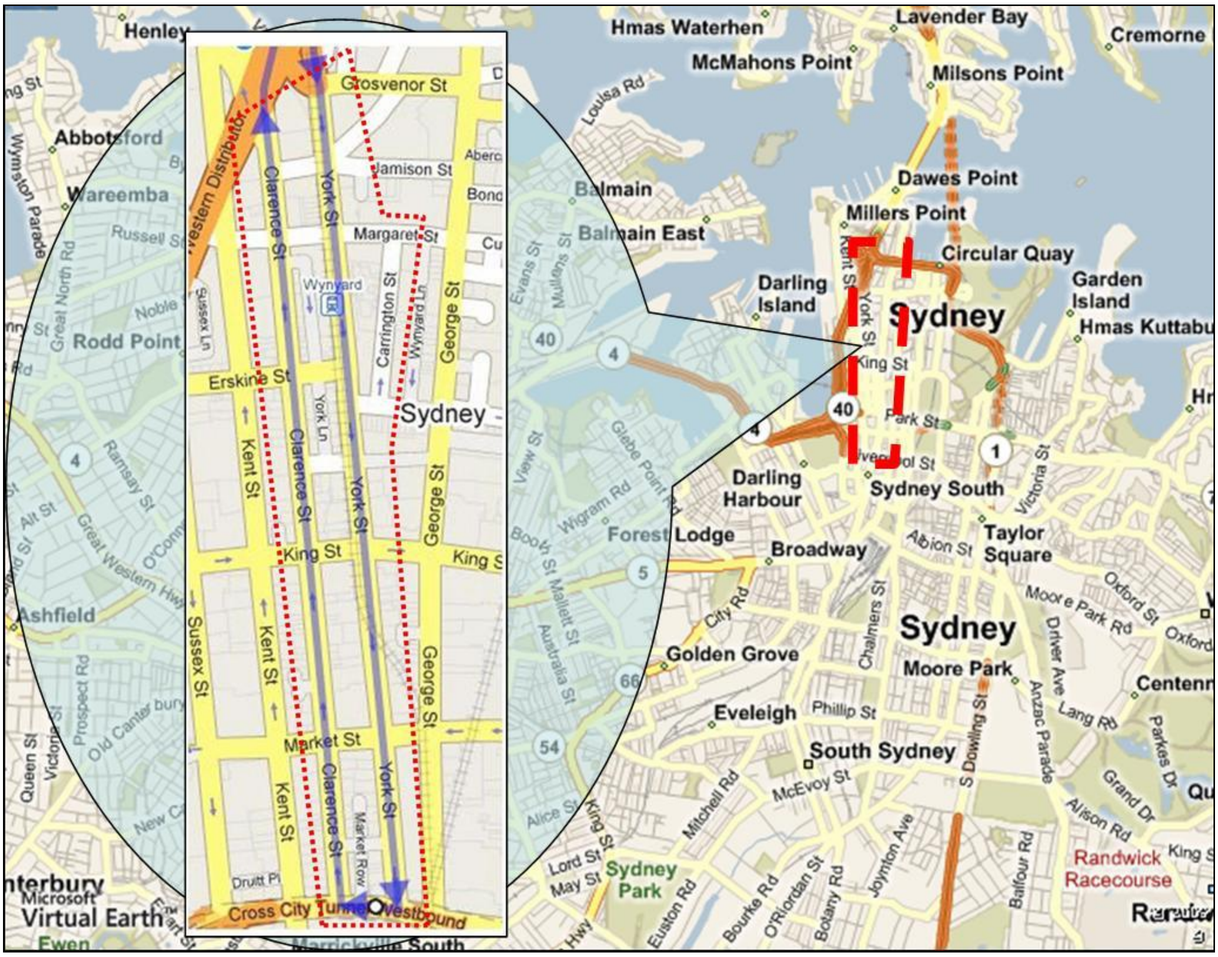

Figure 1 The Sydney CBD and (inset) the study area

Vehicle demand and signal control information was based on SCATS traffic detector counts and signal phasing data obtained from the NSW Roads and Traffic Authority (RTA) for a one-week period in March 2007. Data from weekdays were utilised for calculating the average traffic demand and average signal phase times by 15 minute intervals.

Detailed bus route information for the study area was extracted from the ITIS database. The ITIS (Integrated Transport Information System) database contains all the public transport routes running in the Sydney's Greater Metropolitan Area. The database is maintained by the Ministry of Transport, and is used by the 131500 Transport Infoline service. It includes for each route the number of services, the time of day and the day of week of each service, the identity of each stop with its x-y coordinates and the operator of the service, public (STA) or private. This information was used to create the public transport lines for each route serving the city through the study area. More than 150 lines in the morning and evening peak period were modelled. Since the study area is a major destination for work based trips, there are a large number of buses that terminate/start services at various locations throughout the CBD.

Bus dwell times at the bus stop locations at Lang Park, Wynyard Park, QVB (Queen Victoria Building) on York Street and Wynyard Station on Clarence Street were obtained from a dwell time survey conducted by AECOM. These bus stops were considered as major scheduled stop locations within the study area.

Data Input Process

Due to the data extensive nature of simulation modelling, the data input process was automated as far as possible to make it reliable and easily reproducible. The process utilized Excel spreadsheets and VB-macros, Python Scripts and Access database as data processing and input tools. Aimsun allows users to create python scripts to make changes to the model, traffic parameters or to the data input process. Python (a C ++ based computer programming language) has been used to develop some procedures during the course of this study for automating the input process for public transport lines, bus timetables and control plans in the model. Another set of Python Scripts were developed to convert binary SCATS data into readable format. Macros were coded in Microsoft Excel to process the signal information obtained from SCATS. A database was created using Access to calculate the 15 min average traffic volumes from the detector counts.

Traffic Demand can be input in Aimsun either in the form of an OD matrix or Traffic States. Trips between origin and destination centroids were defined to develop an OD matrix for the AM peak model. Input link flows were assigned in Traffic States for the PM peak model.

The mean dwell times were calculated from the data collected from the survey. This information was incorporated in the model for each hourly time slice for the bus routes accordingly. Aimsun provides two ways of entering the timetable data for a public transport services: Fixed or Interval based timetable. In this study the timetable was coded as interval based since the frequency of inbound and outbound bus services was available.

Model Calibration

The AM and PM peak base models were calibrated using the capacity and demand calibration parameters. Capacity calibration includes adjusting the link parameters, such as Yellow Box Speed, maximum speed, distance zones, to alter the capacity of a link, section or segment. The demand or flow on a section is dependent on the total input demand, route assignment and turning flow percentage. Demand calibration is thus achieved by making adjustments to these parameters in an iterative process. The morning peak model was calibrated by adjusting the number of trips between origin and destination centroids. For the evening peak model, the internal link flow turning percentages were adjusted to match the detector count data from SCATS. The model was assessed against the calibration criteria outlined in the Design Manual For Roads And Bridges (DMRB, UK DoT 1997), using the goodness of fit measure called the GEH statistic. The DMRB requires the GEH statistic to be below a value of five for at least 85% of individual turn flows. A summary of GEH statistic values for the AM and PM peak models is presented in Table 1.

Table 1 Summary of GEH statistics for all detector locations

	Very Good	Good	Review	Incorrect
Peak Period	<2	>2 and <= 5	>5 and <=10	> 10

	Very Good	Good	Review	Incorrect
Peak Period	<2	>2 and <= 5	>5 and <=10	> 10
AM	38%	43%	29%	3%
PM	56%	35%	8%	0%

Bus services were calibrated by comparing the modelled and timetabled number of buses entering and exiting the network via the Sydney Harbour Bridge (see Table 2).

Table 2 Timetabled vs modelled bus numbers entering the study area from SHB

	7–8am	8–9am	9–10am	**AM**	3.30-4.30	4.30-5.30	5.30-6.30	**PM**
Timetabled	184	282	143	**609**	94	195	213	**502**
Modelled	176	257	171	**604**	69	190	224	**483**
Difference	-8	-25	28	**-5**	-25	-5	11	**-19**

Table 2 shows that the AM and PM peak period models recorded 5 and 19 less buses entering the study area than what was timetabled. This is because in the Aimsun output database a bus is counted only when it completes the defined route. Therefore, at the end of simulation the buses which have not left the network due to congestion are not counted by the software.

Challenges of Modelling Intricate Bus Operations

The modelling of detailed bus operations under highly congested conditions – caused mostly by the buses themselves – presented unusual challenges to the modellers and to the software platform. One of these challenges was the modelling of "Dead Running" buses. The number of services terminating and departing from the bus terminals in the corridor is highly unbalanced: in the AM peak there are much more services arriving in the CBD while in the PM peak more services are departing. During the AM peak, the buses terminating in the CBD but not used immediately for a departing service, leave the area, going back to the same point where they entered. Similarly, in the PM peak, buses departing from the CBD, arrive from the same direction just a few minutes before their scheduled departure time. To model an accurate number of buses entering and leaving the study area, it was necessary to model the Dead Running (not-in-service) buses along with the regular bus numbers in the corridor. The Dead Running buses were modelled as separate services running on a frequency calculated from the inbound or outbound services.

The bus stops in the CBD serve both as scheduled bus stops for inbound bus services and as terminal starting points for the outbound services. During the simulation, it was observed that there was a conflict between the buses being generated from a bus stop and the inbound buses servicing the same bus stop. This led to buses blocking each other and an eventual break down of the model. To overcome this problem, a set of clone bus stops were created on top of existing bus stops – one for inbound and the other for outbound service.

The large number of buses queuing in front of a long bus stop also led to unrealistic situations where buses blocked each other's route causing a total break down of the model. These problems were reported to the software developer (TSS Transport Simulation Systems in Barcelona), who provided a new improved version of the software that was able to deal with these extreme levels of bus congestion.

Developing Future Management Options

Forecast Bus Growth

The outputs from the base year AM and PM models have shown high levels of bus congestion and delay for all passengers, consistent with the observed conditions on the ground. This is a major concern for the Transport Planning Division of the Ministry of Transport (TPD), as it is expected that the number of bus services will significantly increase in the next 5 to 10 years. The main objective of the simulation study was to investigate how this increase can be accommodated in the area and how to optimise the bus service operations and minimise the economic and environmental impacts of congestion.

Based on the expected increase, a 30% (representing 2016/2017) and 14% (representing 2011/2012) growth in bus demand was forecast for modelling future year scenarios. In order to evaluate the current traffic arrangements against this growth in bus demand, a 'Do Nothing' scenario was modelled with 30% increase in bus demand assuming private traffic remain at the current level. Simulation results showed that 78 buses were unable to enter the network via the Sydney Harbour Bridge (SHB) during the morning peak period (see Figure 2). The length of queue (1092 m) in such a scenario would cover most of the SHB (1149 m). In the evening peak period model, heavy queuing was observed which eventually led to a complete gridlock in the network due to the increased number of outbound buses. This situation was made worse with the increase in number of 'Dead Running' buses trying to enter the network via the SHB.

The results of the 'Do Nothing' scenario revealed that the network with current traffic management arrangements would not be able to cope with a 30% growth in bus demand. Following on from these results, the 'Do Nothing' model was simulated with a 14% increase in bus demand. The simulation results showed that in the morning peak period 57 buses were unable to enter the network via SHB. In the evening peak period, grid lock was observed during the last hour of simulation (5.30-6.30 PM) with the surge in bus frequency.

As a result of the performance analysis of the base case models, traffic management strategies were developed by the TPD in consultation with the bus operators. The scenarios were developed from the calibrated base models (AM and PM) representing 2007/2008 conditions for both morning and evening peak periods. The increase in bus demand was implemented by increasing the frequency of service for each bus route within each time slice for the three hour simulation period. The alterations made to bus operations and the traffic operations management were incorporated for the specific scenarios modelled.

Representation of Delay

In developing the future management scenarios it was important to understand the sources and components of delay, as it can help in determining where and how much improvement can be achieved by various management measures. Microsimulation can help in this process as it allows modelling scenarios that are not realistic but can reveal individual components of the total delay.

The average travel time was used as the measure of performance for the bus operations. The total travel time is considered to comprise of Dwell Time (DT), Free Flow Travel Time (FF) and Other Delay (OD), including delay caused by interaction between buses and private cars and by signal control. The Dwell Time (DT) is a known input data in Aimsun, based on the surveys conducted at the bus stops for this study. Free Flow travel time is the travel time when vehicles are allowed to travel under free flow conditions, i.e. without any delay from traffic control or traffic congestion due to other vehicles. For obtaining the Free Flow Travel

Time for buses, the model was simulated without any traffic signals. In this way, the total delay in the travel time obtained is due to only the friction between vehicles and the dwell time. The dwell time was subtracted from the total travel time to obtain the free flow travel time for buses.

Thus, to evaluate the components of total travel time, the Bus Dwell Time and the Free Flow Travel Time obtained from the simulation without signal control were deducted from the Total Travel Time values from a standard simulation run for each secnario.

Management Options

A series of traffic management strategies were developed by the TPD to improve the bus operations performance in the CBD. The strategies were designed in a staged manner with each scenario inheriting the measures modelled in the parent scenario along with some additional changes in the traffic operations management schemes. The developed strategies include alterations made to the scheduled bus stops, pick up/ drop off locations for bus services and some traffic management strategies in the form of road closures and changes to traffic signal plans for affected intersections. The scenarios were designed specifically to address issues in both morning and evening peak periods and hence some of the changes were exclusive to either of the two peak periods. The development of these management options follows a pyramidal hierarchy with each option carrying over features present in the parent scenario. The various strategies are detailed in the following sections. The notations AM and PM after the scenario codes below indicate to which time period the scenario was applied.

Relocation of Scheduled Bus Stops (Scenario 1 - AM): The bus stops at Wynyard are scheduled stops for most of the inbound bus services coming into the city via SHB. A large proportion of the delay in the AM Peak was caused by buses queuing before these bus stops. In order to redistribute the heavy bus traffic from this bus stop, the scheduled stops for some of the selected bus routes were relocated to bus stops north or south of Wynyard.

Relocation of Terminal Bus Stops (Scenario 2 – AM/PM): In order to maximize the kerb space available for set down and pick up operations of buses during morning and evening peak periods, specific changes were made to terminal (start or end of service) stops for bus services. This made possible to allocate all of the Wynyard kerb side (150m) space to inbound services in the AM and outbound services in the PM peak.

Elimination of Conflict with General Traffic (Scenario 2C – AM, Scenario 2A/2B – PM): The major bus flow (inbound and outbound) in the CBD area is in north-south direction. In the AM peak, the conflicting cross street movement from Grosvenor Street accounts for a sizable part of the cycle time, thereby reducing the green time available for bus movements (see Figure 1). In the PM peak outbound bus services from Carrington Street have to give way to heavy westbound traffic on Margaret Street while moving out. Under this scenario, the Grosvenor Street traffic was diverted to Lang Street to give a continuous green phase to inbound buses entering the CBD via SHB. Similarly in the evening peak period, westbound traffic on Margaret Street was diverted equally to Jamison Street and Grosvenor Street.

Results from Modelled Options

The various scenarios described in the previous section were modelled and simulation results obtained. A comparative analysis of average bus travel times along two of the main corridors – between SHB and QVB (AM and PM peak) and Wynyard to SHB (PM peak) – is presented in this paper. This provides a comparative overview of the various scenarios with respect to their performance against each other. The 'Do Nothing' scenario, representing the current traffic management conditions and an assumed increase of 14% in bus demand, is included as a basis for comparison.

Morning Peak Period (7-10 AM)

The number of buses queuing on the SHB, unable to enter due to congestion in the study area, is shown in Figure 2. The results indicate that the measures implemented in Scenario 2C provide an efficient movement of inbound buses into the study area via SHB. Only this scenario can accommodate the surge in bus frequency between 8 to 9 AM.

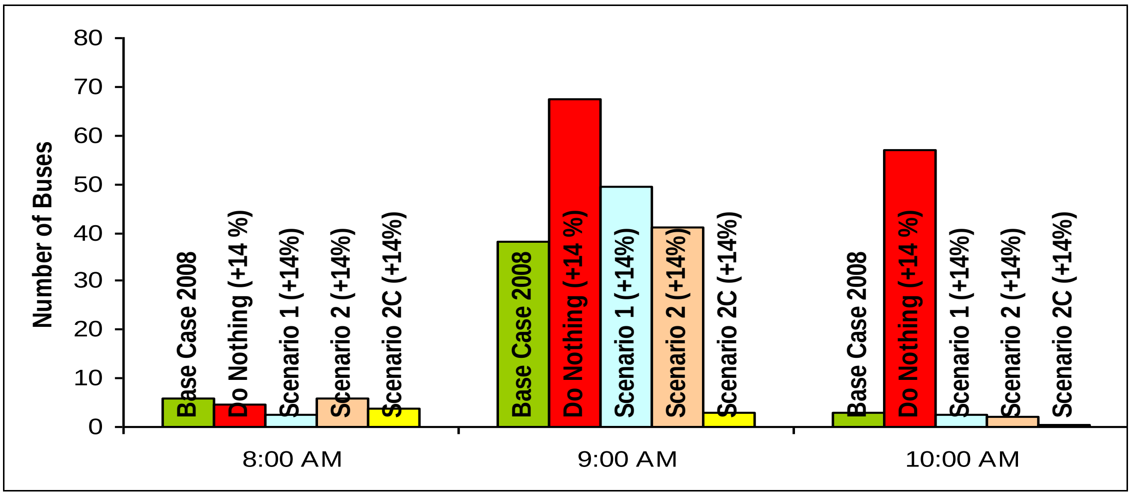

Figure 2 Number of Buses waiting outside the network on SHB (AM peak)

Figure 3 shows a comparison of the mean travel times for buses travelling from SHB to QVB in various scenarios for the AM peak. The travel time for the 'Do Nothing' scenario cannot be reported from the simulation due to the large number of buses unable to enter the study area as shown in Figure 2. The proposed 3 alternatives can achieve a mean travel time comparable to the Base Case conditions, among them the set of measures implemented in scenario 2C show the least total travel time for the corridor.

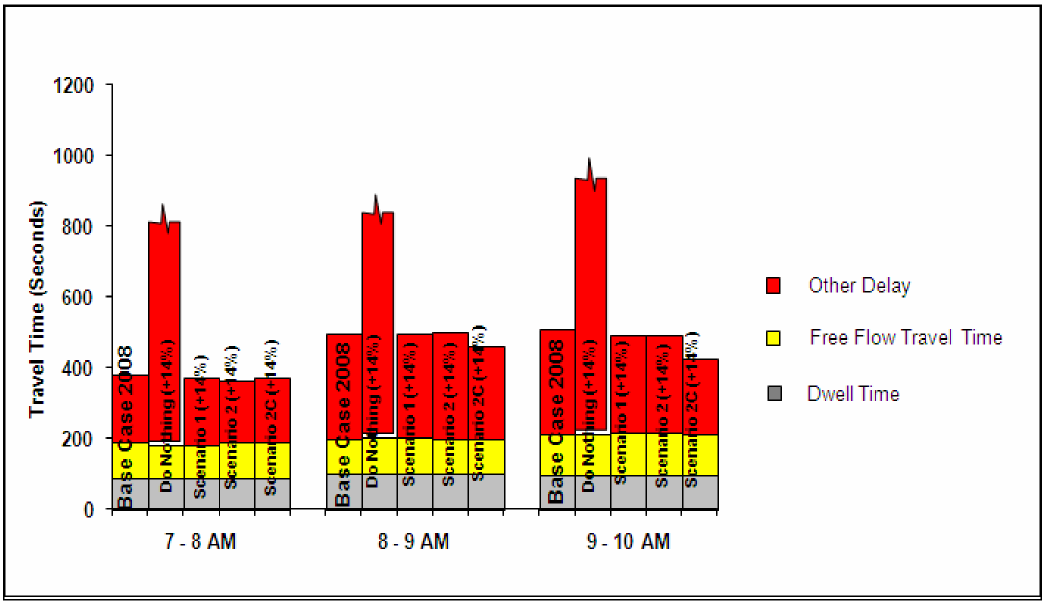

Figure 3 Mean Travel Time for buses from SHB to QVB (AM peak)

Evening Peak Period (3.30 – 6.30 PM)

Figure 4 shows the mean travel times for outbound buses travelling from QVB to SHB in various scenarios for the PM peak. Again, the travel time for the 'Do Nothing' scenario is shown as unmeasurably high, due to the complete breakdown of the simulation in that scenario. The 3 alternative options are able to reduce the delays to a level comparable with the Base Case scenario, and Scenario 2B provides the least travel time.

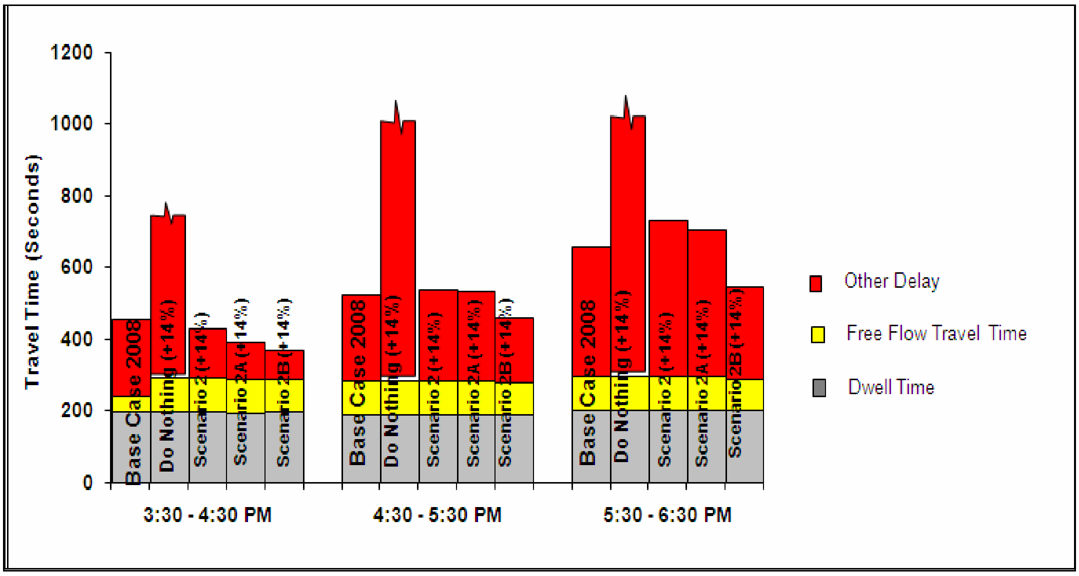

Figure 4 Mean Travel Time for buses from QVB to SHB (PM peak)

Figure 5 represents the mean travel time for the buses starting from Wynyard and leaving the study area via the Sydney Harbour Bridge. Results indicate that only the redirection of conflicting private traffic (scenario 2A/2B) is effective in reducing the delay the outbound buses leaving the study area via the Sydney Harbour Bridge.

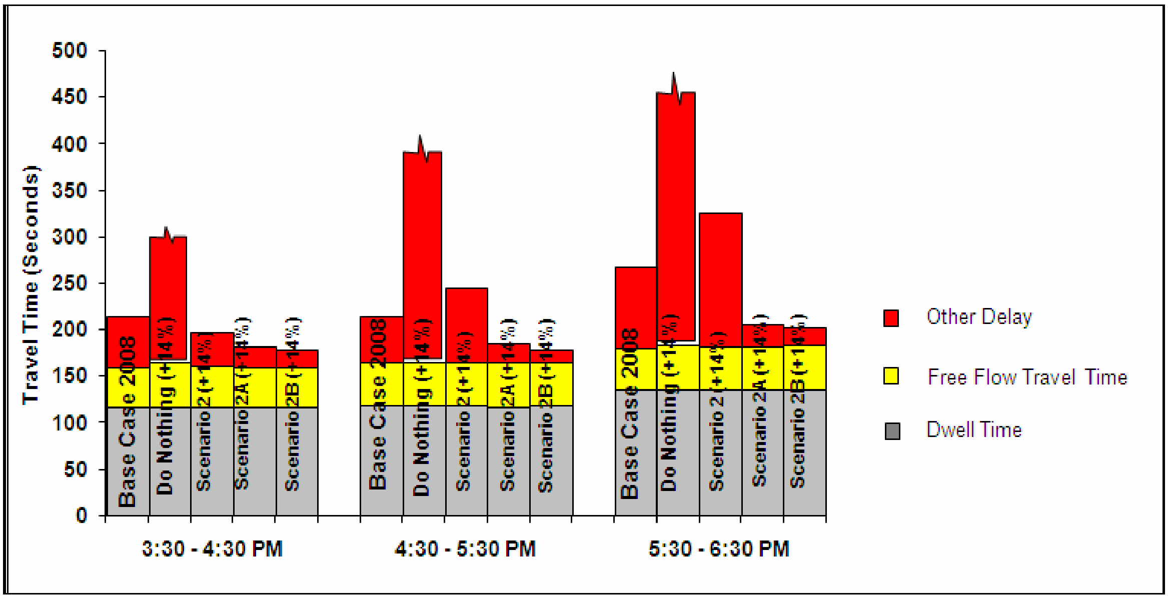

Figure 5 Mean Travel Time for buses from Wynyard to SHB (PM peak)

It is also worth noticing that the dwell time is such a significant proportion of the total travel time, much higher in the PM peak for outbound buses than in the AM peak for arriving buses. These were the dwell time obtained from the survey conducted at bus stops. As a mitigation measure, a 'Cashless' ticketing system was considered by the TPD MoT. Under this scheme, there would be no sale of tickets onboard bus and the passengers will need to have the prepaid ticket/travel pass before boarding the bus. The dwell time in this scenario was assumed to be around 2 seconds per passenger boarding. This measure was expected to reduce the total travel time and delay considerably during the evening peak period in the CBD. However the scenario was not modelled and hence no simulation results were reported.

Conclusions and Recommendations

This study has produced two sets of conclusions. One outcome, in line with the set objectives, was the finding that a combination of modifications in bus routes patterns, bus stop locations and general traffic management measures would be able to accommodate a 14% increase in bus services in the short term while maintaining a reasonable Level of Service for bus operations.

In the morning peak, in addition to making the recommended changes to bus route patterns, the diversion of Grosvenor Street traffic into Lang Street was found to enhance the movement of inbound bus services from the Sydney Harbour Bridge into the CBD area. At the same time, the changes to the bus route pattern in this scenario transform the York Street stands K, L, M and N into set down only thereby providing more kerbside space for the inbound buses. The scenario incorporating these traffic diversions produced the best key performance measures for the bus services compared with the other scenarios.

This study has also produced useful outcomes in terms of simulation methodology with regard to public transport modelling. The modelling of detailed bus operations under highly congested conditions – caused mostly by the buses themselves – presented unusual challenges to the modellers and to the Aimsun software platform and has led to the following conclusions.

- Frequency based Public Transport (PT) Timetable: During the process of modelling it was observed that for each hourly defined time slice, buses are generated as per the corresponding frequency until the program encounters the next time slice schedule. For example, if a bus operates between 7-8am and between 9-10am in the three hour morning peak period, but there are no services between 8 to 9 am, Aimsun continues to generate buses from this particular bus line between 8-9 AM with same frequency as for 7-8 AM. The problem was resolved by using a fixed timetable with appropriate departure times for these services to ensure accurate bus demand generation.
- Public Transport (PT) Timetable: The PT timetable allows only one vehicle type to be generated for the entire duration of a Schedule Slice. Under this arrangement, it becomes difficult to define different types of buses operating within a single time slice of a Frequency based time table.
- Bus Stops: Aimsun does not allow a bus stop to be modelled as both 'Terminal' and 'Set-down'. In the CBD, some bus stops serve as both starting point for outbound and set down for continuing inbound services.
- Public Transport Simulation Outputs: Aimsun provides comprehensive simulation outputs but it does not produce public transport results with respect to each scheduled bus stop.
- Modelled and Simulated Timetable: Buses are generated as per the defined timetable; however there is no method to check if buses generated under a Frequency based timetable arrive at the scheduled bus stops on expected time.

In this study, a way around these limitations was worked out using Aimsun API and other innovative techniques to obtain the required results. However, these limitations have been reported to TSS (Transport Simulation Systems) and some of these issues are now being incorporated into the latest version of the software.

References

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