

## MANAGEMENT OF COMPETING DEMANDS ON URBAN FREIGHT CORRIDORS

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*Abstract:* This paper compares the performance under various scenarios of an urban traffic corridor section subjected to a range of vehicle types.

A micro-simulation-based model of the corridor was developed from first principles to stochastically assign characteristics and headways for each vehicle and then to track each vehicle as it moved along the corridor. Kinematic behaviour of the different vehicle types (ranging from passenger cars through to B-doubles) were obtained from GPS data collected during a series of chase car surveys on an urban arterial freight route in suburban Brisbane. The car-following and lane-selection algorithms used by the model are outlined in the paper. In order to account for the variability between runs, multiple simulation runs were typically conducted using different random number seeds. Corridor performance was reported in terms of intersection capacity and delays as well as travel speeds and stop rates for each vehicle type.

The performance of the corridor was found to be sensitive to traffic control measures including the speed limit and traffic signal controller settings such as cycle time and progression design speed. A range of freight policy scenarios were examined, including the effects of increasing freight volumes, freight vehicle mode choice, and vehicle type-specific lane restrictions. Some policies having the potential to improve corridor traffic performance and freight efficiency were able to be identified.

*Keywords:* Signalised intersection, coordination, microsimulation, progression, heavy vehicle, B-double.

## **1. INTRODUCTION**

The limited road space in Australia's urban areas services ever-increasing volumes of both private and commercial traffic. These two are often considered to be in competition, with high-capacity urban corridors frequently also serving as major freight routes.

An increasing disparity between vehicle types is also apparent. Large freight vehicles (LFVs), such as B-doubles, are becoming more popular with operators due, in part, to their accessibility to urban areas. The Survey of Motor Vehicle Use (ABS 1972-2005) has recorded a steady increase in the use of B-doubles, from 14 per cent of total freight tonne-kilometres carried in 1998 to 25 per cent in 2004. This accounted for almost all of the increase in road freight carried over this period.

Despite the fact that fewer vehicles are required for a given freight task (Haldane and Bunker 2002), individual vehicles have a greater effect on corridor capacity and the delay experience by all vehicles on the corridor. It is this effect of an individual vehicle on the surrounding traffic that is most noticeable by the motoring public.

This paper reports on an investigation by Queensland University of Technology into the effects of large freight vehicles on urban traffic corridor performance as part of an Australian Research Council Linkages Grant, with Queensland Department of Main Roads as the industry partner.

The project aims to quantify these effects, and to examine the effectiveness of a range of freight policy and traffic management options in minimising adverse effects.

## **2. BACKGROUND**

The concerns of an increasing freight volume being carried on urban arterial roads have lead to a number of strategic measures being identified as having the potential to manage these competing demands. Several of these strategies, such as geometric constraints or route or area bans serve to discourage freight movements on a particular route, potentially moving the problem elsewhere and imposing additional costs to enforcement officers, operators, and ultimately to the consumer.

The alternative approach is to manage, rather than limit freight movements on a particular route. Strategies may be able to be developed to continue to cater for a range of road user requirements, reducing overall transport costs without disadvantaging any particular group.

One of the most cost-effective traffic management options is to ensure that traffic signal settings are appropriate for the prevailing conditions. Traffic signals are generally vehicle-actuated and linked to a central control system to optimise network performance. Despite this, on a major freight route, it may be worth placing a greater emphasis on the needs and requirements of trucks at signalised intersections.

To examine the effectiveness of some of these traffic management measures and of some freight policy options, a range of simulations were conducted using a specifically-developed microsimulation package.

### **3. MODEL DEVELOPMENT**

Although existing commercially available microsimulation packages were considered for use in this project, it was generally found they did not adequately characterise both the longitudinal vehicle dynamics (important for slowly-accelerating heavy vehicles) *and* traffic behaviour and control.

As such, a computer-based microsimulation model of an urban arterial corridor with linked vehicle-actuated signals was developed to investigate the sensitivity of traffic measures to changes in existing conditions, as well as the effectiveness of various freight and traffic management strategies.

#### **3.1. Model Framework**

The model was developed from first principles, considering the behaviour and interaction of individual driver-vehicle units (hereafter referred to as “vehicles”) as they move along the corridor. The model is stochastic in nature, making extensive use of random numbers to determine the characteristics, headways and lane assignment for each vehicle when initialising a simulation.

Typically, five vehicle types are used in each simulation – corresponding to passenger cars, 4 wheel drives or light commercial vehicles, rigid trucks, articulated trucks, and B-doubles. Proportions of each vehicle type are specified in the input file, the baseline scenario using the same proportions as found in a traffic survey conducted on an urban arterial corridor.

A large number of simulations, each using a different random number seed, are typically conducted to account for the inherent variability in a stochastic model. The results are accumulated and tabulated at the completion of the simulations.

#### **3.2. Longitudinal Vehicle Behaviour**

At each time step, all vehicles are moved forward along the corridor a distance dependent upon their current speed and acceleration. As explained in Ramsay and Bunker (2004), the vehicle’s maximum acceleration depends on the vehicle type, its current speed, and the grade at the vehicle’s current position.

Additionally, each vehicle is prevented from getting closer than the safe stopping distance to the preceding vehicle. At all times, the vehicles must maintain sufficient separation to ensure that a collision does not occur if the lead vehicle starts to brake from its current speed and a short time later (the reaction time) the following vehicle reacts by braking from its current speed.

#### **3.3. Lane Changing**

Lane changing is an important element of a microsimulation package, particularly when dealing with different vehicle types. The effects of heavy vehicles on urban traffic performance would be much greater if cars were not able to pass them.

The model enables vehicles to change lanes only when it is both advantageous and safe to do so. Lane changing is not conducted at every time step – in reality drivers only look for lane changing opportunities several times a minute, in replicating this behaviour the model runs much faster.

Hidas (2005) identifies three types of lane changing – free, forced and cooperative. The current corridor model does not have lane merging or turning traffic, eliminating the need for considering forced lane changing and cooperative merges. This only leaves free lane changing, in which a vehicle changes lanes by choice and not necessarily with the cooperation of other vehicles.

The decision for a vehicle to consider changing lanes requires both a disadvantage in remaining in the current lane, and an advantage in moving to an alternative lane. In addition to considering the vehicle's current speed and that of vehicles in adjacent lanes, when approaching the back of an intersection queue the decision is based on the expected queue discharge time of the current and adjacent lanes. A longer queue consisting of cars may be more attractive than a shorter queue behind a slowly-accelerating heavy vehicle.

Having identified a desire to change lanes, the lane change is only executed if there is no chance of colliding with either the leading or trailing vehicle in the adjacent lane.

### **3.4. Traffic Control**

Traffic signals in the model operate on a common cycle time, with user-specified offsets between adjacent signals. Vehicle detectors are placed upstream of the stop line, and the controller logic determines the length of the green time allocated to the main corridor through movement, following the description given in Austroads (2003).

Vehicles respond to traffic lights by stopping if safe to do so if the signal is not green. Car-following ensures that vehicles form a horizontal queue back from the stop line, and discharge at an appropriate rate after the signal turns green.

### **3.5. Model Calibration**

Model calibration is covered in detail in a previous CAITR paper by the authors (Ramsay and Bunker 2004). Briefly, a traffic counter was used to provide an estimate of the traffic flow patterns (headway distribution, flows and vehicle type distribution and lane utilisation) that is typical of an urban arterial traffic corridor. This was used to calibrate the traffic generation component of the model.

The performance capabilities of individual vehicles were determined from a GPS-equipped chase car survey, in which a number of vehicles were followed along an urban arterial traffic corridor, recording their in-service speeds and accelerations.

To alleviate concerns that relying on instrumentation fitted to a chase car is not as accurate as fitting it to the subject vehicle itself, a laden B-double fitted with a GPS receiver was driven along an urban arterial traffic corridor whilst a chase car fitted with another GPS receiver followed it. Near-identical results in estimating the speed and acceleration profile of the B-double were obtained from both sets of instrumentation.

### 3.6. Model Implementation

Two versions of the corridor model (CorMod) have been developed – a Windows-based application (CorModW) which produces a trajectory diagram of a simulation, as shown in Figure 1; and a console-based application (CorModC) which can run a large number of simulations with different random number seeds and output the results to a text file. The Windows version is useful in identifying features of a particular simulation, whereas the console version is useful for batch processing a number of lengthy simulations.

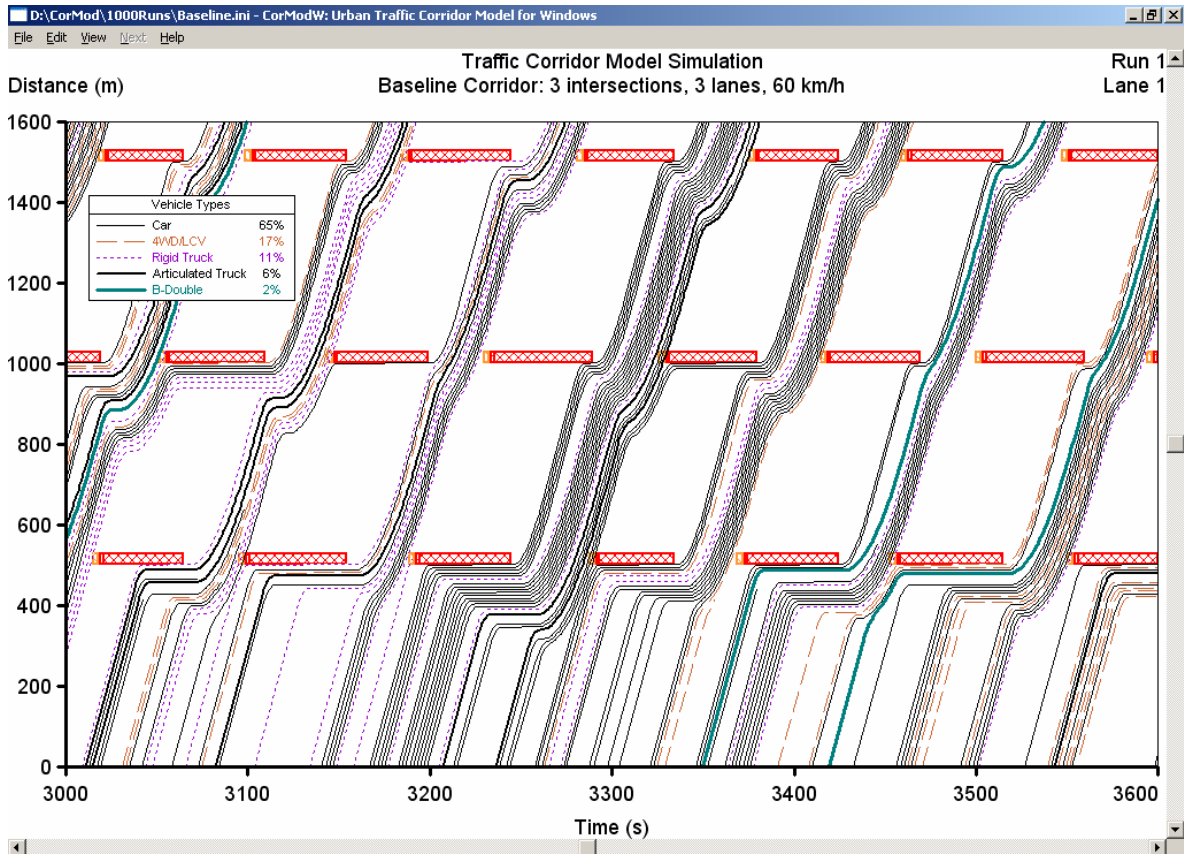


Figure 1 – CorModW display

## 4. FREIGHT POLICIES

Road freight volumes are predicted continue to increase for at least the next 15 years (BTRE 2002). A range of simulations of a three-lane, three intersection urban traffic corridor were conducted, in which the freight volume was varied from 60% through to 200% of the current value.

A steady decrease in travel speeds, increase in delay and reduction of intersection capacity was found as the freight volume was increased. Decreases in speed were slightly greater for cars than trucks, trucks being less likely to be significantly impeded by other trucks than cars would be.

A number of freight policy and traffic management scenarios were considered to minimise these unfavourable effects on traffic performance.

#### 4.1. Freight Vehicle Mode Changes

An increased freight volume could be carried by a greater number of existing freight vehicles, or a similar number of larger freight vehicles. The following scenarios were examined:

- Existing composition of cars, LCVs, rigid trucks, articulated trucks and B-doubles
- Car-only, in which all freight is diverted to an alternative route
- No-B-doubles, with their freight being carried by increased numbers of smaller trucks
- More B-doubles, carrying some of the freight which was on smaller trucks
- Some B-triples, carrying some of the freight which was on other freight vehicles

Figure 2 shows the travel speed of vehicles on the corridor under each of these scenarios (as well as the lane utilisation scenarios covered in the next section). Of the four scenarios in which freight is carried on the corridor, an increased use of B-doubles offers a slight increase in speed on the corridor for all vehicle types. Introduction of B-triples (comprising 3 trailers, about 33 metres long and weighing up to about 80 tonne) appears to reduce speed on the corridor, their assumed poorer performance impeding traffic more than the greater number of vehicles they replace. It should be noted that the longitudinal performance of B-triples was only estimated, based on a decreased power-to-mass ratio, they could not be tested in-service since they are not permitted in urban areas.

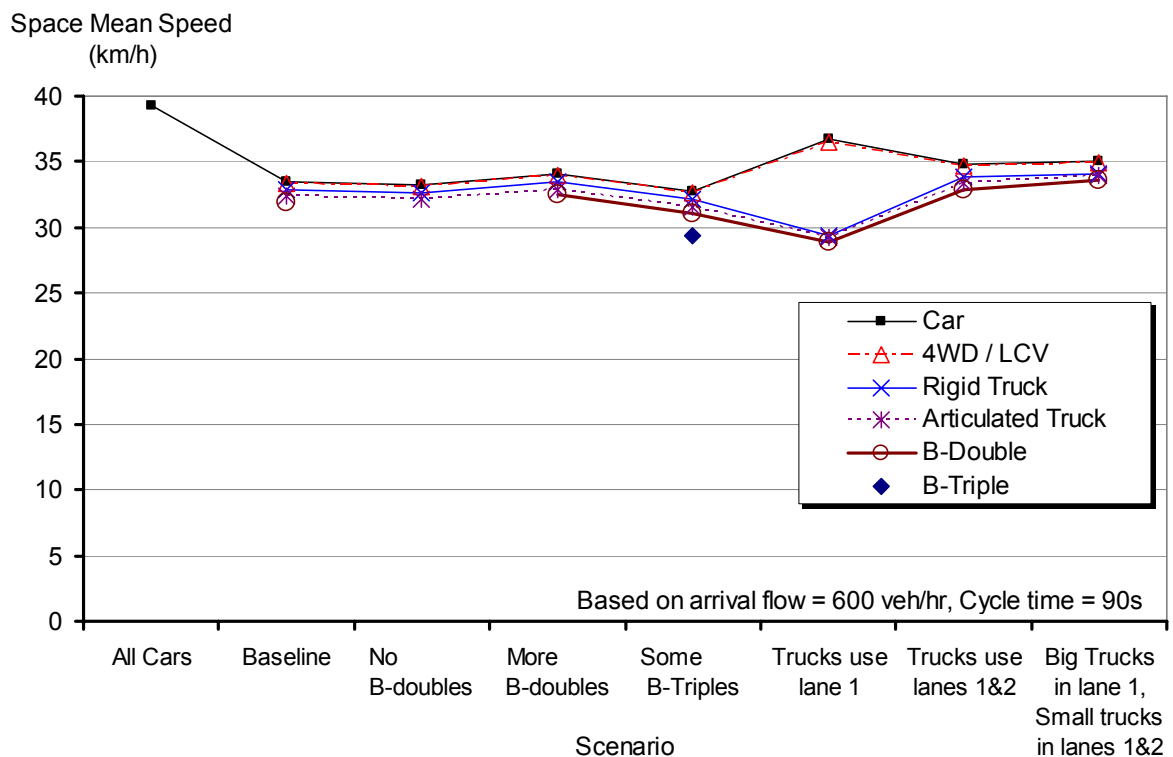


Figure 2 – Space Mean Speed for different freight and traffic management scenarios

## 5. TRAFFIC MANAGEMENT

Three traffic management-related issues were examined – lane utilisation by specific vehicle types, specification of an optimum progression design speed (the offsets between adjacent signals), and active detection of heavy vehicles to prevent signals changing from green as a heavy vehicle approaches.

### 5.1. Lane Utilisation

A number of simulations were conducted in which specific vehicle types were restricted to only using particular lanes. The following lane restrictions were considered:

- Baseline: All cars and trucks may use any of the three lanes
- All trucks (except light commercial vehicles (LCVs)) must use lane 1. Cars, 4wds and LCVs may use any of the three lanes
- All trucks (except LCVs) may use lanes 1 or 2. Cars, 4wds and LCV may use any lane
- Large Trucks (articulated and B-double) must use lane 1, small trucks may use lanes 1 or 2. Cars, 4wds and LCVs may use any lane.

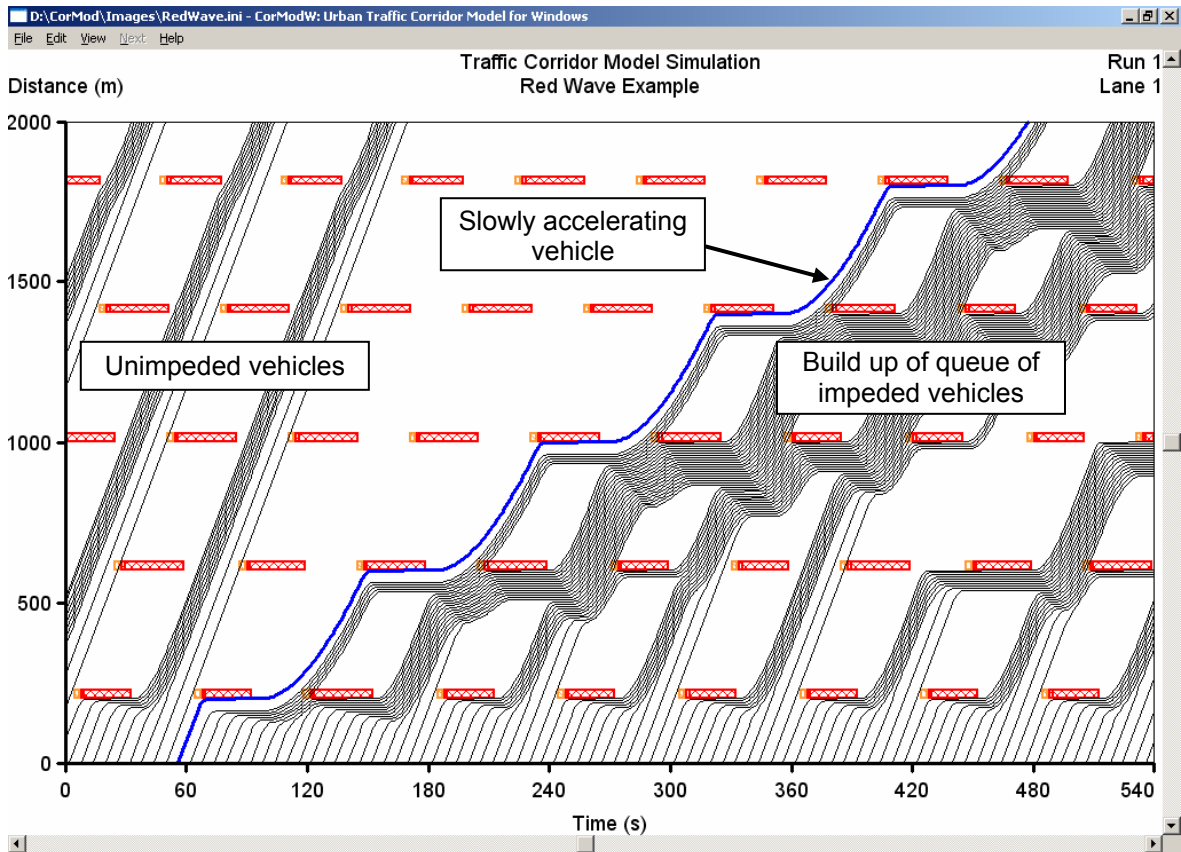
Results of these scenarios are presented in Figure 4, together with the freight mode scenarios. Restricting all trucks to lane 1 gave the greatest travel speed to cars, however the speeds of trucks was lower than for any other scenario. Further examination revealed the truck lane to be very congested, whereas the car lanes were both free-flowing.

Permitting trucks to use two of the three lanes relieved the congestion, whilst still leaving cars free to pass unimpeded in their own lane. The greatest benefit in terms of travel speed for all vehicle types occurred when the large and small trucks were separated.

Al-Kaisy and Jung (2004) conducted a similar investigation using the same lane utilisation scenarios, albeit on a non-signalised corridor. They also found that having each vehicle type relatively unencumbered by other types gave the greatest travel speeds.

### 5.2. Progression Design Speed

Ogden (1999) suggests that trucks can be disadvantaged by linked signals if the offsets between signals are based on car travel times, which slower-accelerating trucks cannot match. In the worst case, these slower vehicles may face a 'red wave' rather than the intended 'green wave', arriving at every signal just as it turns red. Following vehicles are also disadvantaged, as is shown in Figure 3.



**Figure 3 – ‘Red Wave’ experienced by a slowly-accelerating vehicle, acting as a moving bottleneck**

A number of simulations were conducted on a corridor consisting of three intersections, spaced 500 metres apart. The progression design speed (PDS) was varied from 20 km/h (offsets of 90 seconds) through to 70 km/h (offsets of 25 seconds). The space mean speeds of the larger vehicle types were lower than for cars at all PDS values, and the optimum PDS (giving the highest space mean speeds) was found to be the same for all vehicle types (Figure 4).

The number of stops per vehicle also was found to be dependent upon PDS, however different optimum speeds occurred for different vehicle types. As shown in Figure 5, trucks had fewest stops on a corridor with a PDS of 40 km/h, compared to cars and 4wds / light commercial vehicles having fewest stops at a PDS of 45 km/h. This was attributed to trucks being more likely to arrive at the rear of a queue and not having to stop when PDS is 40 km/h, whereas cars would have arrived there earlier and would have had to stop.

Although the “Red Wave” phenomenon shown in Figure 3 could be produced in the simulation under carefully controlled conditions, it was very rare to see it amongst the general simulations. This was attributed to the interactions between individual vehicles, particularly their lane-changing and car-following behaviour, and to the use of vehicle actuated signals.



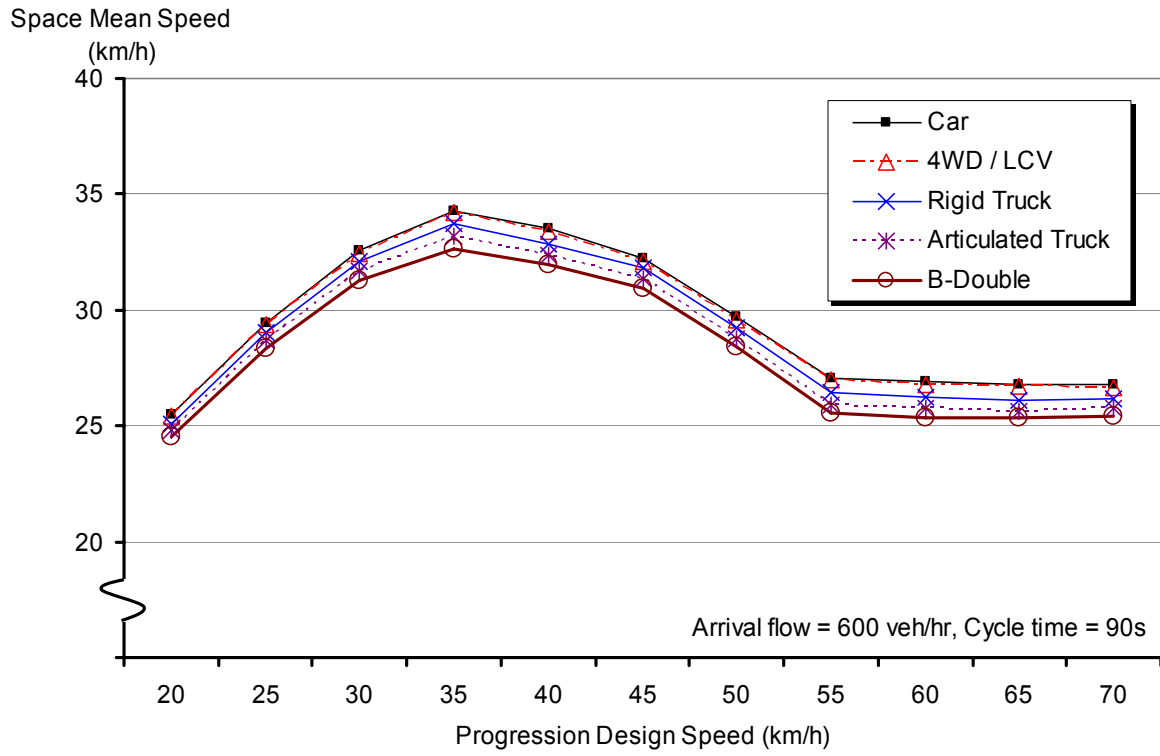


Figure 4 – Effect of Progression Design Speed on Space Mean Speed

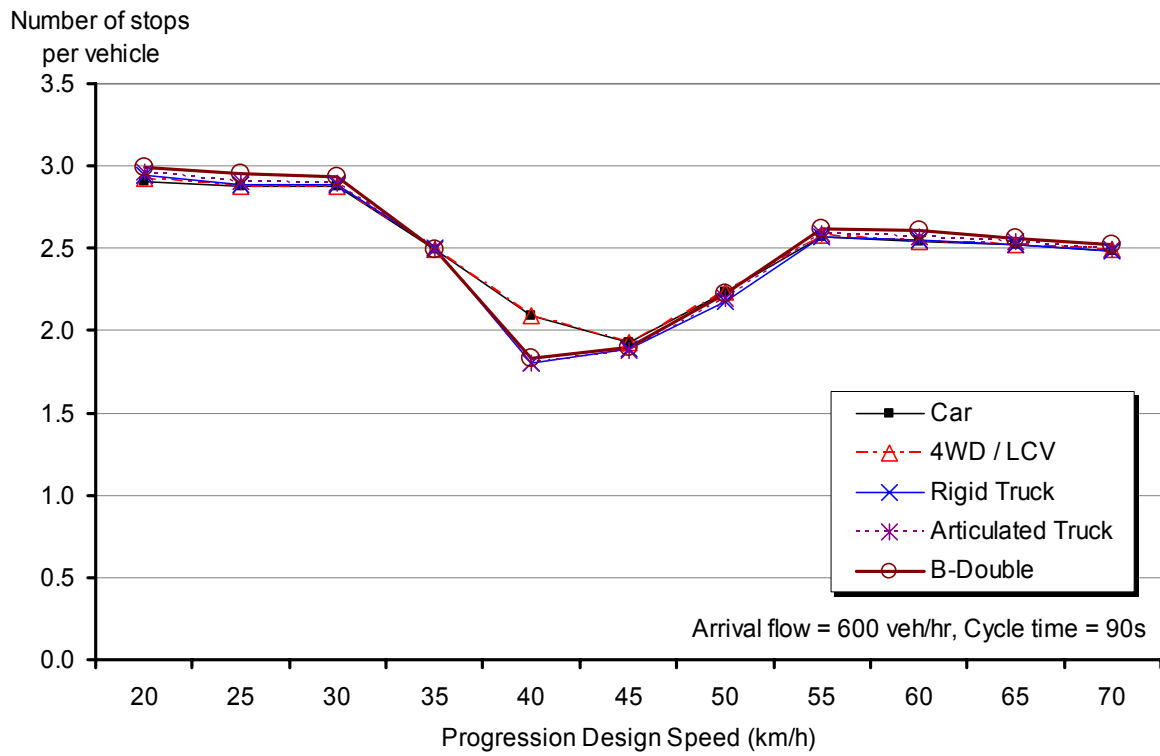


Figure 5 – Effect of Progression Design Speed on Vehicle Stop Rate

### 5.3. Heavy Vehicle Detection and Green Time Extension

An examination of the composition of vehicles at the front of intersection queues in the baseline simulations found an over representation of heavy vehicles. Articulated trucks comprised 5.9% of all vehicles used in the baseline simulation, and B-doubles comprised 1.5%. At the front of intersection queues, 6.6% of vehicles were articulated trucks and 2.0% were B-doubles. This is attributed to the greater headway in front of a heavy vehicle leading to an increased probability of the traffic light changing from green as the heavy vehicle approaches it.

Changing a traffic light from green in front of an approaching heavy vehicle will delay the progress of the heavy vehicle, as well as subjecting the following vehicles to a slower acceleration rate when the signal changes to green. Often the heavy vehicle driver is reluctant to stop when confronted with a changing traffic light, and may still be passing through the intersection when a conflicting traffic movement starts.

Detection of an approaching heavy vehicle, and holding the green signal until it has passed is a possible means of reducing these delays and risks. Sunkari *et al.* (2000) developed a truck priority detection algorithm, implementing it at an isolated rural intersection in Texas. The benefits in reduced pavement maintenance costs (through reduced truck braking and acceleration) were said to outweigh the cost of implementing truck detection. In a congested urban corridor scenario, additional benefits may be realised in terms of reduced delays and accident rates. Many traffic networks, including Brisbane City Council's BLISS system, have transit priority schemes that hold a green signal on or change a signal to green for an approaching bus or tram.

The simulation model was modified to include additional advance detectors at each intersection. Existing detectors, located 35 metres before the stop line, were not suitable since these detectors had to be located beyond the stopping distance for heavy vehicles at the corridor speed limit. These new detectors, located 150 metres before the stop line, are only activated by articulated trucks or B-doubles. The time taken for the heavy vehicle to reach the intersection is calculated based on its speed and length, and a timer starts counting down from this value. If a call to terminate the movement is received, and the value of this timer is less than 10 seconds, then the green signal is held on until the timer reaches zero, corresponding to the heavy vehicle reaching the intersection.

To ensure that the conflicting traffic movements are not disadvantaged, the next green period for the main corridor through movement is shortened by same time that the green had previously been extended by. Figure 6 shows the trajectory diagram of an intersection which changes from green as a heavy vehicle approaches. Figure 7 shows the same intersection with a heavy vehicle detection and green time extension implemented. The green time is extended for a sufficient time to permit the heavy vehicle to safely pass through the intersection on a yellow signal, with the next vehicle (a car) appearing at the front of the queue and the queue able to discharge faster than otherwise.

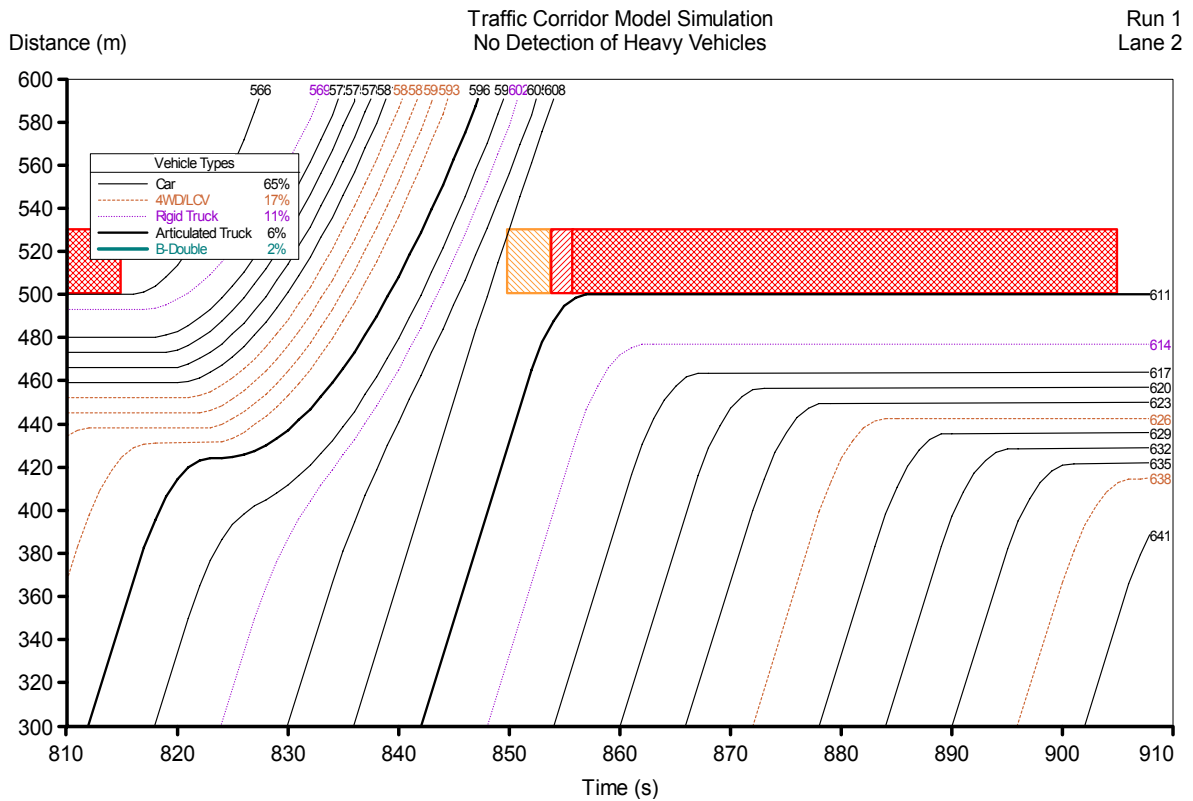


Figure 6 - Heavy vehicle (#611) arriving at the front of a queue

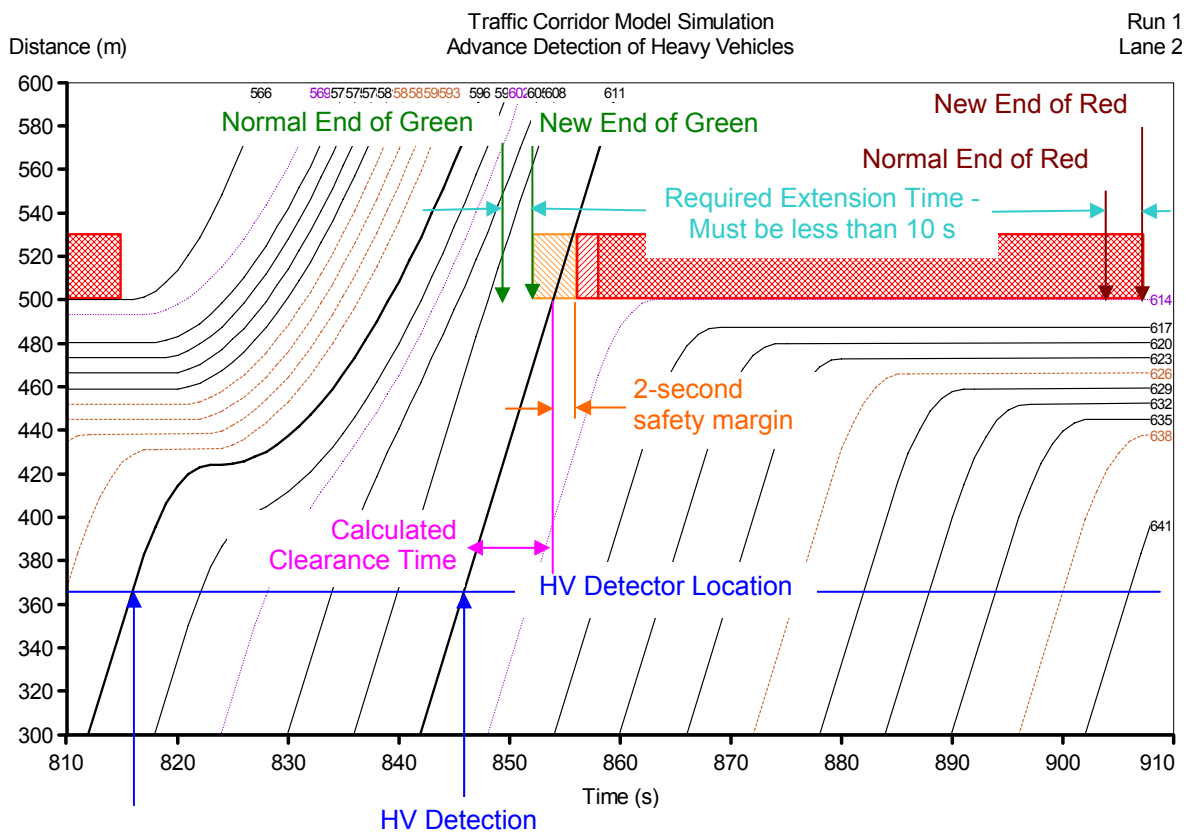
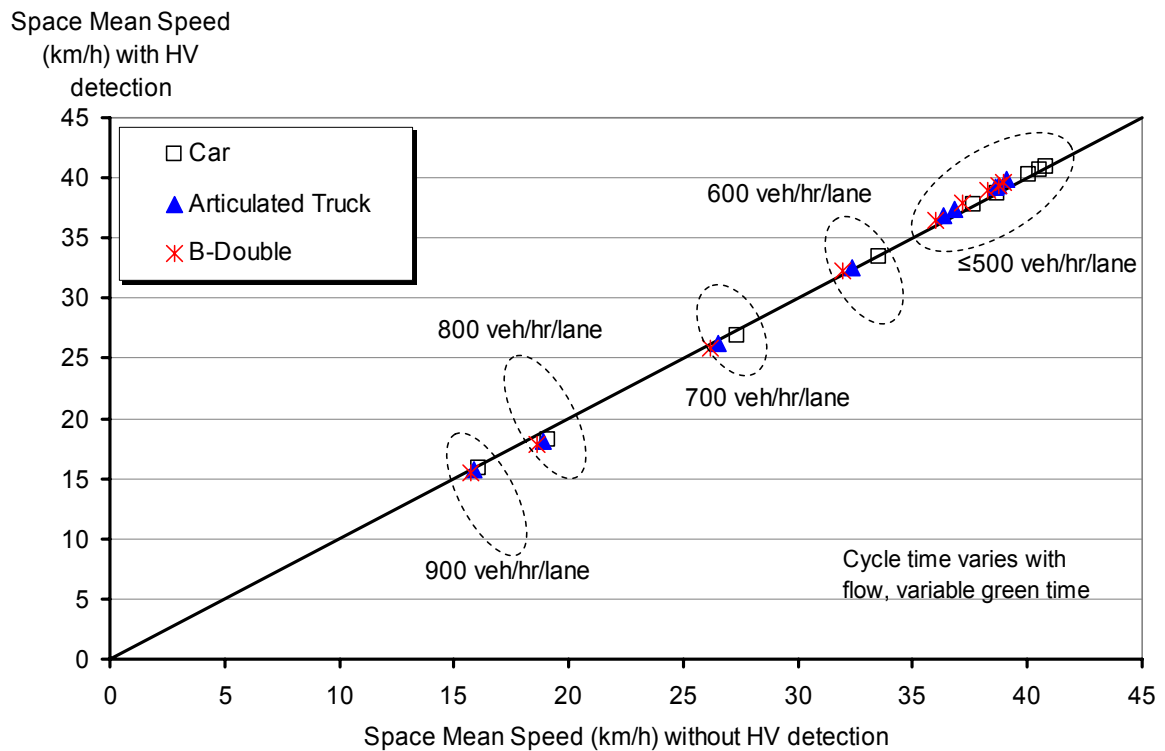


Figure 7 - Detection of heavy vehicle and extending the green period

To test the effectiveness of heavy vehicle detection and green time extension, a number of simulations were conducted with and without the detection enabled.

The proportion of articulated trucks at the front of the intersection queues decreased from 6.6% to 5.7%, and the proportion of B-doubles from 2.0% to 1.6%. It was not possible to completely eliminate heavy vehicles from the front of the queues, since some required more than the maximum 10 seconds green time extension, some were following other heavy vehicles which had already used the green time extension, and some were impeded by other vehicles and had to stop at the intersection.

This reduction in heavy vehicles at the front of the intersection queues had a beneficial effect at low traffic flows ( $\leq 500$  vehicles per hour per lane) for all vehicle types. Figure 8 shows the speeds of various vehicle types at different arrival flow rates. Symbols above the diagonal line correspond to the space mean speed for that vehicle type being faster with heavy vehicle detection enabled. There may be some disadvantages in using heavy vehicle detection at higher arrival flows – possibly due to the shorter green time being available for the subsequent cycle.



**Figure 8 – Speeds of various vehicle types with and without HV Detection**

Although the simulation model does not explicitly model opposing traffic movements, the average green time allocated to the main corridor through movement did not change significantly when detection was enabled. Thus, a similar amount of green time would be available for opposing traffic movements whether detection was enabled or not.

## 6. CONCLUSIONS

A model has been developed to predict the traffic-related effects of large freight vehicles in an urban arterial traffic corridor. Some benefits can be achieved by implementing appropriate freight policy and traffic management options, such as active detection of heavy vehicles. In addition to explicitly setting out to keep freight moving through an urban road network, overall gains in traffic efficiency may be realised through the reduction of moving bottlenecks on the network.

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