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PASSENGER CAR EQUIVALENCE SHOWS HIGHER EFFICIENCY FROM B-DOUBLES THAN SEMI-TRAILERS ON AN URBAN MOTORWAY

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KEYWORDS

Multi-combination vehicle (MCVs), B-Doubles, Semi-Trailers, Passenger Car Equivalence (PCE), Following Behaviour

ABSTRACT

Multi-combination vehicles (MCVs) in urban areas are known to impact on productivity, safety, infrastructure wear, congestion and the environment. As the size of the heavy vehicle fleet is growing (ABS 1972-2001), it can be assumed that freight operators are experiencing greater efficiency in larger vehicles. How do these larger vehicles influence road capacity, the number of movements required and ultimately the operating characteristics of roads?

A testing program was undertaken to observe passenger car behaviour around MCVs in a longitudinal sense. Video footage was collected on a four lane divided mainline motorway section that provides access to the Port of Brisbane, Australia. This section was level, straight and away from ramp junctions. It experiences high traffic volumes with a one-way AADT of approximately 33,500. The percentage of class 4 heavy vehicles, which includes semi-trailers and B-Doubles, is 6.7%. The route is currently designated for B-doubles, which is the most common MCV in Australian urban areas.

The research showed for the facility and conditions tested that even though the passenger car equivalent (PCE) is 15% higher for a B-double than a prime mover semi-trailer combination, B-doubles are still more road efficient as they carry more freight.

A better appreciation of PCEs of these vehicles would aid road authorities in quantifying the longitudinal behavioural impacts.

INTRODUCTION

Multi-Combination Vehicles (MCVs) have accessed rural and remote areas for some time, however there is an increasing pressure to allow operators to access a higher proportion of urban roads, as the origin, or more commonly the destination, lies within the urban area.

Government authorities responsible for assessing routes and issuing permits require information regarding impacts and productivity gains before access can be authorised. This paper focuses on the impact on traffic capacity of the most common urban MCV, the B-double.

AIM

The aim of this study was to determine the most efficient heavy vehicle on an uncongested, straight and level urban motorway mainline section in terms of longitudinal temporal requirements within a lane.

Objectives

The objectives were as follows:

1. Determine a suitable method to calculate PCE factors for individual heavy vehicle types.
2. Identify PCE factors for semi-trailers and B-doubles.
3. Compare the number of passenger cars equivalents required to transport a given freight task using each of these two heavy vehicles.

DEFINITIONS

Vehicle Pair: For this longitudinal study, a vehicle pair is considered as two successive vehicles in the same lane.

Vehicle Convoy: The phrase ‘vehicle convoy’ is used to describe three successive vehicles in the same lane.

The Rear-to-Rear Headway is the time between the rear of vehicle 1 passing a certain point on the road and the rear of vehicle 2 passing that same point. Figure 1 shows the rear-to-rear headway in the right lane (median lane). It is noted that the average headway is the inverse of traffic flow rate.

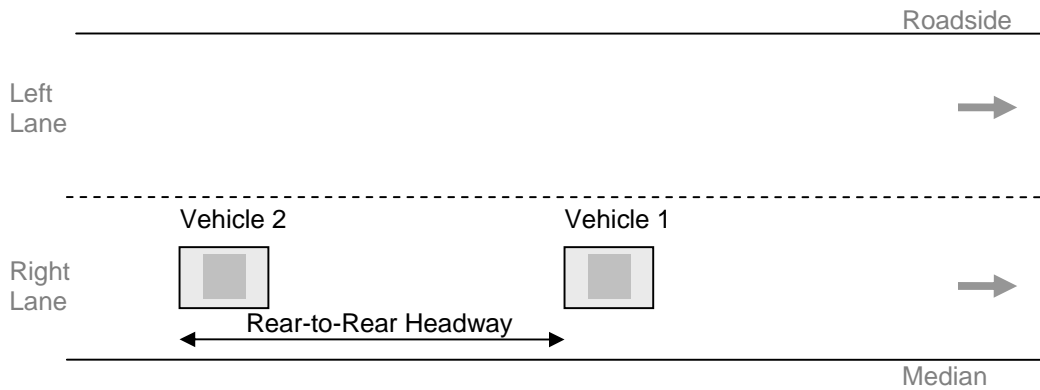


Figure 1: Headway Illustration: Includes time for vehicle length

The passenger car equivalent (PCE) is used to compensate design traffic volumes for the presence of inferior performing vehicles such as heavy vehicles, which require more road time. The US Highway Capacity Manual (HCM) (Transportation Research Board 2000) defines a passenger car equivalent as ‘*the number of passenger cars that are displaced by a single heavy vehicle...*’ The PCE calculation is explored in the following section.

THEORY

The HCM uses a heavy vehicle factor (f_{HV}) to increase the observed traffic volume to an equivalent number of passenger cars (Equation 1).

$$v = \frac{V}{f_{HV}} \tag{Equation 1}$$

where

$$f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)} \text{ (Transportation Research Board 2000)}$$

where

v = Equivalent volume (Flow Rate) of passenger cars (pc/h/ln)

V = Total volume (Flow Rate) of mixed traffic (veh/h/ln)

f_{HV} = Heavy vehicle adjustment factor

P_T, P_R = Proportion of trucks and recreational vehicles respectively

E_T, E_R = PCE factors for trucks and recreational vehicles respectively

Equation 1 considers trucks and recreational vehicles; however, this equation may be generalised for any number of vehicles types. Further, any equations derived from Equation 1 may also be generalised for any number of vehicle types. Equation 2 represents a generalised form of Equation 1.

$$f_{HV} = \frac{1}{1 + P_1(E_1 - 1) + P_2(E_2 - 1) + P_3(E_3 - 1) + \dots + P_n(E_n - 1)} \quad \text{Equation 2}$$

where

$P_1, P_2, P_3, \dots, P_n$ = Proportion of vehicles in each class

$E_1, E_2, E_3, \dots, E_n$ = PCE factors for vehicles in each class

Herein, the derivation will consider two vehicle types including passenger cars (PC) and the subject heavy vehicle (HV). Substituting Equation 2 into Equation 1 yields:

$$v = \frac{V}{1/[1 + P_{PC}(E_{PC} - 1) + P_{HV}(E_{HV} - 1)]}$$

Given that $V_{PC} = VP_{PC}$, $V_{HV} = VP_{HV}$ and $V = V_{PC} + V_{HV}$, it may be demonstrated that:

$$v = V_{PC}E_{PC} + V_{HV}E_{HV} \quad \text{Equation 3}$$

where

V_{PC}, V_{HV} = Volume of passenger cars & subject heavy vehicle respectively.

The final equation suggests that the PCE factor for a particular vehicle type may be multiplied by the volume of that vehicle type in a stream of vehicles. This equation adds the theoretical volume effect of passenger cars to the theoretical volume effect of heavy vehicles, to reach the volume of equivalent passenger cars. Again, this equation may be generalised to reflect additional vehicle types.

Methods to Determine PCEs

This study is concerned with calculation of the PCE factors (E_{PC}, E_{HV}) within a lane for a mainline segment. They will be calculated here by considering the vehicle length and headways before and after the subject vehicle. Other methods for calculating PCE are discussed in 'A Review of the Impacts of Large Freight Vehicles on Urban Traffic Networks' (Ramsay and Bunker 2003).

This method calculates PCE using a convoy of three vehicles (PC: HV: PC). The PCE is approximated by considering the headways between heavy vehicles and passenger cars. It does not consider the effect of multiple heavy vehicles arriving consecutively, which is a limitation that shall be explored in future research.

Consider the vehicle types in the traffic lane Figure 2a) to be mixed randomly. Focusing on headways between convoys of PC: HV: PC, all other headways are disregarded. The traffic sub-stream extracted from the original stream as shown in Figure 2b) reflects only the headways contributing to the vehicle convoys in question. These sub-streams may be compiled to form continuous vehicle convoys (Figure 2c), which may be used to estimate PCE.

The traffic stream in Figure 2c) extends for m vehicles and the total time needed for the sub-stream C to pass is equal to time T .

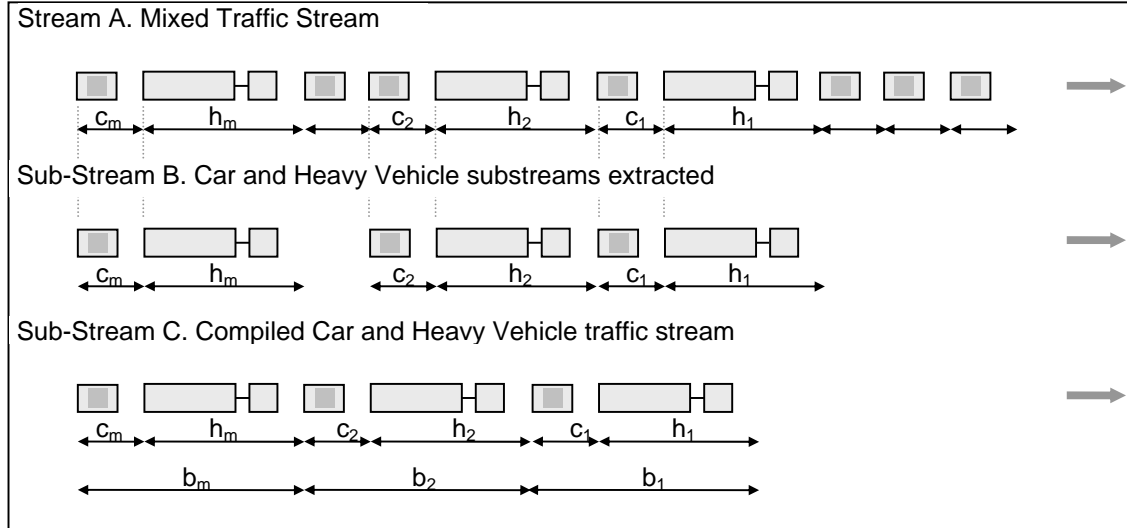


Figure 2: Method of rearranging mixed traffic streams to extract convoys of three vehicles

From Figure 2, it follows that:

$$b_i = c_i + h_i \tag{Equation 4}$$

where

c_i = passenger car headway behind leading heavy vehicle

h_i = heavy vehicle headway behind leading passenger car

b_i = total rear-to-rear headway of passenger car: heavy vehicle: passenger car convoy

The mean of the convoy headway \bar{b} from the entire sample of m convoys may be defined as follows:

$$\bar{b} = \frac{\sum_{i=1}^m b}{m} = \frac{\sum_{i=1}^m c + \sum_{i=1}^m h}{m} \tag{Equation 5}$$

The total duration T of the rearranged convoy stream may be defined as follows:

$$T = \sum_{i=1}^m b = \sum_{i=1}^m c + \sum_{i=1}^m h = m\bar{b} = m(\bar{c} + \bar{h}) \tag{Equation 6}$$

While these equations focus on the headways between heavy vehicles and passenger cars, it is possible to assign a theoretical zone of passage for each vehicle. Notionally, the zone used by each vehicle to pass a roadside point consists of part of the headway before the

vehicle, the time taken for the vehicle body to pass, and part of the headway after the vehicle.

It follows that the total duration T alternatively consists of the summation of a notional time for the passage of all the passenger cars a , plus the summation a notional time for the passage of all the heavy vehicles t . This equation is similar to Equation 3 for the convoy set under consideration.

$$T = \sum_{i=1}^m a + \sum_{i=1}^m t = m(\bar{a} + \bar{t}) \tag{Equation 7}$$

where

a = notional time of passage of a passenger car

t = notional time of passage of a subject heavy vehicle

Substitution and rearrangement of Equation 6 and Equation 7 yields:

$$E_{HV} = \frac{\bar{t}}{\bar{a}} = \frac{\bar{b} - \bar{a}}{\bar{a}} \tag{Equation 8}$$

where

E_{HV} = Passenger car Equivalent for the subject heavy vehicle

In Equation 8, it has been assumed from the definition of PCE (E_{HV}) from the HCM that the PCE of a particular heavy vehicle equals the ratio of a notional passage of a heavy vehicle to a notional passage of a passenger car.

Krammes and Crowley (1986) considered independent vehicle pairs rather than vehicle convoys. They considered the headway between HV: PC (c) and PC: HV (h) to yield a larger sample size. Refer to Figure 3.

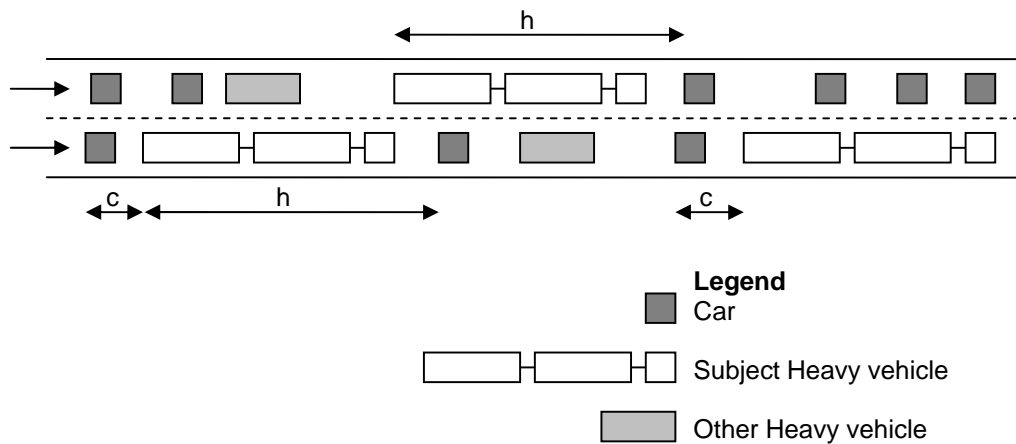


Figure 3: Rear-to-rear headway measurements for Final PCE calculation (c & h)

While the concept of the vehicle convoy is implied, the increased sample size improves the statistical reliability. Equation 8 was modified to produce Equation 9 accordingly.

$$E_{HV} = \frac{(\bar{c} + \bar{h} - \bar{a})}{\bar{a}} \quad \text{Equation 9}$$

The factor a (notional effect of a passenger car) may be estimated as the measured headway between two consecutive passenger cars. Essentially, this imagines the notional zone of influence around the passenger car to be shifted to align with the rear bumpers of the passenger car pair, which is directly measurable.

The mean of all headway values may be taken over the entire sample under LOS E operation to determine the PCE for the subject heavy vehicle class in uncongested flow conditions tending towards capacity.

It is noted that this approach excludes headways between successive heavy vehicles, which is a consideration that shall be made in future research. Further, between-lane effects when subject vehicles are travelling alongside heavy vehicles in an adjacent lane are implied in the data, but not explicitly addressed at this stage.

DATA COLLECTION

A manual data collection process called screen superimposition was adopted. This section documents the methods, testing program, sample size and error minimisation.

Method

A video camera was placed on the pedestrian walkway of an overpass over the subject motorway mainline segment. Video footage was recorded and analysed digitally using a program that allows frame-by-frame analysis. Traffic data was measured by drawing a scale on an overhead transparency sheet and overlaying it on the computer screen while the video was playing (Figure 4).



Figure 4: Computer Setup for data processing: Scale drawn on clear plastic overlay

The video footage was viewed with the intention of capturing the information for the testing. Four pieces of information were collected from each vehicle that passed:

1. **Time of front of vehicle crossing the reference line:** As the front of the vehicle passed over the reference line, the frame number (time) was noted (Figure 5a).
2. **Time of rear of vehicle crossing the reference line:** Similarly, several frames later, the frame number was noted as the rear of the vehicle passed over the reference line (Figure 5b).
3. **Vehicle Classification:** Vehicles were visually classified into 13 classes according to their length, connection type and height. Only passenger cars, semi-trailers and B-doubles were considered further.
4. **Five minute volumes of passing traffic.**



Figure 5: Screen capture as the a) front of the vehicle crosses the reference line b) rear of the vehicle crosses the reference line

Testing Program

The data collection process was firstly trialled and then refined in a pilot testing program. The pilot footage was recorded in off peak conditions and it was found that due to the lower volumes, it was not common for vehicles to be travelling at the minimum headway. Subsequent testing was undertaken during heavy flow conditions at peak periods, but not during congestion.

The final data collection was undertaken in mid December 2003. Refer to Table 1. The data from all four test intervals was combined to form one sample for the analysis. Only data drawn from footage of Level of Service (LOS) E conditions, according to the HCM methodology, was used.

Table 1: Record of data collection dates and times

Test	Date/ Time	Interval Duration	Interval Volume (veh)	Flow Rate (veh/h/ln)	Congestion & Level of Service *	Comments
Pilot	22/9/03 Mon Noon	1min 41s	75	1337	Nil LOS C	
1	16/12/03 Tues 17:14	61min 18s	2931	1434	Nil LOS C	By 5:30pm, heavy vehicle volumes were diminished.
2	17/12/03	45min	3012	1974	Moderate	By 8:30am, high volumes

	Wed 07:37	47s			LOS E	had dissipated.
3	18/12/03 Thurs 07:37	50min 32s	3239	1923	Moderate LOS E	At 8:10am, accident noticed 200m upstream. Survey was abandoned.
4	19/12/03 Fri 07:18	62min 13s	3908	1884	Nil LOS E	

*(Transportation Research Board 2000)

Sample Sizes

Even though approximately four hours of footage was collected, the sample size was small due to the large amount of data processing required. Each minute of video footage collected required one hour of manual data processing.

As the heavy vehicle of most interest is the B-double, the data was collected on B-doubles and the vehicles immediately surrounding the B-doubles. Therefore, data collection commenced at the vehicle ahead of every B-double (in the same lane) and ceased at the vehicle following the B-double (in the same lane) (Figure 6). Volume information was collected on all vehicles.

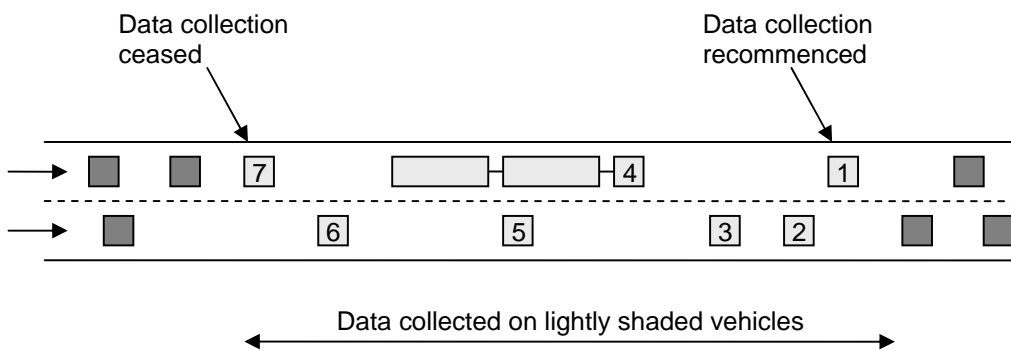


Figure 6: Data collected between vehicle preceding B-double and following B-double

However, data was collected on every vehicle during the initial 20 minutes of the Wednesday time interval (Table 1), to provide an aggregate sample stream to determine an approximate percentage of heavy vehicles. This information was also used in understanding how cars are positioned around vehicles other than B-doubles, for example semi-trailers and other passenger cars. Refer to Lennie and Bunker (2004; 2005).

Testing Location Selection

Following the development of a data collection method, a test location was chosen to satisfy the objectives and the requirements of data collection.

Video footage was collected on the Gateway Motorway, which is a four lane divided urban motorway section that provides access to the Port of Brisbane and Australia Trade Coast enterprise zone. It has two 3.5m lanes in each direction and 2m sealed shoulders. This section was level, straight and away from ramp junctions. It experiences high traffic volumes with a one-way AADT of approximately 33,500. The route is currently designated for B-doubles, which is the most common MCV in urban areas.

Sources of Error: Identification and Minimisation

- **Frame Capture Rate:** Errors are introduced by the PAL (Phase Alternation Lines) video capture rate of 25 frames per second. Its effect was minimised by allowing each vehicle to pass over the reference line by one frame.
- **Perspective:** Representing a 3D space on a 2D surface (computer screen) introduces a perspective problem called parallax phenomenon. In this test, the error occurred due to varying heights of vehicles. This error was resolved by making the reference point the underside of the vehicle body.
- **Human Error:** Manual data processing was undertaken at a slow pace for short durations.
- **Occlusion:** Occlusion occurs when one vehicle obstructs the view of another. This was minimised by placing the camera high above the carriageway centreline. Human judgment was used to judge event times when occlusion occurred.
- **Vehicles Changing Lanes:** Vehicles changing lanes were excluded from the PCE calculations; however, they were included in the volume calculations.

RESULTS

The data was separated into lanes and arranged into the appropriate vehicle pairs for use in Equation 9. It should be noted that only LOS E conditions were considered as PCE is intended for capacity calculations.

Sample Size

Data was collected on 2244 vehicles, of which 989 vehicles arrived in the left lane and 1255 vehicles arrived in the right. Of the 2244 vehicles, 1603 vehicles arrived in the longitudinal vehicle pairs described earlier, where the lagging vehicle was a passenger car, regardless of the size of time gap. Refer to Figure 7.

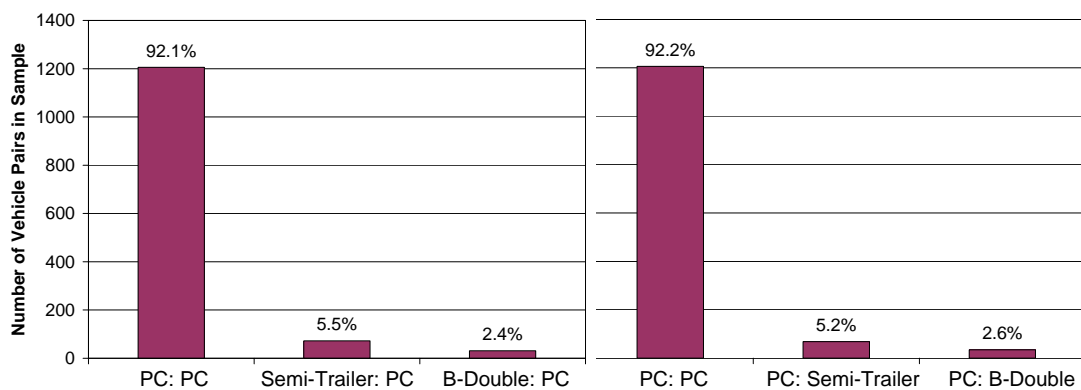


Figure 7: Sample sizes of vehicle pairs (by category): a) Factor c_i b) Factor h_i

PCE for Semi-Trailers and B-Doubles

The factor c_i used in the PCE calculation represents the passenger car headway behind the subject vehicle. It should be noted that passenger cars are also included as subject vehicles, since it is useful to determine the passenger car PCE in each lane. Table 2 presents the means, standard deviations and sample sizes.

Table 2: Statistics for passenger car headway lagging the subject vehicle (c_i) in seconds

Statistic	Passenger Car			Semi-Trailer			B-double		
	Left	Right	Both	Left	Right	Both	Left	Right	Both
Mean (s)	1.66	1.39	1.48	1.8	1.31	1.64	1.79	1.51	1.71
Standard Deviation (s)	0.61	0.61	0.62	0.77	0.64	0.76	0.55	0.55	0.55
Sample Size	397	809	1206	49	23	72	22	9*	31

* Small Sample Size

The factor h_i used in the PCE calculation represents the subject vehicle headway behind a passenger car. Statistical measures are presented Table 3.

Table 3: Statistics for the subject vehicle's headway lagging a passenger car (h_i) in seconds

Statistic	Passenger Car			Semi-Trailer			B-double		
	Left	Right	Both	Left	Right	Both	Left	Right	Both
Mean (s)	1.66	1.39	1.48	3.17	2.27	2.85	3.47	2.14	3.16
Standard Deviation (s)	0.61	0.61	0.62	1.14	0.84	1.13	1.26	0.25	1.25
Sample Size	397	809	1206	44	24	68	26	8*	34

Initial observations are that:

- the mean \bar{c} and \bar{h} both increase as subject vehicle size increases.
- the values are smaller in the right lane.

The mean PC: PC headway (\bar{a}) for the entire sample was 1.48 seconds and the standard deviation was 0.62 seconds.

The PCE factors were determined according to Equation 9. Refer to Table 4.

Table 4: PCE factors for three vehicles in left, right and both lanes for the facility tested at LOS E

Subject Vehicle	Left Lane	Right Lane	Both Lanes
Passenger Car	1.25	0.88	1.00
Semi-Trailer	2.37	1.42	2.04
B-double	2.56	1.47	2.30

Initial observations are that

- Consistent with the c and h variables increasing with vehicle size, the PCE factors also display this relationship. This increase in PCE with vehicle size is at least partly due to the increased vehicle length.
- Right lane PCEs are smaller than left lane PCEs. This includes the PCE for a passenger car in the right and left lane, which is consistent with values of \bar{c} and \bar{h} .

Since the standard deviations for c and h were quite large, the PCE standard deviation will also be relatively large, reflecting variation in driver behaviour and vehicle size, and the minor amount of unused road-space under LOS E conditions.

The HCM, which is widely used in Australia for motorway capacity analysis, assigns a PCE value of 1.5 for trucks and buses travelling on level terrain, which is the terrain type for the study location. It is noted that the HCM methodology implies PCE to be constant across all LOS ranges. This analysis is concerned with the LOS E range, which is critical in terms of operation prior to the brink of congestion and the associated LOS F range, and hence capacity estimation. However, future research to investigate whether PCE varies with LOS range may be useful.

The HCM methodology also considers PCE constant across all lanes. This research has established that PCE does vary with lane at the location studied. The HCM value of PCE is implied to be an average across lanes, which may be satisfactory for capacity analysis, but does not provide the further insight of this paper into differences in behaviour of traffic between lanes.

The constant PCE value for trucks and buses on level terrain may be appropriate considering that this includes rigid trucks, buses and articulated trucks; however for the facility type under the conditions tested, a more refined capacity estimate could be obtained by assigning individual PCE factors to each class of heavy vehicle. PCE factors determined in this paper may also contribute further to the understanding of the variation in traffic impact across the heavy vehicle spectrum. PCE factors for rigid trucks and buses may also be determined by extending the technique described herein.

PCE factor per Tonne of Freight

Haldane and Bunker (2002) showed that, even though the larger MCVs have lower acceleration rates and initiate more delay at intersections, they are still more traffic-efficient due to their increased payload. This has been investigated further in this study.

The average payload for B-doubles and semi-trailers was sourced from the Heavy Vehicle Management Division of Queensland Department of Main Roads (Cranitch and Newton 2004) from a weigh in motion (WIM) site located on the southbound carriageway of the Gateway Motorway at Toombul (Figure 8). This WIM site lies approximately 10km north of the Belmont test section. Significant proportions of heavy vehicle traffic enter and leave the Gateway Motorway between the Toombul and Belmont to visit the Port of Brisbane, however, the average payloads in both cases are bound for the port and Australia Trade Coast so the use of data from this WIM site is considered to be representative.

Other details from the payload statistics are listed below:

- Average payload is calculated on laden and unladen vehicles.
- Classification of vehicles was achieved using the configuration of the vehicle rather than the length. Therefore, the average payload for B-doubles will include measurements from 19m, 23m and 25m B-doubles. This bias is expected to cause some under estimation of the B-double payload.
- Payload data was collected over one year between July 2002 and June 2003. Approximately 300,000 semi-trailers and B-doubles were counted.

- The average payload is calculated by assigning an average tare mass to each class of vehicle. This tare mass is then subtracted from the gross combination mass (GCM) to yield the payload. This is then averaged for all vehicles in each class.

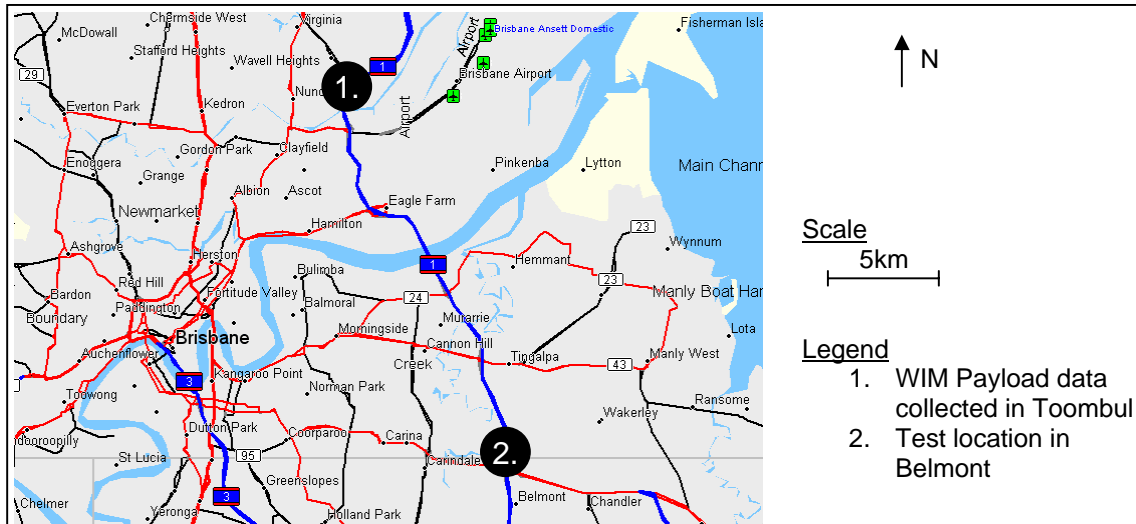


Figure 8: Map of eastern Brisbane showing test location and WIM site

Table 5 shows that for the facility and conditions tested, even though the B-Double PCE is larger than the semi-trailer PCE, the B-Double is still more efficient in traffic capacity terms by about 35 percent.

Table 5: Vehicle traffic-efficiency comparison using PCE and payload under conditions examined

Vehicle	PCE	Payload (t)	Traffic Efficiency (Payload t/ PCE)
Passenger Car	1	0.5	0.5
Semi-Trailer	2.0	12.32	6.16
B-Double	2.3	19.14	8.32

Haldane and Bunker (2002) also provided an example of moving 1,000 tonnes of freight from point A to point B and its effect on the traffic stream using different vehicles. A similar example has been developed using semi-trailers and B-doubles on the straight, level mainline segment under the conditions tested.

Table 6: PCEs required to transport 1000t of freight under conditions examined

Vehicle	Payload (t)	Number of Trips to move 1000t	PCE	Mainline Segment PCEs
Semi-Trailer	12.32	81	2.0	162
B-Double	19.14	52	2.3	120

The table shows that the B-double would use fewer PCEs to transport a given amount of freight. Therefore, even though the passenger car drivers tended to shy away from B-doubles more than semi-trailers longitudinally (Lennie and Bunker 2005) and that their PCE is higher, B-doubles displaced 35% fewer equivalent passenger cars per tonne of freight on this mainline motorway segment under the LOS E conditions studied.

CONCLUSIONS

This paper determined the Passenger Car Equivalence (PCE) within each lane on a straight, level two lane, unidirectional mainline segment of the Gateway Motorway, Brisbane, Australia under LOS E conditions. The HCM approach to PCE was used as the frame of reference for this study. For this facility the following key findings were drawn:

- The PCE increased as vehicle size increased. This was most likely caused by the increased vehicle length and shy distances kept by following passenger car drivers.
- Averaging for both lanes, the PCE factor for a B-Double is 1.15 times larger than PCE factor for a semi-trailer even though the vehicle is 1.2 to 1.3 times longer.
- PCE were approximately 1.5 times larger for all vehicle types examined when travelling in the left (kerbside) lane compared to vehicles travelling in the right (median) lane. This indicates that drivers in the median lane are more aggressive than those in the kerbside lane under LOS E conditions.
- Under level of service E conditions, which are the most critical to appreciate, B-Doubles can be considered to displace 35% fewer equivalent passenger cars per tonne of freight than semi-trailers.

Outcomes for Industry

The main outcome for industry was that B-Doubles were found to be more traffic-efficient freight vehicles for the typical two lane unidirectional mainline segment studied under LOS E conditions. Other issues such as safety and damage to infrastructure also need to be considered in the uptake of B-Doubles across the road freight industry.

Further research shall be undertaken on the effects of consecutive heavy vehicles on PCE, and between-lane effects for vehicles in a lane adjacent to the heavy vehicle.

REFERENCES

- ABS (1972-2001). Survey of motor vehicle use. Canberra, ACT, Australian Bureau of Statistics.
- Cranitch, P. and S. M. Newton (2004). Brisbane Freight. S. Lennie. Brisbane, Queensland Department of Main Roads.
- Haldane, M. and J. Bunker (2002). Examining the Impact of Large Freight Vehicles on Signalised Intersection Operation. 2002 AITPM National Conference: Travelator, Traffic and Transport "On the Move", Perth, Australian Institute of Traffic Planning and Management Inc.
- Krammes, R. A. and K. W. Crowley (1986). "Passenger Car Equivalents for Trucks on Level Freeway Segments." Transportation Research Record, Transportation Research Board, National Research Council, Washington, D. C 1091: 10-16.
- Lennie, S. and J. Bunker (2004). Using Lateral Position Information as a Measure of Driver Behaviour around MCVs. 27th Australasian Transport Research Forum (ATRF), Adelaide, 29 September - 1 October.
- Lennie, S. and J. Bunker (2005). "Following behaviour behind semi-trailers and B-doubles is similar on a motorway section". Submitted to Transport Engineering in Australia, Engineers Australia, Barton, ACT.

- Ramsay, E. and J. Bunker (2003). A Review of the Impacts of Large Freight Vehicles on Urban Traffic Networks. Brisbane, School of Civil Engineering, Queensland University of Technology.
- Transportation Research Board (2000). Highway Capacity Manual. Washington DC, National Academy of Science.