Effectiveness of the Dwell-on-Red Signal Treatment to Improve Pedestrian Safety during High-Alcohol Hours

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Abstract

The Dwell-on-Red (DoR) signal treatment aims to reduce the number and severity of pedestrian-vehicle crashes that occur during high-alcohol hours (HAH) at signalised intersections. The treatment involves reverting to an all-red phase when there is no traffic demand during late evening and early morning. This causes vehicles to slow down or stop thereby reducing average speeds on intersection approaches. Lower speed is known to be beneficial to traffic safety particularly for vulnerable road-users. DoR was trialled at a metropolitan intersection in Melbourne. An observational study was carried out at this intersection and revealed a number of serious safety problems during late evening hours. As part of the evaluation of effectiveness speed and flow data were collected using detectors placed 10 and 50 metres upstream of the stop-line. The treatment was found to bring about a significant reduction in average speed at both detector positions. Significant changes were also found in the proportions of vehicles travelling at less than or equal to 30 km/h and greater than 50 km/h at the 10 metre detector position, and for speeds greater than 50 km/h at the 50 metre detector position. These findings indicate a potential reduction in fatal and serious injury risk. While DoR has a minimal impact on traffic performance, its effectiveness was found to be heavily dependent on traffic-flow. This aspect has an important bearing on future applications.

Keywords

Traffic signals, Pedestrian safety, High-alcohol hours

1. Introduction

Motor vehicle collisions with pedestrians are recognized as a serious road safety problem in most countries around the world. It is generally estimated that pedestrians represent between 10% and 20% of all road fatalities in western countries [1, 2, 3]. Alcohol is also implicated in the aetiology of many pedestrian crashes. For pedestrians, as for many other road-user categories, the risk for fatal or serious injury is known to increase significantly with higher blood alcohol concentrations (BAC) levels, particularly those in excess of 100mg/100ml [4, 5, 6, 7, 8, 9].

In Australia, studies indicate that 20-30% of pedestrian casualties have a BAC in excess of 150mg/100ml [10]. Similarly, in the US, BAC levels at or above 100mg/100ml have been reported in 30-40% of pedestrian fatalities and casualties, the same data showed that nearly 90% of pedestrians killed had a BAC of 80mg/100ml or higher [3]. Research findings from several countries indicate that a significant proportion of alcohol-related pedestrian fatalities and serious injuries occur during late evening and early morning hours [11, 3]. The crash data from the State of Victoria, Australia for 2002-2006 shows that 56% of all pedestrian fatalities and 44% of all serious injuries occur between the hours of 6 p.m. and 6 a.m. These hours are regarded as high-alcohol hours by VicRoads (Roads Corporation Victoria). Research findings in both Australia and other countries also suggest that weekend late evening and early morning hours are over-represented in the crash data relating to alcohol-related pedestrian casualties [11, 12].

According to the Victorian Parliamentary Road Safety Committee [13], effective solutions to combat the problem of alcohol-affected pedestrians should focus on exposure prevention and reduction. Pedestrians (and other road-users) should not be allowed to reach unsuitable BAC levels prior to exposure in traffic. Unfortunately, the effectiveness of responsible alcohol service courses has been found to be very poor. More often than not, these courses have little or no lasting effect [14, 15, 16, 17].

Traffic engineering approaches that attempt to reduce levels of crash risk and outcome severity for pedestrians usually focus on infrastructure design and speed reduction measures. Most infrastructure design solutions focus on providing adequate facilities to separate or improve interactions with vehicular traffic thereby providing additional protection and reducing exposure. There is considerable amount of research in relation to the safety and accessibility effects of commonly used infrastructure treatments, such as e.g. intersection redesign, pedestrian fencing, improved lighting, the provision of central refuges, improved traffic signalling, and so forth. Though poorly documented, there has also been a considerable amount of practical trialling and field work by traffic engineers that aim to improve pedestrian safety while at the same time maintaining a good level of traffic system efficiency. A number of the more successful treatments in terms of reducing crash risk and outcome severity are those related to traffic signal operation [18, 19].

Vehicle speed is known to be an important factor in determining the outcome severity of a crash. There have been a number of research studies that have estimated the risk of pedestrian fatality and serious injury in relation to vehicle impact speed. In a recent research study carried out by Scully and colleagues [20], the consensus of an expert panel determined that the IHRA [21] estimates of serious injury risk in relation to vehicle impact speed were those most representative of Australian vehicle-pedestrian crashes. The expert panel also determined that the fatality risk estimates of Anderson and colleagues [22] in relation to vehicle impact speed were most representative of vehicle-pedestrian crashes in Australia. This decision was reached after discussing the work of Kloeden and colleagues [11, 3] and the earlier work of Josksch [25] and Nilsson [26]. The risk of serious injury and fatality for pedestrians with respect to the impact speed of the striking vehicle, are shown below in Figure 1. This diagram indicates that vehicle-pedestrian collisions at impact speeds of 30 km/h have a 10% pedestrian fatality risk and a 45% risk for serious injury, whereas collisions at impact speeds of 50 km/h have almost a 90% fatality risk and a 95% risk for serious injury.

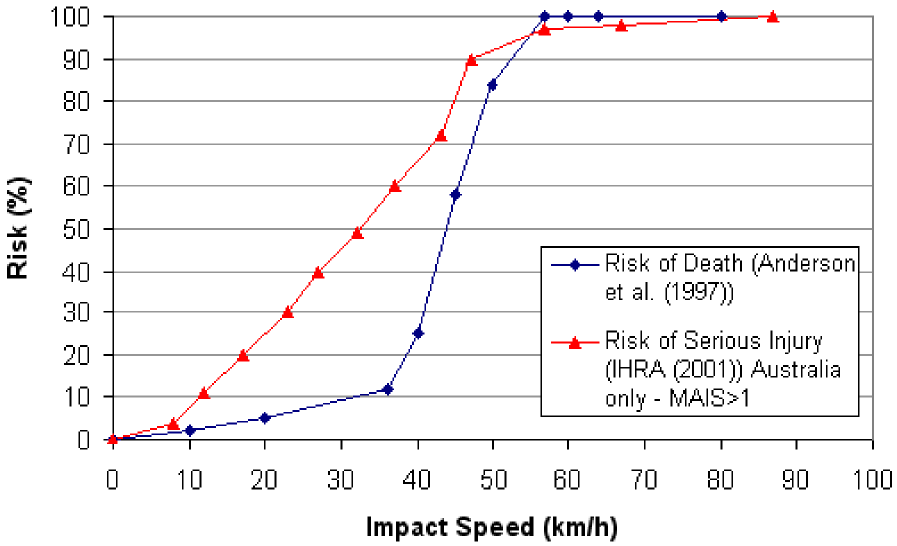

Figure 1. Consensus view of the risk of death and serious injury with respect to impact speed for pedestrians stuck by a car (from Scully *et al.* [20])

The substantial amount of literature suggesting the relationship between speed and crash risk suggests that lowering average vehicle speeds in areas where alcohol-affected pedestrians are likely to be present should bring about positive traffic safety improvements. A potential solution to the safety problems at signalled intersections during high-alcohol hours; where there are often alcohol-affected pedestrians crossing on red has been proposed by Corben and colleagues [27]. This particular solution is based on the use of a Dwell-on-Red signal treatment that introduces an ‘all-red’ signal phase in situations where there is no vehicular or pedestrian demand. The signal phase displays a red traffic signal in all directions causing approaching traffic to stop and slow down more frequently.

A trial with this ‘Dwell-on-Red’ signal treatment was carried out in the provincial city of Ballarat in Victoria [1]. This trial showed significant reductions in average speeds near the stop-line where there was a nine per cent reduction in average speed; and 30 metres upstream of the stop-line where there was a 28 per cent reduction in average speed. There was also a positive increase in the proportion of vehicles travelling at speeds of less than or equal to 30 km/h, and a reduction in the proportion of vehicles travelling at speeds greater than 50 km/h. These proportionate changes in the speed profile are representative of a considerable safety improvement.

The present study represents a continuation of the earlier work by Lenné and colleagues [1]. In this instance the effectiveness of the Dwell-on-Red signal treatment is trialled at a metropolitan Melbourne intersection with a view to assessing its effectiveness in reducing pedestrian-vehicle crash-risk during high-alcohol hours. It is also envisaged that the trial will provide further useful information that can be used to determine its future application at other signalled intersections

2. Method

2.1. On-site Traffic Safety Observation and Evaluation of Dwell-on-Red Effectiveness

This report is divided into two distinct parts. The first part describes on-site traffic safety observation study that was conducted in accordance to the principles of the traffic conflict technique described by Hydén [28]. This study was intended to gain an understanding of the existing safety problems at the chosen site, but also to assess the extent to which the DoR treatment could resolve the safety problems that were identified. A more detailed description of the traffic conflict technique method and the findings are provided in Chapter 3.

The second part of this report is concerned with an evaluation of the effectiveness of the DoR treatment. This evaluation focuses on several key performance indicators. The most important indicator is average speed. Others include the proportion of vehicles travelling at speeds of less than or equal to 30 km/h, and the proportion of vehicles travelling at speeds greater than 50 km/h. A description of the data analysis techniques used and the main findings are described in Chapter 4.

2.2. Chosen Intersection

A metropolitan Melbourne signalised cross-intersection was chosen for the second Dwell-on-Red trial. Both roads passing through this intersection are medium-sized arterial roads that carry a lot of traffic during morning and afternoon peak hours. The intersection is situated several kilometres east of the Melbourne Central Business District. The choice of intersection was based on a review of crash statistics focusing particularly on vehicle-pedestrians incidents during high-alcohol hours and several other key factors. A diagram of the intersection is shown in Figure 2. The intersection is controlled by six main signal groups for vehicle traffic, two groups for trams approaching from either direction, and 4 groups for each of the pedestrian-crossings that traverse each leg of the intersection. The signal controller has 7 phases including the Dwell-on-Red pivot phase. A number of the signal phases are designed to accommodate the tram-traffic passing through the intersection. The posted speed limits on the approach roads to the intersection are 60 km/h. There is, however, a restriction to 40 km/h for vehicles travelling on the south western-leg during all hours except 2 a.m. to 6 a.m. in the morning. It should also be noted that there are trams passing through the intersection along the south-west/north-east axis in both directions.

2.3. Evaluation Period for Dwell-on-Red

The Dwell-on-Red (DoR) signal treatment was implemented in early November and further adjusted in mid November 2007. While evaluation data was collected during one full month running from the start of November until well into December, the data used for evaluating the effectiveness of DoR represented the last full week in November following final adjustments to the signal logic. Data representing the last full week in November 2006 was used for the purposes of comparison.

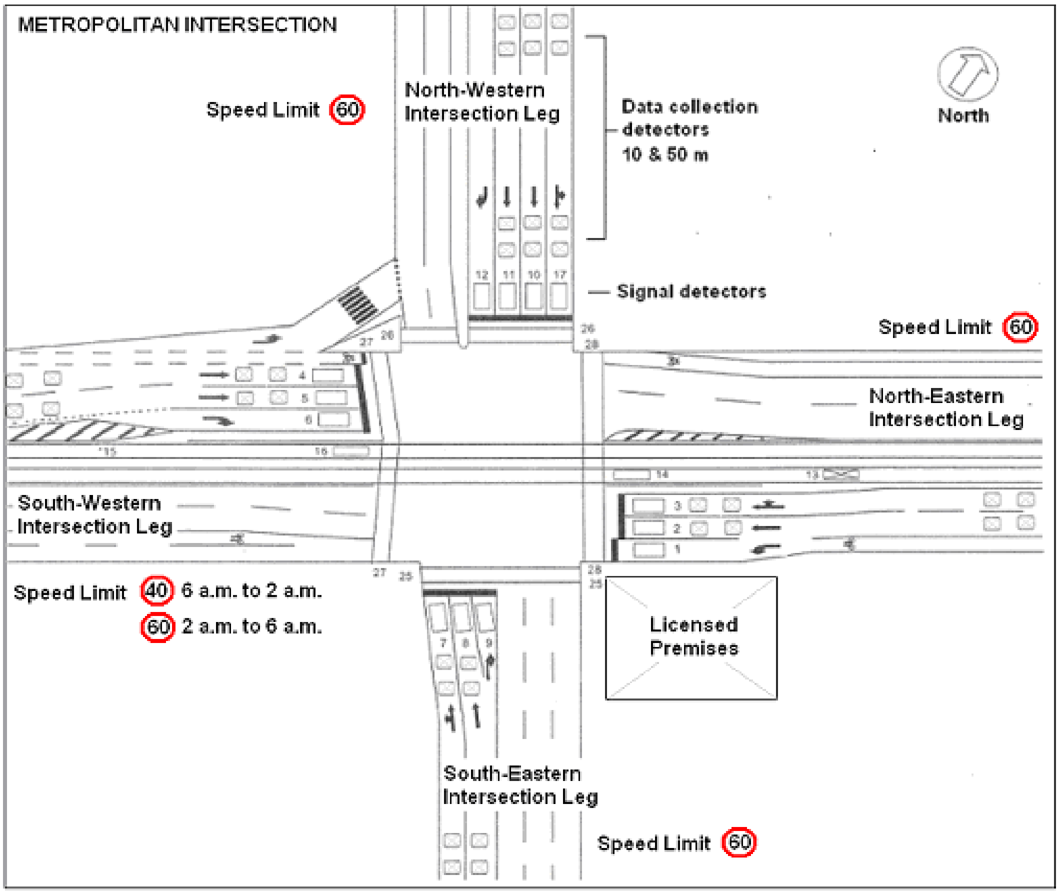

Figure 2. Intersection layout showing detector locations for the signal groups and data collection.

2.4. Dwell-on-Red Treatment Implementation and Configuration

The Dwell-on-Red (DoR) signal treatment involves the use of a special all-red signal phase that is called when there is no traffic or pedestrian demand following the termination of a preceding phase. When the all-red signal phase is called, all traffic signals at the intersection (including the pedestrian signals) will display a red traffic signal for a minimum time-period of 15 seconds. This phase will continue until there is demand registered at any of the detectors or pedestrian signal push-buttons. The all-red signal phase is implemented in the signal controller logic as the "pivot phase". This is essentially the default phase that is called at the start of each signal cycle whether or not there is any traffic demand. The DoR treatment is operational and can be activated if there is no demand between 9 p.m. and 5 a.m. This operational period is believed to be representative of high-alcohol hours [29].

2.5. Data Collection

In order to evaluate the effectiveness of the Dwell-on-Red treatment individual vehicle data was collected using designated magnetic induction loops installed in the roadway at 10 and 50 metres upstream of the stop-line (see Figure 2). The data collected included: speed, passage time, time-gap, and vehicle axle length and vehicle type. The 10 metre detectors are situated as close as possible to the stop-line without impeding the standard signal detectors. The detectors at 50 metres were intended to collect speed data that was more indicative of crash risk given the braking distance needed at the posted speed limit prior to the stop-line and pedestrian crossing. Speed closer to the stop-line and pedestrian crossing is believed to be more indicative of potential injury severity for pedestrians. Data was collected for a four-week period in November-December 2006 and during the same period in 2007.

2.6. Traffic Volumes

The daily traffic volumes recorded at these detectors on each day of the week are shown in Figure 3 for the before and after periods in 2006 and 2007. The traffic volumes for the before and after period for times corresponding to that when the DoR signal treatment was operational during the after-period are shown in Figure 4. This figure shows that the highest traffic volumes occurred during Saturdays and Sundays. This highlights the attractiveness of the area during evening and early morning hours as a result of the fact that the intersection being a popular destination for entertainment and leisure with many cafés, bars and restaurants. The average daily traffic volume for the week is quite similar for the before and after condition demonstrating the validity of the data for comparative purposes.

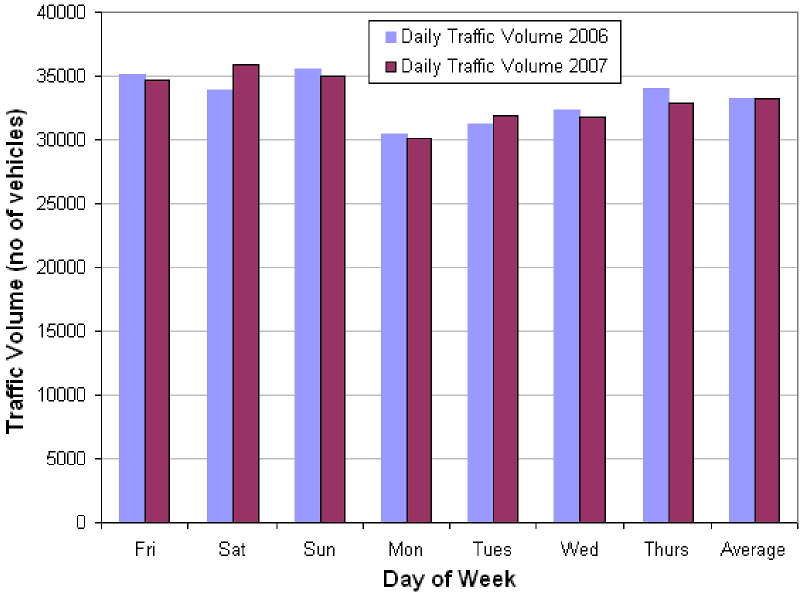

Figure 3. Daily and average traffic volume passing through the intersection.

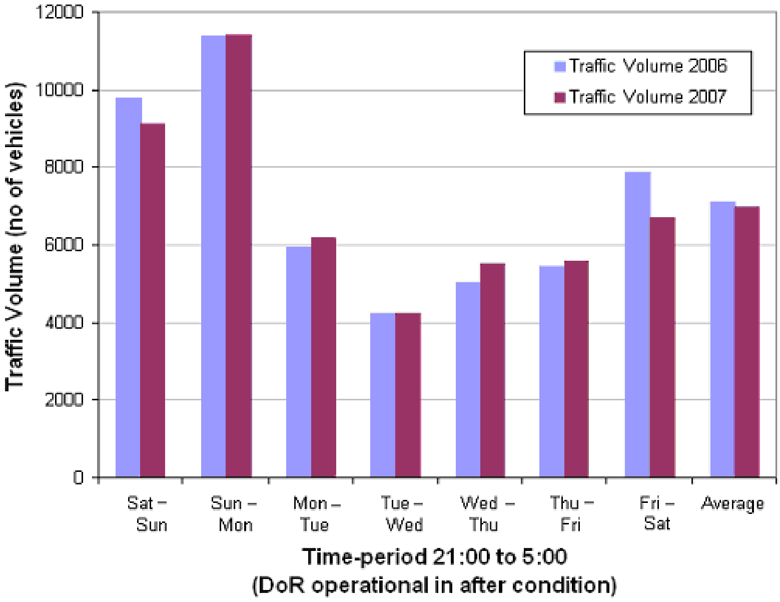

Figure 4. Daily and average traffic volume passing through the intersection during times when the DoR signal function was operational in the after-period.

2.7. Crash History

The VicRoads CRASHSTATS database indicated that there had been 20 police reported casualty crashes at the intersection during the latest five-year crash period (01/01/2002 - 31/12/2006). The data showed that there have been 6 pedestrian casualty crashes resulting in 3 serious injuries and 3 minor injuries to the pedestrians, and 2 involving cyclists both resulting in minor injuries. All 6 of the pedestrian accidents occurred during high-alcohol hours.

2.8. Differences between the Ballarat and Metropolitan Melbourne Dwell-on-Red Trials

There are a number of important differences between the Ballarat and metropolitan Melbourne trials that prevent a direct comparison of results. Not only were there large differences in geometric layout of the two intersections, there were also major differences in the volumes of traffic passing through the intersection and the numbers of crossing pedestrians. The volumes were higher for the metropolitan Melbourne intersection, which also showed a different volume profile over time with considerable evening and weekend traffic. These volume differences suggest a different activation potential for the DoR treatment. As mentioned earlier, the metropolitan Melbourne intersection also caters for trams, a factor that influences intersection design and traffic signal system configuration. There were many differences in the location of the traffic signals as well as the general signal phasing, signal group configurations and placement of signal heads.

The most important difference with regard to the purpose of this study was that the DoR signal treatment was implemented differently at each of the two sites. At the metropolitan Melbourne intersection, the all-red phase was only activated in situations where there was no traffic demand. In Ballarat, the all-red phase was automatically introduced during every signal cycle, irrespective of traffic demand. This meant that there were a great many more all-red phase activations. Another important difference concerned the location of the detectors installed to collect data. At the Ballarat intersection, the detectors were placed closest to the stop line and 30 metres upstream on each intersection approach road. At the metropolitan Melbourne intersection, the detectors were placed at 10 metres and 50 metres upstream of the stop-line. These differences are related to technical issues that are beyond the scope of this report.

3. Conflict Observation Study: Determining Existing Traffic Safety Problems

3.1. Background and Purpose of the Conflict Observation Study

In order to determine the extent of the traffic safety problems during high-alcohol hours at this intersection, a conflict observation study was carried out in accordance with the technique developed by Hydén [28]. Hydén describes a conflict as: "*The time that is remaining from when the evasive action is taken until the collision would have occurred if the road users had continued with unchanged speeds and directions*". The aim of a conflict observation study is to identify and quantify all unsafe interactions between road users at a particular site during a predetermined time-period). According to Hydén, the number of serious conflicts recorded is statistically correlated to the number of police reported accidents. An important advantage of the conflict technique is that it can provide a useful safety profile at a specific location from a relatively short period of observation. Statistical crash data, on the other hand, often takes several years before it can be regarded as statistically stable. One of the questions surrounding the use of this technique is related to the subjective nature of the observed time-to-collision values that are based on observer's estimates of vehicle speed and distance to a common conflict point.

A key objective of this particular observation study was to determine the suitability of the Dwell-on-Red treatment at the site in relation to the existing safety problems. It was anticipated that observation studies in addition to an analysis of existing crash data would provide an invaluable insight into past and present levels of safety, and ultimately result in recommendations for safety enhancement.

3.2. Conflict Observation Study Time-Periods

The conflict observation study was carried out during the time-periods listed in Table 1 below. During these time-periods the Dwell-on-Red treatment was operational, however, the high traffic volumes during weekend evening hours prevented the activation of the all-red phase. The observation study was carried out by one of the authors of this paper who has training and experience in the use of this technique.

Table 1. Dates, times and weather conditions for the conflict observation study.

Date	Observation Times		Weather	
	Start	End	Conditions	Temperature
Friday, 9th November	21:00	00:00	Dry	15 C
Saturday, 10th November	21:00	00:00	Mostly Dry	14 C
Friday, 16th November	21:00	00:00	Dry	18 C
Saturday, 17th November	21:00	00:00	Dry	17 C
Friday, 23rd November	21:00	00:00	Dry	19 C
Saturday, 24th November	21:00	00:00	Mostly Dry	16 C
Total Time	18 hours			

3.3. Main Results: Serious and Non-serious Conflicts

In total, 23 conflicts were recorded during the 18 hours of conflict observation at the intersection. The observations included 20 serious conflicts and 3 minor conflicts. The conflicts, representing unsafe interactions between different road-users, are plotted in a standard conflict diagram in Figure 5. The Time-to-Accident value determined from each unsafe interaction represents the conflict proximity. When plotted against speed, this also shows the relative severity of the conflict. Serious and non-serious conflicts are separated by a line determined from the work of Hydén [28].

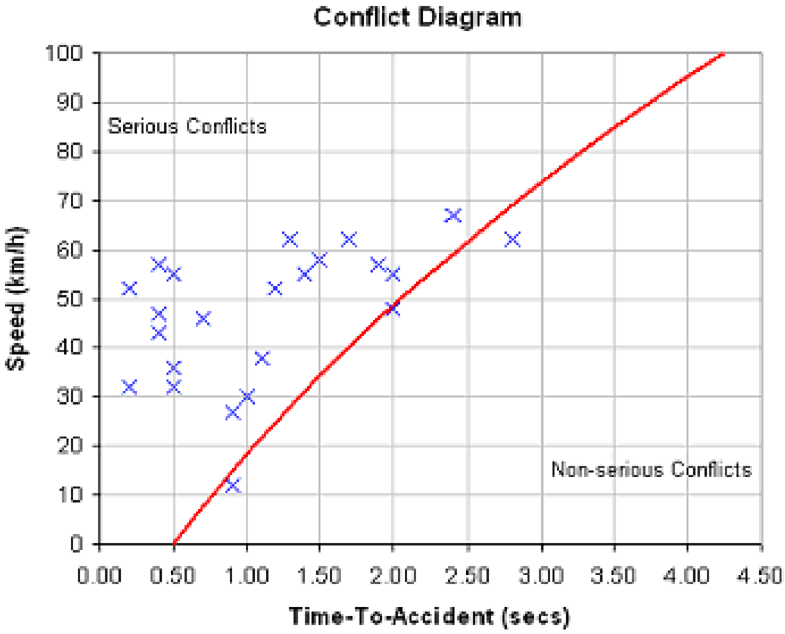

Figure 5. Summary of conflicts occurring at the intersection.

In total, 14 of the serious conflicts, and 1 minor conflict occurred on Saturday evenings; 6 serious conflicts and 2 minor conflicts occurred on Friday evenings. The observations showed that 17 of the 20 serious conflicts, and 1 of the 3 minor conflicts, were between vehicles and pedestrians. The remaining conflicts were all between vehicles. One of the vehicle-pedestrian conflicts involved a bus, and another a motorcycle. All other vehicle-pedestrian conflicts involved private vehicles, i.e. cars. All of the vehicle-vehicle conflicts involved cars, although 3 of the conflicts (2 serious and 1 minor) involved taxis. Almost all of the vehicle-pedestrian conflicts occurred on the pedestrian crossing on the north-eastern side of the intersection. This leads to the licensed premises (see Figure 2).

For all vehicle-pedestrian conflicts, the pedestrians had crossed on a red pedestrian signal; some also crossed some metres further back from the pedestrian crossing on the south-eastern leg. Further, all pedestrian conflicts occurred on the left-side of the pedestrian crossing against the oncoming stream of traffic approaching from the south-western leg of the intersection.

3.4. Pedestrian Behaviour

During the conflict observation studies, pedestrian counts were also made for the signalled pedestrian crossings on each intersection arm. The count documented the number of pedestrians crossing on red. The data suggested that there were a large number of people crossing the south-eastern leg on Friday and Saturday evenings in the hour before midnight. This pedestrian crossing provides access to licensed premises on the north-eastern corner of the intersection. The study also revealed that there were a great many pedestrians crossing on red. According to earlier research by amongst others Baas [30], this may be due to some extent to the relatively long waiting times.

3.5. Conclusions from the Conflict Observational Study

In conclusion, the observation study showed evidence of a significant safety problem during late evening hours on Fridays and Saturdays. This problem was largely caused by the large number of pedestrians who show disregard for the pedestrian traffic signals on the south-eastern leg pedestrian crossing and make their way over on red despite the fact that there is poor lighting, high vehicle speeds for vehicles approaching from the south-west, and no pedestrian island for protection midway across the road. Given the existing problems at this site, a number of possible solutions that were likely to improve traffic safety were suggested. It was considered unlikely that the safety problems resulting from vehicle-pedestrian interactions would be satisfactorily resolved by the adoption of the Dwell-on-Red treatment. Suggestions included speed limit reductions, improved lighting, and the introduction of a pedestrian refuge on the south-eastern leg of the intersection. Alternative signalling treatments that involved less waiting time for pedestrians were also recommended as a measure that had safety improvement potential.

4. Effectiveness of the Dwell-on-Red Signal Treatment

4.1. Analysis of Dwell-on-Red Effectiveness

In order to assess the effectiveness of the Dwell-on-Red signal treatment a custom generalized linear model was used to analyse the speed change at the two detector positions on each of the four approaches to the intersection [31]. The main treatment condition compared speed data during late evening and early morning hours (from 9 p.m. to 5 a.m. for a before and after period. The before-period represented speed data from the last week in November 2006, and the after-period represented the same week during 2007. The DoR signal treatment was implemented and was operational during 9 p.m. to 5 a.m. in November 2007. The data analysis assessed the ability of the DoR signal treatment to predict speed change at each of the two detector positions (10 and 50 metres) during the time-period when it was operational. The analysis also incorporated a control condition for the same before and after periods. The control condition was based at the same intersection and but was based on the hours of the day when DoR was not operational (i.e. from 5 a.m. to 9 p.m.).

An identical statistical analysis model was used to assess the ability of the DoR signal treatment to predict changes in the proportions of vehicles travelling below 30 km/h and above 50 km/h at each of the two detector locations in the before and after periods. A similar control condition was also used. The rationale behind these additional analyses was that speeds less than or equal to 30 km/h are representative of a 10 per cent fatality risk for pedestrians struck by vehicles, while speeds greater than 50 km/h are representative of a 90 per cent fatality risk.

For the purposes of this report, the results presented for the 10 and 50 metre detector locations are based on aggregated data representing the overall picture for all intersection approach roads. Comments relating to specific to individual approach roads are however included in the result descriptions where appropriate.

4.2. Frequency and Duration of All-Red Phase Activations

The data analysis regarding signal operation revealed an average of 202.4 all-red phase activations per operational period (9 p.m. in the evening to 5 a.m. the following morning). Similarly, the DoR all-red phase was active 3804.4 seconds on average per operational period. The average duration for an all-red phase activation was 18.8 seconds in length (minimum duration per activation was 15 seconds).

The frequency of all-red phase activations during weekdays was greater than that during weekends (Friday evening to Saturday morning and Saturday evening to Sunday morning). The higher traffic volumes during weekend late evening and early morning hours resulted in fewer activations (see Figure 6 below, and Figure 4 presented earlier). This was expected given the intersection location in a popular suburb with many restaurants, cafes, bars and night-clubs.

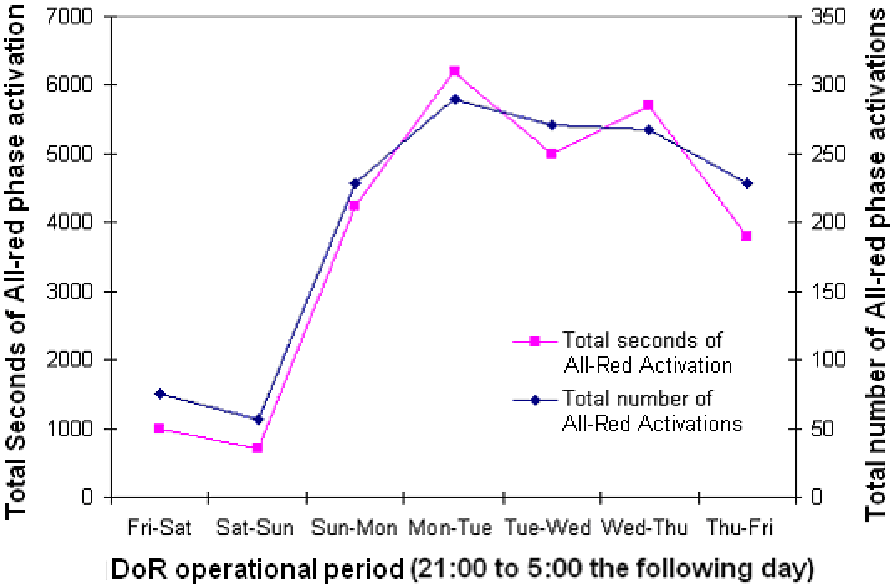

Figure 6. Total number of all-red activations and the total number of activation seconds.

The number of all-red activations also varies greatly according to hour; this is again due to changes in traffic-flow rates at the intersection. A strong relationship was found between all-red phase activation time in seconds per hour and the hourly traffic-flow rates during the one-week study period when DoR signal treatment was operational (see Figure 7).

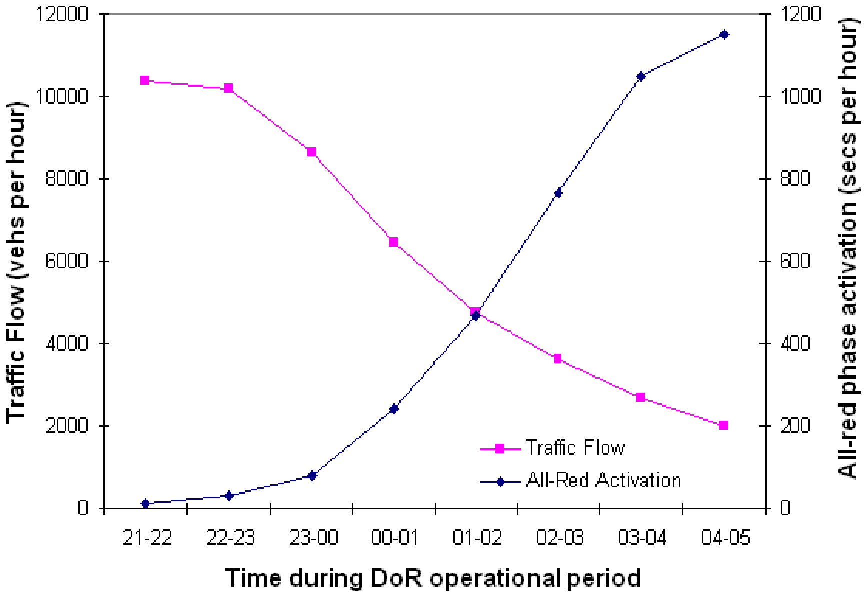

Figure 7. The relationship between all-red activation time in seconds per hour and the hourly traffic-flow during the one-week study period when DoR was operational.

4.3. Impact on Average Speed and 85th Percentile Speed

A key impact variable for the evaluation of DoR effectiveness was average vehicle speed. These results are shown below in Table 2. At the 10 metre detectors average vehicle speed was found to drop in the comparison of the data for the before and after-periods in the treatment condition by approximately 1.4 km/h (DoR was operational during the 21:00 to 5:00 time-period which also represented the after period of the treatment condition). In the control condition, when DoR was not operational there was an overall reduction of 0.6 km/h in average speed in the comparison of before and after data. The analysis revealed that the predicted change in average speed was significant as a result of the DoR signal treatment even after taking into account the before and after speed change in the control condition (Wald Chi-Square 11.95, *df* 1, $p<0.001$).

The 50 metre detector position showed similar results with a 0.6 km/h change in speed in the treatment condition for the before and after data, and a 0.1 km/h speed change in the before and after data for the control condition. The data analysis indicated that this change in speed was also significant even when considering the speed change in the control condition (Wald Chi-Square 4.95, *df* 1, $p<0.03$). Changes in average speed were found for all of the intersection approach roads at the 10 metre detector position, and at two of the four 50 metre detector positions.

Table 2. Average vehicle speeds and standard deviations for the 10 and 50 metre detector positions for the treatment and control during the before and after conditions (DoR was operational in the treatment/after condition).

	10 metre detector position		**50 metre detector position**	
	Average Speed (km/h) Before	**Average Speed (km/h) After**	**Average Speed (km/h) Before**	**Average Speed (km/h) After**
Treatment condition	30.3 (±15.2)	28.9 (±14.7)	34.2 (±13.4)	33.6 (±13.0)
Control condition	30.7 (±15.3)	30.1 (±15.5)	33.7 (±14.0)	33.6 (±14.3)

The lack of impact at two of the 50 metre detectors on the south-western and north-eastern approaches was believed to be due to the fact that the 50 metre detector was located beyond the point at which vehicles start to brake for the traffic lights if they show red. This suggests that it is generally representative of free-flow speed if there are no queues before the traffic lights. If the 50 metre detectors are beyond the braking point in free-flow conditions, it is expected that there would be no change brought about by the DoR treatment when compared to the control conditions. This appeared to be the case on the south-western and north-eastern approaches. At the two other 50 metre detector positions the effects are most probably due to the higher volumes of traffic which rarely allow for free-flow conditions at the 50 metre detector location. In these circumstances, the effect of the signals is amplified further upstream causing a greater reduction in average speed measured at the50 metre detector.

Changes in 85th percentile speed were consistent at all detector locations with positive speed reductions in the before and after data for the treatment condition (see Table 3). The 85th percentile speeds in the before and after data comparison for the control condition showed no difference at either of the two detector positions. The overall 85th percentile speeds results therefore suggest a clear positive safety impact related directly to the DoR signal treatment. The data for each individual approach road revealed, however, that there were several cases where 85th percentile speeds increase. This was found at the two detector positions on the south-western approach, and the 50 metre detector position on north-eastern approach.

Table 3. 85th percentile speeds for each of the two detector positions for the treatment and control, before and after conditions (DoR was operational in the treatment/after condition).

	10 metre detector position		**50 metre detector position**	
	85th Percentile Speed (km/h) Before	**85th Percentile Speed (km/h) After**	**85th Percentile Speed (km/h) Before**	**85th Percentile Speed (km/h) After**
Treatment condition	49	47	49	48
Control condition	49	49	50	50

4.4. Changes in the Speed Distribution

The distributions of speed were also analysed by looking at the proportion of vehicles travelling less than or equal to 30 km/h and the proportion of vehicles travelling greater than 50 km/h at both the 10 and 50 metre detector positions.

10 Metre Detector Position

The results relating to the proportion of vehicles travelling less than or equal to 30 km/h at the 10 metre detector position are shown in Table 4. The data for the after period shows a 4.1% overall increase compared to the before period for the treatment condition, but also a 2.3% overall increase in the before and after data comparison related to the control condition. The analysis of this data showed that this effect was statistically significant even when taking into account the increase found in the before and after data comparison for the control condition (OR = 0.98, 95% CI = 0.97–0.99, p <0.0001). This suggests a positive safety outcome with regard to the fatality risk for pedestrians struck by vehicles at speeds of 30 km/h or less. The proportion of vehicles travelling greater than 50 km/h at the 10 metre detector position was also reduced by 2.2% to 9.9% overall in the after-period compared to the before period for the treatment condition. A small increase of 0.2% was found in the comparison of the before and after data for the control condition. The overall reduction, taking into consideration the decrease found in the before and after data comparison for the control condition, was statistically significant (OR = 1.02, 95% CI = 1.02–1.03, p < 0.0001) suggesting a positive outcome with regard to the reduction in fatality risk for pedestrians struck by vehicles at speeds of 50 km/h or higher.

Table 4. 10 metre detector position: Proportions of vehicles travelling less than or equal to 30 km/h and greater than 50 km/h for the treatment and control data in the, before and after conditions (DoR was operational in the treatment/after condition*)*.

	Proportion of vehicles travelling at 30 km/h or less		**Proportion of vehicles travelling at 50 km/h or higher**	
	Before	**After**	**Before**	**After**
Treatment condition	57.1%	61.2%	12.1%	9.9%
Control condition	56.0%	58.3%	13.3%	13.5%

50 Metre Detector Position

The speed data collected from the 50 metre detector positions were also categorised into vehicles travelling less than or equal to 30 km/h or greater than 30 km/h, and less than or equal to 50 or greater than 50 km/h (see Table 5). The proportion of vehicles travelling at 30 km/h or higher increased overall by 1.4% in the after period when compared to the before period for the treatment condition. However, there was also a 1.3% increase for the corresponding data in the control condition. Taking into account the relative difference found in the control condition, the data analysis indicated that this effect was not statistically significant (OR = 1.00, 95% CI = 0.92–1.06, $p = 0.821$). This result may be due to the distance of the detector from the stop-line.

At 50 metres from the stop-line most vehicles will not have braked to a level of 30 km/h or less if the traffic lights show red unless there is a slowing down or stopping effect that is amplified upstream by preceding vehicles. The proportion of vehicles travelling greater than 50 km/h at the 50 metre detector positions was reduced by 1.5% in the before and after period comparison for the treatment condition. There was also a corresponding 0.9% increase in the before and after data comparison for the control condition. The data analysis showed that the overall reduction for the treatment condition was statistically significant when taking into account the relative changes in the control condition (OR = 1.02, 95% CI = 1.02–1.03, $p < 0.0001$). This finding at the 50 metre detector positions suggest a positive safety outcome with regard to the fatality risk for pedestrians struck by vehicles at speeds of 50 km/h or higher. At approximately 50 metres from the stop-line, many vehicles may have already begun to reduce their speed to 50 km/h or less to stop for the traffic lights if they show red. This appears to be the way in which the DoR signal treatment creates an impact at this distance from the stop-line.

Table 5. 50 metre detector position: Proportions of vehicles travelling less than or equal to 30 km/h and greater than 50 km/h for the treatment and control data in the, before and after conditions (DoR was operational in the treatment/after condition).

	Proportion of vehicles travelling at 30 km/h or less		**Proportion of vehicles travelling at 50 km/h or higher**	
	Before	**After**	**Before**	**After**
Treatment condition	40.4%	41.8%	12.4%	10.9%
Control condition	43.1%	44.4%	13.5%	14.4%

Changes in the speed distributions were also analysed individually for the 10 and 50 metre detector positions on each approach road. This analysis revealed a number of cases where improvements were not found. In particular, the south-western approach was found to have suffered an decrease in the proportions of vehicles that have speeds of 30 km/h or less and an increase in the proportions of vehicles that have speeds of 50 km/h or higher when comparing the before and after data for both the treatment condition and also for the control condition.

4.5. Conclusions Regarding Dwell-on-Red Safety Impact

In summary, the results indicate that the DoR signal treatment brought about significant reductions in overall average speed and also 85th percentile speed. A reduction in speed such as that found is known to be correlated with a reduction in crash frequency and crash outcome severity, particularly for vehicle-pedestrian impacts [18, 19, 20]. At the average speeds recorded at the detector nearest the stop-line, the 1.4 km/h reduction in average speed is estimated to be equivalent to a similar percentage reduction in serious-injury risk for pedestrian-vehicle collisions according to the data presented earlier in Figure 1 that refers to the study by Scully and colleagues [20]. The reduction in fatality risk is somewhat less as a result of the fact that the average speeds are already relatively low.

There were also overall significant positive changes in the relative proportions of vehicles travelling at less than or equal to 30 km/h, and greater than 50 km/h. These changes in the speed distribution suggest an important positive safety impact given what is known in relation to speed levels and the risk for fatality and serious injury. The percentage reductions in risk related to these changes in the speed profile are difficult to quantify statistically.

5. General Conclusions

It was considered important to compare the findings at the Melbourne metropolitan intersection with those from the previous application of this treatment in the provincial city of Ballarat. The previous trial revealed a convincing reduction in average speed and changes in the speed distribution suggesting a positive reduction in crash risk for pedestrians [1]. The results for the Melbourne metropolitan intersection are less distinct. The differences between the provincial and metropolitan results are due almost entirely to the way in which DoR was applied. In the Ballarat trial, the signal treatment was not implemented in a way which was fully responsive to the prevailing traffic conditions.

It is also speculated that DoR is unlikely to have any considerable safety impact in relation to pedestrian-vehicle interactions that occur on far-side intersection pedestrian crossings in situations where the intersection is spatially large. This is because some vehicles may accelerate quickly through the intersection to reach higher average speeds than those found on the near-side pedestrian crossing. This limitation is not likely to be applicable to smaller intersections. At larger intersections other treatments may be more effective in reducing speed. Furthermore, it is hypothesized that DoR may be experienced as frustrating by drivers if it is implemented on a wider scale due to the constant need to stop in situations where there is no other traffic. Arguably, a better solution would incorporate the use of upstream detectors that register the arrival of a car and allow it to pass without stopping provided a suitably low speed is maintained. More research is needed in this area to determine an optimum and sustainable solution.

A further thought regarding this treatment is that although it is intended as a measure to improve pedestrian safety problems during high-alcohol hours, there is no reason why it could not remain operational during all hours of the day. Particularly at smaller and medium-sized intersections, this signal treatment may have a positive safety benefit.

Finally, it is recommended that at least one further trial is conducted at a representative small or medium-sized signalised intersection in metropolitan Melbourne with less traffic volume during late evening and early morning hours. It is also suggested that the DoR signal treatment should be operational during all hours of the day in a future trial. This evaluation should provide sufficient information for guidelines to be developed in relation to potential future applications. It would also be useful to evaluate and compare several other alternative signal treatments that promote better speed adaptation without the need for vehicles to stop in no-demand situations.

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