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The collection of classified vehicle counts in an urban area – accuracy issues and results

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1. INTRODUCTION

The Transport Data Centre (TDC) produces base year and forecast estimates of commercial vehicle movements to, from and within the Sydney Greater Metropolitan Region (GMR), through a process called the Commercial Transport Study (CTS). CTS data is the *only* source of information on freight and other commercial travel movements at small area level (‘travel zone’) for the GMR, and thus provides policy makers and transport planners with critical information needed for informed decision making relating to commercial travel.

To produce estimates of small area commercial vehicle trips, TDC developed a commercial vehicle trip estimation procedure that utilises three major data inputs – trip ends, screenline counts and a prior matrix from a previous large-scale Commercial Vehicle Survey. A more detailed discussion of the estimation process is presented in the paper *‘Estimating commercial vehicle travel movements in an urban area: the Commercial Transport* Study’ (Peachman and Mu, 2000).

One known weakness of the current CTS 1996 base year estimates is that the heavy vehicle screenlines were derived mainly using *assumed* proportions of rigid and articulated trucks from annual average daily traffic (AADT) counts. This is due to the lack of actual classified counts on major freight routes because of the difficulty in obtaining accurate counts on roads characterised by high traffic volume, multiple lanes and heavy congestion. To address this problem, TDC conducted a comprehensive Classified Vehicle Count Study in 2002.

2. THE CLASSIFIED VEHICLE COUNT STUDY

2.1 BACKGROUND TO THE STUDY

The Classified Vehicle Count Study was conducted from May 2002 to June 2003 with the aim of obtaining accurate heavy vehicle counts on major freight routes in the Sydney GMR. The study covered 41 major roads.

Although the CTS requires counts based on ‘rigid’ and ‘articulated’ trucks, it was decided that the study would use the Austroads94 vehicle classification system which has 12 vehicle types (Table 1). It was thought that this would provide the most accurate way of determining classification and had the ancillary benefit of providing additional information about road usage by individual class.

The Centre for Excellence Pty. Ltd. (CFE) was contracted to undertake the pneumatic tube counts and used QTC 4 Tube 4 Million Event counters exclusively.

Table 1. Austroads94 Vehicle Classification Scheme

Class	Description	Class	Description
1	Short (Car, van, wagon, 4WD, Utility, Bicycle, Motorcycle)	7	Four axle articulated (4 axles, 3-4 groups)
2	Short - Towing (Trailer, Caravan, Boat)	8	Five axle articulated (5 axles, 3-5 groups)
3	Two axle truck or bus (2 axles)	9	Six axle articulated (6 axles, 3-6 groups, 7+ axles, 3 groups)
4	Three axle truck or bus (3 axles, 2 groups)	10	B Double (7+ axles, 4 groups)
5	Four axle truck (4 axles, 2 groups)	11	Double Road Train (7+ axles, 5 or 6 groups)
6	Three axle articulated (3 axles, 3 groups)	12	Triple Road Train (7+ axles, 7+ groups)

2.2 TRAFFIC COUNTING DEVICE

There are a number of traffic counting devices that may be used to obtain classification counts. Conventional devices, such as inductive loops, pneumatic tubes, and magnetic sensors, are devices installed directly on the road pavement surface. There are also new technologies such as infrared (passive and active), radar, Doppler microwave, pulse ultrasonic, passive acoustic and video detection sensors. In this study, these less conventional devices were not considered because they are not able to classify using axle sensors, and therefore, are not able to obtain counts by Austroads94 vehicle classes.

Inductive loops, magnetic sensors and pneumatic tubes obtain classified counts using axle patterns and were, therefore, appropriate for this study. However, Inductive loops and magnetic sensors were not considered because they require pavement cut which was not practical for such short duration studies at a multitude of sites.

Pneumatic tube was considered the most practical device for this study. However, historically, pneumatic tubes were considered inaccurate in classification over two lanes in medium to high volume traffic (ATAC, 2000). The problem facing TDC was that the majority of the sites included in the study were multi-lane, of high volume and high commercial traffic. TDC decided to proceed with pneumatic tubes, to assess the level of inaccuracy and attempt to find ways to overcome them, either by developing adjustment factors that can be applied to the tube counts to increase accuracy or if, feasible, by changes to the counting procedures (eg. tube layout, software algorithms).

2.3 THE COUNTING PROCEDURE

Pneumatic tube counter

For this study CFE used the QTC 4 Tube 4 Million Event Counter because it had a sufficient number of QTC counters required for the scale of this project. Moreover, this counter is particularly suitable for multi-lane roads because it is a four tube counter, thus allowing the use of one counter for two lanes of traffic, together with the ability to segregate the traffic into lanes.

The QTC counter also has post-processing software which allows for more in-depth analysis of counts and has the advantage of being able to re-process the count data if changes to the software are made to improve accuracy.

Comprehensive pilot tests

Prior to the main study, CFE conducted various tests to ensure that the main study counting method would result in the most accurate data possible given the time frame for the study. A pre-pilot was first conducted covering two sites to test the feasibility of using a manual counting method to validate the tube counts. Then, a pilot test of four sites was undertaken, testing the use of a three-tube configuration and comparing the results with the manual counts. Finally, a second pilot test was conducted on four of the pre-test and first pilot test sites, this time using a revised three-tube configuration and video validation so that the reasons for count discrepancies could be more fully understood.

The sites chosen for these various tests were those with differing traffic characteristics so that the study was able to capture different inaccuracy scenarios. The sites included Great Western Highway (main link to west of Sydney), Wentworth Avenue (secondary road, close to a major seaport), Lane Cove Road (large volume of light vehicles), Newbridge Road (link to large industrial areas, heavy trucks), Pennant Hills Road (link to north of Sydney, medium trucks), and Victoria Rd/Iron Cove Bridge (link to Sydney CBD, large volume of light vehicles).

In addition to the tests undertaken for this study, CFE also drew on other validation tests they conducted for other projects during the period of this study. These additional tests were for Foreshore Road (main link to Sydney's major seaport), Epping Road (secondary link to west of Sydney), Mowbray Road (congested traffic), and Military Rd (Cremorne).

Video audits

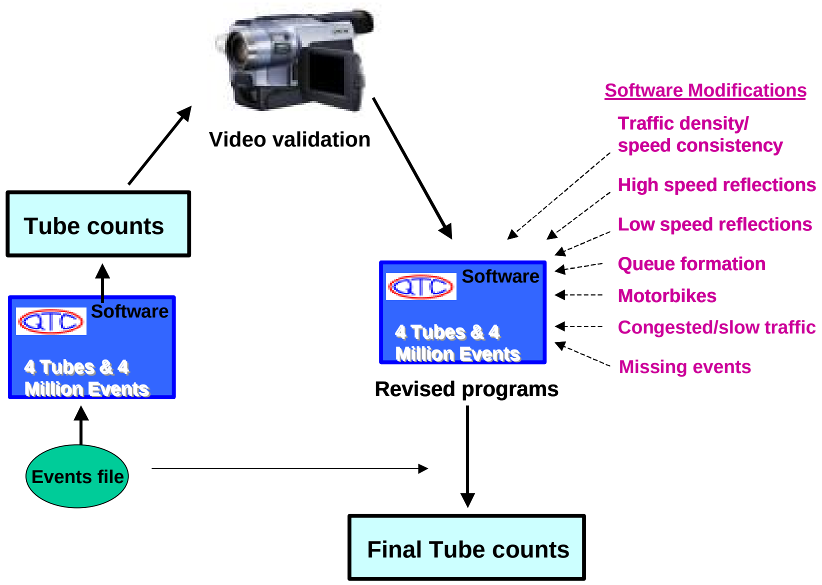
During the pilot studies to address the issue of counter inaccuracy at high volumes on multilane roads, CFE videotaped a two hour peak period at each site in either the morning or afternoon peak, whichever was higher. Every vehicle shown on the videotape was audited against a classified vehicle report produced from the pneumatic tube counter. The results were analysed to determine the causes of the inaccuracies found during the audit. CFE undertook to correct any inaccuracies found in the classification software (Figure 1) until it produced a result that satisfied the accuracy requirements of TDC. *As a result of this process, CFE was able to enhance the software so that significantly more accurate classified counts could be produced from the use of pneumatic tubes than was possible prior to this study*. Details of this enhancement are given in Section 3. The final results of the Classified Vehicle Count Study using this enhanced process are shown in Section 4.

3. INCREASING THE ACCURACY OF PNEUMATIC TUBE CLASSIFICATION COUNTS

3.1 ACCURACY LEVELS

At the start of the project, TDC had concerns with the accuracy of pneumatic tube counts taken over multiple lanes on main roads. The concerns were heightened because the majority of sites to be surveyed were two lane or three lane roads where multilane counting techniques were to be used. Multilane counting with two tubes had proved substantially inaccurate in the past (ATAC 2000) and there were no readily available studies to show the accuracy of multilane counts using four tubes.

Figure 1. How the final tube counts were obtained



In an attempt to overcome the existing problems with producing accurate classified vehicle counts from tube data, CFE firstly compared raw tube data with video data to determine the main scenarios that were producing inaccuracies. It then developed changes to general practice at that stage - in tube placement and in a reinterpretation of how tube data could be used - to produce software that was able to largely resolve the problems for these scenarios. More detail of this process is given later, but CFE's main changes to general practice were:

1. Use of a four-tube layout with four metre spacings for multi-lanes, and
2. The *deliberate* induction of reflections* to aid in classification by blocking the non-counter end of the tubes.

* 'Reflections' are tube events recorded by the counter that are caused by air pulses reflected back onto the air switches after the main air pulse is recorded. They have usually been regarded as a problematic side effect with tube counts, rather than an opportunity for analysis of events.

3.2 ACCURACY ISSUES OVERCOME

The following are the specific accuracy issues found during the video tests which were addressed in the study.

3.2.1 Congested Traffic / Stopped Vehicles

During several of the pilot audits, CFE identified situations in highly queued traffic that arose when a vehicle stopped after the first axle passed the lead tube and the final axle did not pass the tail tube, that is, the vehicle straddled both of the tubes (O__o_o__O). At the time, the tube spacing was one metre and the frequency of this occurrence was high. *It occurred to CFE that a change in tube spacing from one metre to four metres would change the pattern of recorded events and enable the stopped time of the vehicle to be estimated*. By increasing the tube spacing in such a way, a vehicle cannot stop straddled over both of the tubes but must stop within the tubes (o_O__O_o), or stop with one axle, either the first axle or the second axle, between the tubes (_o__O__o__O_). Although it is possible for long vehicles to straddle the tubes, during the peak they are generally less than 10% of the volume and so probabilistically 90% of the vehicles during the peak cannot stop over a four-metre spacing. Once these conditions are forced, it is possible to determine a stopped vehicle and the approximate stopped time, allowing the calculation of the number of queues formed and the queue cycle time to be estimated.

A four metre tube spacing has additional benefits, such as the increased accuracy of the speed and axle spacing calculations (due to the decrease in the significance of any error in tube length or tube spacing). In addition, if a queue forms in both lanes of a multilane unidirectional count and a hidden axle occurs (say with the first axle on the lead tube and both vehicles then stop), when they accelerate and the queue disperses, they will do so at different times and at different accelerations. An increased spacing means that after four metres the difference in speeds and therefore front axle positions will be more than had the spacing been one metre. This decreases the possibility that the front axle will produce a hidden event on the tail tube, or the second axle will produce a hidden event on either the lead or tail tubes.

Although there are benefits to the use of a four-metre spacing, it is not recommended that tubes be spaced at four metres in a queued environment *unless* the classification software is specifically written to accommodate stopped time, as was the case for this study.

The issue resulting from a stopped vehicle straddling the tubes in a single lane, two tube configuration with one metre tube space is that the counter software may not wait long enough to associate the subsequent corresponding axle events correctly. In a multilane environment with a two tube configuration, the counter may register events from other lanes which likewise confuses the classification software. In each of these cases the software is likely to separate these two axles, discarding the first and associating the second with the next vehicle (depending on the relative speeds of the current vehicle's last axle and the next vehicle's first axle). The consequence of this is the generation of a class 2 or class 6 vehicle from the following vehicle and the loss of the first vehicle. Other misclassifications are possible but less probable.

Upon modification of the software to accommodate a four-metre tube spacing and stopped traffic, the software achieved greater accuracy in multilane highly queued traffic. The modified software is capable of correctly associating axles of a vehicle stopped over the tubes for 5 minutes or less. Longer stopped times are possible but impact on the performance of the software.

3.2.2 Traffic Density / Hidden events

During the audit of the Great Western Highway, it was found that the multilane count was significantly affected by 'Hidden Axles' in a particular characteristic of traffic that is not overly common. Hidden Axles cause misclassification and an overall reduction in volume and affect the accuracy of all multilane counts, whether using four tubes or two tubes across two lanes, in a bidirectional or unidirectional configuration.

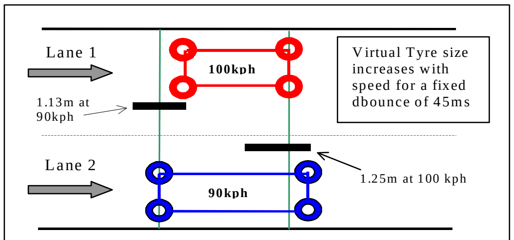
Axles are hidden to the counter when the axles of two vehicles are on one tube at the same time, or within the dbounce time, thereby hiding one or more tube events from the second vehicle to impact the tubes ('dbounce', which is commonly used as a response to the problem of reflections, is the amount of time within which the datalogger will not record an event from a tube sensor after the recording of an event on that tube). The higher the traffic volume, the higher is the potential for Hidden

Axles. However, the closer the vehicles are together (longitudinally) and the closer they are in velocity, the greater is the amount of time that the vehicles' axles (either front or rear) are aligned (laterally), and the higher is the probability that they will impact the tubes simultaneously or within the dbounce time.

Dbounce settings are particularly important in influencing the probability of hidden events. A dbounce of 45 milliseconds will produce a blind spot in the counter which at 70 Kph is 87.5 cm, at 80 Kph is 1m and at 90 km is 1.125m and so on. This means that the relative footprint or virtual tyre size of the tyre increases from around 0.275 cm to 1.375m at 110 Kph. The larger the virtual footprint of the tyre the more likely that two axles will be within that longitudinal space at the same time. At low speeds the virtual tyre footprint is less, being 40 cm at 40 kph. It is important in multilane counts to reduce the dbounce setting as the speed of the traffic increases.

Figure 2. Missed axles

Speed of Vehicle		Blind Spot in metres	
Kph	mps	45ms	35ms
110	30.6	1.38	1.07
100	27.8	1.25	0.97
90	25.0	1.13	0.88
80	22.2	1.00	0.78
70	19.4	0.88	0.68
60	16.7	0.75	0.58
50	13.9	0.65	0.48
40	11.1	0.50	0.39

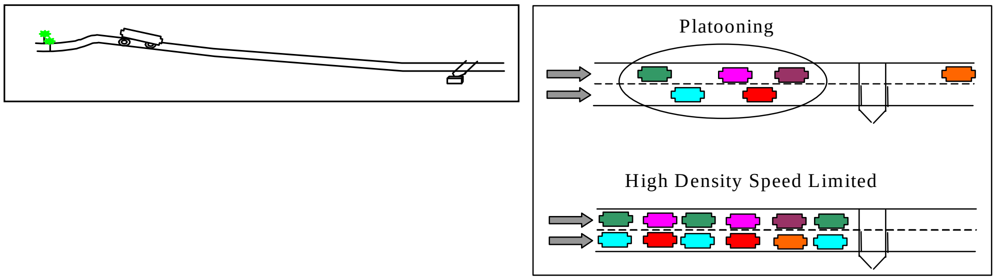


The lane 1 first axle is missed because the blind spot after the lane 2 first axle is 1.25 meters, that is 45ms at 100 kph. The lane 2 second axle is missed because the blind spot after the lane 1 first axle is 1.13m, that is 45ms at 90kph. The resulting vehicle has the lane 1 first axle and the lane 2 second axle at an average of 95 kph.

When the vehicles are accelerating they are almost guaranteed to be travelling at different speeds. Axles travelling at different speeds are more easily associated with each other and overtaking vehicles spend less time travelling beside other vehicles.

On the Great Western Highway, CFE inadvertently generated a situation on the day of the video audit that produced "high density speed limited traffic". This situation increased the number of hidden axles. The location of the tube at the site was at the bottom of a very long, straight, four-lane, bidirectional, semi-rural section with no intersections or signals. At the beginning of the long straight section was a rise over which the vehicle travelled, then down a long gentle slope to the tube location. On the other side of the rise the traffic was regulated by traffic signals. The speed limit was 70 kph. On the day of the audit, during the peak period, CFE had parked a white Commodore station wagon on the footpath and setup a tripod and video camera. This was in clear view of the traffic coming down the hill. The result was that the traffic lights produced densely packed platoons that stayed tightly packed at a constant speed past the video camera which they assumed was a police speed camera!

Figure 3. Platooning and constant speed



The manifestation of hidden events is either a misclassification or a discarded axle. In low commercial vehicle traffic, misclassifications are mainly from two dual axle vehicles to a single three axle vehicle, primarily class 2 and class 6 and to a lesser extent class 4. Other combinations are possible but less probable. If a misclassification does not take place, the classification software will discard a single unassociated axle. If the distribution of speeds is low, misclassification is more likely. If the distribution of vehicle speeds is high, a discarded single axle is more likely. In either case the volume is reduced by a single vehicle.

In high commercial vehicle traffic the severity of misclassification can vary depending on the situation. If the first axle of an articulated vehicle is hidden, the rest of the vehicle will most likely be discarded entirely, which is a serious result. However, if one of the rear axles is missed, a misclassification downwards is likely, say from class 9 to class 8. This type of misclassification of "long" vehicles may not be so serious, depending mainly on the number of classes to be classified.

In response to hidden axles, CFE developed "sharing" routines that require any two of four events to be recorded only to overcome hidden events. When an event is missed the sharing routines look into the other lane for vehicles that may have interfered with the current vehicle and caused the missed event. If found and the use of an axle or event from the other vehicle makes sense, the missing event is replaced by sharing the event from the other vehicle. The increased tube spacing to a distance of 4 metres helped to overcome the situation in the main project since the increased distance helps to exploit any slight differences in speeds between the vehicles. Over a long distance any vehicles travelling at fractionally different speeds will be further apart than at a smaller distance.

3.2.3 Crossing lanes/Missing events

During the video audit of slow moving traffic on Epping Road, it was found that the counter was not recording the events from some very slow moving cars at the rate of approximately 1 in 50 vehicles. The condition under which this occurred was highly congested crawling traffic. In the vast majority of cases, only one of the two tubes, either the lead or tail tube would miss the axle and the other tube would record its event, even though each axle was travelling at the same speed over both tubes.

At Botany Road, traffic lights regulated the entry of vehicles from a side street. When light minivans entered Botany Road they took wide turning circles and crossed the tubes at a position much closer to the lane line on the passenger side. Vehicles travelling along Botany Road and through the lights travelled more centrally in the lane. If the light minivan travelled wide enough to drive over the road tape which was placed on the lane line, that wheel event was not recorded by the counter.

Conditions making Missing Events more likely to occur:
- the vehicle impacts the tube at the maximum distance from the kerb,
- the vehicle is travelling at low speed,
- the tube has excessive tape over which the wheel runs,
- the tube has an internal restriction such as a polycarbonate insert or joiner,
- the tube has a long distance behind the kerb,
- the tube has a high angle of deflection behind the kerb and
- the tube is wound several times around a small diameter sign pole
- the tube has a small hole in it

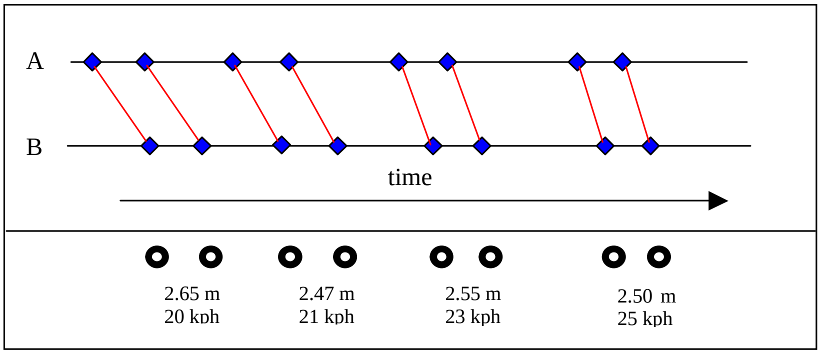
Depending on the sensitivity of the air switches, weak pulses may not activate the air switch and therefore result in a missed event. The type and thickness of tube, the length of tube behind the kerb, the straightness of the tube behind the kerb, the distance from the kerbside anchor to the point of impact of the vehicle, the amount of road tape used, and the presence of any internal diameter restriction all detrimentally effect the strength of the pulse. A small hole in the tube will also cause ad-hoc missed events by reducing the pulse (as opposed to a big hole which will record no events). It may be the case that since the introduction and now widespread use of road tape, particularly in respect of the increasingly poor road surfaces on main roads, over enthusiastic use of road tape and/or the use of polycarbonate inserts may result in missing events at low speeds.

At various other sites during the audit it was noticed that on occasion a vehicle changed lanes over the tubes in such a way as to avoid contact with either the lead or tail tube. This is sometimes an unavoidable situation that results in missed events.

In any case, when an event is missed the resulting event pattern is missing one of the events required to form an axle, the effect of which depending upon the situation, would result in either a missing vehicle, or a misclassification in much the same way as a hidden axle. If the situation occurs on a vehicle with a clear headway and no closely following vehicles, then depending on the number of missing events, the vehicle may be corrected or may be missed. If the situation occurs in dense, slow moving traffic, either in a single lane count or a multilane count, then a misclassification would occur, typically to a Class 2, Class 6 or 8, 10 or 11, depending on the number of vehicles, the particular speed of the vehicles, the axle spacings and inter-vehicle spacings. There is one characteristic, however, that indicates that this misclassification has occurred, and that is that the speed of the resulting vehicle is always much lower than (around half) that of both the preceding and the following vehicles.

For example, Figure 4a is an axle pattern for a single lane count in crawling, high volume traffic (not a real case nor to any scale).

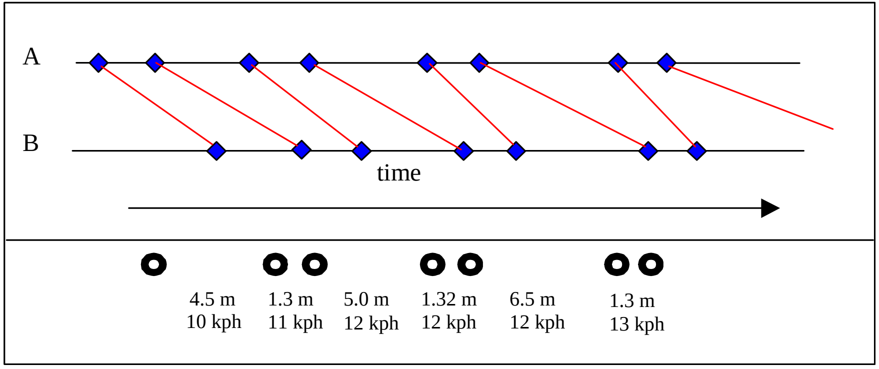
Figure 4a. Axle pattern, single lane count



If for some reason the first axle B event is not recorded by the counter, then potentially the software may incorrectly associate the wrong A and B events together (Figure 4b). The effect would be that the axle speeds would drop. When this happens, the axle spaces are then reduced since distance = speed * time. This has the effect of reducing the real axle spacings as well as the inter-vehicle spacings. In some situations the resulting axle pattern may be misclassified. In the following example a class 10 would result.

CFE was able in all cases to correct the software to accommodate missing events. The corrections were achieved by determining the time of day, whether the traffic is congested or free flowing, whether the speed of the vehicle is consistent with the previous and following vehicles, whether the interaxle accelerations are consistent, and whether comparing the current vehicle axles with an assumed series of vehicles that would be produced if the event was not missed, would produce a better or worse classification.

Figure 4b. Incorrect association of events



3.2.4 Reflections / Phantom Events / Ghost Events

When auditing the tube counts undertaken on Foreshore Road Botany CFE found that a recurring inaccuracy was producing the misclassification of Class 1 (o…o) and Class 3 (o…..o) vehicles as Class 4 (o……o.o) vehicles. Upon analysis of the events recorded by the counter, CFE discovered that ‘reflections’ (also known as phantom or ghost events) recorded at high speeds on both the lead and tail tubes were the cause of the misclassification.

‘Reflections’ are tube events recorded by the counter that are caused by air pulses reflected back onto the air switches after the main air pulse is recorded. Cars typically cause reflections only at high speed and trucks can cause reflections at lower speeds. The occurrence of reflections is the reason counter manufacturers include a counter configuration item termed a “dbounce” or “tube timers”. This is the amount of time in which the datalogger will not record an event from a tube sensor after the recording of an event on that tube.

Conditions making Reflections more likely to occur:

- the vehicle impacts the tube at the minimum distance from the kerb,
- the vehicle is travelling at high speed,
- the tube has no tape or the wheel misses the tape,
- the tube has no internal restriction such as a polycarbonate insert or joiner,
- the tube has a short distance behind the kerb and
- the tube is straight behind the kerb to the counter at a low angle of deflection.
- the non-counter end of the tube is blocked or knotted

Reflections in single lane counts at medium speeds may be overcome by setting an appropriate dbounce. However, at high speeds and in multilane counting, setting higher dbounces also increases the risk of missed events. For example, if the dbounce is set to 45 milliseconds then each axle of a vehicle travelling at over 100 kph within 1.3 metres of a previous axle will be missed. If you have a count where articulated vehicles are being miss-classified to shorter vehicles at high speeds, then the dbounce may be set too high.

In a multilane environment, either bidirectional or unidirectional, the dbounce represents a “dead time” in which axle events from passing vehicles (in the case of bidirectional counts) or overtaking vehicles (in the case on unidirectional counts) are hidden by events from vehicles which impact the tubes almost simultaneously (see

Hidden Axles). This is the reason counter manufacturers recommend lower dbounce values on bidirectional two tube counts.

CFE was able to enhance the classification software to fully utilise the occurrence of reflections at high speeds and reprocessed the event file which resulted in the removal of this inaccuracy. Since events which are not recorded by the counter due to a dbounce setting are lost to the classification software forever, CFE modified the software to *accept* reflections in a way that exploits their presence. This means that the counter does not inadvertently ignore real axle events.

Low Speed Reflections

During the analysis of low speed vehicles and congestion in the audit of Epping Road, it was noticed, quite unexpectedly, that vehicles at *very low speed* were generating reflections and that these reflections were significantly further behind the initial event than those reflections that occur at high speed. In addition, vehicles travelling at moderate speeds and heavy vehicles running over the same tubes during the same period would not cause any reflections. Everything currently known about reflections suggested that they were due to a strong pulse, generated by a high speed vehicle or heavy vehicle, rebounding within the tube and dying off in amplitude over a very short period of time. Alternatively some had suggested that trampolining of the tube on the road, or reverberation of the air switches was the cause of reflections.

CFE then determined that there may be two types of reflections, high speed reflections and low speed reflections and that each of these is produced by different mechanisms. The reflection produced at low vehicle speed was the result of the release of tube air pressure when the tyre releases the tube, while high speed (or normal) reflections are the result of historically known causes, such as air pressure rebounds, air switch reverberations or tube trampolining. The effect of low speed reflections is multiple closely spaced slow moving axles. The typical result would be class 1 vehicles migrating to class 4 or class 5, or longer vehicles migrating up one class depending on the position of the reflection. The indication that misclassification has occurred rather than a missed event or hidden axle is that the resulting vehicles' speed is completely consistent with the surrounding vehicle speeds.

Understanding the phenomenon of low speed reflections, CFE was able to modify the software to fully exploit the presence of low speed reflections in slow moving traffic.

Low speed reflections and high speed reflections provide valuable information to the classification software when fully understood and correctly interpreted.

3.2.5 Motorcycles

During an audit of a count undertaken on the transit lane of the Iron Cove Bridge, CFE identified a misclassification that was due to a particular situation when buses travelling at low speeds are followed closely by one or more motorcycles travelling at the same speed. This situation is exacerbated in transit lanes due to a high proportion of motorcycles when the traffic in the transit lane slows to a constant speed of around 40 kph during peak periods. In the case of the Iron Cove Bridge, the non-transit lanes were heavily queued making the transit lane a virtual tunnel from which the motorcycles could not exit and instead travelled in groups and in close proximity behind class 3 and class 4 buses. The occurrence of the motorcycle axles with a spacing of around 1.5 metres at a distance of around 7 metres and at the same speed as the bus created a class 7 (o…o…+…o.o) from a class 3 with a following motorcycle and a class 8 (o…o.o…+..o.o) from a class 4 (o….o.o) with a following motorcycle (o.o). Multiple motorcycles in a tight group produced class 9 (o….o.o + o.o + o.o) and potentially class 10s!

Once this issue was identified CFE was able to overcome the inaccuracy using more stringent pattern matching and by utilising the presence or absence of reflections.

3.3 ACCURACY LEVELS ATTAINED

The results of the audits undertaken showed that in various tested traffic environments including high speed, low speed free flowing, congested, high commercial vehicle and low commercial vehicle situations, the counting technique used is capable of acceptably high accuracy in classification over single and multiple lanes (Table 2).

Table 2. Comparison of tube and video counts

Military Road, Cremorne, Eastbound	**AADT 30000 VehPerDirection over 3 lanes (Nested + Single) 85% Speed 65 Kph Audit Duration : 2HR PM Peak**													
Lane 1 – Kerb	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	96	1	79	0	0	7	0	0	0	0	0	0	0	183
Video Count	96	1	78	0	0	7	0	0	0	0	0	0	0	182
Tube Error	*0*	*0*	*+1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*+1*
Percentage Difference	*0.00*	*0.00*	*+1.27*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*+0.55*
Percentage Error	*0.00*	*0.00*	*+0.55*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	
Lane 2 – Middle	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	1606	6	94	8	2	11	1	0	6	0	0	0	0	1734
Video Count	1605	6	92	7	2	11	1	0	6	0	0	0	0	1730
Tube Error	*+1*	*0*	*+2*	*+1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*+4*
Percentage Difference	*+0.06*	*0.00*	*+2.12*	*+12.5*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*+0.23*
Percentage Error	*+0.05*	*0.00*	*+0.10*	*+0.05*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	
Lane 3 – Median	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	1808	4	36	3	1	1	0	0	0	0	0	0	0	1853
Video Count	1810	4	35	3	1	1	0	0	0	0	0	0	0	1854
Tube Error	*-2*	*0*	*+1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*+1*
Percentage Difference	*-0.11*	*0.00*	*+2.78*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*+0.05*
Percentage Error	*-0.10*	*0.00*	*+0.05*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	
Mowbray Road, Chatswood, Westbound	**AADT 13000 VehPerDirection over 2 lanes (Nested) 85% Speed 55 Kph Audit Duration : 1.5HR AM Peak**													
Lane 1 – Kerb	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	573	1	34	0	3	0	0	0	0	0	0	0	0	611
Video Count	574	1	31	0	3	0	0	0	0	0	0	0	0	609
Tube Error	*-1*	*0*	*+3*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*+2*
Percentage Difference	*-0.16*	*0.00*	*+0.09*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*+0.33*
Percentage Error	*-0.16*	*0.00*	*+0.49*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	

Lane 2 – Middle	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	723	1	37	10	2	0	1	0	1	0	0	0	0	775
Video Count	738	1	25	11	2	0	1	0	1	0	0	0	0	779
Tube Error	*-15*	*0*	*12*	*-1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*-4*
Percentage Difference	*-2.07*	*0.00*	*32.43*	*-9.09*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*-0.51*
Percentage Error	*-1.93*	*0.00*	*+1.54*	*-0.13*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	

Foreshore Road, Port Botany, Northbound

AADT 18000 VehPerDirection over 2 lanes (Single)
85% Speed 95 Kph
Audit Duration : 2HR AM Peak

Lane 1 – Kerb	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	841	2	140	46	15	3	25	43	240	26	0	0	0	1381
Manual Count	839	2	141	46	15	3	25	43	240	26	0	0	0	1380
Tube Error	*+2*	*0*	*-1*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*+1*
Percentage Difference	*+0.23*	*0.00*	*-0.71*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.07*
Percentage Error	*0.14*	*0.00*	*-0.07*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	*0.00*	

Cowpasture Road, Hoxton Park

AADT 27000 VehPerDirection over 2 lanes (Nested/Bi-Directional)
85% Speed 70 Kph
Audit Duration : 2HR AM Peak

Lane 1 – Northbound	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	1814	20	122	55	5	1	4	8	71	12	0	0	0	2112
Manual Count	1817	20	117	53	4	1	6	9	72	12	0	0	0	2111
Tube Error	*-3*	*0*	*+5*	*+2*	*+1*	*0*	*-2*	*-1*	*-1*	*0*	*0*	*0*	*0*	*+1*
Percentage Difference	*-0.17*	*0.00*	*4.10*	*3.64*	*20.00*	*0.00*	*-33.33*	*-11.11*	*-1.39*	*0.00*	*0.00*	*0.00*	*0.00*	*0.05*
Percentage Error	*-0.14*	*0.00*	*0.24*	*0.09*	*0.05*	*0.00*	*-0.09*	*-0.05*	*-0.05*	*0.00*	*0.00*	*0.00*	*0.00*	

Lane 2 – Southbound	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	1125	3	158	59	4	2	11	5	48	3	0	0	0	1418
Manual Count	1172	6	148	51	8	2	9	9	68	5	0	0	0	1478
Tube Error	*-47*	*-3*	*10*	*8*	*-4*	*0*	*2*	*-4*	*-20*	*-2*	*0*	*0*	*0*	*-60*
Percentage Difference	*-4.01*	*-50.00*	*6.33*	*13.56*	*-50.00*	*0.00*	*18.18*	*-44.44*	*-29.41*	*-40.00*	*0.00*	*0.00*	*0.00*	*-4.06*
Percentage Error	*-3.18*	*-0.20*	*0.68*	*0.54*	*-0.27*	*0.00*	*0.14*	*-0.27*	*-1.35*	*-0.14*	*0.00*	*0.00*	*0.00*	

Two-Lanes NB/SB Combined	**Cls1**	**Cls2**	**Cls3**	**Cls4**	**Cls5**	**Cls6**	**Cls7**	**Cls8**	**Cls9**	**Cls10**	**Cls11**	**Cls12**	**Cls13**	**Total**
Tube Count	2939	23	280	114	9	3	15	13	119	15	0	0	0	3530
Manual Count	2989	26	265	104	12	3	15	18	140	17	0	0	0	3589
Tube Error	*-50*	*-3*	*15*	*10*	*-3*	*0*	*0*	*-5*	*-21*	*-2*	*0*	*0*	*0*	*-59*
Percentage Difference	*-1.67*	*-11.54*	*5.36*	*8.77*	*-25.00*	*0.00*	*0.00*	*-27.78*	*-15.00*	*-11.76*	*0.00*	*0.00*	*0.00*	*-1.64*
Percentage Error	*-1.39*	*-0.08*	*0.42*	*0.28*	*-0.08*	*0.00*	*0.00*	*-0.14*	*-0.59*	*-0.06*	*0.00*	*0.00*	*0.00*	

The Military Road data shows that high accuracy was attained for a three-lane road using one counter in a multilane four tube nested configuration and one counter in a single lane two tube configuration, both with four metre spacing.

In the kerb lane of Foreshore Road utilised by very large numbers of articulated vehicles, one counter in a single lane two tube configuration produced two errors only. The first was the misclassification of a class 3 vehicle to a class 1 vehicle. With the recent introduction of long wheel based utilities and commercial vans, the 3.2m delimitation between a class 1 and class 3 vehicle is now more sensitive to errors in tube spacing, differences in untensioned tube lengths, tube alignment and vehicle acceleration. The second error was an overcounted class 1 vehicle and such errors may be due to vehicles changing lanes over the tubes. Foreshore Road is a significant result indicating the correct interpretation and use of reflections in a heavy vehicle, high speed environment.

At Mowbray Road the results exhibit a misclassification between class 1 and class 3 vehicles. This is the result of an incorrect estimation of the amount of time a vehicle is stopped over the tubes. As it is not possible to measure the amount of time the vehicle is stopped, currently the classification software estimates the time and removes it from the axle spacing. Occasionally an underestimation results in the migration of a class 1 vehicle to class 3 vehicle. Although Military Road has a higher volume of traffic during the peak period, the number of queues formed over the tubes are less than at Mowbray Road and were of shorter duration hence the count result did not suffer from long stopped times in the same way.

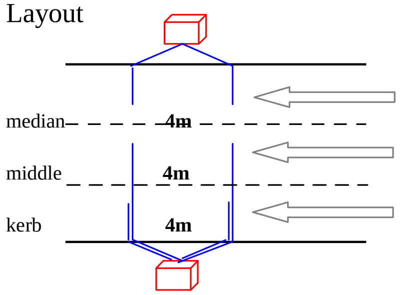
The Cowpasture Road audit is a significantly accurate classification result for a bidirectional two-lane road using a single counter. Cowpasture Road has 1700+ vehicles per hour bidirectional with a high proportion of commercial vehicles and traffic congestion. Most counter manufacturers recommend that two tube counters should not be used in such as traffic environment. From the results it is clear that the southbound lane has lower accuracy than the northbound lane. The cause of this inaccuracy is that there is a high proportion of crossing vehicles that produce hidden events in the non-kerbside southbound lane.

4. CLASSIFIED COUNT RESULTS

The Classified Vehicle Count Study collected classification counts on 41 major roads in the GMR. For each count site, two directions of travel were measured over a seven-day period using pneumatic road tubes. Vehicles were classified individually and reported as 15 minute and hourly classification counts by lane and combined by direction. In total 180 traffic lanes were collected in 71 kerb lanes, 46 median lanes and 59 middle lanes.

As a result of tests undertaken, CFE used a four-tube layout with 4-metre spacings (Figure 5), using one counter placed on the kerbside in what they call a "Nested" configuration. To collect three lanes of traffic CFE therefore used two counters and six tubes and for four lanes, two counters and eight tubes. CFE used a four metre tube spacing and blocked the non-counter end of the tubes to induce reflections, practices which are against current industry convention which is to use a one metre spacing and valve the non-counter end of the tube.

Figure 5. Multilane Nested Tube Layout



Study results

Table 3 shows the proportions of car, rigid and articulated trucks on the roads surveyed (The table is sorted in descending order of total volume of “All trucks”, ie. rigid and articulated trucks).

Table 3: Vehicle proportions, Average weekday, Both directions*

Road name	Total	All trucks	%Car	%Rigid	%Artic
Western Mwy Merrylands	146,787	17,296	88.2%	7.9%	3.8%
General Holmes Dr Botany	142,075	12,572	91.2%	6.1%	2.7%
Western Fwy Eastern Creek	107,962	11,481	89.4%	6.8%	3.9%
Hume Highway Ingleburn	76,833	9,909	87.1%	5.9%	7.0%
Pennant Hills Rd Pennant Hills	61,635	9,366	84.8%	9.0%	6.2%
Sydney Newcastle Fwy Wahroonga	69,210	8,867	87.2%	6.3%	6.6%
Sydney Newcastle Fwy Mooney Mooney	63,552	8,426	86.7%	6.0%	7.2%
Southern Cross Drive Eastlakes	113,534	8,244	92.7%	5.9%	1.4%
South Western Fwy M5 Prestons	73,513	8,008	89.1%	6.2%	4.7%
James Ruse Dr Camellia	69,988	7,746	88.9%	7.5%	3.6%
Silverwater Rd Silverwater	80,705	7,670	90.5%	7.6%	1.9%
Sydney Newcastle Fwy Wyong	55,845	7,402	86.7%	5.7%	7.5%
Foreshore Rd Botany	35,878	6,885	80.8%	11.6%	7.6%
Hume Highway Enfield	59,121	6,251	89.4%	8.1%	2.5%
Canterbury Rd Bankstown	49,811	6,149	87.6%	9.9%	2.5%
Woodville Rd Villawood	44,151	5,651	87.2%	8.6%	4.2%
Newbridge Rd Milperra	51,915	5,466	89.5%	7.8%	2.7%
Cumberland Hwy Canley Heights	45,856	5,376	88.3%	7.1%	4.6%
Western Fwy Jamisontown	55,457	5,186	90.6%	6.0%	3.3%
Princes Hwy Sylvania	89,493	5,076	94.3%	4.7%	1.0%
Lane Cove Rd North Ryde	78,735	4,924	93.1%	5.7%	1.2%
Pacific Hwy Wahroonga	60,815	4,713	92.2%	6.0%	1.7%
Military Rd Spit Junction	59,636	4,469	92.5%	6.6%	0.8%
Parramatta Rd Leichhardt	51,501	4,315	91.6%	6.8%	1.5%
Beecroft Rd Epping	55,162	4,264	92.3%	7.1%	0.6%
Cowpasture Rd West Hoxton	27,167	4,260	84.3%	10.0%	5.7%
Western Motorway Homebush	78,145	4,208	94.6%	3.9%	1.5%
New England Hwy Newcastle	34,596	4,198	87.9%	7.4%	4.7%
Gore Hill Freeway	90,820	4,109	95.5%	3.8%	0.7%
Pennant Hills Rd Pennant Hills	59,784	3,483	94.2%	3.8%	2.1%
Botany Rd Botany	25,870	3,402	86.8%	10.8%	2.4%
Windsor Rd Kellyville	44,934	3,398	92.4%	6.1%	1.5%
King Georges Rd Blakehurst	50,419	3,262	93.5%	5.4%	1.1%
Five Islands Rd Cringila (Port Kembla)	44,278	2,924	93.4%	4.4%	2.2%
Hume Highway Ramps Eagle Vale	50,912	2,837	94.4%	4.2%	1.4%
Great Western Hwy Eastern Creek	32,931	2,773	91.6%	6.1%	2.3%
Southern Fwy F6 Waterfall	38,716	2,533	93.5%	4.2%	2.3%
O'Riordan Street Alexandria	23,150	1,985	91.4%	7.4%	1.1%
Victoria Rd Drummoyne(Holiday)	57,677	1,643	97.2%	2.7%	0.2%
Sydenham Rd Sydenham	15,658	1,453	90.7%	7.9%	1.3%
Pacific Hwy Tighes Hill Newcastle	24,258	1,176	95.2%	4.3%	0.6%
Merrylands Rd Greystanes	18,129	1,153	93.6%	6.1%	0.3%
Great Western Hwy Minchinbury	23,894	979	95.9%	3.1%	1.0%

*Preliminary estimates subject to the completion of TDC validation of results.

Table 4 shows the roads that have the highest proportions of rigid trucks and how these trucks are spread across four time-of-day periods. These roads are mainly links to ports, intermodal terminals and large industrial areas. The table also shows that about half of the rigid trucks travel during the off-peak period.

Table 4: Roads with high proportion of rigid trucks, Average weekday, Both directions

Road name	%Rigid	Rigid	AM peak 7am-9am	Off-peak 9am-3pm	PM Peak 3pm-6am	Night 6pm-7am
Foreshore Rd Botany	11.6%	4,152	15.9%	48.3%	19.9%	16.0%
Botany Rd Botany	10.8%	2,783	15.7%	51.8%	14.5%	18.0%
Cowpasture Rd West Hoxton	10.0%	2,709	13.4%	46.6%	16.9%	23.1%
Canterbury Rd Bankstown	9.9%	4,917	11.1%	44.4%	19.9%	24.6%
Pennant Hills Rd Pennant Hills	9.0%	5,547	17.1%	46.1%	20.1%	16.7%
Woodville Rd Villawood	8.6%	3,793	12.4%	48.0%	21.6%	18.0%
Hume Highway Enfield	8.1%	4,768	15.3%	41.4%	26.1%	17.2%
Sydenham Rd Sydenham	7.9%	1,245	17.1%	51.4%	17.4%	14.1%
Western Mwy Merrylands	7.9%	11,660	19.1%	40.5%	25.0%	15.4%
Newbridge Rd Milperra	7.8%	4,068	12.3%	48.1%	18.7%	20.8%

Table 5 shows the roads that have the highest proportions of articulated trucks. The majority of these roads are those linking Sydney to other regions (ie. roads in Italics). It also shows that a very large proportion of inter-regional trips occur at night.

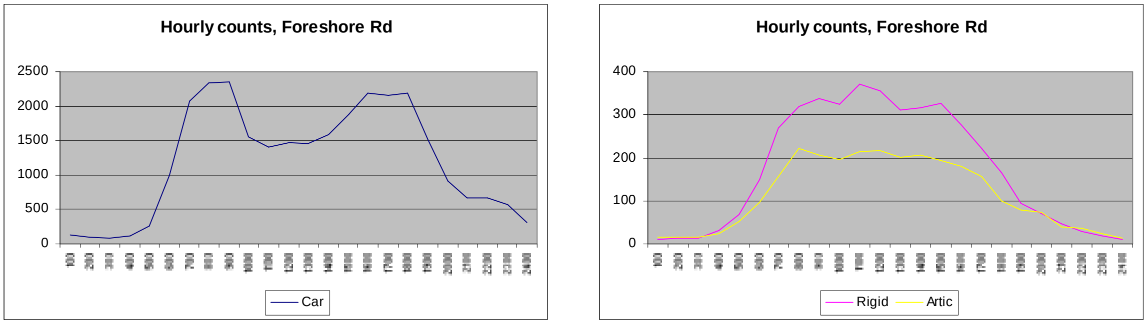
Table 5: Roads with high proportion of Artics, Average weekday, both directions

Road name	%Artic	Artic	AM peak 7am-9am	Off-peak 9am-3pm	PM peak 3pm-6pm	Night 6pm-7am
Foreshore Rd Botany	7.6%	2,733	15.7%	44.9%	16.0%	23.4%
Sydney Newcastle Fwy Wyong	7.5%	4,198	8.6%	34.0%	13.9%	43.5%
Sydney Newcastle Fwy Mooney Mooney	7.2%	4,607	8.1%	33.6%	13.2%	45.1%
Hume Highway Ingleburn	7.0%	5,396	9.7%	33.7%	12.7%	44.0%
Sydney Newcastle Fwy Wahroonga	6.6%	4,536	8.7%	35.9%	11.7%	43.7%
Pennant Hills Rd Pennant Hills	6.2%	3,819	8.8%	35.8%	13.1%	42.3%
Cowpasture Rd West Hoxton	5.7%	1,550	10.4%	41.4%	14.0%	34.2%
New England Hwy Newcastle	4.7%	1,625	11.1%	35.8%	15.0%	38.1%
South Western Fwy M5 Prestons	4.7%	3,421	10.6%	36.5%	13.0%	39.9%
Cumberland Hwy Canley Heights	4.6%	2,132	10.3%	39.0%	13.9%	36.8%

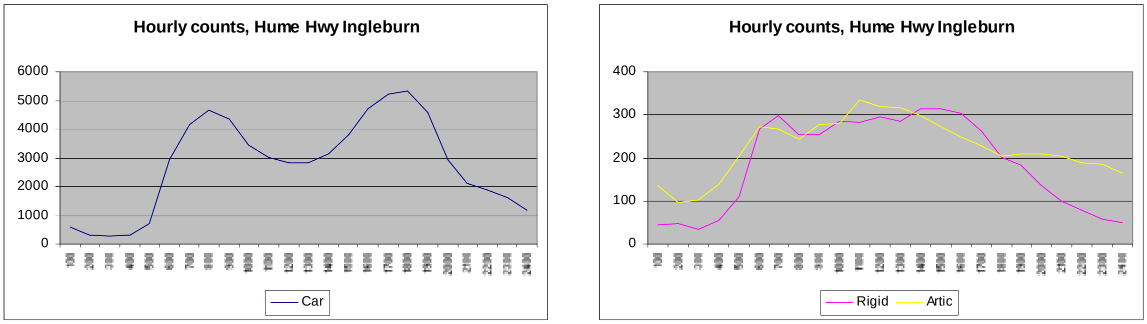
Figure 6 shows the hourly distribution of traffic (both directions) for car and trucks. The graphs show similar patterns for car (bidirectional) while trucks tend to be more concentrated during hours when car traffic is diminishing.

Figure 6: Hourly counts on selected roads, Average weekday

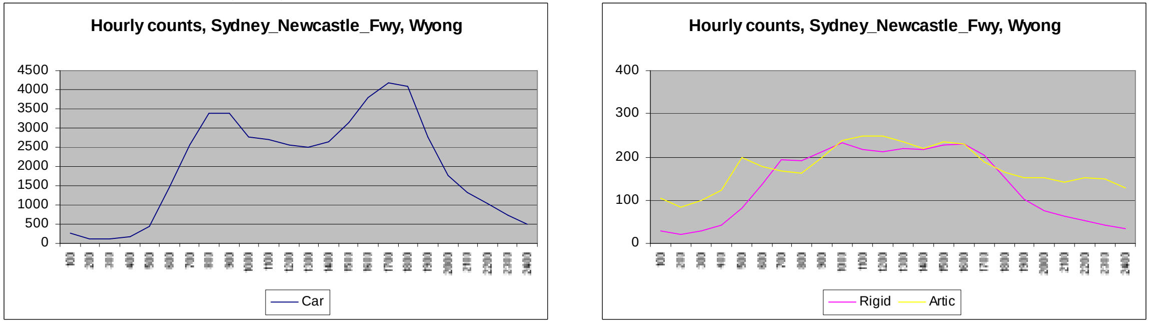
Road servicing major seaport (Port Botany)



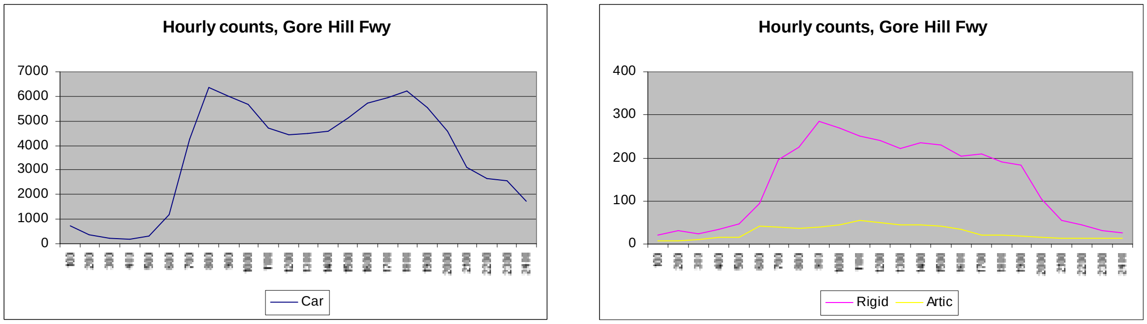
Road link to west of Sydney GMR



Road link to north of Sydney GMR



Road servicing CBD



5. SUMMARY AND CONCLUSION

Prior to this study, there was a general acceptance that pneumatic counts undertaken on *single lane* roads with high volumes and on *multiple lanes* with medium-to-high volumes are inaccurate. These inaccuracies do exist but an understanding of the inaccuracies can lead to significant improvements in data accuracy through modified practices (eg. use of four metre tube spacing; use of four tubes for multiple lanes) and through changes to the processing software algorithms to allow for a full range of traffic scenarios.

The study demonstrated that a four tube counter is able to obtain classified counts on multilane roads in accordance with axle based classification schemes such as Austroads94, by lane and with acceptable levels of accuracy. Therefore, it provides a cost-effective method of counting classified traffic by allowing the use of one counter over two lanes with four tubes and thereby negating the need for polycarbonate inserts.

As a result of this study, TDC has now collected accurate classification counts for the main roads in the Sydney GMR. The availability of actual and accurate counts of rigid and articulated trucks on Sydney’s main roads will enable TDC to update its base year estimates and produce more accurate results to be used for forecasting commercial trips. In addition, because the study obtained hourly counts, TDC will also be able to expand its estimation process in the future to include *time of day* estimates, in line with its personal travel model which has AM peak, off-peak, PM peak and night estimates of trips.

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