Effect of Heavy Vehicles at Australian Traffic Circles and Unsignalized Intersections

R. J. TROUTBECK

The technique for estimating the capacity of traffic circles in Australia has employed a gap-acceptance approach. For this approach the influence of heavy vehicles was essentially ignored because the sites were typical and had about 5 percent heavy vehicles. The parameters used to quantify the gap-acceptance behavior of drivers had included the behavior of the heavy-vehicle drivers. The use of this technique has now been extended beyond a simple analytical process and is incorporated into the SIDRA analysis program. The consequences of including a high proportion of heavy vehicles needs to be estimated. The passenger car unit (pcu) technique for estimating the influence of heavy vehicles and another technique using three factors to modify the gap-acceptance parameters for drivers of heavy vehicles and drivers accepting a gap just ahead of a heavy vehicle are discussed. In both cases an analytical assessment was done. Values for these terms, which modify the gap-acceptance parameters, are evaluated from field studies and are reported. It was concluded that the pcu method is reasonable but that the modified gap acceptance approach provides greater understanding and flexibility. The values found will assist others in evaluating the influence of heavy vehicles at traffic circles and unsignalized intersections.

Drivers negotiate unsignalized intersections by accepting and rejecting gaps in opposing traffic. A driver is assumed to review the gaps in several streams as well as the queueing in some of the streams. The process is a difficult one and it is often simplified. When there is a substantial proportion of heavy vehicles at the unsignalized intersection, then capacity will be affected through changes in behavior. The behavior of drivers entering a traffic circle or an unsignalized intersection and the changes in behavior when there is a greater proportion of heavy vehicles are described in this paper.

Behavior parameters have been collected and analyzed at traffic circles, but the behavior is expected to be similar to that experienced at unsignalized intersections. The behavior at traffic circles is simple because drivers only need to give way to one or two circulating streams going in one direction. Hence they are very simple unsignalized intersections.

The numbers given in this paper are only seen to be indicative at this stage. More extensive data should be collected and studied using such intersection analysis tools as SIDRA (*1,2*).

GAP-ACCEPTANCE BEHAVIOR

At unsignalized intersections, drivers are assumed to behave consistently and all drivers are assumed to behave identically. These assumptions, when applied together, have been found to give reasonable results (*3–5*). For practical purposes these assumptions will continue to be used.

Gap-acceptance behavior assumes that entering drivers accept gaps, and enter the unsignalized intersection, when the headway between the opposing vehicles is greater than the critical acceptance gap, T. It is further assumed that entering drivers will follow each other into the unsignalized intersection at headways equal to the follow on time, T_o, if there is a long headway between the opposing vehicles.

Gap-Acceptance Behavior Expected at Traffic Circles

Gap-acceptance behavior is expected to be similar at traffic circles for which the opposing traffic is the circulating traffic for each leg. Each entry leg is considered to be an independent T-intersection. The major stream, or the priority stream, is the circulating traffic that passes in front of the entering drivers. This circulating traffic excludes the drivers who exit at the same leg. Troutbeck (*6*) discusses the consequences of these assumptions.

The entering behavior of drivers was found to be dependent on the circulating or opposing flow and on the flows in the entry lanes at an approach. The greater the circulating flow the shorter are the gap-acceptance parameters—that is, the shorter are the gaps that are acceptable to the entering drivers (*7*). Although this cannot be quantified or proven by the data directly, it is hypothesized that as the speeds of the circulating vehicles are decreased as a result of greater circulating flows, drivers then feel more comfortable in accepting shorter gaps, and some circulating drivers will yield right of way to the entering drivers. This would result in the observed gap-acceptance parameters decreasing with higher circulating flows. This could result from drivers either changing their behavior when they are delayed (*8*) or sizing up the intersection before they approach, leading to lower gap-acceptance characteristics at the higher flow sites. The author favors the latter because an earlier study of overtaking behavior did not find a relationship between delay and gap-acceptance behavior (*9*). The outcome is the same, however.

R. J. Troutbeck, Queensland University of Technology, Two George Street, GPO Box 2434, Brisbane Q4001, Australia.

Gap-Acceptance Behavior Expected at Unsignalized Intersections

A similar relationship between the speed of opposing vehicles and driver behavior has been observed at two-way stop or give-way intersections. Brilon (*10*) reported that Harders (*11*) found that gap-acceptance parameters were influenced by the speed of opposing vehicles. This speed influence has been incorporated into the *Highway Capacity Manual* (HCM), Table 10-2 (*12*).

Similarly, there are likely to be differences in the behavior of drivers in adjacent slip lanes if there is uncertainty in the path drivers will take after the slip lane. This behavior pattern is likely to be similar to that observed at entries to Australian traffic circles (*7*).

USING PASSENGER CAR EQUIVALENTS FOR HEAVY VEHICLES

The influence of heavy vehicles at unsignalized intersections and traffic circles can be evaluated using a heavy-vehicle equivalent as in the 1985 HCM. The influence of heavy vehicles will be evaluated using analytical techniques to estimate the performance of Australian traffic circles. These techniques are described by Troutbeck (*7*) and are now included in Australian practice (*13*). Similar trends are expected for other forms of unsignalized intersections.

The base case will be a traffic circle with a single circulating lane, a maximum diameter between the islands at the entries (inscribed diameter) of 40 m, and a 4-m entry lane. A single-lane traffic circle is used in this analysis, although the trends are the same at larger traffic circles and at traffic circles with more than one lane. The dimensions of the traffic circle are shown in Figure 1, and the entry capacity is shown in Figure 2. In Australian guides the capacity of a traffic circle is the maximum flow that can be expected at that entry, if all other flows remain the same.

The traffic at the traffic circle sites used in the analysis of driver behavior (*7*) included about 5 percent trucks. In AustRoads (*13*), the effect of trucks was not considered necessary if there were less than 5 percent trucks. If the passenger car equivalent of heavy vehicles is changed, then the predicted entry capacity would change. Under these conditions the traffic composition factor to convert between vehicles and passenger car units (pcu) is given by

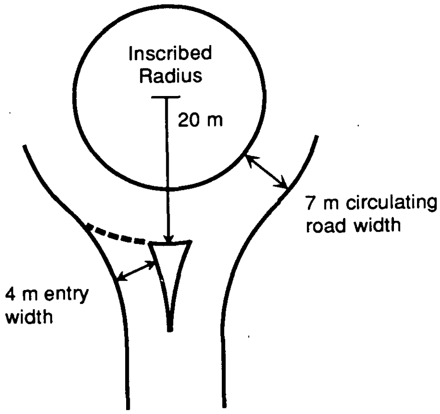

FIGURE 1 Dimensions of single-lane traffic circles.

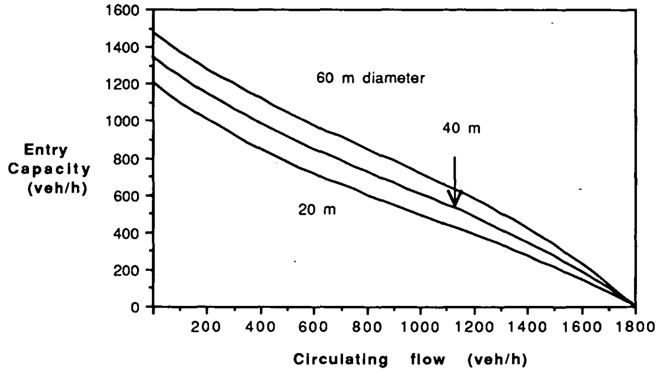

FIGURE 2 Entry capacity of single-lane traffic circles with different inscribed diameters.

$$f_c = 1 + (p_{\mathrm{HV}} - 0.05)\,(e_{\mathrm{HV}} - 1) \tag{1}$$

where

p_{HV} = proportion of heavy vehicles,
$p_{\mathrm{HV}} > 0.05$, and
e_{HV} = passenger car equivalent of a heavy vehicle.

Passenger car equivalents between 1.5 and 2 are acceptable values for a heavy vehicle (*12,13*).

Using Equation 1, an increase in the proportion of heavy vehicles in the circulating stream increases the pcu value of the circulating flow. This then results in a decrease in capacity. On the other hand, an increase in the proportion of heavy vehicles in the entry stream increases the traffic composition factor and reduces the arrival capacity in units of vehicles per hour (veh/hr). The effect of changing the proportion of heavy vehicles in both lanes are additive. The combined effect is to lower the predicted capacity by about the same amount for all circulating flows.

GAP-ACCEPTANCE PARAMETERS FOR HEAVY VEHICLES

Instead of using passenger car equivalents to factor the flows to account for heavy vehicles, it is preferable to use a gap-acceptance approach. The gap-acceptance approach describes driver behavior at these intersections. This approach gives an increased understanding of the mechanisms used and is consistent with the analysis technique used by AustRoads (*13*). Entry capacity can be influenced by heavy vehicles in two ways. Drivers of heavy vehicles can display different gap-acceptance characteristics when entering a traffic circle or unsignalized intersection. Drivers may wish to accept longer gaps when entering a traffic circle in front of heavy vehicles. Both aspects are discussed in the following sections.

Different Entering Driver Behavior

As has been discussed by Harders (*14*), Catchpole and Plank (*3*), and Bennett (*15*), the entry capacity of a stream of drivers that are not homogeneous is given by harmonic means—that is, the capacity of an entry, Q, is given by

$$\frac{1}{Q} = \frac{\text{prop}_1}{Q_1} + \frac{\text{prop}_2}{Q_2} + \ldots + \frac{\text{prop}_n}{Q_n} \tag{2}$$

where Q_i is the entry capacity of the ith element of the entry stream and prop_i is the proportion of the ith element in the entry stream.

If it is assumed for simplicity that both the critical acceptance gap and the follow-on time are increased by the same gap-acceptance parameter factor, f_{GA}, then

$$T_{HV} = f_{GA} T_{LV} \tag{3}$$

and

$$T_{0HV} = f_{GA} T_{0LV} \tag{4}$$

where T_{HV} and T_{LV} are the critical acceptance gaps for heavy vehicles and cars and T_{0HV} and T_{0LV} are the follow-on times for heavy vehicles and cars.

Heavy-vehicle drivers can be expected to require a longer gap when entering a traffic circle because their vehicles are longer and have generally lower acceleration rates (*16*). Capacity will be reduced, as shown in Figure 3. It is interesting to note that Harders (*11*) found that the gap-acceptance parameter factor for the critical acceptance gap differs from that for the follow-up time.

The results shown in Figure 3 can be used to give an equivalent pcu value for the heavy vehicles. For instance, at a circulating flow of 1,000 veh/hr, the entry capacity for cars is 615 veh/hr. If the critical acceptance parameters are 50 percent longer (gap-acceptance parameter factor = 1.5), then the entry capacity is reduced to 317 veh/hr. This implies an equivalent pcu of 1.94. In fact, a gap-acceptance parameter factor of 1.5 gives similar results to those obtained when a pcu of 2 for heavy vehicles in the entry streams for circulating flows less than 1,500 veh/hr is assumed.

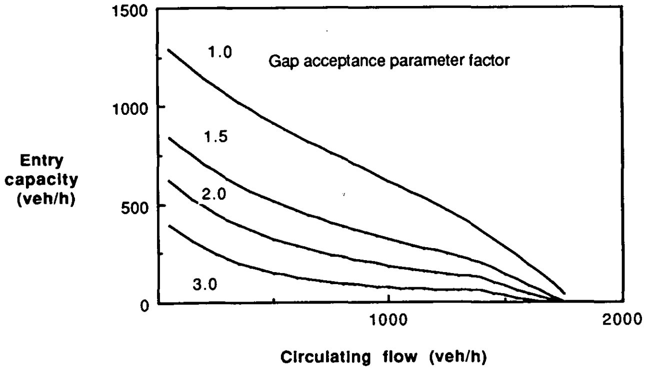

FIGURE 3 Entry capacities for drivers of heavy vehicles that have different gap-acceptance parameter factor values.

If a gap-acceptance factor of 1.5 is adopted, then the entry capacities change with the proportion of heavy vehicles. For less than 20 percent trucks, the reduction in the entry capacity is less than about 12 percent below the capacity estimated when the gap-acceptance properties of heavy vehicle drivers are assumed to be the same as cars.

Effect of Circulating Vehicle Type on Gap-Acceptance Behavior

The effect of drivers having different critical gap-acceptance characteristics that depend on the major stream vehicle types can be estimated if it is assumed that

Q_{LV} = entry capacity when major stream consists of cars (veh/sec),

Q_{HV} = entry capacity when major stream consists of heavy vehicles (veh/sec),

prop_{HV} = proportion of heavy vehicles in major stream, and

q = major stream flow (veh/sec).

Again, the major stream is the circulating stream. Assuming that there is no correlation between gap size and vehicle type, then in a given time period, H, $qH\text{prop}_{HV}$ heavy vehicles and $qH(1 - \text{prop}_{HV})$ cars will pass. For the purposes of estimating capacity, this is equivalent to a major stream consisting of a stream of cars for a period of $H(1 - \text{prop}_{HV})$ followed by a stream of trucks for a period of $H\ \text{prop}_{HV}$. The number of vehicles that can enter in each period is then $H(1 - \text{prop}_{HV})\ Q_{LV}$ and $H\ \text{prop}_{HV}\ Q_{HV}$. The total entry capacity, Q, is then

$$Q = \text{prop}_{HV}\ Q_{HV} + (1 - \text{prop}_{HV})\ Q_{LV} \tag{5}$$

Because heavy vehicles are generally longer than cars, it is expected that heavy vehicles present a longer "block" to the entering drivers. If it is assumed that an entering driver merges into the circulating stream so that there is an acceptable minimum headway between the circulating and entering vehicles, then a longer headway will be required between a heavy circulating vehicle and an entering vehicle. Similarly, a circulating stream that consists of only heavy vehicles would have a lower maximum flow than if the stream consisted only of cars. This implies that there should be a longer minimum headway between heavy vehicles. This interaction between the entering driver and different circulating drivers can be modeled using the following notation:

T = critical acceptance gap for drivers accepting a gap before a car;

T_0 = follow-on time for drivers accepting a gap before either a car or a heavy vehicle;

Δ = minimum headway in front of cars (all cars that are following can be assumed to have this minimum headway);

Δ_{HV} = minimum headway in front of heavy vehicles (similarly, all heavy vehicles that are following can be assumed to have this minimum headway); and

$T - \Delta + \Delta_{HV}$ = critical acceptance gap for drivers accepting a gap before a heavy vehicle.

For convenience, Δ_{HV} is considered to be a multiple of Δ. That is,

$$\Delta_{HV} = f\Delta \tag{6}$$

where f is a heavy vehicle headway factor that is greater than 1. For all practical purposes, this factor may be assumed to be equal to the ratio of the average length of heavy vehicles to cars. This factor affects the distribution of gaps in the circulating stream. It is assumed that there are $1 - \alpha$ vehicles that are following others (in bunches). Then there will be $(1 - \alpha)$ prop_{HV} heavy vehicles with a headway of Δ_{HV}, and $(1 - \alpha)$ $(1 - \text{prop}_{HV})$ cars with a headway of Δ, and the remainder will have a headway greater than Δ_{HV}. The term, α, is the proportion of nonbunched or free vehicles.

Increasing the heavy-vehicle headway factor reduces the predicted capacity, but only by a few vehicles per hour. It is expected that an f-value of 1.5 gives reasonable, but unsubstantiated, results. If the proportion of heavy vehicles is greater than 10 percent, and assuming an f-value of 1.5, the error is roughly dependent on the proportion of heavy vehicles.

Another influence is that drivers may perform differently when accepting gaps in front of heavy vehicles than when accepting gaps in front of cars. The critical gap for drivers accepting a gap in front of heavy vehicles will be greater than when accepting a gap in front of cars. For convenience, the critical acceptance gap is assumed to be t_f times greater than the critical acceptance gap for cars. The follow-on times for the entering drivers are assumed to be the same when the gap is terminated by either a car or a truck as the extra time has been accounted for in the critical acceptance gap. That is,

$$T_{CHV} = t_f T_{CLV} \tag{7}$$

and

$$T_{0CHV} = T_{0CLV} \tag{8}$$

where the subscript C refers to the circulating stream and t_f is the truck factor. Changing the truck factor from 1.0 to 2.0 has only a marginal effect on the estimate of capacity.

The effect of the headway factor and the truck factor are similar, and either factor could be used to explain the influence of heavy vehicles in the opposing (circulating) streams. Their effect can then be combined.

Combined Effect of Heavy Vehicles in Circulating and Entry Streams

The influence of heavy vehicles at traffic circles described includes the following three effects:

- Heavy vehicles have slower accelerations and require a longer critical gap,
- Heavy vehicles have a greater occupancy in the circulating stream on the road system and therefore reduce the available time for merging, and
- Heavy vehicles cause entering drivers to adjust their behavior.

The combined effect of the gap-acceptance parameter factor, the truck factor, and the heavy-vehicle headway factor are additive. Figure 4 shows this combined effect and the effect of each factor when there are 20 percent trucks on both the entry and circulating streams. All factors should be incorporated into the model, although the gap-acceptance factor has the greatest influence and predominates.

The reduction in capacity from both effects resulting from an increase in heavy vehicle percentages is about 60 veh/hr for each 10 percent increase in the proportion of heavy vehicles. The likely overestimation from ignoring the presence of heavy vehicles is less than 10 percent, given that the proportion of heavy vehicles is less than 15 percent and that the circulating flow is less than 1,500 veh/hr.

TRUCK FACTOR AND GAP-ACCEPTANCE FACTOR

Evaluation

A suburban traffic circle on the Breakfast Creek and Montpelier roads in Brisbane was used for a field study to evaluate the gap-acceptance parameters to be evaluated for each variable type. This site was chosen because it had about 25 percent trucks in both the entry and the circulating streams.

The data collected consisted of the type of entering vehicle and the gaps that were rejected or accepted. Data on the type of vehicle at the end of the gap were also collected. This enabled the following data to be compiled into a data table:

- The size of the accepted gap if the gap was terminated by the presence of a car,
- The size of the accepted gap if the gap was terminated by a heavy vehicle,

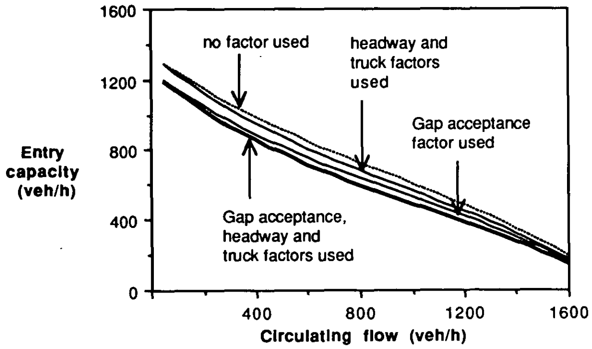

FIGURE 4 Predicted entry capacity when gap-acceptance parameter factor is applied, when heavy-vehicle headway and truck factor is applied, when no factors are used, and when all factors are applied (20 percent trucks assumed).

- The largest rejected gap in front of a heavy vehicle, and
- The largest rejected gap in front of a car.

The data were analyzed using a modified gap-acceptance method. For a conventional gap-acceptance method, the largest rejected gap and the accepted gap are used to predict the parameters for the critical gap distribution given that the form of the critical gap distribution is specified. The lognormal function has been found to be acceptable (*17*) as it has nonzero values and is skewed to the right. It is used here.

The conventional maximum likelihood technique requires that likelihood of n drivers having a largest rejected gap of x_i and an accepted gap of y_i subject to the condition that $x_i \leq y_i$, be estimated. If $y_i < x_i$ then the driver was assumed to be inattentive and x_i was set just below y_i. The likelihood is then

$$\prod_{i=1}^{n} [F(y_i) - F(x_i)]$$

The logarithm of the likelihood is then

$$L = \sum_{i=1}^{n} \ln[F(y_i) - F(x_i)] \quad (9)$$

The maximum likelihood estimators for the critical gap distribution are the mean of the logarithms of the critical gaps, μ, and the variance of the logarithms of the critical gaps, σ^2. These are given by differentiating Equation 9 with respect to both μ and σ^2. This technique is further explained in Troutbeck (*17*).

In this case the effect of trucks in the circulating stream was accounted for by assuming that a particular entering driver would accept a gap of size β in front of a car but would require a gap of βt_f in front of a heavy vehicle. The solution was obtained by finding a value of t_f that maximized the likelihood. Figure 5 illustrates the effect of the truck factor on the likelihood function for cars and trucks. The normalized values are factored so that they are 1 for truck factors of 1.0.

As the truck factor is increased above 1, the normalized logarithm of the likelihood functions moves toward a local minimum. The curves are quite shallow, and a range of values could be suitable. This graph shows that truck factors of 1.64 for trucks and 1.23 for cars are suitable. Similarly, the mean of the critical gap distribution or the critical acceptance gap is also a function of the normalized logarithm of the likelihood function. For truck drivers the critical acceptance gap is 5.13 sec; for cars, it is 5.37 sec. This is shown in Figure 6.

Figures 5 and 6 imply that minimum gap required for a car driver to enter on front of a car is 5.37 sec and 5.37 × 1.23 or 6.6 sec when entering in front of a truck. A driver of heavy vehicle would require a gap of 5.14 sec when entering in front of a car and 8.4 sec when entering in front of a heavy vehicle.

It is not impossible for a truck driver to accept a shorter gap than a car driver, particularly if the heavy-vehicle driver assumes that might is right, but it appears to be more acceptable to consider that drivers of both vehicle types have the same critical gap when accepting a gap in front of a car. Figure 6 shows that if the critical acceptance gap for heavy vehicles was increased to 5.37 to match the value for cars, then the increase in the likelihood factor is marginal. The appropriate truck factor at this critical acceptance gap is reduced to 1.37. Truck factors are now 1.23 and 1.37 for cars and trucks entering the stream. This then leads to the critical acceptance gaps given in Table 1.

There are good reasons that the truck factor differs for car drivers and heavy-vehicle drivers. Car drivers often do not fully appreciate the performance of a heavy vehicle and will often allow less-than-desirable road space for heavy vehicles. Heavy-vehicle drivers would be more considerate in this regard. Consequently, the different truck factors for different vehicle types is appropriate.

Distribution of Critical Gaps

The critical acceptance gap used in the preceding is the mean critical gap derived from the maximum likelihood process as described. The distribution of critical gaps is derived from the following data using the maximum likelihood process.

The distribution of critical gaps for drivers of cars and heavy vehicles that accept gaps in front of cars are very similar because of the revision made before. The distribution of critical gaps for drivers accepting a gap in front of a heavy vehicle are shifted to the right and have a greater skew (Figure 7). Many heavy-vehicle drivers would be expected to accept gaps shorter than those expected by drivers of cars. Similarly, many

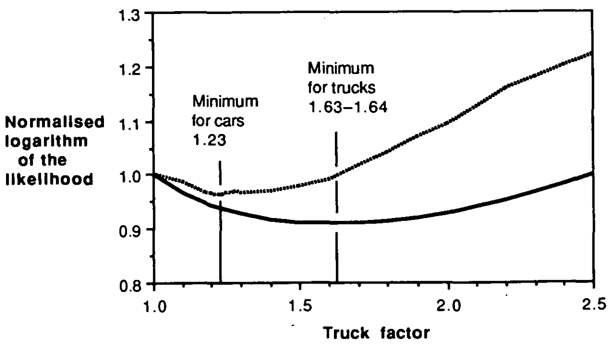

FIGURE 5 Effect of truck factor on normalized logarithm of likelihood.

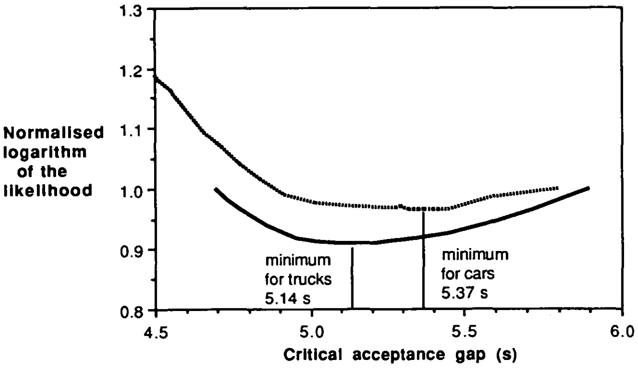

FIGURE 6 Effect of critical acceptance gap on normalized logarithm of likelihood.

TABLE 1 Critical Gap Distribution Parameters

	Entering vehicle type	
Parameter	Car	Heavy vehicle
Critical acceptance gaps for accepted gaps terminated by a car	5.37	5.37
Mean of the logarithms of drivers' individual critical gaps terminated by a car	1.557	1.586
Standard deviation of the logarithms of drivers' individual critical gaps terminated by a car	0.498	0.438
Truck factor	1.23	1.37
Critical acceptance gaps for accepted gaps terminated by a heavy vehicle	6.60	7.36
Mean of the logarithms of drivers' individual critical gaps terminated by a heavy vehicle	1.763	1.900
Standard deviation of the logarithms of drivers' individual critical gaps terminated by a heavy vehicle	0.498	0.438

drivers would accept a gap in front of a heavy vehicle that is shorter than the gaps accepted, in front of an oncoming car, by some car drivers. These drivers may believe that they can accelerate and move ahead of the slower-moving heavy vehicles in the circulating stream.

Whereas the differences in the critical gap distribution are not excessive, the results do indicate likely changes in drivers' gap-acceptance capabilities that could be expected at unsignalized intersections. From the analysis presented here, the gap-acceptance parameter that relates the mean critical gap for car drivers to truck drivers should be set to 1.0. Different truck factors of 1.23 and 1.37 were found for different entering vehicle types of cars and trucks, respectively.

Using these truck factors and the gap-acceptance factor, the influence of the proportion of trucks at the intersection affects the entry capacity only marginally. The reduction in capacity when the proportion of trucks is increased from 5 to 40 percent is still less than 10 percent for circulating flows of less than 1,500 veh/hr.

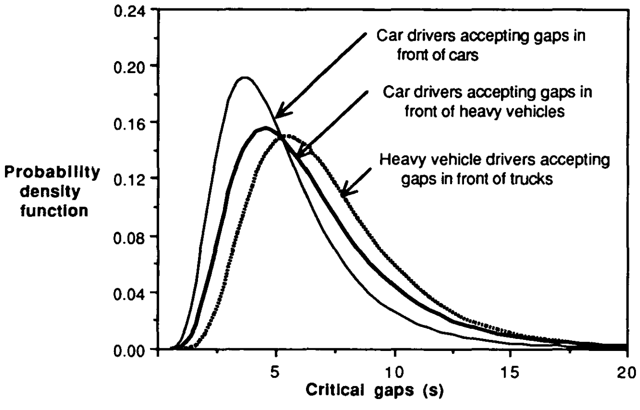

FIGURE 7 Probability density function of critical gaps of drivers of cars and heavy vehicles accepting a gap in front of a heavy vehicle.

DISCUSSION OF RESULTS

The gap-acceptance effect on capacities is similar to the effect estimated using pcu values in that an increase in the proportion of heavy vehicles results in a decreased capacity. These two techniques are different and produce different results. Both techniques have applications. The pcu method is simpler to understand but lacks the explanatory properties of the gap-acceptance approach. The latter approach is expected to offer a better behavioral description of the processes involved in the gap-acceptance behavior at traffic circles and unsignalized intersections.

Effective pcu Values

If a pcu method is used to account for the influence of heavy vehicles, then a pcu value close to 1.5 gives a good representation of the modified gap-acceptance relationships over most of the range of circulating flows. It is assumed here that the truck factors will be the same for all circulating flows. The pcu value is very similar to the one used in the HCM (*12*).

As the opposing flow increases, the pcu equivalent is reduced. This is reasonable at traffic circles because the circulating flow influences the speed. As the circulating flow increases, so the gap-acceptance terms decrease. There could also be fewer differences between the influence of oncoming (circulating) cars and trucks at these slower circulating speeds. This would imply a lower pcu value. The truck factors are only indicative, yet they do provide an estimate of the magnitude of the suitable parameters.

The observations of drivers entering traffic circles included different driver and vehicle types. The critical gap parameters evaluated from these observations are expected to account for some, if not most, of these driver differences. The drivers that accept longer gaps in front of heavy vehicles or the drivers of the heavy vehicles would be in the tail of the statistical distribution for the gap-acceptance parameters. It is therefore often convenient to leave out the effects of these heavy vehicles.

Application of Results to Other Unsignalized Intersections

Currently, many techniques [e.g., those of the HCM (*12*) and Kimber (*18*)] use a pcu method of evaluating the effect of trucks at unsignalized intersections. This is considered satisfactory for the most cases, but it does not give a full behavioral explanation of the influence of heavy vehicles.

The gap-acceptance factors explained in this paper are able to provide a better behavioral description and can be used to evaluate the performance of unsignalized intersections. The notion of a truck factor can be used at all unsignalized intersections, except that the factors could be expected to change as opposing flow increases or as speed increases. Further work to identify the appropriate factors that should be used at all types of unsignalized intersections and under all conditions is needed.

In summary, the concepts of the gap-acceptance factors described in this paper can be applied to all types of unsignalized intersections.

RECOMMENDATIONS AND CONCLUSIONS

The sensitivity of techniques and parameters used to account for the effect of heavy vehicles at traffic circles has been addressed in this paper. It was pointed out that similar effects are likely to be experienced at other unsignalized intersections. Field data were used to evaluate the likely influence and magnitude of the theoretical parameters that describe the effect of heavy vehicles. Major conclusions from this preliminary study are

- The pcu method of adjustment is seen to be a satisfactory alternative to adjust for the proportion of heavy vehicles. This technique is a simple one and is easily incorporated into a procedure.
- The gap-acceptance approach is more descriptive and is able to offer a driver behavioral interpretation on the effect of heavy vehicles.
- The gap-acceptance parameter factor, which is the ratio of the critical acceptance gap for drivers of cars to the critical acceptance gap for drivers of heavy vehicles, is the term that has the greatest influence on the estimate of capacity. However, in the limited field studies, this factor was found to be equal to 1.0. It was therefore discarded.
- The truck factors relate the critical gap distribution to the vehicle type that terminates the gap. There were different values for the different entering vehicle types, which was thought to result from the drivers' attitudes toward heavy vehicles.
- Pcu values of 1.5 applied to the circulating stream only give similar results to the modified gap-acceptance technique that used the truck factors identified in this report. As circulating factors increase, the pcu equivalents are likely to decrease.

REFERENCES

1. R. Akçelik. *Introduction to SIDRA-2 for Signal Design*. Research Report 148. Australian Road Research Board, Victoria, 1987.
2. R. Akçelik. *Calibrating SIDRA*. Research Report 180. Australian Road Research Board, Victoria, 1990.
3. E. A. Catchpole and A. W. Plank. The Capacity of a Priority Intersection. *Transportation Research B*. Vol. 20B, No. 6, 1986, pp. 441–456.
4. R. J. Troutbeck. Current and Future Australian Practices for the Design of Unsignalised Intersections. In *Intersections Without Traffic Signals* (W. Brilon, ed.), Springer-Verlag, Berlin, Germany, 1988, pp. 1–19.
5. H. Wegmann. A General Capacity Formula for Unsignalised Intersections. In *Intersections Without Traffic Signals II* (W. Brilon, ed.), Springer-Verlag, Berlin, Germany, 1991, pp. 177–191.
6. R. J. Troutbeck. Traffic Interactions at Roundabouts. *Proc., 16th Australian Road Research Board Conference*, Vol. 16, No. 5, 1990, pp. 17–41.
7. R. J. Troutbeck. *Evaluating the Performance of a Roundabout*. Special Report 45, Australian Road Research Board, Victoria, 1989.
8. W. Kittelson and M. Vandehey. Delay Effects of Driver Gap Acceptance Characteristics at Two-Way Stop-Controlled Intersections. In *Transportation Research Record 1320*, TRB, National Research Council, Washington, D.C., 1991.
9. R. J. Troutbeck. *Overtaking Behaviour on Australian Two-Lane Rural Highways*. Special Report 20, Australian Road Research Board, Victoria, 1981.
10. W. Brilon. Recent Developments in Calculation Methods for Unsignalised Intersections in West Germany. In *Intersections Without Traffic Signals* (W. Brilon, ed.), Springer-Verlag, Berlin, Germany, 1968, pp. 111–153.
11. J. Harders. Grenz- und Folgezeitlücken als Grundlage für die Leistungsfähigkeit von Landstassen. (Critical Gaps and Move-Up Times as a Basis of Capacity Calculations for Rural Roads.) Schrifteneihe Strassenbau und Strassenverkehrstecknik, Heft 216, 1976.
12. *Special Report 209: Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1985.
13. *Guide to Traffic Engineering Practice. Part 6—Roundabouts*. AustRoads, Sydney, Australia, 1993.
14. J. Harders. Die Leistungfähigkeit nicht signalgeregelter städtischer Verkehrsknoten. (*The Capacity of Unsignalized Urban Intersections*.) Schriftenreihe Strassenbau und Strassenverkehrstechnik, Heft 76, 1968.
15. D. W. Bennett. Elementary Traffic Flow Theory and Applications. In *Traffic Engineering Practice*, 3rd ed. (K. W. Ogden and D. W. Bennett, eds., Monash University, Melbourne, Australia, 1984.
16. J. R. Jarvis. In-Service Vehicle Performance. *Proc., Society of Automobile Engineers/Australian Road Research Board 2nd Conference on Traffic Energy and Emissions*, Melbourne, 1968, pp. 21.1–21.15.
17. R. J. Troutbeck. *Estimating the Critical Acceptance Gap from Traffic Movements*. Physical Infrastructure Centre Report 92-5. Queensland University of Technology, Australia, 1992.
18. R. M. Kimber. *The Traffic Capacity of Roundabouts*. Laboratory Report 942. U.K. Transport and Road Research Laboratory, Crowthorne, Berkshire, England, 1980.

Publication of this paper sponsored by Committee on Highway Capacity and Quality of Service.