21st Australasian Transport Research Forum
Adelaide, September 1997

Negative Effects of Speed Control Devices on Vehicle and Pedestrian Flow Characteristics

K S Weerasekera
School of Civil Engineering
University of New South Wales

Peter Hidas
School of Civil Engineering
University of New South Wales

Michael C Dunne
School of Civil Engineering
University of New South Wales

Abstract:

This paper describes a research study conducted at the University of New South Wales, Australia, that investigated previously unknown effects of speed control devices on fundamental characteristics of traffic, such as vehicle headways, pedestrian crossability, absorption capacities and average delays to vehicles from driveways attempting to enter the main stream of traffic. Headway data were collected, under various levels of traffic flows and at various distances from the devices, from seven sites in the Sydney Metropolitan Area. In excess of 420,000 headways were analysed using automatic macro functions developed for this purpose in Visual Basic. The results demonstrate the traffic calming devices to have an impact on vehicle headway distributions, and on pedestrian and vehicle crossability, and average delays to vehicles entering from side-streets and driveways. The extent of this impact varies mainly with the distance from the device and the traffic flow. The effects are maximum at locations just before and after the devices and gradually decrease with the distance from the devices at all traffic flows but the magnitude of these effects also increases with flow. This study revealed that some previous claims about the seriousness of such effects were largely exaggerated and these disbenefits are small compared to the benefits achieved by these devices by way of speed and accident reductions. This paper provides an overview of the research objectives, the survey and analysis methods, and a comprehensive presentation and interpretation of the results and conclusions of the study.

Contact Author:

Peter Hidas
School of Civil Engineering
University of New South Wales
Sydney NSW 2052

telephone: (02) 9385 5988 fax: (02) 9385 6139
email: P.Hidas@unsw.edu.au

Introduction

Traffic calming was originally developed in the Netherlands under the well-known term '*woonerven*' during the late 1960s and early 70s. Since then it has been developed much further and many countries have successfully adapted these schemes with various modifications to suit their local conditions. Russel and Pharaoh (1990) saw traffic calming as 'the attempt to achieve calm, safe and environmentally improved conditions on streets' by way of a variety of measures such as removal of extraneous traffic, vehicle speed reduction, measures aimed to improve the safety of pedestrians and drivers, enhancements of the street environment and encouragement to motorists to drive calmly.

To achieve these desirable conditions in Australia various physical speed control measures such as vertical (speed humps, raised platforms) and horizontal (slow points and mid block islands) displacement devices have been successfully applied. Vertical displacement devices were originally applied in local residential streets where traffic volumes are low and environmental conditions are of prime importance but late last decade the usage was extended and they are now increasingly used on major routes through activity areas such as commercial centres or country town roads.

Numerous studies have been conducted to test the effectiveness and impacts of these devices on traffic conditions (Watts 1973; Sumner and Baguley 1978, 1979; Jarvis 1980, 1981; Taylor and Rutherford 1986). Previous studies have been conducted on vehicle speeds, journey times, accident rates, traffic flow changes, noise levels and community reactions to these devices. These studies have shown that speed control devices have large benefits to the community by way of reduction in speed and accidents but that there are a few minor disbenefits by way of increased travel times and noise and pollution in the vicinity of the devices (Sumner and Baguley 1979; Sumner *et al* 1978; Van Every and Holmes 1992). There have also been occasional contradictory views by residents living near these devices concerning increase in delays to vehicles entering from driveways and delays to pedestrians in their crossing attempts near these devices (Holdsworth 1992; Mostyn 1992). Some authors have tried to attribute these negative effects to changes in the traffic stream caused by the speed control devices. But there is no evidence currently available to support or reject this assumption. This research investigates the effects of speed control devices on some fundamental characteristics of traffic. It should be stressed that this study is not directed against physical speed control devices, but is an attempt to investigate and quantify some of the minor disbenefits caused by the devices.

Methodology

Pilot study

First a pilot study was conducted around a mid-block speed control device to observe the effect on headway distributions of the device. As shown in Figure 1, the vehicle headways were measured at two locations (Location 1 - 75 metres before the speed control device, and Location 2 - 10 metres after the speed control device) using two video cameras The results indicated a small positive "shift" in the headway distribution after the device as shown in Figure 2 This is evidence that there would be consequent changes in other characteristics of the traffic such as average delays to vehicles at driveways, absorption capacities of minor roads, pedestrian crossabilities and crossing delays etc Based on the pilot study results it was decided to carry-out detailed studies near these devices on a larger scale

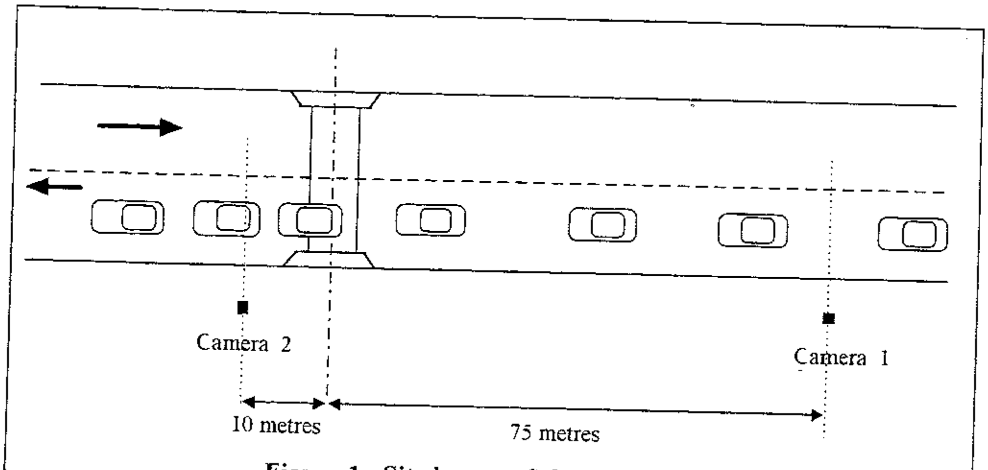


Figure 1 Site layout of the pilot study

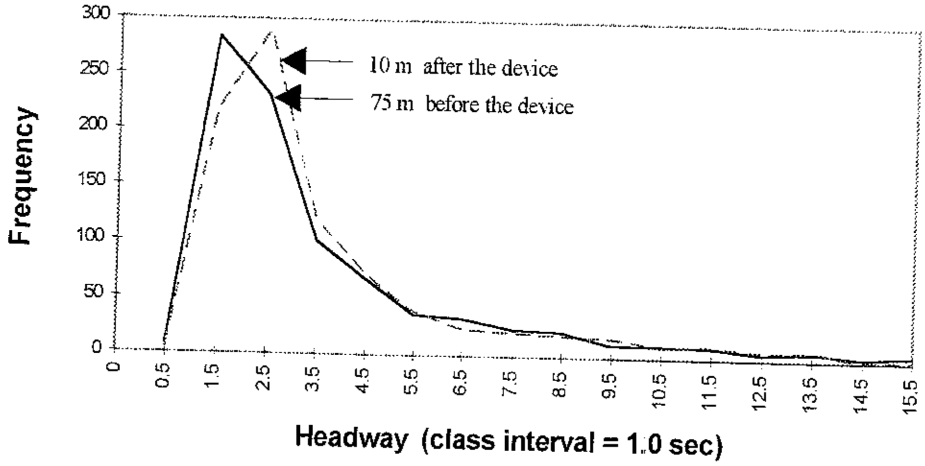


Figure 2 Headway distributions (before and after the speed control device) for 1.0 second class intervals (mid-points of class intervals in seconds are shown on the horizontal axis)

Detailed Surveys

Vehicle headway data were collected at seven survey sites in the Sydney metropolitan area where all the survey sites were mid-block speed control devices (either raised platforms, speed humps or mid block islands) with high uninterrupted traffic flows and minimum interference from parking, frontage land use and pedestrian activity and without any interference from turning traffic in the vicinity

With the help of two VDAS 3000 data loggers (Fraser, 1981) connected to four treadle switches vehicle headway measurements were collected at four points before the device and four points after the device at 30 metre intervals as shown in Figure 3 All the surveys were performed with this site layout for a duration of 11 hours starting from 7:00 AM to ensure consistency of the results

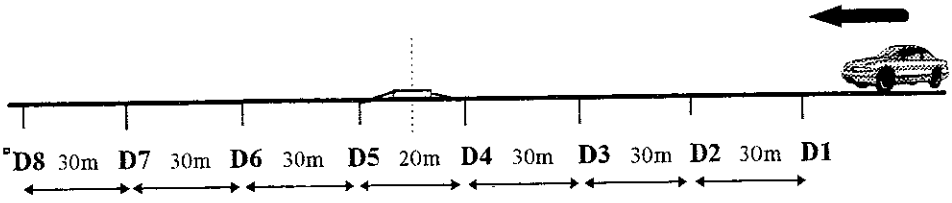


Figure 3 Layout of the detailed surveys

To investigate the effects of the devices under different traffic flows, the survey data were classified into increments of 100 vph traffic flows and separately analysed To obtain these 100 vph traffic flow ranges the total headway data sample was separated into 5 minute intervals and the flow rates for each of these 5 minute samples were calculated and the samples were regrouped into 100 vph traffic flow ranges

This study consisted of analysing more than 420,000 vehicle headways collected from the seven survey sites (through 8 observation points at each site) The analysis of this large amount of data was carried-out in Microsoft Excel spreadsheets, using macro functions written in Visual Basic

Data analysis

Headway distributions

The vehicle headway distributions were investigated for 0 5 second and 1 0 second class intervals for different levels of traffic flows at the eight observation points D1 to D8 indicated in Figure 3 When comparing the headway distributions, perceivable changes could be observed at different distances from the device The changes became more pronounced at points closer to the device The biggest change always occurred just before and just after the device (i e , at D4 and D5) and the distribution at D8 approached the original distribution at D1 The changes in these distributions at different distances from the device (D1 to D8) and the variation with vehicular flow rates were studied and the statistical significance of these differences were checked

Average delays to vehicles at driveways

Average delay is the average time a driver is expected to spend at a driveway waiting to enter the main stream of vehicles on the major road It is a function of the major road flow and it is also influenced by the nature of the headway distribution on the major road

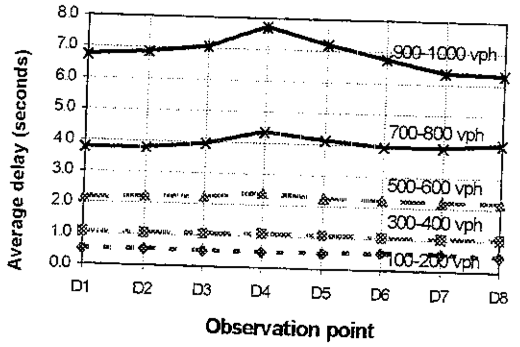


Figure 4 Change in average delays

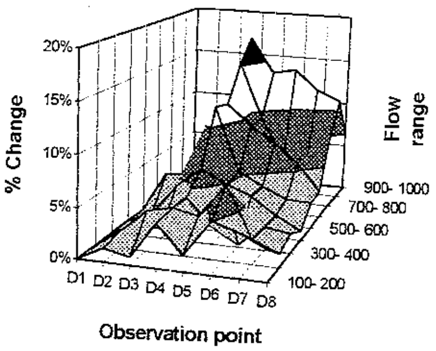


Figure 5 Percentage change in average delays

Average delays were calculated at each observation point for each traffic flow level separately, using Tanner's model (Tanner, 1962) [see Appendix] When using Tanner's formula a critical gap of 4 seconds and a move-up time of 2 seconds for the minor road vehicles were assumed Figure 4 shows the absolute changes and Figure 5 shows the percentage increase in average delays at Wardel Road, Dulwich Hill It can be seen that at flows over 600 vph there is a noticeable increase in the average delays to vehicles from driveways around the device and that the increase is more pronounced at higher flows The spatial extent of the effect also seems to be dependent on the flow level: at high flows the increase in average delay near the device extends 30 to 50 metres from the device, while it quickly approaches the original value at lower flows Further calculations indicate that the behaviour in average delay values was similar at all other survey sites and that, at all seven survey sites the increase in average delay near the device was less than 3 seconds at all flow levels

Absorption capacities

The term 'absorption capacity' means the maximum possible flow (or arrival rate) that can enter or cross a major flow from a minor approach such as the leg of a T-intersection or from a driveway

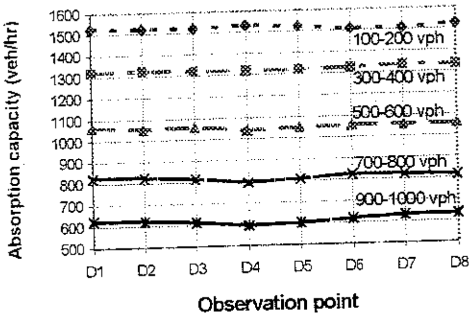


Figure 6 Change in absorption capacities

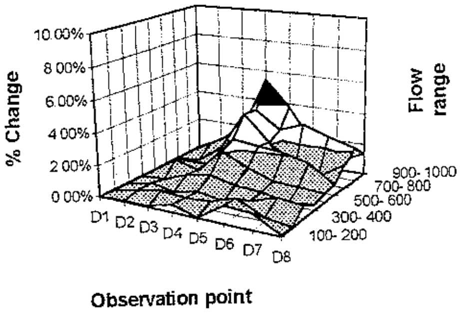


Figure 7 Percentage change in absorption capacities

Absorption capacities at different distances for different flow levels were calculated using Tanner's model (Tanner, 1962) [see Appendix]. The results for all seven sites showed a decrease in the absorption capacity near the device. The magnitude of decrease increases slightly with the flow, but this change is not as prominent as for the average delays. Figure 7 indicates the percentage change in absorption capacity, and for better illustration the percentage decrease in absorption capacity is indicated as positive in this diagram. Figures 6 and 7 show that at flows over 700 vph there is a noticeable decrease in the absorption capacities around the device and that the decrease is more pronounced at higher flows up to about 900 vph while at very high and very low flows the change is not as marked. The spatial extent of the effect seems to be dependent on the traffic flow level.

The maximum percentage changes in the absorption capacity are less than 5% at all traffic flow levels. This indicates that the impact of the devices on absorption capacity may be minor. The statistical significance of these differences will be tested in the section 'Statistical tests'.

Analysis of crossability

The opportunities for pedestrians to cross a stream of traffic in one direction may be quantified using the data on time gaps in the traffic. From the headway distribution data the total proportion of a given period of time that is available for pedestrians to cross safely one lane of traffic in one direction can be calculated. This proportion expressed as a percentage is called the 'crossing opportunity index' (Westerman *et al.* 1989).

The crossing opportunity index (COI) is calculated as follows :

$$COI = \frac{\sum I^1}{\text{Length of survey}} \times 100$$

where;

$$I^1 = I_g - K \qquad \text{if } I_g > K$$

$$I^1 = 0 \qquad \text{otherwise}$$

I_g = Time gap between vehicles (a gap is defined as the time difference between the passage of the rear axle of a vehicle and the passage of the front axle of the next vehicle at a particular point)

K = Minimum crossing time (ie, minimum time required to cross the lane at a particular crossing speed including reaction time of the pedestrian), i e

= $I + R_T$, where

I = Minimum time required to cross a single lane of traffic at a particular crossing speed

R_T = Pedestrian reaction time

In the calculation of crossing opportunity index the first step is to determine the length of every time gap in the survey period, and to deduct the minimum crossing time from it The negative values are discarded (because a negative value indicates insufficient time to cross) and the positive values aggregated This total is then divided by the length of the survey period and expressed as a percentage

The calculation of the crossing opportunity index involves comparing the time gaps between individual vehicles in one lane with the critical gap required for a pedestrian to cross the road The length of the critical gap is variable, depending on the walking speed and the reaction time of the pedestrian The crossing speed of pedestrians varies considerably with the individual abilities of people To obtain a more complete picture of the crossing opportunities. the following three levels of pedestrian crossing speeds were used in this study:

1) A jog across the street at 8 km/h (2 1 m/s)
2) A normal walk across at 5 km/h (1 4 m/s)
3) A slow walk across at 2 km/h (0 5 m/s)

Crossing opportunity indices are calculated for the 8 detectors separately at each survey site and for each flow range Figure 8 shows the crossing opportunity indices calculated for different traffic flow ranges for a normal crossing speed of 5 km/h at Wardel Road, Dulwich Hill Figure 8 shows that by far the most important factor in the value of the crossing opportunity index is the flow level, but at flows over 500 vph there is a noticeable decrease in the crossing opportunity index around the device and that the decrease is more pronounced at higher flows The spatial extent of the effect also seems to be dependent on the flow level: the decrease at the highest flow range persists at 100m after the device, while it quickly approaches the original value at lower flows This same trend of the crossing opportunity indices was observed at all other survey sites The tests to check the statistical significance of these differences were performed and the results are summarised in the next section

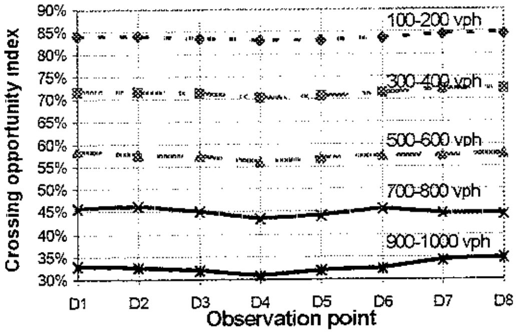


Figure 8 Variation of crossing opportunity indices, Wardel Road

Statistical tests

Differences of headway distributions

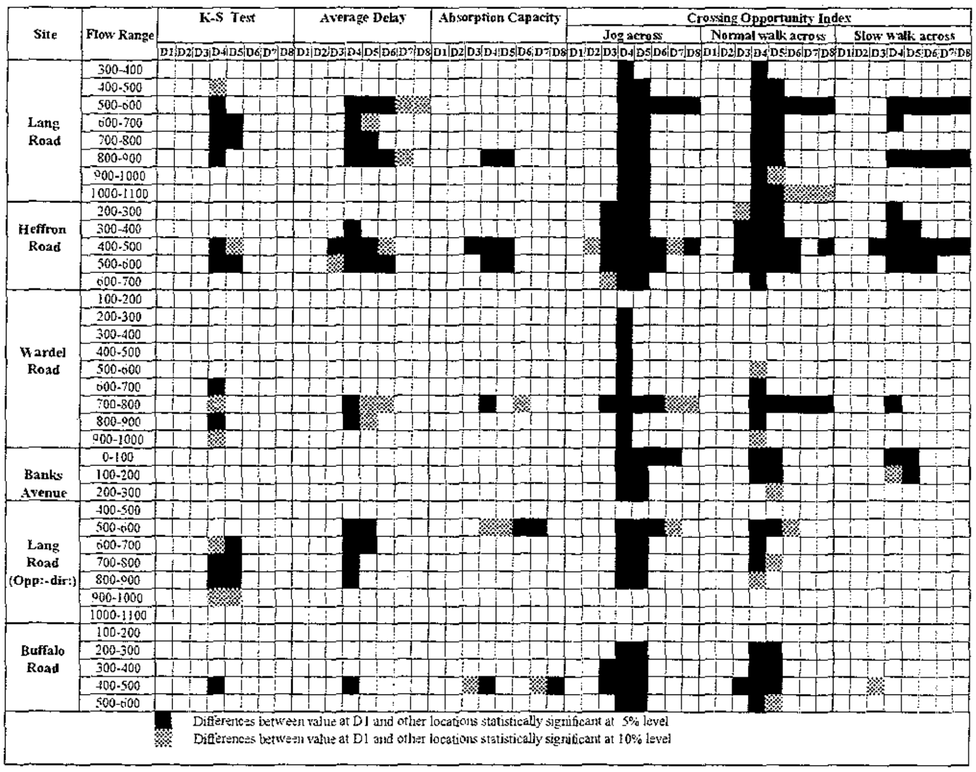
The differences in the headway distributions (mainly at the observation points closer to the devices) were investigated statistically to observe the level of significance of the differences An assumption is that the first observation point (D1) is sufficiently remote from the device so that the flow characteristics are not influenced by the device at this point This assumption seems to be justified from the previous speed profile studies conducted around these types of devices (Taylor and Rutherford 1986; Macdonald 1995) Also it was noted during the field observations at all the survey sites that the earliest application of brakes occurred about 75 metres from the device

K-S two-tail two-sample test : The differences between the headway distributions at the first observation point, and those at other observation points were checked by the Kolmogorov-Smirnov two-tail two-sample test These tests provide a direct comparison of the distributions without making any assumptions about the type of the distribution (Siegel 1956). The results obtained are summarised in Figure 9 at the end of this paper

In the comparison of headway distributions the Kolmogorov-Smirnov tests revealed statistically significant differences at a 5% level for traffic flows in the range 500 to 900 vph but not at lower and higher traffic flows (see Figure 9) The statistically significant differences occurred only just before and after the device

Randomised block design

The statistical significance of the differences in average delays to vehicles at driveways, absorption capacities and crossing opportunity indices between the first (D1) and the other observation points (D2 to D8) was investigated using the technique of analysis of variance (ANOVA) Since the large samples at different traffic flow ranges are made up of 5 minute independent samples. these 5 minute samples were considered as separate blocks in the ANOVA tests Randomised block design was applied to these 5 minute independent samples and subsequently Tukey's and Scheffee's tests (Neter *et al* 1996) were used to identify the observation points which are different from D1 at 5% and 10% levels of significance The results are summarised in Figure 9



■ Differences between value at D1 and other locations statistically significant at 5% level
▨ Differences between value at D1 and other locations statistically significant at 10% level

Figure 9 Summary of statistical tests

Validation of results

During this study the surveys were repeated at 3 sites (repeat surveys had the same site layout and survey duration) one year after the initial surveys to check on the repeatability of the results The repeat surveys produced results of the same order (for average delays to vehicles at driveways, absorption capacities of minor roads and crossing opportunity indices) leading to the same conclusions No field measurements were conducted of average delay to vehicles at driveways or pedestrian delays near the devices. due to difficulties of obtaining adequate samples at different flow levels and at different distances from the devices to compare with the computed results To obtain an adequate number of field measurements near these devices under these different conditions is far beyond the scope of this study

Conclusions

The results of this study confirm that physical speed control devices do have an impact on vehicle headway distributions, which causes changes in pedestrian and vehicle crossabilities, and average delays to vehicles trying to enter the main flow from driveways These effects are maximum near the devices and their effects gradually reduce when the distance from the device increases. These effects also increase with the traffic flow levels and are statistically significant at higher flows at locations near the devices

The impacts on pedestrian crossabilities are the most affected and absorption capacities are the least affected Impacts on pedestrians with higher crossing speeds are greater than for lower crossing speeds There are statistically significant decreases in pedestrian crossing opportunities at the 5% level for almost all traffic flows between 200 to 1000 vph at locations just before and after the devices for higher and normal crossing speeds

The difference in average delays for vehicles at driveways are statistically significant at the 5% level for traffic flows between 500 to 900 vph confined to sections of 30 to 50 metres around the devices The maximum absolute differences in average delays at these seven sites is less than 3 seconds at any flow level

Absorption capacities are the least affected by these devices and at all sites the maximum difference in them between any two points at any flow level never exceeds 50 vph The decrease in absorption capacity when expressed as a percentage change from the first observation point, was always less than 6% at all sites even for flow levels above 500 vph

The results of this study confirm that physical speed control devices have certain negative side-effects on traffic flow characteristics which may be important for road users, particularly for pedestrians, and that for medium to high traffic flows these effects are significant in statistical terms, but in practical terms the magnitudes of these negative effects are minor These minor disbenefits to pedestrian and drivers are confined to 30 to 50 metres around the devices and are outweighed by the benefits offered by these devices by way of reducing speeds and accidents An important conclusion of this study is that physical speed control devices can be used in traffic calming schemes without environmental detriment to pedestrians and drivers up to flows of 1000 vph, and some further consideration is needed at higher flows This study provides sufficient information to eliminate some unsubstantiated criticisms of these devices when used in traffic calming schemes where the traffic flows are well below 1000 vph

It was noted during this study that there appear to be no previous studies on critical gaps for vehicles leaving driveways including the case of vehicles reversing onto main roads from driveways Data collection in this area may be a topic for further research

Acknowledgement - The authors wish to thank Professor Jim Douglas for his assistance and guidance in the statistical analyses of this study

Appendix

Tanner's Results

Average delay ($\overline{w_2}$)

Tanner's formula for the average delay ($\overline{w_2}$) to minor road vehicles due to the vehicles on the major road, when the system is in statistical equilibrium is as follows :

$$\overline{w_2} = \frac{0.5\,E(y^2)/Y + q_2\,Y\exp(-\beta_2 q_1)[\exp(\beta_2 q_1) - \beta_2 q_1 - 1]/q_1}{1 - q_2 Y[1 - \exp(-\beta_2 q_1)]} \qquad \text{-------} \; (1)$$

where:

y = block length

$Y = E(y) + 1/q_1$

$$E(y) = \frac{\exp\{q_1(\tau - \beta_1)\}}{q_1(1 - \beta_1 q_1)} - \frac{1}{q_1}$$

$$E(y^2) = \frac{2\exp\{q_1(\tau - \beta_1)\}}{q_1^2(1 - \beta_1 q_1)^2}[\exp\{q_1(\tau - \beta_1)\} - \tau q_1(1 - \beta_1 q_1) - 1 + \beta_1 q_1 - \beta_1^2 q_1^2 + 0.5\beta_1^2 q_1^2/(1 - \beta_1 q_1)]$$

q_1 = arrival rate on major road
q_2 = arrival rate on minor road
β_1 = minimum following time of major road vehicles
β_2 = move-up time of minor road vehicles
τ = critical gap (minimum headway in the major road traffic acceptable to minor road traffic, and is greater than β_1)

For a single vehicle at a driveway since there is no queuing in the driveway so that $\beta_2 = 0$ The minor road traffic flow, which is the flow from the driveway can also be taken as zero, i e $q_2 = 0$

Then equation (1) reduces to

$$\overline{w_2} = \frac{\exp[q_1(\tau - \beta_1)]}{q_1(1 - \beta_1 q_1)} - \tau - \frac{[1 - \beta_1 q_1 + \beta_1^2 q_1^2]}{q_1(1 - \beta_1 q_1)} + \frac{0.5\beta_1^2 q_1}{(1 - \beta_1 q_1)^2} \qquad \text{-----} \; (2)$$

Absorption capacity of minor road

For infinite delays the denominator of $\overline{w}_2$ in equation (1) tends to zero as q_2 increases Hence the greatest flow that can pass on the minor road under the assumed conditions is:

$$q_2(\max) = \frac{q_1(1-\beta_1 q_1)}{\exp[q_1(\tau-\beta_1)][1-\exp(-\beta_2 q_1)]} \qquad ---- (3)$$

References

Fraser, P J (1981) The ARRB Vehicle Detector Data Acquisition System (VDDAS), *Australian Road Research Board Technical Manual ATM No 12*, May 1981

Holdsworth, G R (1992) Evaluation of Local Area Traffic Management schemes - The Trouer's Ditch experience in the city of Brindlecome, *Roadbuilder and Construction Equipment Journal*, April 1992

Jarvis, J R (1980) The off-road testing of road humps for use under Australian conditions, *Proceedings of the 10th Australian Road Research Board Conference*, 10 (4), 293-305

Jarvis, J R (1981) Towards the use of road humps on public roads in Australia, *Local Area Traffic Management Seminar*, Royal Melbourne Showgrounds, Ascot Vale. June 1981

Macdonald, G (1995) Quantifying vehicular user behaviour, *Paper presented at the 7th World Conference on Transport Research*. Sydney 1995

Mostyn. S (1992) One small hump - a mountain of worry, An article published in the *Sydney Morning Herald of 6th October 1992*

Neter, J, Kutner, M H, Nachtsheim, C J and Wasserman, W (1996) *Applied Linear Statistical Models*, Richard D. Irwin, Inc, US

Russell, J and Pharaoh, T (1990) Speed management and the role of traffic calming in road safety, *Research Paper No. 35 Department of Town and Country Planning*, Heriot-Watt University: Edinburgh

Siegel, S (1956) *Nonparametric Statistics for the Behavioural Sciences*, McGraw-Hill Book Company, NY

Sumner, R, Burton, J and Baguley. C (1978) Speed control humps in Cuddesdon Way. Cowley, Oxford, *TRRL Supplementary Report SR 350*, Transport Research Laboratory. Crowthorne

Sumner, R and Baguley, C (1978) Speed control humps in Norwich and Haringey. *TRRL Supplementary Report SR 423*, Transport Research Laboratory, Crowthorne

Sumner, R and Baguley, C (1979) Speed control humps in Kensington and Glasgow, *TRRL Supplementary Report SR 456*, Transport Research Laboratory, Crowthorne

Tanner, J C (1962) A theoretical analysis of delays at an uncontrolled intersection. *Biometrika*. 49 (1-2), pp 163-170

Taylor, M A P and Rutherford, L M (1986) Speed profiles at slow points on residential streets, *Proceedings of the Australian Road Research Board*, 13 (7-9)

Van Every, B and Holmes, M (1992) Local Area Traffic Management: effects on the environment. engineering and the environment, *Local Government Engineering Conference*, Adelaide, 18-19 March, 1992, Department of Transport, Adelaide

Watts, G R (1973) Road humps for the control of vehicle speeds, *Transport and Road Research Laboratory Report 597*, TRRL, UK

Westerman, H, Black, J A, Lukovich, T and Allan, A (1989) Environmental adaptation of sub-arterial shopping strings ; towards preliminary guidelines, 89/2, *The Environmental Planning & Management Series, University of New South Wales, Australia*