MONASH University
Accident Research Centre

FACTORS AFFECTING CRASHES AT SIGNALISED INTERSECTIONS

by

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Abstract:
This report presents the results of a study of signalised intersections in Melbourne, focussing on the differences in site and operational characteristics between sites with a "high", "normal" and "low" accident frequency over the 5 years 1987-91, based upon an analysis of accident data and entering traffic volumes. The study indicated that the majority of the variation in accidents was not explained by traffic volumes, but by other factors. While no single factor was identified which would lead to a dramatic improvement in safety at signalised intersections, a range of measures were identified which would likely contribute to improved safety if applied at specific sites where relevant.

Key Words:
(IRRD except when marked*)
Signalised intersection, accident analysis, traffic flow, site investigation, traffic safety, collision, research report

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EXECUTIVE SUMMARY

In 1992-93, MUARC undertook a comprehensive study of crash patterns at signalised intersections in Victoria (Ogden and Newstead, 1994). One of the outcomes of that study was a recommendation that further work be done, focussing on a detailed examination of sites with a poor crash record. This recommendation was accepted, and this report presents the results of that study.

It is reasonable to suppose that, all else being equal, the more traffic that an intersection carries, the more accidents will occur there. Therefore, any analysis of the factors contributing to crashes at a signalised intersection must take account of the traffic flow. This project takes account of this factor explicitly, by considering those sites which had both higher and lower accident frequencies than might be expected on the basis of variations in accident frequency due to traffic flows alone.

Data were collected for a range of sites with a poor accident record, for which VicRoads had traffic data for the number of entering vehicles. For comparison, a range of nearby sites with a better accident record was also included in the data base.

Analysis of the data indicated that about 21 per cent of the variation in accidents was statistically explained by variations in traffic flow. Thus, the majority of the variation in accidents is explained by other site or operational factors.

Details of a range of site characteristics were obtained, and analysis was performed on the basis of three intersection groups: those which, in relation to the volume of entering traffic, had a "high", "normal" or "low" accident frequency over the 5 years 1987-91.

The results of this analysis are that factors other than just traffic volumes are contributing to accidents at signalised intersections. However, the study was not able to identify any single prime factor which would lead in itself to a dramatic improvement in safety at signalised intersections. Nevertheless, based on this and previous studies, a range of strategies or measures was identified which, if applied at specific sites where appropriate, will contribute to safety. These include:

- particular attention to sites with an upgrade approach
- potential for the use of coloured or textured pavements on approaches
- potential for use of skid resistant pavements
- continued use of fully controlled right turns where the relevant guidelines are met
- potential for active detection of the approach of a heavy vehicle
- selective use of active advance warning saying "prepare to stop" or similar
- continued use of mast arms where the relevant guidelines are met
- use of exclusive right turn lanes where space exists or can be cost-effectively provided
- avoidance of use of narrow lanes at intersections where possible
- provision of a median where possible

- recognition of a reduction in conspicuity created by visual "noise" (e.g. advertising)
- recognition of the effect of complex decision environments on driver performance
- conversion of signals to roundabouts where relevant guidelines are met

The study also suggests that:

- research be conducted on driver perception on approach to a signalised intersection
- an educational campaign highlighting signalised intersections as "the most dangerous site on the road" be considered
- Traffic flow data be collected for those signalised intersection sites with very high accident frequencies, so that a further study of these sites could be undertaken; at present this information is not available.

The key is that those responsible for the design and operation of signalised intersections carefully appraise each site on its merits, have regard to known accident characteristics of signalised intersections, and apply sound and judicious engineering judgement to determine what particular features will likely contribute to safety at that site. The above recommendations will be useful in this regard.

FACTORS AFFECTING CRASHES AT SIGNALISED INTERSECTIONS

1. Introduction

In 1992-93, MUARC undertook a comprehensive study of crash patterns at signalised intersections in Victoria (Ogden and Newstead, 1994). This was envisaged as the first stage of a possible multi-stage program of research into crashes at signalised intersections, and as such, one of the products of that work was a set of proposals for further research which would have the potential to make a significant contribution to improved safety at signalised intersections. These proposals were in five categories, as follows:

- detailed examination of sites with a poor crash record,
- pedestrian safety at signalised intersections,
- alcohol impaired drivers and traffic signals,
- driver information processing and decision making, and
- specific site-related studies.

Subsequent to the completion of this first phase, MUARC was directed to continue its work on safety at intersections, initially by focussing on the first of these five areas.

The recommendation in the earlier report was as follows:

> "The analysis has clearly shown that some sites have a poor crash record. There is nothing yet known about whether there are specific reasons for that poor record. An obvious initial step is to relate crashes to exposure measures, in particular traffic flow; this information is available for many intersections from SCRAM data. Other physical features may be examined - lane configuration, size of intersection, complexity of movements, etc....
>
> It is suggested that a detailed analysis of about 50 of the worst 100 sites be conducted, and their characteristics compared with a control sample. Some of the information will be available from the data set used in the present study, other data would be required from VicRoads, and site investigations would be required."

Specifically, the objectives of the study were:

- to analyse crash patterns at signalised intersections with a poor crash record and compare these with a suitable sample of other signalised intersections,
- to determine traffic flows and examine physical features of both sets of sites and compare characteristics,
- hence to identify any generic features or characteristics which are associated with a poor safety performance, and
- to make recommendations about safety measures which may be adopted to reduce the number and/or severity of crashes at signalised intersections.

It is reasonable to suppose that, all else being equal, the more traffic that an intersection carries, the more accidents will occur there. Therefore, any analysis of the factors contributing to crashes at a signalised intersection must take account of the traffic flow. This project takes account of this factor explicitly, by considering those sites which had both higher and lower accident frequencies than might be expected on the basis of variations in accident frequency due to traffic flows alone.

This report details the results of these investigations. Section 2 presents the results of a small, highly focussed literature review specifically concerned with the subject matter of this project. (A comprehensive literature review on safety at signalised intersections was undertaken during the first phase (Ogden and Newstead, 1994)).

Section 3 details the data sources, in relation to accident data at specific sites, traffic flow data for those sites, and the collection of field data.

Section 4 then outlines how the data were analysed to identify sites for subsequent analysis. Basically, accident frequency for a site was plotted against traffic flow (sum of entering flows) at that site, and on this basis, sites were categorised into three groups, "normal" (where the accident frequency was closer to a line of best fit through the accident-flow data), "high" and "low" (where accident frequency was above or below what might be expected on the basis of the accident-flow curve.)

Section 5 then presents the results of the analysis, in terms of detailed site differences between the three categories established in Section 4.

2. Accidents at Signalised Intersections

The previous report in this study (Ogden and Newstead, 1994) included a comprehensive literature review of the factors associated with accidents and safety at signalised intersections. It is therefore not necessary to repeat that treatment here. However, it is useful to report in overview form those factors which have been found to be particularly associated with accidents at signalised intersections as these may assist in focussing on data needs and in providing insights into data analysis. We therefore report here in overview form a summary of what is generally known or believed about the influence of a range of factors on safety at signalised intersections.

Controlled right turns

Fully controlled right turns are effective in reducing crashes at signalised intersections, especially right-through crashes. Partially controlled right turns, in which right turners may filter through opposing traffic before or after having an exclusive phase, have not been shown to be (Bui, Cameron and Foong, 1991; Corben, Ambrose and Foong, 1990; Parsonson, 1993; Craven 1985).

Leading right turns

Controlled right turns should preferably use a leading right turn (i.e. the right turn phase should be introduced before the through movement phase) to reduce the risk of a through vehicle driver running the red and colliding with a right turning vehicle. (Triggs, 1981; Howie and Oulton, 1989).

Inter-green times

Increasing the inter-green times, including the provision of an all-red interval, reduces crashes, but the long-term effects on driver behaviour (i.e. whether drivers have a greater tendency to run the red if they know that there is a long inter-green time) are not understood. (Triggs, 1981; Stein, 1986; Cairney, 1988).

Advance warning

The provision of advance warning to the motorist of an impending change to a red phase can be effective when the signals are not visible until late in the approach, e.g. if they are over a crest or around a curve. This provision should be used selectively so that their effectiveness is not diminished by over-use. (Eck and Sibra, 1985; Howie and Oulton, 1989).

A variation is to actively detect vehicles which are travelling at a speed which will put them in the dilemma zone (i.e being able to neither stop comfortably before the stop line nor clear the intersection before the onset of red). A short extension of the inter-green time can then be called up. There is little documentation on the effectiveness of such a practice (Zegeer and Deen, 1978).

Red light cameras

Red light cameras can have an effect on accidents, especially right angle accidents, if motorists who may otherwise run the red perceive that there is a risk of detection (South, et al, 1988).

Provision of mast arms

Overhead mast arms, which mean that the driver receives plenty of advance warning of the presence of the intersection as well as a more conspicuous display, has safety advantages (Bhesania, 1989; Parsonson, 1993).

Skid resistant pavements

The provision of skid resistant pavements on the approach to a signalised intersection has a positive effect on safety (Kumar and Cunningham, 1992).

Sight distance

Restricted sight distance to approaching vehicles reduces the time available to a driver to assess speed and trajectory of the approaching vehicle. Therefore, increasing the sight distance through the provision of overhead mast arms or advanced warning devices (see above), or the installation of fully-controlled right turns are effective strategies (Corben and Foong, 1990).

Bends

Similarly, drivers are less able to judge the speed and trajectory of vehicles if they approach along a horizontal curve, so once again a fully controlled turn arrangement is likely to be effective (Corben and Foong, 1990; Parsonson, 1993).

Number of opposing lanes

Gap selection is more challenging if there are multiple opposing lanes, so full control is more likely to be justified if there are three or more opposing lanes (Corben and Foong, 1990).

Gradient

Grades affect both the braking ability of vehicles and the visibility of the intersection and approaching traffic. Intersections with grades (especially uphill approaches) are more likely to have a higher accident problem (Corben and Foong, 1990).

Traffic characteristics

Although no explicit indication was found that would indicate a relationship between traffic characteristics (e.g. proportion of trucks and buses, usage of the intersection by pedestrians and cyclists), it would be reasonable to suppose that these might be factors which could affect the accident history and accident patterns at a site.

Environment

Similarly, the environment at a site might be expected to have an influence on accident patterns. Aspects such as the orientation of an approach with respect to the setting or rising sun are commonly supposed to have an influence (Corben and Cunningham, 1989). Local environment factors such as land use, the presence or otherwise of bus and tram stops, the existence of service roads to serve abutting land uses, and the presence of parked vehicles (e.g. parking controls such as a clearway) might be expected to be influential.

3. Data Sources and Site Selection

As discussed in Section 1, three types of data were needed for this study:

- accident data
- traffic flow data
- field data

3.1 Accident Data

The accident data used for this study were the same as those used for the previous phase, i.e. information from the Victorian Road Accident Data Base maintained by VicRoads, for the 5-year period 1987-1991. This data base included crashes which occurred at a signalised intersection, or within 100 m of such an intersection.

Since the eventual purpose of this research is to develop countermeasures which may be applied to reduce the number of crashes at signalised intersections, the first step in analysing the data was to identify the worst sites, i.e. those having the most crashes over the study period.

In this way, 232 sites were identified, these being all of those signalised intersections with 16 or more accidents recorded for the five year period 1987-91.

3.2 Traffic Flow Data

For the sample of 232 sites, it was then necessary to establish which of these had reliable traffic flow data available. VicRoads does not routinely collect traffic flow data. However, at signalised intersections, the SCRAM traffic signal control system allows such data to be collected. This system is invoked from time to time for specific purposes, e.g. traffic planning, transport project evaluation, etc. Data from any such collections are maintained by VicRoads' Information Services Department.

Thus, the Information Services Department was sent the list of 232 sites and upon interrogation of their files determined that 55 of these sites had traffic flow data for all approaches.

These data basically enabled a good estimate to be made of approach flows on all legs. They did not in general isolate turning volumes separately. They included notation as to "special days", e.g. school holidays, enabling data for any day that was clearly anomalous to be excluded. In this way, estimates of the average daily entering volumes for the 55 sites were extracted and made available to MUARC for analysis.

This gave data on traffic flows at sites with a poor crash record. It was necessary also to consider sites which did not have a high accident frequency. Accordingly, each of the 55 sites isolated above was examined, and if there was an adjacent intersection which also had reliable traffic flow data (as outlined above), this was added to the sample. There were 21 such sites.

This sample of 76 intersection sites thus constituted the data base for the study. Data for these sites are presented in Section 4.

3.3 Site Data

The third data need related to site characteristics. Based upon the literature review and professional judgement, a list of measurable, quantifiable variables which could be potentially related to signalised intersection safety was developed. These variables are listed in Table 1, which is a reproduction of the field survey form. Using this form, each site was visited, and the necessary information collected and entered into the form. The exception to this was for the date of SCRAM connection and the linking type; these entries were on file from the previous phase of the study and the data were transferred across from the site data base.

A second round of site inspections took place at a later stage of the study, after certain sites had been identified as having a "high" or a "low" accident experience. These visits were assisted by distributions showing the DCA codes for the accidents occurring at each intersection.[1] This activity was part of the analysis phase and will be described in Section 5 below.

3.4 Data Files

The information from each of these three sources - accidents, traffic flows and site characteristics - was entered into a data base at MUARC, and analyses were performed by MUARC staff.

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[1] Ideally, detailed collision diagrams would have been used. However, these were not available and the production of such diagrams was well beyond the resources for this study.

4. Identification of Sites with Extreme Accident History

4.1 The Influence of Traffic Flow

As discussed in chapter 1, a key focus of the study was to attempt to isolate and identify some of the factors other than traffic flow which contributed to the occurrence of accidents at signalised intersections. In other words, it is reasonable to suppose that an intersection which carries higher traffic volumes will be expected to have more accidents, all else being equal. But after allowing for traffic flow, there will still likely be some variation in accidents, and the purpose is to attempt to identify the factors associated with that variation.

Thus the first step has to be to attempt to isolate the effect of traffic flow on accidents. This is akin to correcting for exposure (Hodge and Richardson, 1978). It is not, in this study, necessary to define and thus calculate exposure precisely, because exposure per se is not the point of the exercise. Rather, what we are trying to do here is to identify those sites in which much of the variation in accidents is accounted for by traffic flow in order that we may study, not those sites, but the remaining sites in which there are factors other than flow at work.

Nevertheless, exposure would be a useful criterion for excluding the mid group of sites - those whose accident history is neither higher or lower than some "expected" value. A number of measures of intersection exposure have been proposed, mostly for unsignalised intersections. The most common are the sum of entering flows (Sanderson et al, 1985), the product of conflicting flows (Tanner, 1953), the square root of the product of conflicting flows (Bennett, 1966), or the mean (or the geometric mean) of the average entering flows (Chapman, 1973).

Most of these theoretical distributions (including the simulation study conducted by Hodge and Richardson, 1978) were based upon unsignalised intersections. A comprehensive review of conflict analysis at signalised intersections by Hughes (1991, p 4) described some of the difficulties of applying the concept of exposure to signalised intersections:

> The complex nature of vehicle interactions and traffic control confuses the concept of exposure at traffic signal controlled sites. Some accident types such as rear end accidents exhibit the same number of opportunities as if signals were not a feature. However, the existence of signals alters the likelihood of certain other accidents occurring.

Thus, the factor of particular interest is exposure measures at signalised intersections. Three studies were located which examined this issue. The first was a major study undertaken at the University of North Carolina for the US Federal Highway Administration by Council, Stewart and Rodgman (1987).

The outcome of this work was a series of empirically-derived regression equations expressing exposure for several specific accident types (e.g. head-on, rear-end, sideswipe, etc) and intersection characteristics (unprotected left turn (equivalent to our right turns), protected, etc). The independent variables in these equations were items such as intersection width, cycle length, number of lanes, traffic flows and green splits.

This work, although probably the most comprehensive effort in terms of attempting to quantify exposure at signalised intersections (albeit empirically) was not applicable to the present study, for three reasons. First, it implies fixed cycle times, whereas cycle times are variable with the

SCRAM software used throughout Melbourne. Secondly, it requires turning volumes in order to estimate exposure for certain road user movements, and such data were not available for the present study. And thirdly, even if these formulae were able to be used, the results, in terms of exposure measures for particular movements, would have required accident data to be disaggregated for those movements. While the data could be disaggregated in this way, the resulting accident frequencies at any given site would have been so low as to prevent any form of statistical analysis.

Hence, the work of Council, Stewart and Rodgman (1987), while interesting, was not able to be applied to this study.

The second study was undertaken in Toronto, Canada, by Hauer, Ng and Lovell (1988). They related particular accident types (e.g. rear end, angle, turning, sideswipe, approaching) to the traffic flows to which the colliding vehicles belonged. They concluded that the sum of entering volumes was not a satisfactory basis for comparing the safety of intersections.

They then built several models relating the number of crashes at an intersection to the related measure of traffic flow, and on this basis were able to estimate the number and type of accidents that could be expected at any given intersection. Comparing this with the actual accident experience at that site enabled sites which were "deviant" to be identified.

The approach is certainly useful but like the Council, Stewart and Rodgman (1987) study described above, it obviously depends upon the availability of traffic flow (including turning volume) data and intersection accident data for a wide range of intersections. While it is theoretically superior to the approach which we later adopt in this study, these data needs precluded us from adopting this approach fully. The notion however of estimating the number of crashes which might be "expected" at a site and thus identifying sites which have a crash record substantially different from this expected value was however adopted in this study.

The third study which investigated exposure at signalised intersections was conducted by Hughes (1991) of the Western Australia Main Roads Department for a Master of Engineering Science at Monash University. Hughes developed models for accident frequency (for various road user movements) in terms of various measures of exposure, and examined the predictive power of the resulting equations.

Hughes (op cit, p 50) summarised the conclusions of this aspect of his study as follows:

> Three typical measures of exposure were explored - total entering traffic, product of the average traffic on the intersecting roads, and the square root of this product. In support of Chapman (1973), a detailed comparison did not discern a great difference between the validity of any of these. Any one should not be preferred over the others since none had a strong theoretical basis. *It was suggested that the sum of the entering traffic was preferred since it was the simplest to calculate and avoided any misunderstanding.* (our emphasis)

In summary then, for our purposes here, it seems to be satisfactory to use sum of entering traffic flows as the measure of traffic. This has the advantage that it does not require us to disaggregate the data to the extent that analysis becomes statistically unsound, it does not require turning movement data (which we do not have), and it appears, empirically, to be as theoretically sound as any other measure.

On this basis therefore, we plotted for the 76 sites discussed in Section 2:

- the accident data (average accidents per site per year for the five year period 1987-1991) against
- the average daily entering traffic flow (sum of the average daily flows across all legs of the intersection).

These data are plotted in Figure 1.

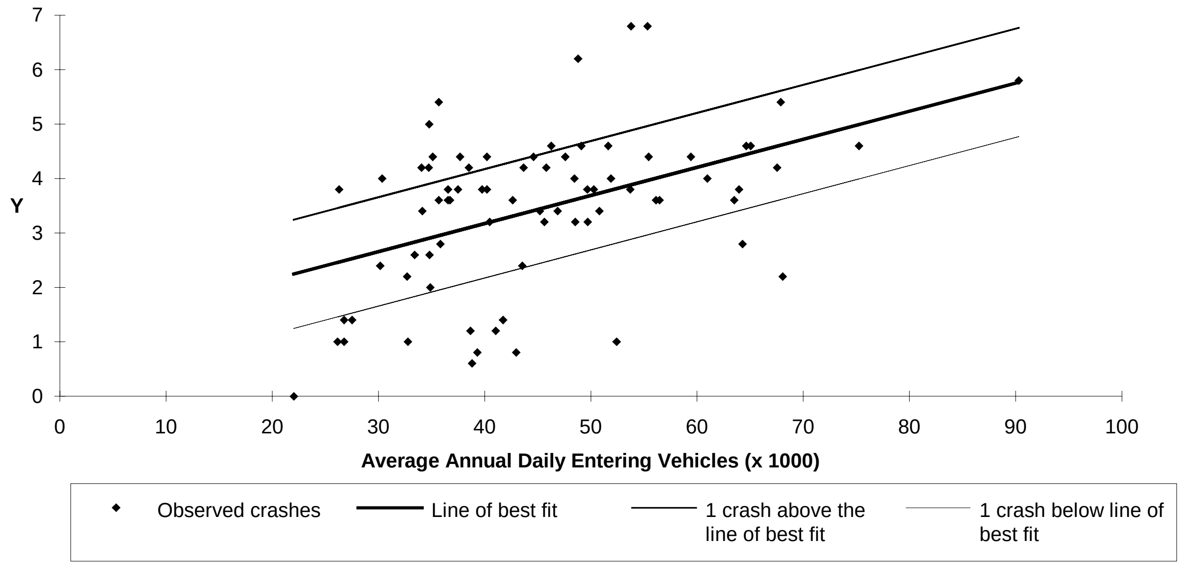

Figure 1 Plot of accidents against traffic

It can be seen from Figure 1 that the daily traffic flow in terms of entering vehicles was in the range 22,000 to 90,000 veh/d. The data thus covers the range of typical urban signalised intersection flows. The average annual accidents per site ranged from zero to nearly six[2].

The equation for the line of best fit (unconstrained to go through the origin) was:

CRASHES = 1.079 + 0.052 x FLOW

The R^2 for this equation is 0.21, i.e. about 21 per cent of the variation in accidents is statistically explained by variations in traffic flow. This small proportion explained by variations in traffic flow reinforces the need for studies such as this, since it implies that the majority of the variation

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[2] It is of interest to note that the sites with the highest accident frequency in our sample - Sydney Rd/Bell St and Flemington Rd/Gatehouse Street/Harker Street - had a total of 34 accidents for the five years 1987-91. This compares with the worst site in the State (Princes Hwy/Springvale Rd) which had 76 accidents. However there were only eleven signalised intersection sites in the State which had more than 34 accidents in the period. None of these eleven sites had complete traffic flow data for all legs, otherwise we would of course have included them in our sample.

in accidents between signalised intersections is not explained by variations in traffic flow (at least in the way we have measured it here), and that the search continues for other causal factors.

Fundamentally, the line should go through the origin (zero flow should mean zero accidents). However, since it is invalid to extend the line beyond the limits of the data, the fact that the line does not go through the origin is not a point of any significance. Out of interest however, we may note that the equation for a line constrained to go through the origin is:

CRASHES = 1.43 x FLOW

The R^2 for this line is 0.06, i.e. it explains much less of the variation than does the unconstrained equation.

4.2 The Influences of Factors other than Traffic Flow

Figure 1 enables us to isolate the sites where it appears that variations in traffic flow do not explain variations in accidents. Essentially, points well above the line represent sites which have a "high" accident history (i.e. they have more accidents than would be expected on the basis of their traffic), while points well below the line have a "low" accident history. With points closer to the line, the accident history is more largely explained by traffic.

It is the outliers - the "high" points and the "low" points - that we are interested in for this study. For our purposes therefore, we (arbitrarily) considered that a band about the line of best fit with one accident per year more or one accident per year less than the number of accidents represented by that line were "normal" sites - i.e. the variation in accidents was more or less as expected by the variation in traffic. There were 49 of our 79 sites in this group.

There are 15 sites in each of the "high" and "low" categories - sites where the accidents appear to be influenced (for better or worse) by factors other than traffic. These are each therefore 19.7 per cent of our total sample.

The sites and their accident/traffic data are shown in Tables 2, 3, and 4. These show accident data (average crashes per year for the five years 1987-91) and volume data (estimated daily sum of entering volumes) for the 76 sites.

The remainder of the study compares the site characteristics for these three groups, "high", "normal" and "low", and especially differences between "high" and "low".

5. Analysis of Site Characteristics

5.1 Site Data

Having categorised sites as "high", "normal" and "low" in the way described in Section 4, the next step was to examine a range of site characteristics to determine what, if anything, could be identified which might explain the differences in accident histories.

This task obviously had to involve the collection and analysis of site-specific data. As described in Section 3.3, this involved two aspects - the collection of a range a detailed site characteristic data, and a series of subsequent site visits to observe traffic behaviour. This latter aspect did not involve every site. The sites visited included every site in the "high" category, together with an adjacent site where there was flow data available (see Section 3.2). There were six such sites. A valuable part of the analysis was a comparison of these six matched pairs.

The following discussion outlines the results of these analyses. The order follows that on the field data collection form, shown in Table 1.

5.2 Variation with Site Characteristics

5.2.1 Number of Lanes

Although data were collected on the number of lanes on each approach, the results were inconclusive as most approaches had two through or shared through/left turn lanes. Figure 2 shows the distribution of the number of through (including left/through) lanes. It can be seen that sites in the "high" group tended to have a smaller number of lanes, with only 3 per cent of approaches having more than two lanes. By contrast, nearly 16 per cent of approaches at sites in the "low" group had more than two lanes, while about 9 per cent of approaches at sites in the "normal" group had more than 2 lanes.

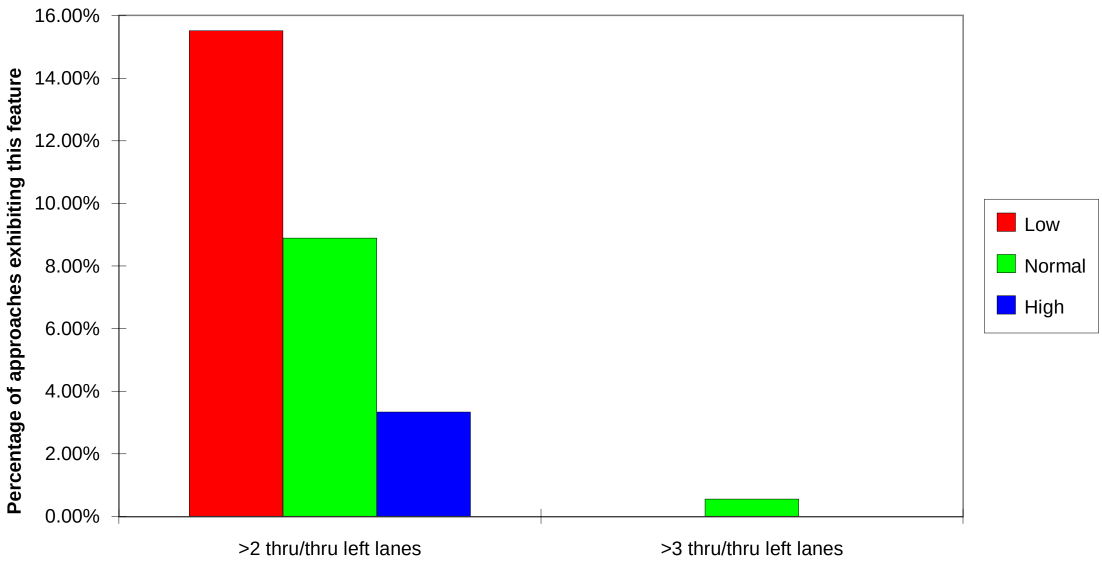

Figure 2 Distribution of the number of through lanes (including shared thru/left) by intersection group

Table 1 Field Data Collection Form

MONASH UNIVERSITY ACCIDENT
SIGNALISED INTERSECTION SURVEY

RRP **LOCATION** **DATE OF SURVEY**

NO. OF LEGS **DATE SCRAM** **LINKING TYPE**

CYCLE TIME **CONTROLLER TYPE**

NORTH APPROACH	
No. exl thru or thru left lanes	
No. excl right turn lanes	
No. shared thru/right lanes	
No. excl left turn lanes (no slip)	
No. excl left turn lanes (slip)	
Lane width (thru)	
Lane width (right)	
Median width (S for splitter)	
Tram safety zone (y/n) (US,DS)	
Bus stop (y/n) (US,DS)	
Land use (R,C,I,E,O)	
Clearway (am/pm/24h/never)	
Overhead mast arm (y/n)	
Gradient (DD,D,L,U,UU)	
Right turn(S,PC,FC)	
Service road (y/n)	

SOUTH APPROACH	
No. exl thru or thru left lanes	
No. excl right turn lanes	
No. shared thru/right lanes	
No. excl left turn lanes (no slip)	
No. excl left turn lanes (slip)	
Lane width (thru)	
Lane width (right)	
Median width (S for splitter)	
Tram safety zone (y/n) (US,DS)	
Bus stop (y/n) (US,DS)	
Land use (R,C,I,E,O)	
Clearway (am/pm/24h/never)	
Overhead mast arm (y/n)	
Gradient (DD,D,L,U,UU)	
Right turn(S,PC,FC)	
Service road (y/n)	

EAST APPROACH	
No. exl thru or thru left lanes	
No. excl right turn lanes	
No. shared thru/right lanes	
No. excl left turn lanes (no slip)	
No. excl left turn lanes (slip)	
Lane width (thru)	
Lane width (right)	
Median width (S for splitter)	
Tram safety zone (y/n) (US,DS)	
Bus stop (y/n) (US,DS)	
Land use (R,C,I,E,O)	
Clearway (am/pm/24h/never)	
Overhead mast arm (y/n)	
Gradient (DD,D,L,U,UU)	
Right turn(S,PC,FC)	
Service road (y/n)	

WEST APPROACH	
No. excl thru or thru left lanes	
No. excl right turn lanes	
No. shared thru/right lanes	
No. excl left turn lanes (no slip)	
No. excl left turn lanes (slip)	
Lane width (thru)	
Lane width (right)	
Median width (S for splitter)	
Tram safety zone (y/n) (US,DS)	
Bus stop (y/n) (US,DS)	
Land use (R,C,I,E,O)	
Clearway (am/pm/24h/never)	
Overhead mast arm (y/n)	
Gradient (DD,D,L,U,UU)	
Right turn(S,PC,FC)	
Service road (y/n)	

There was only one site with more than three through lanes in the sample, and it was in the "normal" group.

Sites in the "high" group have a greater tendency to have only two through or through/left lanes on each approach. Sites in the "normal" and "low" group are more likely to have 3 or more lanes on an approach, although in each group, two through or through/left lanes is by far the most common configuration.

5.2.2 Right Turn Configuration

Figure 3 shows the distribution of right turn configurations for the three intersection groups, showing the proportion of approaches with exclusive right turn lanes and the proportion with shared right/through lanes.

It can be clearly seen that sites in the "high" group are less likely to have an exclusive right turn lane; only some 42 per cent of approaches at such sites have an exclusive right turn lane, compared with 56 per cent at "low" sites and 51 per cent at "normal" sites.

Conversely, 55 per cent of approaches at "high" sites feature a shared right/through lane, which is higher than the 36 per cent at "low" sites and 46 per cent at "normal" sites.

There is a clear tendency for sites with exclusive right turn lanes to be safer than those with shared right/through lanes.

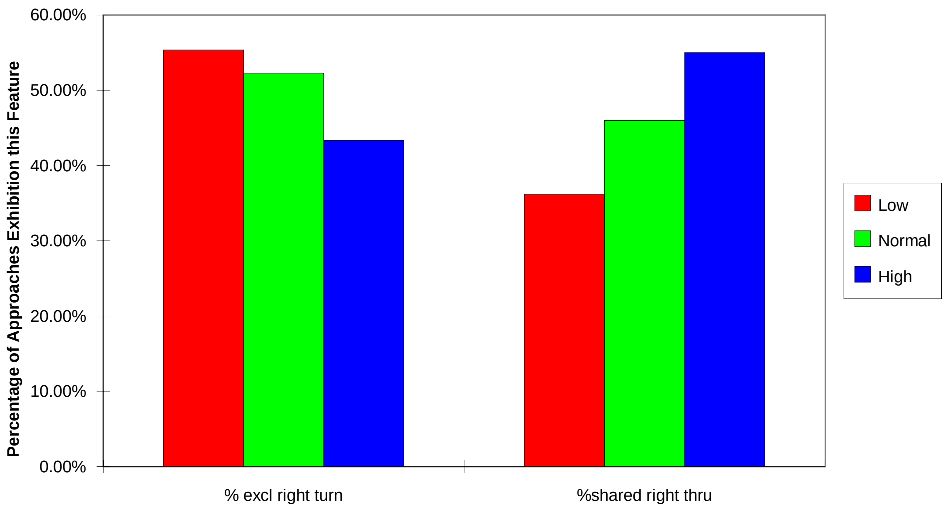

Figure 3 Right turn configuration by intersection group

5.2.3 Left Turn Configuration

For completeness, a similar analysis was performed in respect of left turn lanes. Figure 4 shows the distribution of left turn configuration for the three groups, showing the proportion of approaches with exclusive left turn slip lanes and the proportion with exclusive left turn lanes (but no slip lane).

Although the percentages are quite small (indicating that most approaches in each group had shared left/through lanes), there is nevertheless a clear tendency for sites in the "low" group to have an exclusive left turn lane including a slip lane, compared with both the "normal" and "high" group.

Results for the situation where there is an exclusive left lane but no slip lane are inconclusive, as both the "high" and "low" groups perform better then the "normal" group.

> *Left turns featuring a slip lane appear to be safer but the numbers are quite small and this result is not conclusive.*

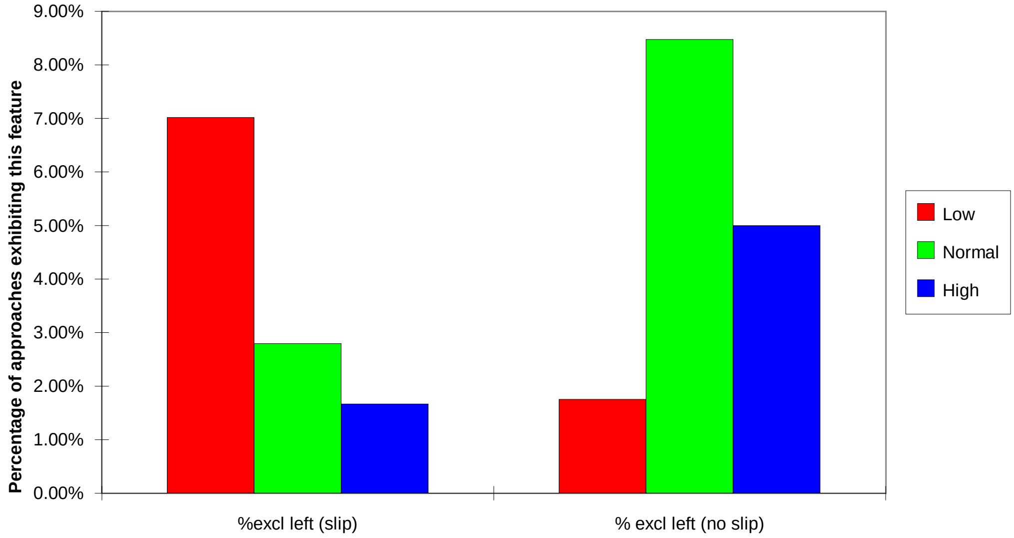

Figure 4 Left turn configuration by intersection group

5.2.4 Lane Width

Figure 5 shows the distribution of lane widths for the three intersection groups. It can be seen that generally sites in the "high" group have a narrower lane width than sites in the "normal" or "low" group, by typically about 50-100 mm.

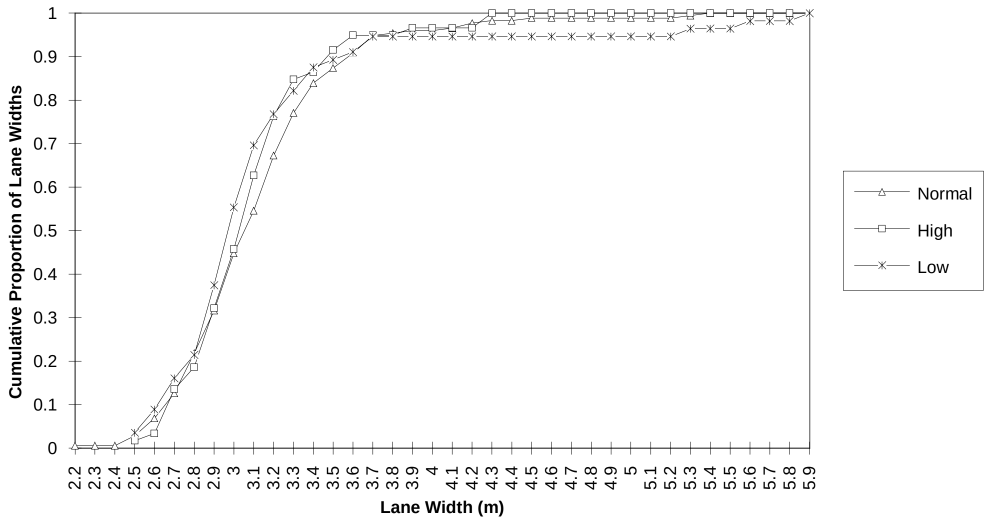

Figure 5 Left turn configuration by intersection group

It is also worth noting from this figure that approach lanes at urban signalised intersections in Melbourne are quite narrow; the "standard" lane width typically used in Australia is 3.5 m, but 97 per cent of sites in the "high" group and nearly 90 per cent of sites in the other groups are less than this. At the other end of the distribution, 40 per cent of lanes in the "high" group are 2.7 m or less, while about 22 per cent of lanes in the "low" group are of this width. Clearly these narrow lanes have resulted from the need to maximise capacity at signalised intersections, and installing the maximum number of lanes (including turn lanes) that can be fitted into a limited space.

> *Overall, lanes in the "high" accident group of intersections are slightly narrower (by 50-100 mm) than lanes in the "normal" group.*

5.2.5 Median and Median Width

Figure 6 shows the proportion of approaches which had a median (defined as a painted or raised island of at least 0.9 m in width). It can be seen that sites in the "high" group were much less likely to have median (only 8 per cent of approaches at sites in this group had a median, compared with 24 per cent of approaches at sites in the "low' group and over 30 per cent in the "normal" group. This clearly indicates that the presence of a median contributes to safety, and the absence of a median is associated with sites which have an accident history. This may be because such sites are located in areas where it is difficult to install a median because of restricted space, or it may be because lack of funds has prevented intersection reconstruction and remodelling.

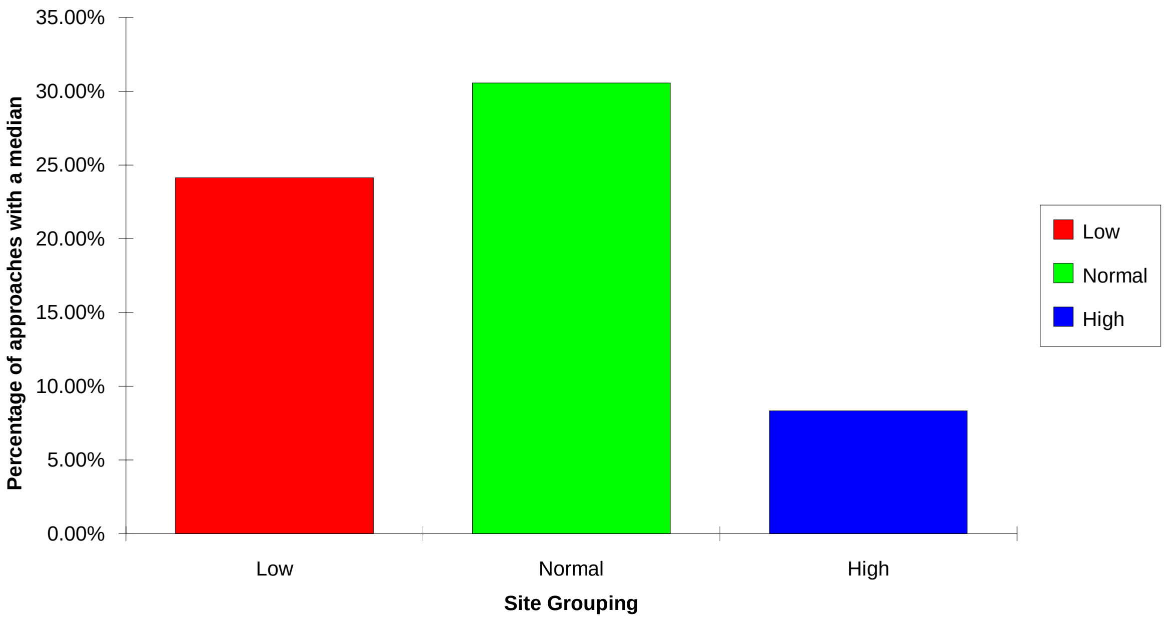

Figure 6 Proportion of approaches with a median by intersection group

Median width is also of some importance. Figure 7 shows the distribution of median widths for those approaches which had medians. For narrow medians (less than 1.8 m) there is no clear pattern, mainly because there were no approaches in the "high" group with widths between 1.0 m and 1.5 m. However, intersections in the "low" group had consistently wider medians than the "normal" group, while for medians greater than 1.8 m, the "high" group had consistently narrower medians than the "normal" group. The widest median in the "high" group was only 2.6 m, whereas 50 per cent of approaches at sites in the "low" group were wider than this.

Sites with approaches having a median tend to be safer than those without a median, and there is some evidence that wider medians are safer.

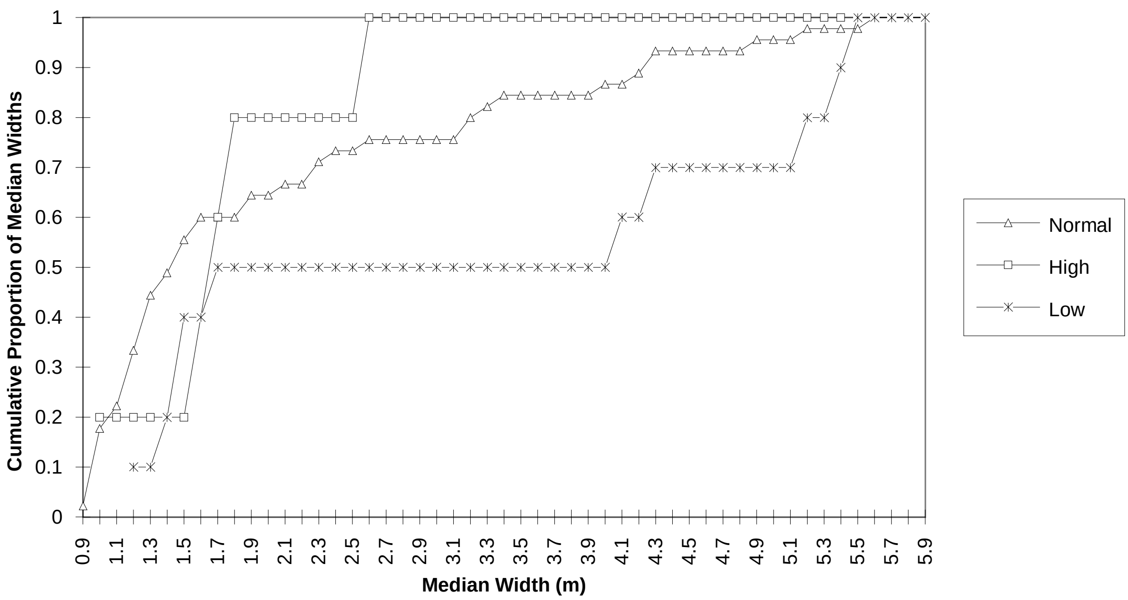

Figure 7 Distribution of median widths by intersection group

5.2.6 Tram and Bus Stops

Figure 8 indicates that there is a slight but consistent tendency for approaches at the "high" sites to have a bus stop present; these approaches were over-represented in the "high" group relative to the "normal" group while the "low" group was under-represented.

This trend was evident for bus stops both upstream and downstream of the intersection. However, in both cases, the numbers of approaches involved and the differences between the three groups were quite small. Overall, about 21 per cent of approaches in the "low" group had a bus stop, while about 31 per cent of approaches had a bus stop in the "high" group.

Similarly, with tram stops (Figure 9) there was a much greater tendency for these to be present in approaches in the "high" group than in the "low" group, but the proportion of approaches with a tram stop in the "high group" was almost the same as the "normal" group.

The presence of tram safety zones was also investigated (Figure 10), but the results were inconclusive. Both "high" and "low" groups showed a lesser association with tram stops than the "normal" group, so it cannot be said that there is any evidence of an association between tram safety zones and the overall intersection performance. In any case, the number of approaches involved is quite small.

There is a suggestion that in the data that bus stops (and to a lesser extent tram stops) are associated with approaches in the "high" group, but sample size is small and conclusive evidence is not present.

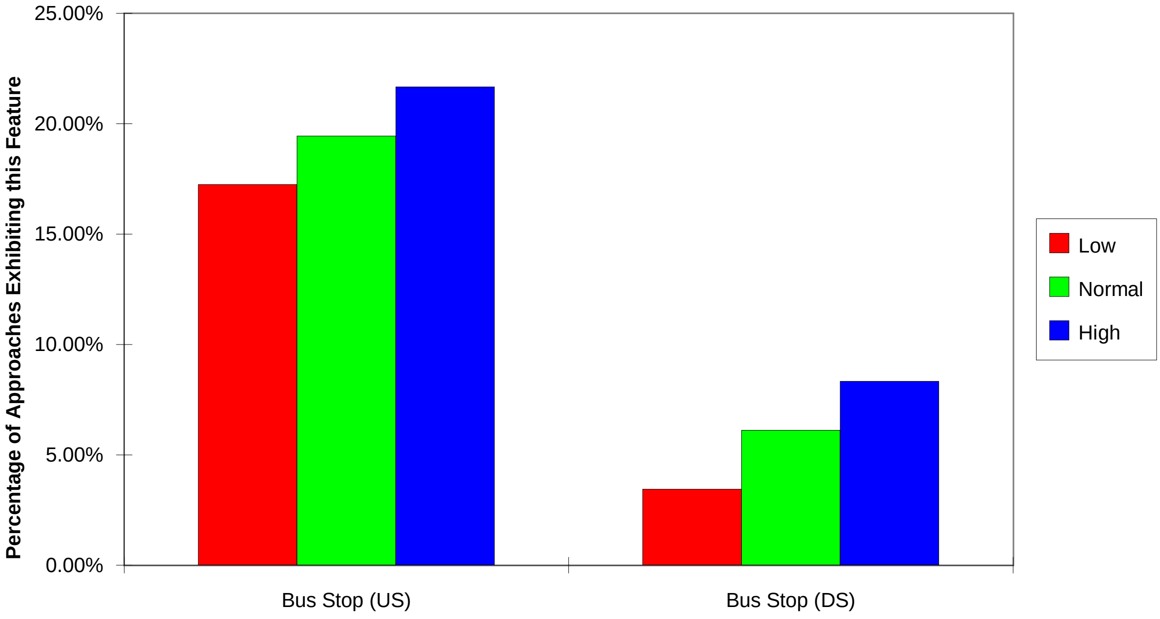

Figure 8 Proportion of approaches with bus stops, by intersection group

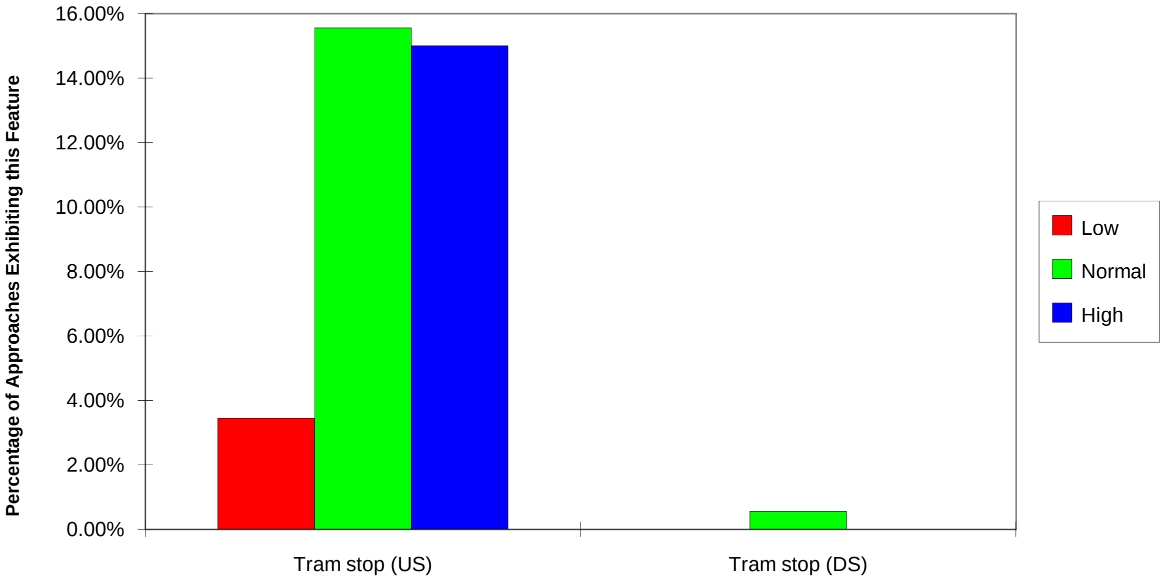

Figure 9 Proportion of approaches with tram stop, by intersection group

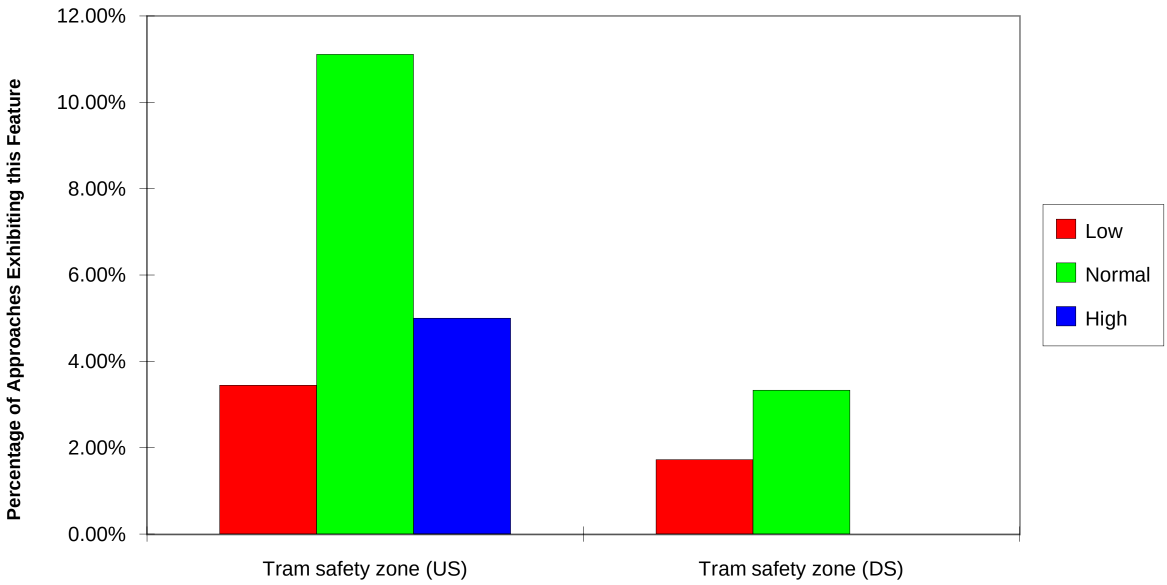

Figure 10 Proportion of approaches with tram safety zone by intersection group

5.2.7 Land Use

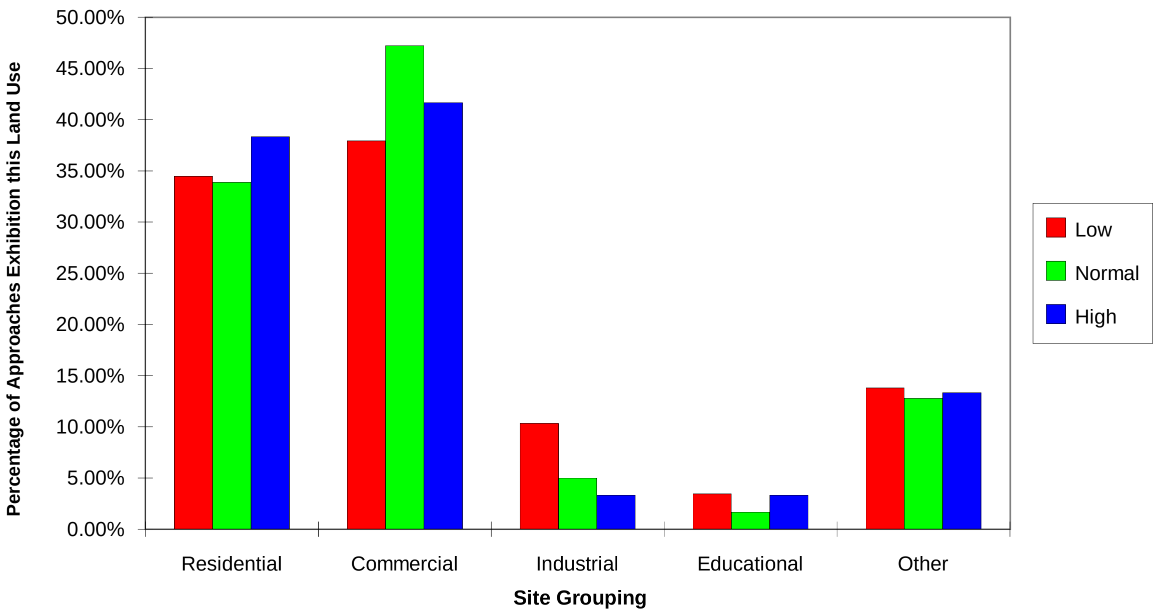

Figure 11 Proportion of approaches by land use and intersection group

Figure 11 shows the distribution of land use by approach in each of the three intersection groups.

Approaches in the "high" group were slightly over-represented (compared with both the "low" and "normal" groups) in residential areas. Conversely, they were under-represented in industrial land uses. In all other cases (commercial, educational and other land uses) there was little difference between the three groups, or an inconclusive result (e.g. with commercial land use, both the "high" and the "low" groups were less than the "normal" group in the proportion of approaches associated with that land use.

There is some tendency for the safer intersections to be have industrial land uses on the approaches, and for the less safe intersections to have residential land uses. With other land uses there is no clear pattern either way.

5.2.8 Clearways

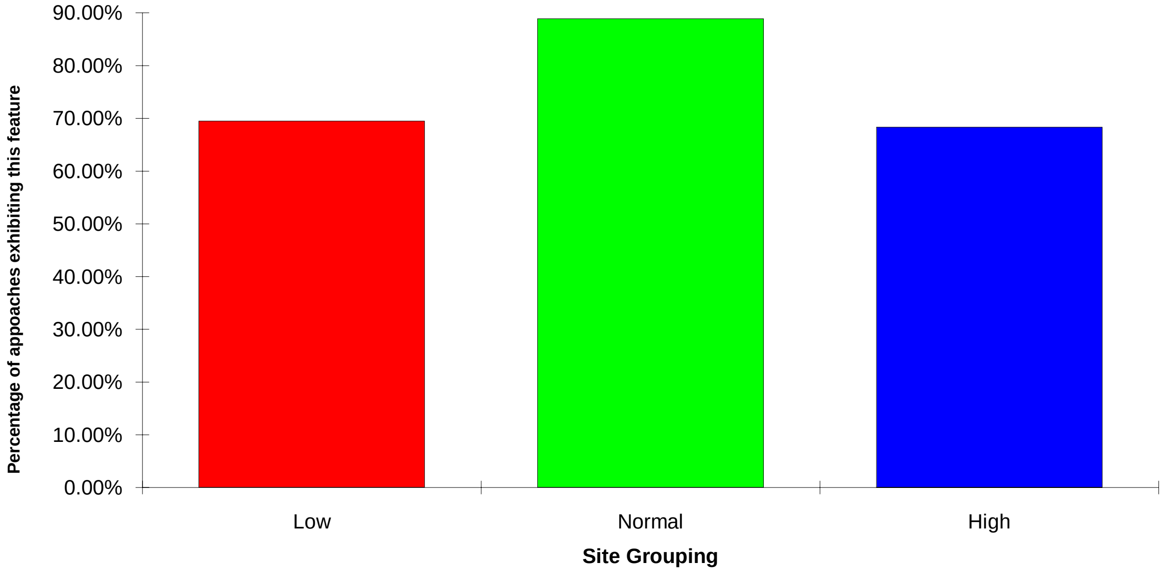

Figure 12 Proportion of approaches with clearway provision (any time) by intersection group

Figure 12 shows the proportion of approaches with clearways conditions at any time of the day, according to the three intersection groups.

It can be seen that both "low" and "high" groups had a similar proportion of approaches with clearway conditions, and that both of these were less that the proportion of approaches at "normal" sites with clearway conditions. Hence, it would appear that clearways are not associated with the difference in accident occurrence.

There is no discernible effect of clearways on the difference in accident patterns at signalised intersections.

5.2.9 Mast Arms

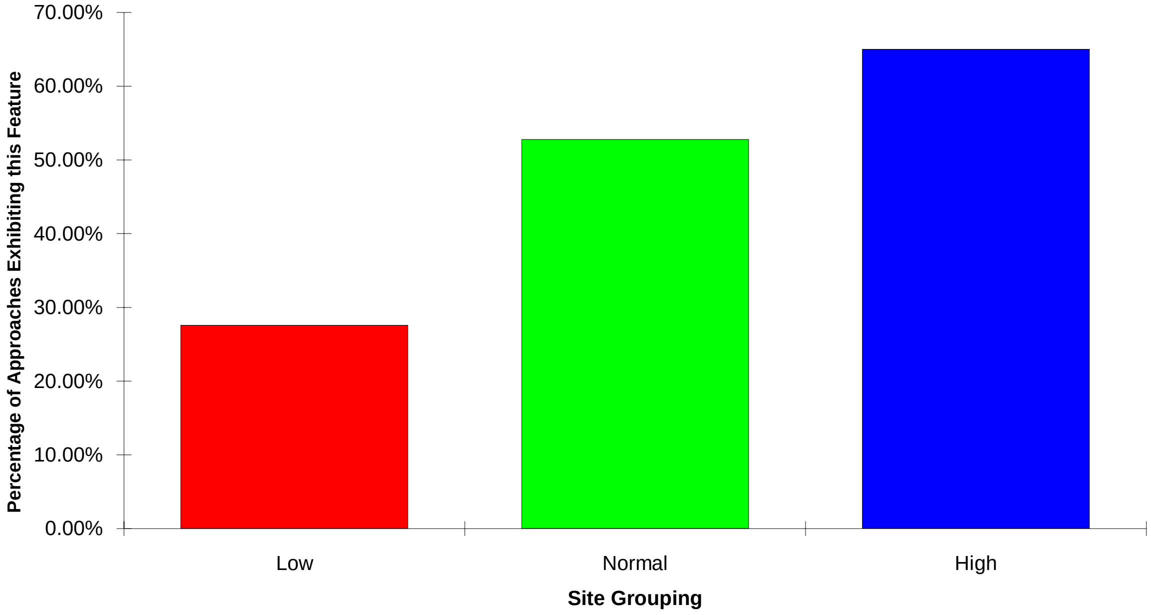

Figure 13 Proportion of approaches with Mast Arms by intersection group

Figure 13 shows the proportion of approaches with overhead mast arms for the signal displays, for the three intersection groups.

It can be seen that a much higher proportion of approaches in the "high" group have mast arms, relative to both the "normal" and "low" group. At first sight, this result is counter-intuitive; it appears to indicate that mast arms are associated with the least-safe intersections. However, a correct interpretation is that the least safe intersections have had mast arms fitted (possibly in response to their safety performance, or maybe their traffic flow), but that in spite of this, these sites continue to have a poorer safety record.

> *Mast arms are more likely to be present at approaches in the "high" group. This suggests that, while mast arms have been shown elsewhere to contribute to safety, they nevertheless cannot prevail if other conditions contributing to hazard are present. Conversely, many intersections, depending on their traffic flow, sight distance etc, function safely without overhead mast arms.*

5.2.10 Gradient

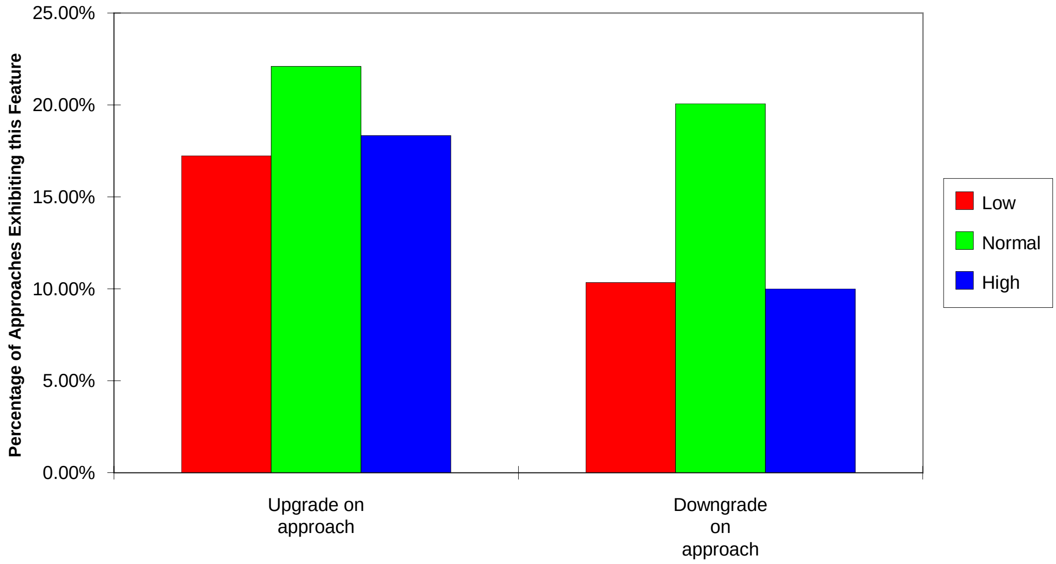

Figure 14 Proportion of approaches with upgrade or downgrade by intersection group

Figure 14 shows the proportion of approaches which are either upgrades or downgrades, for the three intersection groups. It can be seen that this information is inconclusive, as there are lower proportions of both upgrades and downgrades with both "high" and "low" groups compared with the "normal" group.

Gradient was not indicated as a significant factor.

5.2.11 Right Turn Control

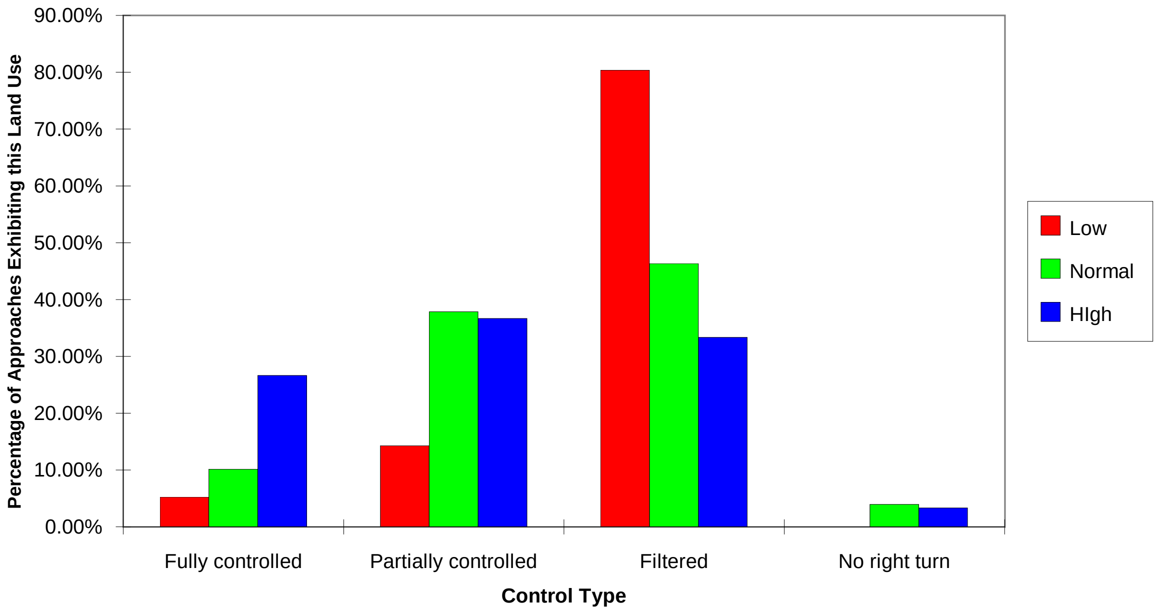

Figure 15 Proportion of approaches by types of right turn control, by intersection group

Figure 15 shows the proportion of approaches by type of right turn control (fully controlled, partially controlled, and filtered), for each of the three intersection groups.

It can be seen that a much higher proportion of approaches in the "high" group have fully controlled right turns, relative to both the "normal" and "low" group. At first sight, this result is counter-intuitive; it appears to indicate that full control of right turns is associated with the least-safe intersections. However, a correct interpretation is that the least safe intersections have had fully controlled right turns installed (possibly in response to their safety performance), but that in spite of this, these sites continue to have a poorer safety record. In fact, some 80 per cent of sites in the "low" group do not have fully controlled right turns, indicating that there are factors at work other than the extent of control of right turn movements. This is partly related to the accident type prevalent at the respective intersection groups (see Section 5.3)

> *Notwithstanding the proven safety effectiveness of full control of right turns in treating for certain types of intersection crash, the sites with a "high" accident history have a strong tendency to have fully controlled right turns, whereas those in the "low" group tend to have filtered right turns.*

5.3 Accident Types

The previous discussion has focussed on the site features which were found to be associated with the three intersection groups, "high", "normal" and "low".

To complement this analysis, it is helpful to consider also the types of accident which are occurring at each of these three groups. This is shown in Figure 16, where accident type is represented by the DCA groups used in the previous study (pedestrian accidents, accidents involving vehicles from adjacent approaches, rear end collisions, right turn against accidents, and others).

The most striking feature of this presentation is that the "high" intersection group has a significantly higher proportion of accidents in the adjacent approaches category - 29 per cent, compared with 22 per cent for the "normal" group and 19 per cent for the "low" group.

Pedestrian accidents are marginally more common in the "low" group, while the results for both rear end and right turn against are inconclusive with no clear pattern being evident.

5.4 Site Inspections

The data presented in Section 5.2 was related to features present at the site. They were collected prior to any designation of a site as having a "low", "normal" or "high" accident history. A second round of site visits was then undertaken after sites were so designated, in an attempt to discern any features which may have stood out as contributing to the accident history of the site in question. Every site in the "high" category was visited, together with an adjacent site where there was flow data available to form a matched pair (see Section 3.2).

Table 2 summarises the characteristics of the matched pair sites, showing the Melway location, the accident history (including main DCA codes), the traffic flow including the proportion of the flow in the main direction, and details of major site works undertaken since 1987 (which may of course affect both the accident patterns and any conclusions which may be drawn from a site inspection).

This table indicates that the paired intersections are reasonably comparable in their traffic characteristics, and being closely located to each other, the usage and ambience will also be similar. However, they show markedly different accident histories, so form a reasonable basis for investigating whether anything can be discerned that would explain the different safety performance. Also, the table reveals that there has not been a great deal of physical change at these sites in recent years, so the current situation closely reveals the site characteristics appropriate to the accident data base.

Table 3 shows a summary of the field notes for each of these matched pair sites. The aim in this presentation was to attempt to highlight any feature of the sites in the "high" accident group which might explain the occurrence of accidents at that sites, while for those in the "low" group it was to attempt to identify any features which made that site particularly safe.

The impressions formed from this exercise, taken together with the other site visits, may be summarised as follows:

- Sites with a poor record typically had one or more approaches on an upgrade. In some cases, this resulted in a crest just in advance of the intersection, preventing the driver from getting a clear indication of the intersection presence or location. There may also be behavioural implications here; is the view of the intersection foreshortened in some way, giving the driver a misleading visual cue? Or are drivers more reluctant to brake on an uphill approach? We have no definitive answers to these questions, but they would seem to be worthy of further investigation by behavioural psychologists.
- In similar fashion, very often there was a line of poles as the dominant visual cue on an approach or approaches. These may give the drivers a sense of progression along the road, perhaps focussing their attention further ahead, and tending to encourage higher speeds and/or less inclination to stop at a yellow signal. Again, we are not competent to make an authoritative comment, but believe that it is a question worth investigating.
- The sites with a low accident history often had essentially local traffic on one or more legs; this observation is supported by the fact that at several of the intersections in the "low" group, traffic flow in one road was significantly greater than in the other. This implies that the traffic volumes are less, the speeds may be lower, and drivers are familiar with the intersection. There are no direct policy or design conclusions to be drawn from this, but the implication is that all intersections are not alike in their usage or driver behaviour. In comparing intersection safety performance, this should perhaps be taken into account in some way.
- Several of the sites in the "high" group had a quite complex decision making environment - as well as noting and obeying the traffic control signals, drivers may have had to be alert for changes in road geometry, changes in road alignment, pedestrians, trams, etc. This can lead to information overload and hence to reduced decision-making performance (Ogden, 1989).
- Similarly, several of the "high" sites exhibited a high level of visual "noise" or clutter, e.g. with illuminated advertising signs. Traffic control devices (especially signals) have to compete with this noise for attention, and sometimes were not especially

conspicuous. Moreover (to complement the previous point), this adds to the general "busy" ambience of the site.

- Almost all intersections in the "high" group in our sample were undivided. This may be more a feature of the sample selection, which was determined largely by what sites VicRoads had traffic flow data for. However, the general point concerning the relative safety of divided roads is worth noting.

Table 2 Details of "high" and "low" matched pairs

HIGH GROUP	LOW GROUP
Darebin Rd/Station St, Thornbury Location: Melway ref, Map 31 A7 Av annual accidents: 4.4 main DCA: Right turn against 50% Adjacent direction 23% Av entering volume: 40,200 veh/d % of traffic in main direction: 60% (Station St) Changes since 1987: remodel for right turn phase from Station St (1993)	**Darebin Rd/Victoria St, Thornbury** Location: Melway ref, Map 30 J6 Av annual accidents: 1.4 main DCA: Right turn against 42% Adjacent direction 28% Av entering volume: 26,800 veh/d % of traffic in main direction 51% (Victoria St) Changes since 1987: nil
Plenty Rd/Gower Rd, Preston Location: Melway ref, Map 18, H12 Av annual accidents: 4.0 main DCA: Adjacent direction 55% Right turn against 25% Av entering volume: 30,400 veh/d % of traffic in main direction: 66% (Plenty Rd) Changes since 1987: audiotactiles (May 1992)	**High St/Cramer St, Preston** Location: Melway ref, Map 18 G12 Av annual accidents: 0.8 main DCA: Adjacent direction 50% Av entering volume: 39,300 veh/d % of traffic in main direction: 68% (High St) Changes since 1987: audiotactiles (May 1992)
Sydney Rd/Bell St, Coburg Location: Melway ref, Map 17 H12 Av annual accidents: 6.8 main DCA: Right turn against 41% Rear end 24% Av entering volume: 53,800 veh/d % of traffic in main direction: 55% (Bell St) Changes since 1987: Partially controlled right turn north to west (November 1990)	**Bell St/Reynolds Pde, West Coburg** Location: Melway ref, Map 17 C11 Av annual accidents: 0.8 main DCA: Rear end 63% Av entering volume: 43,000 veh/d % of traffic in main direction: 82% (Bell St) Changes since 1987: Mast arm on east approach (Oct 1991)
Maribyrnong Rd/Ascot Vale Rd, Ascot Vale Location: Melway ref, Map 28 J9 Av annual accidents: 5.0 main DCA: Right turn against 52% Other (?) 24% Av entering volume: 34,800 veh/d % of traffic in main direction: 52% (Maribyrnong Rd) Changes since 1987: Split phase, Ascot Vale Rd (June 1991)	**Maribyrnong Rd/Union Rd, Ascot Vale** Location: Melway ref, Map 28 G8 Av annual accidents: 1.0 main DCA: Pedestrian 80% Av entering volume: 26,200 veh/d % of traffic in main direction: 74% (Maribyrnong Rd) Changes since 1987: remodel to include detector ops for trams, and install right turn phase from east (March 1988)
Kingston Rd/Old Dandenong Rd, Heatherton Location: Melway ref, Map 78 H11 Av annual accidents: 4.2 main DCA: Right turn against 48% Adjacent direction 33% Av entering volume: 34,000 veh/d % of traffic in main direction: 59% (Kingston Rd) Changes since 1987: nil	**Boundary Rd/Old Dandenong Rd, Heatherton** Location: Melway ref, Map 88 A2 Av annual accidents: 1.0 main DCA: Right turn against 60% Rear end 40% Av entering volume: 26,800 veh/d % of traffic in main direction: 51% (Old Dandenong Rd) Changes since 1987: minor upgrade of controller (1988)

Table 3 Field observations at "high" and "low" matched pair sites

HIGH GROUP	LOW GROUP
Darebin Rd/Station St, Thornbury	**Darebin Rd/Victoria St, Thornbury**
high speed traffic poor sight distance in one quadrant slight crest beyond intersection (s/b) slight crest before intersection (w/b, n/b) uphill approach, n/b, e/b SEC poles - subliminal delineation major regional arterials visual noise affecting signal conspicuity high proportion of truck traffic?	high proportion of local traffic good visibility on each approach short cycle times? pedestrian fencing
Plenty Rd/Gower Rd, Preston	**High St/Cramer St, Preston**
slight crest before intersection, e/b uphill approach, e/b SEC poles - subliminal delineation trams in Plenty Rd skewed geometry	low speed local traffic good visibility commercial environment
Sydney Rd/Bell St, Coburg	**Bell St/Reynolds Pde, West Coburg**
complex decision environment trams in Sydney Rd hotel on one corner uphill approach, n/b change of road status (divided to undivided) poor sight triangle in 3 quadrants closely spaced signals, s/b change in road alignment south of Bell	level approach good visibility looks like a tee local traffic only on north leg full control of turns
Maribyrnong Rd/Ascot Vale Rd, Ascot Vale	**Maribyrnong Rd/Union Rd, Ascot Vale**
complex decision environment tram turns through 90^o, w and n legs poor visibility in one quadrant SEC poles - subliminal delineation? slight upgrade, n/b high speed traffic?	local traffic on north leg good visibility full control of turns (trams on 3 legs)
Kingston Rd/Old Dandenong Rd, Heatherton	**Boundary Rd/Old Dandenong Rd, Heatherton**
uphill approach, e/b, n/b and s/b SEC poles - subliminal delineation high speed - isolated site? high truck volumes? crest before intersection, e/b skewed geometry right turn lane on 2 approaches only	good visibility curved alignment on 3 approaches no pedestrians? rural environment
Toorak Rd/Chapel St, Sth Yarra	**Punt Rd/ Domain Rd, Sth Yarra**
trams on 4 legs complex decision environment uphill approach, w/b pedestrians	local traffic on eastern leg

6. Conclusions and Recommendations

Based upon the analysis described in Section 5, and considering also the information presented in Section 2, the following conclusions and recommendations are presented:

1. Because there seems to be an association between **upgrade approaches** to signalised intersections and accident occurrence, it is suggested that those responsible for making decisions about signalisation should take this into account as one of the factors in design, and pay particular attention to such possibilities as a longer inter-green time or a fully controlled right turn at such locations.

2. Signals operate by separating vehicles in time, and therefore it is essential to maximise the recognition and obedience of signals by approaching drivers. Since many accident types involve driver misjudgment of the existence and/or location of the intersection, the use of **differently coloured and/or textured pavements** on approaches to intersections with a high crash frequency is suggested as a possibility worthy of consideration. This measure would improve recognition of the signalised intersection ahead.

3. Further to (2), the adoption of pavements with a higher **skid resistance** could be a positive contribution on approaches where there is a likelihood or evidence of drivers having to brake heavily, e.g. on downgrade approaches.

4. On the basis of previous work, it is clear that the practice of re-modelling intersection signal phasing, especially to introduce exclusive **right turn phases** is effective and should be continued where the appropriate guidelines are met.

5. In some intersections where there are significant flows of trucks or buses, special provision could be made for these vehicles. Both have difficulty in braking heavily; trucks because of potential instability and buses because of concerns about passenger comfort or safety. **Active detection of the approach of a heavy vehicle** (including its speed) is technically possible, and the extension of a green phase by a second or two to allow its safe passage could in some cases be efficacious.

6. In exceptional cases where the signal is hidden from view (e.g. on a bend or over a crest) the installation of **active advance warning** saying "prepare to stop" (or similar) is likely to be effective. These devices should be used sparingly however, so that their impact is not diminished by over-use.

7. The use of **mast arms** to enhance the advance warning of the presence of a signalised intersection is endorsed on the basis of past experience, even though this study did not establish a correlation.

8. An important conclusion of the study is that there is some evidence to suggest that accidents at signalised intersections are to an extent affected by driver visual mis-perception of the presence of an intersection or the appropriate response to it. Particular aspects are where an intersection is approached on an up-grade (especially if the intersection itself is slightly over a crest), and where there is a line of utility poles giving a subliminal delineation and perhaps encouraging higher speeds or misjudgment. We therefore recommend that **research** be undertaken on this issue.

9. We repeat the recommendation made in the earlier study that consideration be given to an **educational campaign** aimed at alerting drivers to signalised intersections as being "the most dangerous site on the road", to be used in conjunction with the proposed expanded red light camera program.

10. Approaches with separate **exclusive right turn lanes** are preferable, and they should be provided where warranted and justified.

11. There is some tendency towards higher accident frequencies at sites with **narrower lanes**. Therefore, lanes of less than normal width should be avoided where possible.

12. Similarly, the provision of a **median** appears to contribute to safety, and these should be provided where possible; even a narrow median (e.g. 0.9 m, although 1.2 m is probably a more practical minimum if a signal is to mounted in it) can show advantages.

13. There is some evidence that **visual "noise"** (e.g. with advertising signs, especially if they are illuminated) contributes to accidents, probably because signals are less conspicuous. In designing and installing traffic control devices, road authorities should not contribute to this "noise", but signals design and location should take this factor into account (e.g. use of mast arms, signal brightness.)

14. Similarly, there is evidence to suggest that accidents are associated with sites that have a higher degree of **complexity**. Thus, those responsible for signal design and operation should be aware that in such cases, there may be a need to simplify the decision environment, e.g. by use of fully controlled right turns, or replacement (where appropriate) of the signals with a roundabout.

15. It is noted that the sample of sites used in this study did not include the worst sites in the State. (Our worst site was the twelfth worst site in the State, and had about half the accident frequency of the worst site.) This leads us to note that this study has not been able to contribute much to knowledge about accidents at the **very high frequency** sites; perhaps these are in a separate category, and consequently a further study of these sites could be considered.

16. Further to the previous point, the reason that sites with a very high accident frequency were not included is that data on entering volumes are not available for these sites. We suggest that it would be worthwhile for VicRoads to have information about traffic flow at the worst signalised intersections in the State, and suggest that such **traffic volume data** be collected.

17. Earlier work (Corben and Foong, 1990) concerning guidelines for conversion of signalised intersections to **roundabouts** is mentioned; several of the sites identified may have met those guidelines, and would therefore be candidates for conversion as a possible accident countermeasure.

In general, our conclusion is that this study has demonstrated that factors other than just traffic volumes are contributing to accidents at signalised intersections. While we have not been able to identify any single prime factor which would lead in itself to a dramatic improvement in safety at signalised intersections, we have nevertheless identified a range of strategies or measures which, if applied at specific sites where appropriate, will contribute to safety.

The key is that those responsible for the design and operation of signalised intersections carefully appraise each site on its merits, have regard to known accident characteristics of signalised intersections, and apply sound and judicious engineering judgement to determine what particular features will likely contribute to safety at that site. The above recommendations will be useful in this regard.

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