

# EVALUATION OF TOLL COLLECTION PERFORMANCE USING TRAFFIC SIMULATION

Nick Poon and Hussein Dia

*Department of Civil Engineering  
The University of Queensland  
Brisbane, Queensland 4071  
[nickpoon@hotmail.com](mailto:nickpoon@hotmail.com), [H.Dia@uq.edu.au](mailto:H.Dia@uq.edu.au)*

---

## Abstract

With the continuing steady increase of vehicles on Brisbane roads, Brisbane is expected to experience gridlock situations by 2011 unless significant changes are made to roadways or methods of transport. Intelligent transport systems are one of the limited responses remaining to reducing traffic congestion. As there is a limit to how much additional area may be devoted to roadways, it is vital to ensure that current roadway networks are managed to their full potential.

Intelligent Transport Systems can be evaluated either by field research or by laboratory simulation models. Field research is extremely costly and time consuming. Simulation is a more appropriate way of evaluating Intelligent Transport Systems.

The Gateway Bridge is vital to the South East Queensland region as it provides access to Brisbane Airport and the Port of Brisbane. Current traffic volumes are considered to be approaching the capacity of the Bridge under its current toll plaza configuration. This thesis evaluates the implementation of an Intelligent Transport System approach to improving the capacity of the current toll plaza configuration.

Using AIMSUN, a microscopic simulation package, the thesis developed a model of the Gateway Bridge for the purpose of evaluating toll collection performance. Toll booth delay and section time data were collected in the field enabling the construction and calibration of a base model that closely resembled the current situation. Calibration was to an adequate confidence level to ensure integrity of results.

A number of scenarios were run aimed at quantifying the performance of different toll collection mechanisms and analysing the impact fully automated E toll systems would have on future flows

Results from this Intelligent Transport Systems evaluation, showed that four fully automated E toll lanes could support expected 2011 traffic flows.

## **1.0 Introduction**

This thesis aims to develop a microscopic traffic simulation model capable of evaluating toll booth performance. The research was based in Brisbane and thus the Gateway Bridge was chosen as a convenient subject.

The bridge will initially be modelled and analysed under present operating conditions. The study aims to investigate future scenarios and assess the capability of the bridge to support expected increased flows.

Advancements in traffic modelling technologies have seen the popularity of traffic simulation increase significantly during the last decade. Once considered a strategic advantage, simulation has rapidly become an entry requirement in traffic planning and design.

Leading traffic simulation packages contain user-friendly interfaces and exceptional computational power. Additional features include three-dimensional real-time modelling.

### **1.1 Objectives**

The study aims to construct a traffic simulation model of the current Gateway toll plaza configuration. The model will be calibrated to ensure it accurately represents current flow conditions. Section times collected from the field will be used as the primary parameter for calibration. Once calibrated, the model will be used to test and quantify the impact of a number of scenarios aimed at increasing the efficiency of the toll area. The thesis aims to determine what changes are necessary to support increased future flows.

Scenarios include increasing the proportion of heavy vehicles using the toll booths, simulating the current model under increased flows, introducing full E toll conditions and determining the minimum number of lanes required to meet demand under these conditions.

By analysing the results of the different scenarios, recommended future toll plaza configurations will be presented. Any limitations of the study in conjunction with directions for further research will conclude the report.

### **1.2 E toll**

E toll is one of the world's most advanced electronic toll collection system. It involves the use of a small transponder that is fitted to the inside of the windscreen of the driver's vehicle. The transponder automatically deducts toll payments from the driver's E toll account as he/she passes through. A single beep sounds, acknowledging that the transaction has been successful (Queensland Motorways, 2004a).

Should a transaction not be successful or a vehicle without E toll pass through, an image of the offending vehicle will be captured and kept on record as proof that payment did not occur. A notice of non-payment will initially be issued and if no action is taken within 30 days, a toll evasion fine will be incurred (Queensland Motorways, 2004c).

## **1.3 Future of the Bridge**

Approximately 100,000 vehicles travel across the Gateway Bridge everyday. A study by Connell Wagner (2004) found the bridge to be currently operating close to capacity during peak periods.

The primary function of the bridge is to service Brisbane's sea and airports and provide an option that allows North-South traffic to bypass Brisbane's metropolitan area. The Gateway Bridge is integral to servicing the South-East Queensland region and promoting further growth in the area.

With the current bridge and associated toll plaza nearing capacity, a second bridge is to be constructed adjacent to the existing bridge. It too will allow for six lanes of traffic enabling the bridges to operate uni-directionally.

## **2.0 Literature Review**

### **2.1 Microscopic Traffic Simulation**

A *microscopic* approach means that each and every vehicle in the network is continuously modelled throughout the simulation time period as it travels through the designated road network. A vehicle's movement from its origin to destination is tracked as a result of its reactions to stimulus such as traffic signals and the movements of other vehicles (Anderson, and Souleyrette, 2001).

The main advantage of microscopic simulation is that each motorist is analysed at an individual level. However, to gain results on a microscopic level, input data must also be provided on a microscopic level (Chrobok et al., 2002). Thus, it is important to recognise that the quality of output obtained (no matter how sophisticated the program) is only as good as the quality of input provided (Levinson, 2003). The quality of the input not only includes the integrity of the data, but also realising due care when physically inputting the data into the system (Dittberner and Kerns, 2002).

Microscopic traffic simulators aim to realistically emulate the flow of individual vehicles in a road network. They are capable of replicating complex dynamic traffic systems that are difficult or impossible to simulate using traditional mathematical models (Transport Simulation Systems, 2002). By allowing the formulation of a dynamic traffic network many more functions are available such as individual vehicle route guidance systems (Mahmassani, 2001). Researchers are currently developing the option of dynamic destination choice (Anderson, and Souleyrette, 2001). This would add a further dimension to microscopic traffic simulators.

Key components to an effective simulation model include: an accurate representation of the road geometry, detailed models of individual vehicle behaviour, vehicle class characteristics, verified input flows and control signal timings (Barceló, Casas, Ferrer and Garcia, 2000).

During simulation, the program breaks the model down to first principles including car following, gap acceptance, lane changing and other modelling parameters that account for the

physical system entities. From these, the program is able to produce quantifiable outputs such as flows, speeds, occupancies, travel times and average queue lengths that operators are able to analyse.

It is generally agreed that microscopic traffic simulators provide the most in-depth analysis into traffic flow conditions (Chrobok et al., 2002). This depth of analysis has seen them rise over the past decade to become the leading practical analysis tool in traffic management (Haas, 2000: 1).

## **2.2 Choosing a Simulation Package**

Many existing simulation packages may be adequate for a given modelling project. Each package has its advantages and limitations. Macroscopic models for instance, do not adequately capture the level of detail needed for the evaluation of most Intelligent Transport System projects as these projects require the modelling of interactions between individual vehicles and the transportation system (Lind, Hugosson and Algers, 1997). Each model has specific strengths and limitations that should be evaluated on a “case-by-case basis” (Bloomberg and Dale, 2000).

Based on previous research by Panwai and Dia (2004; 2005) evaluating the merits of different car following models incorporated in leading commercial microscopic simulation packages, GETRAM was chosen for use in this thesis. GETRAM is comprised of two packages, TEDI and AIMSUN. TEDI’s graphical user interface enables the construction of the desired traffic network (Barceló, 2001). The network is then imported to AIMSUN, which may be used to define modelling parameters and simulate traffic results from the model (Barceló, and García, 1999).

AIMSUN is capable of analysing any type of or combination of road network system (urban, arterial, highway etc) with respect to origin / destination (O/D) or traffic flow input parameters. All signalisations are available and individual vehicles are categorised into vehicle classes with user-defined physical dimensions and vehicle characteristics. Vehicle characteristics include movement parameters such as acceleration rates, deceleration rates and maximum desirable speeds. Further parameters include fuel consumption rates and exhaust pollutant levels.

In running simulations of a given model, criteria may be defined as to how a vehicle will move through the system. Shortest path, shortest time or other user – defined cost functions may be chosen as the primary criteria. AIMSUN is capable of modelling and collecting data from all types of traffic detectors. This allows for real time outputs ranging from vehicle presence and queue lengths to average speed and travel times.

AIMSUN accommodates the integration of a complete public transport system detailing stops, timetables, reserved bus lanes and bus ways. The operator has the option of defining traffic incidents before or during the simulation period. Variable message signs (VMS) are also at the operator’s disposal. All output data may be saved and archived as ASCII files or in an ODBC database format for ease of future reference (Transport Simulation Systems, 2004a).

AIMSUN is fully integrated with the GETRAM environment. AIMSUN3D, also by GETRAM, is an extension to the AIMSUN (two-dimensional) traffic simulation program

(Transport Simulation Systems, 2003). AIMSUN3D displays simulations saved as scenarios in three-dimensional format. Every aspect of reality may be modelled from the shape and colour of vehicles to the size of trees and architecture of roadside buildings. AIMSUN3D provides an aesthetically appealing presentation for observation of proposed network changes.

## **2.3 Input Data Requirements**

Microscopic simulation is characterised by the high level of detail at which the system is modelled. The quality of the model is highly dependent on the availability and accuracy of the input data. Therefore the user must be aware that in order to build a complete model there are a number of input data requirements. Each scenario must contain a network layout, traffic demand data, a traffic control plan, a public transport plan and a set of initial conditions. These inputs are defined when the model is being constructed in the TEDI user interface (Transport Simulation Systems, 2004b).

### **2.3.1 Network Layout**

An AIMSUN traffic network model is composed of a set of sections connected to each other through nodes, which may contain different traffic features. To build the network model, the following input data are required:

- A map of the area, preferably digitised in .DXF format.
- Details of the number of lanes for every section, including reserved lanes and side lanes (on and off ramps).
- Possible turning movements for every junction, including details about the lanes from which each turning is allowed and solid lines marked on pavement.
- Speed limits for every section and turning speed for allowed turns at every intersection.
- Detectors: position and measuring capabilities.
- Variable Message Signs: position and possible messages to be displayed.

### **2.3.2 Traffic Demand Data**

- Centroid definitions: traffic sources and sinks
- Vehicle types and attributes
- Vehicle classes for reserved lanes
- Where possible, origin/destination matrices detailing the starting point and desired exit point from the system for each individual vehicle, otherwise
- Traffic flows in vehicles per hour for each class of vehicle

### **2.3.3 Traffic Control**

AIMSUN takes into account different types of traffic control: traffic signals, give way signs and ramp metering. The first and second types are used for junction nodes, while the third type is for sections that end up in join nodes. The input data required to define traffic control are as follows:

- Signalised junctions: location of signals, the signal groups into which turning movements are grouped, the sequence and duration of each phase and the offset for the junction.
- Unsignalised junctions: definition of priority rules and location of Give way and/or Stop signs.
- Ramp metering: location, type of metering and control parameters (green time, flow or delay time).

## 2.4 Theoretical Underpinnings

The theory underpinning the logic used by AIMSUN during simulation is based on traffic modelling and traffic control actions, such as ramp metering. Traffic modelling includes traffic demand data, vehicle entrance processes, vehicle modelling parameters and actually modelling vehicle movement.

Traffic demand data includes vehicle classification and input flows and turning proportions. Vehicle entrance processes determine headway distributions for vehicles entering the system and any resulting virtual entrance queues.

Vehicle modelling parameters can be grouped into three categories according to the level at which they are defined: vehicle attributes, local section parameters and global network parameters.

Vehicle attributes are defined at the level of vehicle type. It is possible to define not only mean values for the attributes of each vehicle type, but also the deviation, minimum and maximum values. An example may be the length of a certain class of vehicle.

Local parameters are related to sections. These parameters are applied locally to the vehicles when they are driving along the section, but may change as a vehicle enters a new section.

Global parameters are valid throughout the whole network and are defined neither at the vehicle or section level. They are used for all vehicles driving anywhere in the network during the entire simulation experiment. These include:

- Driver's Reaction Time – this is the time it takes a driver to react to speed changes in the preceding vehicle. It is used in the car-following model and for implementation reasons it is also taken as the simulation time step or cycle.
- Reaction Time at Stop – this is the time it takes for a stopped vehicle to react to acceleration of the vehicle in front, or to a traffic light changing to green. In this study reaction time is extended to include the time taken to react to a boom gate rising at a toll booth.
- Queuing Up Speed – vehicles whose speed decreases below this threshold value (m/s) are considered to be stopped and consequently, join a queue.
- Queue Leaving Speed – vehicles that are stopped in a queue whose speed increases above this threshold value (m/s) are considered to leave the queue and no longer to be at a standstill.

During their journey along the network, vehicles are modelled according to vehicle behaviour models including car-following and lane-changing. Drivers tend to travel at their desired

speed in each section but are affected by factors in the environment such as preceding vehicles, adjacent vehicles, traffic signals, signs and blockages that alter their behaviour.

AIMSUN uses car following, speed calculation, influence of adjacent lane, lane changing and gap acceptance algorithms to update the behaviour of vehicles at each simulation step.

Ramp metering is used to limit the input flow to certain roads or freeways in order to maintain certain smooth traffic conditions. The objective is to ensure that entrance demand never surpasses the capacity of the main road. Green time, flow and delay metering are the three types available.

For further explanation please refer to the manuals themselves (Transport Simulation Systems, 2004).

## **3.0 Methodology**

### **3.1 Data Collection**

The study was interested in simulating worst-case scenario conditions. This meant identifying a specific day and time during the day where the Gateway Bridge experienced its greatest flow rates. A set time period over which to simulate was also necessary.

Any weekday morning was judged to experience the greatest flows. Being a working day it was thought more vehicles would be commuting to workplaces than on the weekends. The morning peak period was identified as more likely to witness intense flow rates as people start work in a more confined time period than they leave work. Basing the target period on vehicles commuting to workplaces, it was decided to focus on North-bound flows, as these vehicles would be vehicles travelling inbound to Brisbane's Central Business District.

AIMSUN's input requirements specify that flow rates be entered as vehicles per hour (vph), thus an arbitrary simulation and data collection period of one hour was chosen. This one hour period was deemed adequate to obtain results representative of peak flows over the bridge.

The quality of the output produced by AIMSUN is only as good as the quality of the data put into the program. Microscopic simulations require large quantities of input data in order to model the flows of individual vehicles. It is important to build a well calibrated model of current conditions to use as a base for future scenarios. This enhances the integrity of findings made by the study.

#### **3.1.1 Toll Plaza Configuration**

The layout of the current toll plaza was visually observed. Figure one gives a diagrammatic representation (Queensland Motorways, 2004b).

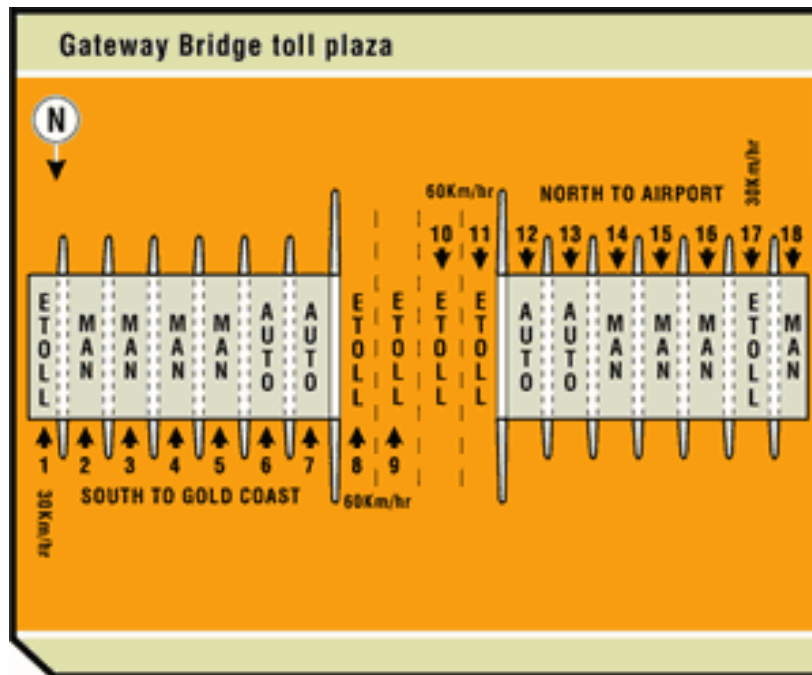


Figure 1 – Current Toll Plaza Configuration

A single Queensland Motorways staff member operates each manual toll booth. Once the toll has been paid and / or change has been given, the operator raises the boom gate and the vehicle is free to continue.

Automatic toll booths require no personnel for operation. A toll recognition structure is located in a similar position relative to the boom gate as the manual toll booth. A catching device enables drivers to insert money into the machine where a counting algorithm verifies the correct toll has been paid before initiating the raising of the boom gate. Sensors under the tarmac determine the class of the vehicle and thus the toll payment required. Change is not given at automatic toll booths. Extended delays occasionally arise in instances where misdirected coins thrown by drivers bounce out of the catching device. An extra staff member / supervisor is always in attendance at the toll plaza ensuring minimal delay periods should this occur.

There are two types of E toll lanes. The central lanes are equipped with recognition devices capable of scanning a vehicles transponder whilst travelling at speeds of up to 60kph. There are no boom gates involved. The outside lanes however, require vehicles to slow to 30kph for transponder scanning. Once payment is verified a boom gate allows the vehicle to pass.

### 3.1.2 Flow Rates

Preliminary modelling was based on 2001 inbound and outbound peak flow rates obtained from GHD's knowledge database. Initially, a standard compound growth rate of 4% per annum was used to estimate current flows before information obtained from Queensland Motorways suggested that a compound growth rate of 6% per annum was more applicable to flows over the Gateway Bridge.



Further approaches to Queensland Motorways led to the acquisition of detailed data specific to the Gateway Bridge toll booths. The data was very recent and representative of average daily traffic conditions. It included vehicle flow rates per lane per hour. Flow data for two 'normal' working days were comparable with previously estimated flow rates.

The study was interested in simulating worst-case scenario conditions and thus an average of the two largest morning hourly flows would be used in the model.

### **3.1.3 Fleet Proportions**

The model required a defined number of vehicle classes to be chosen and set proportions of the total inflow to be designated to individual vehicle classes. Initial modelling identified three vehicle classes (car, motorbike and truck) consistent with fleet proportions for Brisbane city as supplied by RACQ. More specific data obtained from Queensland Motorways enabled calculation of vehicle fleet proportions per hour specific to the Gateway Bridge. This data included a fourth vehicle class identified by Queensland Motorways as vehicles with double axles or trailers.

### **3.1.4 E toll Proportions**

Information attained from Queensland Motorways identified an average of 36% of vehicles utilised E Toll. This data was used in preliminary modelling before more specific data was obtained allowing the percentage of each vehicle class using E toll each day to be calculated. The data used was deemed representative of a 'normal' working day and thus fit for use in the model

### **3.1.5 Delay Times**

Delay time was defined as the interval from when a vehicle became stationary to when the boom gate was raised. AIMSUN accounts for individual vehicle deceleration and driver reaction times, thus the data collected was consistent with the programs control feature requirements. Human controlled, hand held stopwatches were used.

In this study AIMSUN's ramp metering function was used to represent the delay experienced at a toll booth. A random sample of delay times at automatic and manual toll booths was taken. The sample was collected at a time representative of peak flow conditions and consisted of approximately 100 trials for each toll condition.

## 3.2 Data Collation

Graphs were generated from the automatic and manual delay times collected. Figures two and three (below) give a clear visual representation of the range of delay times.

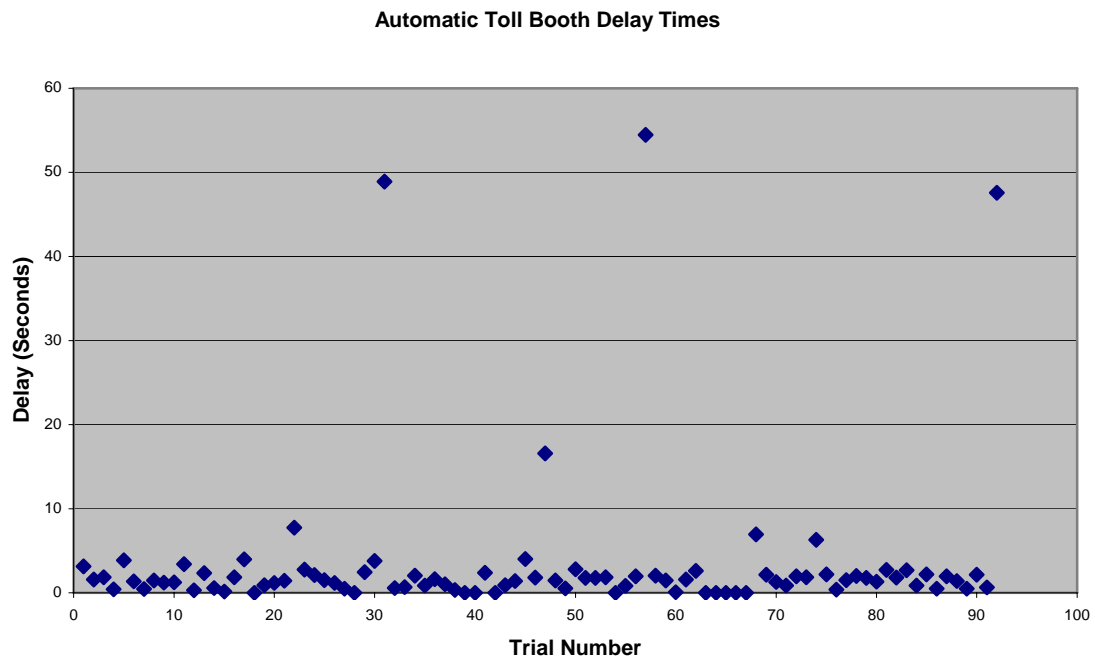


Figure 2 – Automatic Toll Booth Delay Times

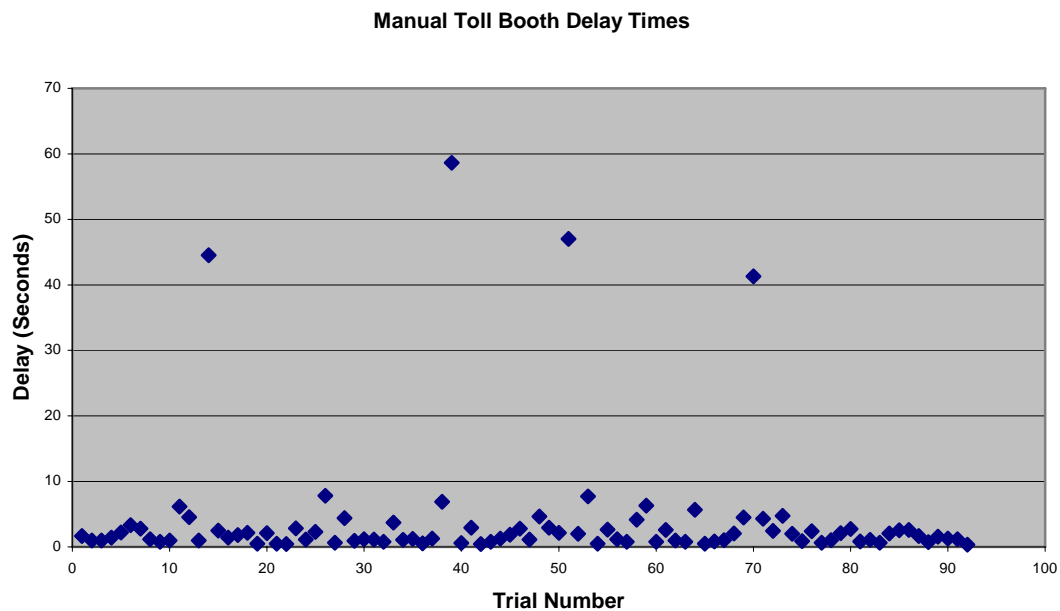


Figure 3 – Manual Toll Booth Delay Times

Mean and standard deviations were calculated for both sets of delay times. From the graphs shown, rogue results were identified as trials returning delay times greater than four standard deviations away from the mean or in excess of four times greater than the mean. These data points were removed from the system.

The adjusted mean and standard deviation for manual delay times was 2.08 and 1.70 seconds respectively. Whilst for automatic lanes they were 1.61 and 1.44 seconds respectively. Figures four and five (below) show the adjusted range of delay times.

**Adjusted Automatic Toll Booth Delay Times**

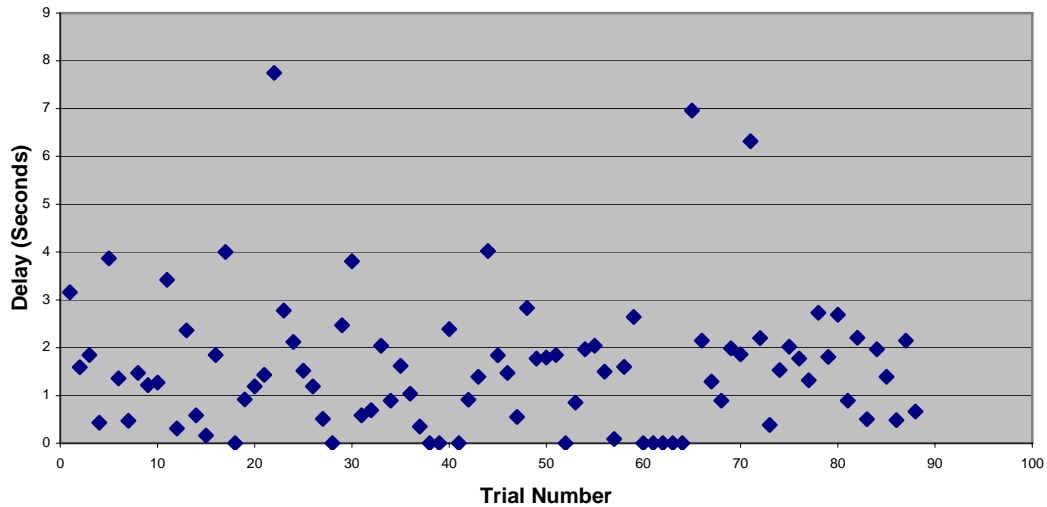


Figure 4 – Adjusted Automatic Toll Booth Delay Times

**Adjusted Manual Toll Booth Delay Times**

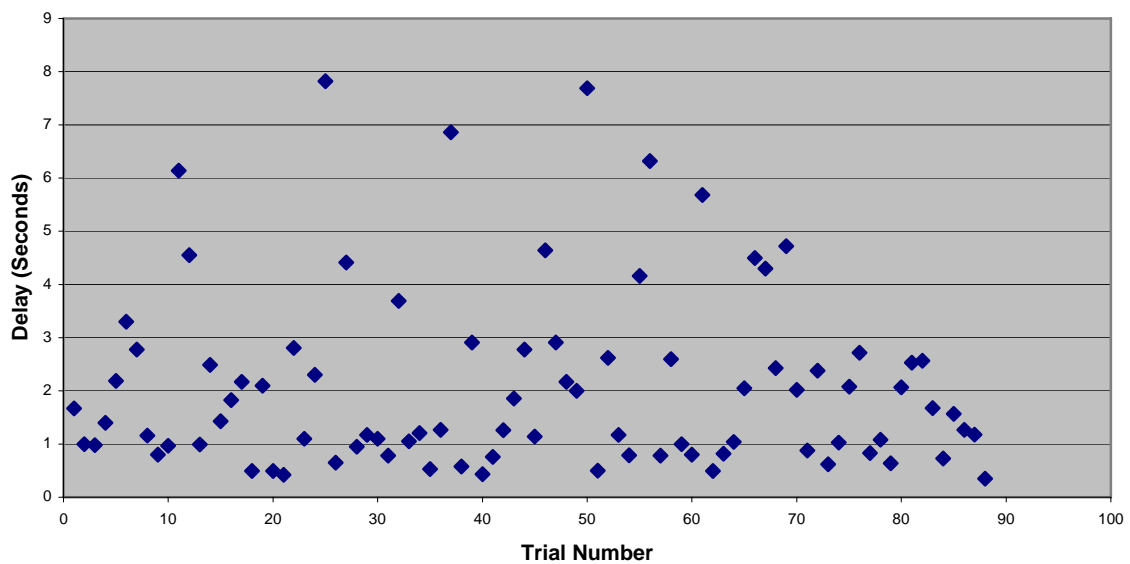


Figure 5 – Adjusted Manual Toll Booth Delay Times

Queensland Motorways data enabled the calculation of daily average E toll lane fleet proportions. Combined with vehicle class flow rates, definitive E toll section flows were deduced. The remaining percentages of each vehicle class allowed automatic and manual lane flows to be obtained. The collated data is summarised in figure 6 (below).

		10	11	12	13	14	15	16	17	18
		1163.5	371	375.25	371	288.25	296.25	312.75	560.5	257.25
2005	MotorBike	3.6	1.9	4.9	4.9	4.9	4.9	4.9	1.3	4.9
	Car	1000.0	198.0	361.8	357.5	274.8	282.8	299.3	420.0	243.8
	Truck	68.6	55.8	8.6	8.6	8.6	8.6	8.6	55.9	8.6
	Long Truck	91.7	115.3						83.8	

Figure 6 – Summary of North-bound Input Flow Data

It was assumed these average values obtained would reasonably represent the hour specified for investigation. This data conformed to TEDI's input requirements allowing a flow rate for each vehicle class to be entered into the model.

### 3.3 Construction of the Model

The first stage in building the model was to replicate the toll plaza and its surrounding area's geometries. By importing the aerial image as a background, a working platform was established. A nine-lane section of road was overlaid onto the image to represent the North-bound approach to the toll booths. Speed limits were applied to the section as observed during current operating conditions. A similar procedure was followed in creating the North-bound exit from the toll booths.

In building the actual toll booth plaza, nine individual sections of road needed to be introduced. This would enable the differentiation of manual toll lanes, automatic toll lanes and E toll lanes. Initially, ramp metering was used to simulate drivers slowing to pay their tolls in both manual and automatic toll lanes. E toll lanes were modelled in accordance with speed limits observed in the field. Ramp metering controls were introduced to the model in manual and automatic toll lanes.

A control plan was created so ramp meters would mimic the delay times observed in the field. A fixed delay ramp meter was deemed the most appropriate control function for simulating delays at toll booths. Mean delay times and standard deviations for manual and automated controls were calculated and inputted into the control plan.

Vehicles were divided into four classes; motorbikes, cars, dual back wheels and double axle or trailer. Default AIMSUN vehicle parameters were used for all vehicle classes. Input flows were entered into the North-bound approach section under the four vehicle classes as vehicles per hour. Average morning peak 'inbound' flows were used as calculated during Data Collation.

This initial network, traffic result and control plan was run in AIMSUN. Overall system flow and individual vehicular flow were observed. Points of congestion were noted, as was the efficiency of the ramp meters acting as toll booths.

In order to obtain a model that resembled traffic flow as observed in the field, an intuitive trial and error approach was adopted. Although this process was very lengthy, it was essential that the model simulated reality as closely as possible before modelling parameters were altered in the calibration process.

The main obstacle was modelling the section of road bottle-necking the initial nine toll booth lanes to three lanes over the bridge proper. The area was trialled as one extended junction, multiple intermittent junctions and finally by utilising the sequential closure of the outer-most lane. This final model was a success with negligible congestion resulting from the vehicles needing to converge to three lanes once exiting the toll booth area.

The scope of this thesis was to identify proportionate increases in altering the types of toll booths used. Thus, having demonstrated that there was no problem in vehicles merging back to three lanes after exiting the toll booths, the model was reduced to solely focus on the toll booth plaza and its immediate surrounds. This made section data collection and data entry much less complex.

In modelling the approach to the toll booths, initially a single nine-lane block of road with no restrictions on lane changing was implemented. This model was unable to simulate reality as random vehicles would try and move to the furthestmost toll booth, or try and change lanes at the last moment causing mass congestion. Numerous layouts were trialled aimed at alleviating the problem. This included breaking the nine-lane section down to different combinations of smaller groups of lanes by introducing solid lines negating vehicles' abilities to change lanes out of the defined lane grouping.

Vehicles' sight distances were increased to enable them to see and assess situations earlier and hence have more time to react accordingly. Increasing the sight distance was justified by first hand observation of the toll plaza. The toll area is very open, straightaway and of very uniform grade.

It was observed that even though vehicles legally have the opportunity to change lanes (as there are no lane markings at all) on their approach, relatively little lane changing occurred once vehicles had entered the approach section. It may be proposed that drivers possessing exact change would seek to pass through an automatic toll. Extended field observation however, found that in the majority of cases drivers were content to remain in their original lane. Thus, it was concluded that relatively little lane changing occurs once in the portion of the road that was modelled, and that eliminating the ability to do so wouldn't negate the accuracy of the results obtained.

After many trials, a final model (below) was chosen that was agreed to satisfactorily represent the overall flow rate and distribution of the observed network.



Figure 7 - The Base Model

Aerial Photograph (Brisbane City Council: iDivision GIS Services, 2001)

### 3.4 Calibration of the Model

The calibration of a model ensures the model created accurately represents reality. This study used section times to calibrate its base model. Section time was defined as the total time taken for a vehicle to pass through the concreted area immediately surrounding the toll booths.

To account for randomness in the simulations a t-test was conducted to determine the number of replications needed to obtain a value within 5% of the mean of the sample with a 95% level of confidence. The procedure is outlined in AIMSUN's user manual (Transport Simulation Systems, 2004a: 166). Running batches of five replications was found to be adequate for the model used in this study.

Outputs of initial simulations run under default parameters somewhat resembled the section time data collected. Alterations to geometry and modelling parameters were made one at a time to further mimic reality and thus obtain section times consistent with the field. Changes to the model needed to be made one at a time to allow visual and theoretical understanding of the effect each change had on the operation of the system.

Final geometrical adjustments were made to toll booth sections to replicate actual observed toll booth lengths. Approach and exit section lengths were altered to coincide with exact entry and exit points used during field data collection.

Input parameters for the model were then varied. The driver's reaction time parameter is a driver's ability to react to stimulus, make and execute decisions. It affects gap acceptance, car following and lane changing algorithms. A decreased reaction time would generally produce a more efficient system. AIMSUN's default value for driver's reaction time and thus simulation step is 0.75 seconds. This value is based on arterial flow conditions. The flow conditions modelled around the toll collection area were deemed to be different. It was reasonable to believe that the vast majority of drivers were conscious of the need to slow down and pay a toll, thus would be decelerating and more alert. Based on this, the driver's reaction time was improved to 0.65 seconds (still within the bounds recommended by AIMSUN).

The flow observed in the automatic toll lanes was not representative of real flows. Based on a variety of trials it was concluded that ramp-metering controls were not suitable for simulating the delays experienced in the automatic lanes. Even though a boom gate was present, vehicles did not approach it as if they were definitely required to stop, as in a traditional ramp-metering situation. In many cases vehicles were observed to be stopping for only a split second and often never actually reached a complete stop. These drivers were observed to decelerate to a crawl as they approached the toll mechanism. They would continue the crawl whilst attaining correct change for the toll before throwing their money into the catcher and continuing to roll forwards in anticipation of the raising of the boom gate. Based on these observations, a reduced speed limit through the toll mechanism area was deemed the most representative control. Different speed limits were applied and resulting flow conditions were observed until conditions reasonably replicating reality were created.

When section time discrepancies between the simulation output and field data were satisfactorily minimal (overall average of 4%), the model was deemed to be calibrated. Having primarily used quantitative measures to calibrate the model, a final qualitative check was undertaken. A visual assessment of the model relative to field observations further validated the model.

### **3.5 Model Testing**

Once the model was calibrated it was re-run under present flow conditions to provide base output data for comparison with future scenarios. The calibrated model found the average section times of the E toll, automatic and manual lanes to be 10, 34.2 and 38.2 seconds respectively.

Section times, delay times and system throughput were the three variables to be measured relative to the current situation. The choice of scenarios was based on possible developments likely to affect flow conditions around the Gateway Bridge. Scenarios aimed at revealing what toll plaza configuration would be required to service anticipated increased flow were also included. The simulations aimed at quantifying the results of the defined scenarios

The scenarios included an increased number of heavy vehicles (due to the expansion of the Port of Brisbane), identifying whether the current toll plaza configuration could adequately support the expected 2011 flows (the expected completion date of the second bridge) and the capacity of the existing plaza layout with every lane operating under E toll conditions. Furthermore, scenarios investigating the viability of using six (expected capabilities of the dual bridges) and four E toll lanes in each direction were considered.

## **4.0 Results and Discussion**

### **4.1 Heavy Vehicles**

Analysis of the heavy vehicles scenario found that an increase (double the original number) in the proportion of heavy vehicles had little bearing on the overall performance of the system. The results showed no change in performance for either the E toll or the automatic lanes. In the manual lane however, the 'Heavy Vehicles' average section time was 37.53 seconds, a slight improvement on the original 38.2 seconds recorded for the base model.

Intuition suggested that an increase in heavy vehicles, characterised by reduced acceleration and braking capabilities, would result in slightly worse section times. Closer inspection of the results of the base model provided a possible explanation for this anomaly. There is one rogue result in the base model. Trial number four shows an average manual section time of over 42 seconds, almost two standard deviations away from the mean. This result may have been caused by trial number four reaching capacity and above average congestion occurring. If this rogue result is temporarily removed from the results, 37.17 seconds becomes the new mean (slightly less than the 37.53 second mean observed for heavy vehicles). Based on the magnitude of this minor discrepancy, the study finds that doubling the quota of heavy vehicles has little impact on the performance of the system.

### **4.2 Current Configuration 2011 Flows**

The results of the second scenario showed that the current toll configuration was unable to support the expected 2011 flows. E toll section times remained the same, which was expected as these lanes were operating at close to free flow conditions. However, section times for the automatic and manual lanes increased dramatically to 47.2 and 101.3 seconds respectively. Extreme congestion and extended delays were apparent. The weighted average was 45.01 seconds, meaning vehicles needed twice as long to pass through the toll compared with today's situation. Drivers using the automatic and manual toll payment mechanisms would experience section times one and a half and two and a half times as long respectively.

### **4.3 Full E toll Implementation**

The three scenarios operating under fully automated E toll conditions exhibited similar results to each other. All toll plaza configurations (9, 6 and 4 lane) were capable of handling the expected 2011 flows. The overall throughput met peak hourly demand, no delays were recorded and the average section time was ten seconds.

Thus under 2011 conditions, the implementation of any one of these three scenarios would result in a four-fold decrease in average travel time through the toll area. By using a fully automated system, drivers previously making toll payments manually would see their section time drop to just one-tenth of its original. Similarly, drivers previously using the automatic toll payment mechanism would pass through the system in one –fifth of their normal time. Immediate implementation would on average halve the time vehicles spend passing through the toll area.



The results are best represented by figure 8 below.

## Mean Section Times (Seconds)

		Scenarios					
		Base			2011 E Toll		
	Field	2005	Heavy Veh	2011	9 Lanes	6 Lanes	4 Lanes
<b>Etoll</b>	10.17	10.00	10.00	10.00	10.00	10.00	10.00
<b>Auto</b>	31.30	34.20	34.20	47.20			
<b>Manual</b>	39.59	38.20	37.53	101.33			
<b>Total Average</b>	<b>Weighted</b>	<b>23.10</b>	<b>22.89</b>	<b>45.01</b>	<b>10.00</b>		

Figure 8 – Summary of Results

The results of the final scenario showed that a 4 lane E toll plaza configuration is capable of servicing the flows predicted for 2011.

## 5.0 Limitations

By using the commercial package AIMSUN, it meant the model built was confined by the capabilities of the program. AIMSUN did not have a built-in toll booth function, thus other available functions were used instead to create the desired traffic condition. Fixed delay ramp metering was used as a substitute for toll booths in the model. Working with a program that had a defined toll booth function may have provided more accurate results, however the model used was well calibrated and represented the toll plaza configuration and flow conditions very well.

Another limitation of the study was AIMSUN's interpretation of virtual entrance queues. The program recognised that virtual entrance queues do form on occasions, however failed to include delay times experienced by vehicles in these queues in the system output. Even though the vehicles were delayed "outside" the defined system boundaries *as a result of the systems inability to support the flows*, no delay was recorded, as the vehicles were never actually delayed "in" the system. Theoretically this may be correct, it is however an impractical result.

Being developed in Europe, the default characteristics in AIMSUN's vehicle class library are specific to European vehicles. These values may or may not closely resemble Australian vehicle characteristics.

During the simulations, no incidents were modelled. The probability of a crash is relatively low, however the consequences of one were not investigated.

All field data was collected with handheld stopwatches thus limiting the accuracy of the data. Data was collected by both members of the thesis team allowing for slightly different interpretations of delay time and section time end points.

The model was calibrated using section times, delay times and overall throughput. It was not however, further validated relative to another independent variable such as queue length.

## **6.0 Conclusions**

The thesis quantified the performance of toll collection mechanisms using microscopic traffic simulation. Current flow conditions through the Gateway Bridge toll area were simulated using a calibrated and validated model constructed from scratch.

The toll collection system and thus the bridge itself were observed to be currently verging on capacity. An unchanged system would be unable to support flows expected in 2011. Mass congestion and extended delays would be unavoidable with average travel times through the toll area doubling. Drivers needing to pay tolls manually would experience travel times up to five times slower than in 2005.

Furthermore, the study showed that the increased use of fully automated E toll lanes would greatly enhance the overall efficiency of the system. Immediate implementation of a four or six lane E toll system would cut average travel time in half. With the flows expected for 2011, either system would result in a four-fold improvement in average travel time. Drivers converting from automatic and manual toll payment methods to E toll would experience section times up to five and ten times faster respectively.

The results from this Intelligent Transport Systems thesis show that expected 2011 traffic flows can be supported by four fully automated E toll lanes.

## **7.0 Directions for Further Research**

Further research into the efficiency of different tolling systems could be carried out using microscopic simulation packages with pre-programmed toll payment functions. A study validating the inclusion of virtual entrance queues delay times into actual system delay times would also be beneficial.

A detailed library of vehicle classes and their corresponding characteristics relative to Australian fleets could be compiled and included as an addition to AIMSUN.

The installation of loop and occupancy detectors at entry and exit points of future toll plazas would enable more accurate data to be collected. Research into new technologies allowing the recognition of E toll transponders at higher speeds would further enhance the efficiency of E toll systems. These are however expensive processes.

In relation to the model itself, advancements could include further calibration using queuing and leaving speed parameters, although this data is hard to collect. Additional validation using another independent variable would further enhance the integrity of the model. Studies into the repercussions of incidents such as crashes or boom gate malfunctions could also be considered.

## 8.0 References

- Anderson, M.D. and Souleyrette, R.R., 2001. "Pseudo-dynamic travel model application to assess traveler information", *Transportation*, 29(3), pp. 307-319.
- Barceló, J. 2001. *AIMSUN Microscopic Traffic Simulator: A Tool for the Analysis and Assessment of ITS Systems*, Barcelona, Technical University of Catalonia.
- Barceló, J., Casas, J., Ferrer, J.L. and Garcia, D., 2000. *Modelling Advanced Transport Telematic Applications with Microscopic Simulators: the Case of AIMSUN2*, Barcelona, Technical University of Catalonia.
- Barceló, J. and García D., 1999. "Some Issues Concerning The Use Of Simulation In Advanced Traffic Management Systems", *20th Conference of the Australian Road Research Board*, Proceedings of the 20th ARRB Transport Research Conference.
- Bloomberg, L. and Dale, J., 2000. *A Comparison of the VISSIM and CORSIM Traffic Simulation Models on a Congested Network*, for publication in the Transportation Research Record, USA.
- Brisbane City Council: iDivision GIS Services, 2001. *the Gateway Bridge, Brisbane, Australia (Aerial Image) 1:10; 000*, BIMAP Ref Num: BM60440, Brisbane City Council, Brisbane.
- Chrobok R., Pottmeier A., Schreckenberg M. and Wahle J., 2002. "A Microscopic Simulator for Freeway Traffic", *Networks And Spatial Economics: Special Issue on Regional Transportation Models*, 2(4), pp. 371-387.
- Connell Wagner, 2004. *Gateway Upgrade Project: Environmental Impact Statement*, Revision 7.
- Dittberner R.A. and Kerns R.T., 2002. "Past President's Award Paper: Traffic simulation in congested urban networks: Pennsylvania Avenue case study", *Institute Of Transportation Engineers Journal*, 72(10), pp. 36-41.
- Haas, C.P., 2000. *Assessing Developments Using AIMSUN*, Auckland, Traffic Design Group.
- Levinson, D., 2003. *Improving the Estimation of Travel Demand for Traffic Simulation*, University of Minnesota.
- Lind, G., Hugosson, B. and Algiers, S., 1997. "Evaluating ITS Strategies : User Needs and Survey of Existing Models", *Proceedings of the 4<sup>th</sup> World Congress on Intelligent Transport Systems*, 21-24 October, Berlin.
- Mahmassani, H.S., 2001. "Dynamic Network Traffic Assignment and Simulation Methodology for Advanced System Management Applications", *Networks And Spatial Economics*, 1(3-4), pp. 267-292.

- Panwai, S. and Dia, H., 2005. "Development and Evaluation of a Reactive Agent-Based Car Following Model", *Proceedings of the Intelligent Vehicles and Road Infrastructure Conference* (IVRI '05), 16-17 February, Melbourne, Australia (ISBN 0-908556-79-9).
- Panwai, S. and Dia, H., 2004. "Comparative Evaluation of Car Following Models", *Presented at Workshop on Traffic Simulation (Bridging Theory and Practice)*, 5-6 August, Customs House, Brisbane, Queensland.
- Queensland Motorways, 2004(a). *Queensland Motorways* [online]. Available from: (<http://www.qldmotorways.com.au/www/index.aspx?ItemID=25>) [Accessed 23 February 2005].
- Queensland Motorways, 2004(b). *Queensland Motorways* [online]. Available from: <http://www.qldmotorways.com.au/www/index.aspx?ItemID=36> [Accessed 23 February 2005].
- Queensland Motorways, 2004(c). *Queensland Motorways* [online]. Available from: <http://www.qldmotorways.com.au/www/index.aspx?ItemID=37> ( [Accessed 23 February 2005].
- Transport Simulation Systems, 2004(a). *GETRAM Open Traffic Simulation Environment: AIMSUN User Manual*, Version 4.2.
- Transport Simulation Systems, 2004(b). *GETRAM Open Traffic Simulation Environment: TEDI User Manual*, Version 4.2.
- Transport Simulation Systems, 2003. *AIMSUN - Advanced Interactive Microscopic Simulator for Urban and non-urban Networks* [online]. Available from: <http://www.kldassociates.com/ProductDescription.html> [Accessed 24 August 2004].
- Transport Simulation Systems, 2002. "Transport Microsimulation", *Euro - China Cooperation Forum*, April 15-20, Beijing, China.