MONASH UNIVERSITY
ACCIDENT RESEARCH CENTRE

INJURY REDUCTION MEASURES IN AREAS HAZARDOUS TO PEDESTRIANS

STAGE 2: COUNTERMEASURE EVALUATION

by

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Injury Reduction Measures in Areas Hazardous to Pedestrians, Stage 2: Countermeasure Evaluation

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Abstract:

Victorians have enjoyed substantial reductions in the annual numbers of pedestrians killed after 1989. Despite these excellent gains, the overall problem remains a serious community concern with 76 persons killed and some 736 persons seriously injured in 1999. A large part of the savings appears due to a general downward trend in Victoria's overall road toll after 1989. While pedestrians appeared to have benefited from measured targeted at drivers, pedestrian crashes in high activity/commercial centres still represent a long-standing problem for which few effective solutions have been found. It is suggested that innovative and comprehensive approaches are needed to moderate excessive vehicle speeds to uniformly lower levels in environments where there is high pedestrian activity. An evaluation was undertaken in areas known to be hazardous to pedestrians utilising a quasi-experimental before-after comparison of speed profiles and vehicle travel times following the implementation of speed moderating treatments. Large reductions of 7.5 km/h in average vehicle speeds over the full length of the treatment survey site were found. These were associated with estimated reductions of 2-3% in fatal pedestrian crashes and of 15% in serious injury pedestrian crashes. Mean speeds at locations within the survey site also reduced by 1.3 km/h. These reductions were associated with expected reductions of 11% in fatal, 8% in serious injury, and 5% in casualty pedestrian crashes. Furthermore, a significant reduction in the proportion of vehicles travelling at or above given speeds was found, particularly as vehicles entered the shopping precinct. In summary, this evaluation demonstrated that small gains in speed reduction can lead to very valuable gains in road trauma for pedestrians in environments where there is high pedestrian activity. Innovative countermeasures, such as those evaluated here, provide a cost-effective approach to moderate vehicle speeds, resulting in general benefit to all road users, especially pedestrians.

Key Words:

Accident, Injury, Pedestrian, Traffic Engineering, Countermeasure, Speeding, Cost-benefit, Speed Limit, Road Environment.

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Preface

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EXECUTIVE SUMMARY

INTRODUCTION

While Victorians have enjoyed substantial reductions in the annual numbers of pedestrians killed after 1989, pedestrian safety remains a serious community concern with 76 persons killed and some 736 persons seriously injured in 1999. Pedestrians have been identified as a group especially vulnerable to injuries sustained in a road crash and calls have been made to improve pedestrian safety through programs aimed at reducing the incidence and severity of crashes to all aged pedestrians.

Pedestrian crashes in high activity/commercial centres are a particular problem and one that needs to be addressed, however, few effective solutions have been found. There are a number of countermeasure options available for reducing the risk of death or serious injury to pedestrians in these areas. However, many of the traditional countermeasures have proved to be unsuccessful in terms of ensuring safe passage for pedestrians and this is reflected in little change in the rate of pedestrian casualty crashes.

The remaining alternative is to develop ways of achieving more moderate vehicle speeds. Indeed, past research provides a compelling case for moderating vehicle speeds in high pedestrian areas. Excessive speed has been shown to be a key factor in both the incidence and severity of pedestrian crashes and it has been shown that only small differences in travel speed can result in large differences in death and serious injury risk.

A concerted and innovative approach is required if real and lasting gains are to be made to pedestrian safety in Victoria's hazardous commercial environments. Denmark and the Netherlands are known for their innovative and enlightened approaches to pedestrian safety and amenity, and some of their philosophies and practices were considered for application in Victoria and elsewhere in Australia.

PROJECT OBJECTIVES

This research was conducted as part of a larger study to examine the possibilities for reducing injuries in areas that are particularly hazardous to pedestrians. The objective of this study was to evaluate some countermeasure options on arterial roads in the Melbourne metropolitan region. Specifically, the project aimed to:

i) Reduce serious pedestrian crashes, through the development of practical new approaches to moderating vehicle speeds, without seriously affecting travel times, and

ii) Evaluate the effectiveness of recommended measures, so that the most cost-effective measures may be introduced at hazardous pedestrian locations in Victoria's urban areas.

PROJECT DESIGN

This project involved the use of a 'before' and 'after' quasi-experimental design where speed profiles and vehicle travel times were compared before and following the implementation of speed moderating treatment(s) at one treatment site (Clarendon Street, South Melbourne) and one control site (High Street, Northcote).

The countermeasure treatments selected for evaluation were: 50 km/h speed limit and physical measures including painted pedestrian refuge between tram tracks, coloured crosswalks at intersections, and pram crossings.

Three surveys were conducted at both the treatment and control sites. During each survey time, free-flowing speeds at several points within the shopping strips and travel time information through the length of the shopping strip were measured. The first surveys comprised the 'before' survey when no treatments were installed. The first 'after' surveys occurred after a traffic control measure in the form of a 50 km/h speed zone was introduced on Clarendon Street. The last 'after' surveys occurred after a second set of physical countermeasures was installed on Clarendon Street.

FINDINGS

At the outset, it should be noted that the quasi-experimental design was utilised in anticipation that this design would ensure that any observed effects of treatment implementation at Clarendon Street could be attributed to the treatments themselves rather than other factors. However, for this type of evaluation to be successful, an appropriate control site needs to be selected. High Street was chosen as the most suitable site, based on the factors indicated in previous sections. During the analysis of the data, however, some problems became apparent in the data collection at the control site, particularly regarding measurement of free-flowing speeds as vehicles left the survey site due to a tram crash upstream and equipment problems. Although the authors believe in the concept of this design, that it ought to provide a rigorous test of the effectiveness of treatment programs, there were some concerns about the reliability of the data collected at the control site. Moreover, to the knowledge of the authors, there was no overall change in speed behaviour in the Melbourne metropolitan area, nor was there any campaign launch aimed to target speed behaviour. There seemed to be no forthcoming explanations as to why speed behaviour had changed on High Street.

Considering these uncertainties regarding the reliability of the control data, an alternative approach is to assume that there was no system-wide change in speed behaviour in the Melbourne metropolitan area and examine the changes in speed behaviour and travel times on Clarendon Street without adjusting for control data. Furthermore, the findings of travel speed reductions were related to pedestrian injury risk.

Mean Speeds over the full length of the shopping strip

Average vehicle speeds were calculated from travel time data as vehicles entered and exited the survey site. Comparison of these data provided some encouraging results in terms of reductions in overall vehicle travel speeds. It seemed that installation of treatments resulted in sizeable reductions in average vehicle speeds throughout the shopping precinct. These reductions in average vehicle speeds were observed after all treatments were installed, compared to before treatment installation. Installation of the 50 km/h speed zone did not affect overall speed behaviour. However, *average* speeds were already below 50 km/h.

- The overall reduction of 7.5 km/h in average vehicle speed throughout the shopping precinct was associated with estimated reductions of 2-3% in fatal pedestrian crashes and of 15% in serious injury pedestrian crashes.

Spot Speed Measurements at free-flowing locations through the shopping strip

While the large reduction in overall speed behaviour was encouraging, smaller but significant reductions in vehicle speeds at selected locations, in the order of 1-2 km/h, were found.

- Reductions in speed of free-flowing traffic at spot locations of 1.3 km/h were associated with expected reductions of 11% in fatal pedestrian crashes, 8% in serious casualty crashes and 6% in casualty crashes.

Proportion of drivers travelling greater than specific speeds

The finding that proportions of vehicles travelling at speeds likely to kill or seriously injure a struck pedestrian, decreased as a result of treatment implementation, also provided strong evidence of the benefits to pedestrians.

- The proportion of vehicles travelling at or above 60 km/h fell from 5% to 4% (i.e. a 20% reduction). Any vehicle travelling at or above 60 km/h is almost certain to kill or seriously injure a struck pedestrian.

- The proportion of vehicles travelling at or above 50 km/h fell from 33% to 28% (i.e. a 15% reduction). Any striking vehicle travelling at 50 km/h has a probability of up to 85% of killing a pedestrian and 90% of resulting in a serious injury pedestrian crash. In terms of real numbers, this relates to a reduction from 240 vehicles every hour to 150 vehicles every hour travelling at or above 50 km/h and posing a significant threat to pedestrians.

- The proportion of vehicles travelling at or above 40 km/h fell from 73% to 68% (i.e. an 8% reduction). Any striking vehicle travelling at 40 km/h has a probability of up to 26% of killing a pedestrian and a 66% probability of resulting in a serious injury pedestrian crash. In terms of real numbers, this relates to a reduction from almost 600 vehicles every hour before treatment installation to only 360 vehicles every hour travelling at or above 40 km/h.

CONCLUSIONS

This evaluation highlighted a number of important findings for pedestrian safety on Clarendon Street:

- If it is accepted that speed behaviour did not change in the Melbourne metropolitan region throughout the study period, this evaluation demonstrated real reductions in vehicle speeds on Clarendon Street as a result of treatment implementation.

- Overall reductions of 7.5 km/h (from 28.3 km/h to 20.8 km/h) in average vehicle speed throughout the shopping precinct were associated with estimated reductions of 2-3% in fatal pedestrian crashes and of 15% in serious injury pedestrian crashes. The smaller reductions of 1.3 km/h (from 44.9 km/h to 43.6 km/h) at locations where free-flowing traffic was measured are associated with expected reductions of 11% in fatal pedestrian crashes, 8% in serious casualty crashes and 6% in casualty crashes.

- There was only marginal change in speed behaviour after installation of the 50 km/h speed zone, however, larger reductions in average and measured speeds throughout the shopping precinct as a result of installation of all treatments were found. This may provide some support to the suggestion that traditional countermeasures by themselves have limited success in reducing pedestrian casualty rates in shopping strip areas. An innovative approach that combines a range of countermeasure applications may be more successful in moderating vehicle speeds in areas of high pedestrian activity.

- If the aim of treatments is to target those drivers that are exceeding the speed limit (i.e., those travelling at or above 50 km/h), the findings show a real effect of treatment implementation. This was particularly evident as vehicles entered the shopping precinct. Here, there was a 25% reduction after installation of the 50 km/h speed limit, and a 35% reduction after all treatments had been installed.

- Travel times increased marginally, however, the large expected reductions in the crash risk of pedestrians as a result of reductions in overall vehicle speeds are considerable, while the impact on motorists travel times is relatively small.

Research indicates that small gains in speed reduction can lead to very substantial reductions in road trauma. The benefits of speed reduction can be related, not only to pedestrian safety, but there are general benefits to other road users including cyclists, motorcyclists and vehicle occupants.

1 INTRODUCTION

There has been a growing awareness of the vulnerability of pedestrians in the last decade. The National Road Safety Strategy document published by the Federal Office of Road Safety (1992) identified pedestrians as a group especially vulnerable to injuries sustained in road crashes. This issue was reiterated in the State of Victoria in the Victorian Road Safety Strategy *'Safety First'* published by Vic Roads, the Transport Accident Commission and Victoria Police. *Safety First* emphasised the need to improve pedestrian safety and stressed the importance of programs aimed at reducing the extent and severity of injuries to all aged pedestrians (VicRoads, Transport Accident Commission & Victoria Police, 1995). The strategy identified a number of high priorities including the identification of high-risk locations and the introduction of engineering design features and treatments to make roads safer for pedestrians. A more recent discussion paper released in Victoria (VicRoads, Transport Accident Commission & Victoria Police, 2000) also discussed the importance of lowering travel speeds in high pedestrian activity precincts and suggested a number of improved road environment initiatives including engineering treatments in higher risk locations.

Victorians have enjoyed substantial reductions in the annual numbers of pedestrians killed after 1989. As illustrated in Figure 1.1, pedestrian fatalities in Victoria averaged 144 per annum during the seven-year period between 1983 and 1989. In 1990 there was a dramatic drop to 93 fatalities in that year. This new level, which steadily decreased during 1991 to 1994 to 64 deaths in that year, represents a 43 percent reduction in pedestrian fatalities, over the period 1983 to 1994. However, the number of fatalities increased again in 1995 to 84 pedestrian deaths, representing a 31 percent increase on the previous year. The increasing trend has not continued, with the number of pedestrian fatalities falling to under 80 deaths per annum from 1996 to 1999.

Figure 1.1: Pedestrian road fatality statistics for Victoria (1983 – 1999).

Figure 1.2 shows the number of serious injuries to pedestrians between 1983 and 1999. Similar to fatal pedestrian crashes, in 1990 there was a substantial drop in crashes involving serious pedestrian injuries, however, this was less dramatic at 26 percent. This level continued to fall in the following four years, resulting in a 33 percent drop from 1989 to 1994. However, after 1994 serious pedestrian injuries again increased until 1996. There was a drop in 1997, followed by a slight increase in 1998.

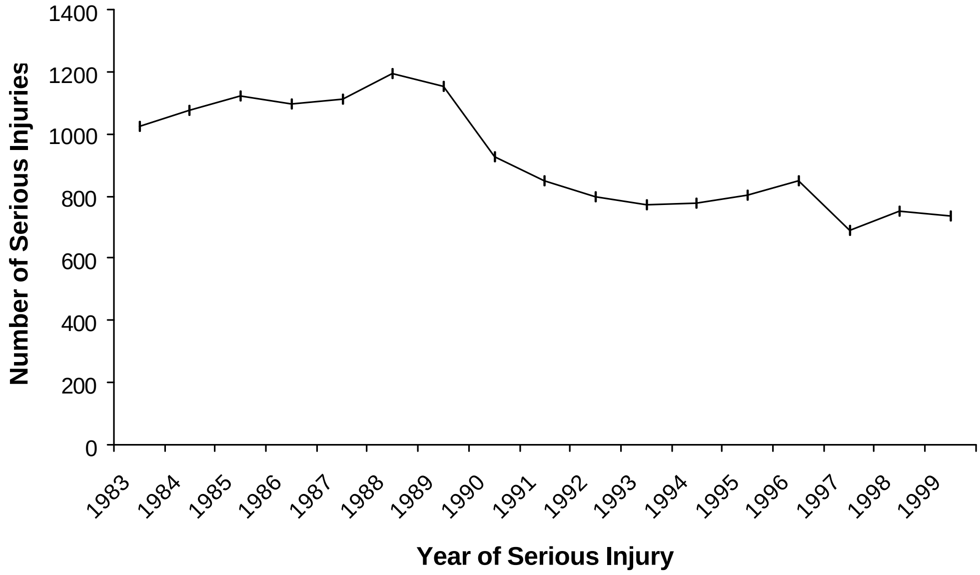

Figure 1.2: Pedestrian road serious injury statistics for Victoria (1983 – 1999).

A major contributing factor in these overall downward trends appears due to a general downward trend that occurred in Victoria's road toll after 1989. It seems that pedestrians benefited significantly from measures targeted at drivers, such as the introduction of speed cameras and a boost in random breath testing which were introduced in 1989/1990. Despite these excellent gains, pedestrian safety remains a serious community concern with 76 persons killed and some 736 persons seriously injured in 1999.

1.1 PROJECT BACKGROUND

Pedestrian crashes in high activity/commercial centres represent a long-standing problem for which few effective solutions have been found. This project addresses the problem of high concentrations of pedestrian casualty crashes along Melbourne's arterial roads, either through strip shopping environments or where certain types of land use generate high levels of pedestrian activity.

There are a number of countermeasure options available for reducing the risk of death or serious injury to pedestrians. One potential solution is to reduce vehicle and/or pedestrian volumes, however, in these common urban situations, such opportunities are usually quite limited. Similarly, efforts to reduce road widths, either by widening footpaths or providing wide medians in order to reduce exposure to crash risk and to simplify the road-crossing task have not received serious consideration, where roads perform an important traffic-carrying function.

Another alternative involves controlling pedestrians so that they are separated from vehicles, either in time or space. For example, traffic signals have been widely used for many years to provide time-separation between pedestrians and vehicles. Traffic signals, however, have largely failed to provide adequate time-separation between pedestrians and vehicles on a consistent basis. Crash records suggest that approximately 20 to 30 percent of Melbourne's reported pedestrian casualty crashes occur at traffic signals or pedestrian crossings. Furthermore, many more pedestrian crashes occur in the near vicinity of these frequently encountered traffic control devices (Corben & Diamantopoulou, 1996). Location-specific investigations undertaken by Corben and Diamantopoulou (1996) substantiate that a sizeable proportion of these crashes at signals involves right or left turning vehicles at intersection signals failing to give way to pedestrians crossing during their turn. A lesser part of the problem involves pedestrians being struck at, or in the immediate vicinity of, mid-block signals.

Similarly, attempts have been made to spatially separate pedestrians and vehicles by constructing underpasses and overpasses, or locating pedestrian precincts above or below street level. Again, these countermeasures have been largely unsuccessful in assuring safe passage for pedestrians. Many pedestrians, particularly older ones, find such facilities inconvenient and/or lacking in personal security and choose not to use them. In other instances they have been too costly to provide.

In addition, black spot evaluations have shown that traditional countermeasures used to treat pedestrian black spots have not shown the intended effect of an overall reduction in casualty crashes (Corben, Newstead, Diamantopoulou, & Cameron, 1996; Newstead, Corben & Diamantopoulou, 1997). Duarte and Corben (1998) investigated the effectiveness of pedestrian facilities used as black spot treatments and found that traditional treatment types such as pedestrian operated signals have had only limited success in reducing the frequency and severity of pedestrian crashes. They concluded that proper and comprehensive initiatives to target pedestrian crash problems are required at pedestrian black lengths, and that 'spot' treatments to address the crash problem occurring along a route are often insufficient.

The remaining alternative is to develop ways of achieving more moderate vehicle speeds. The nature of the relationship between vehicle speeds and the risk of fatal injury to pedestrians is both powerful and well understood. Figure 1.3 illustrates a compelling case for moderating vehicle speeds in high pedestrian activity areas.

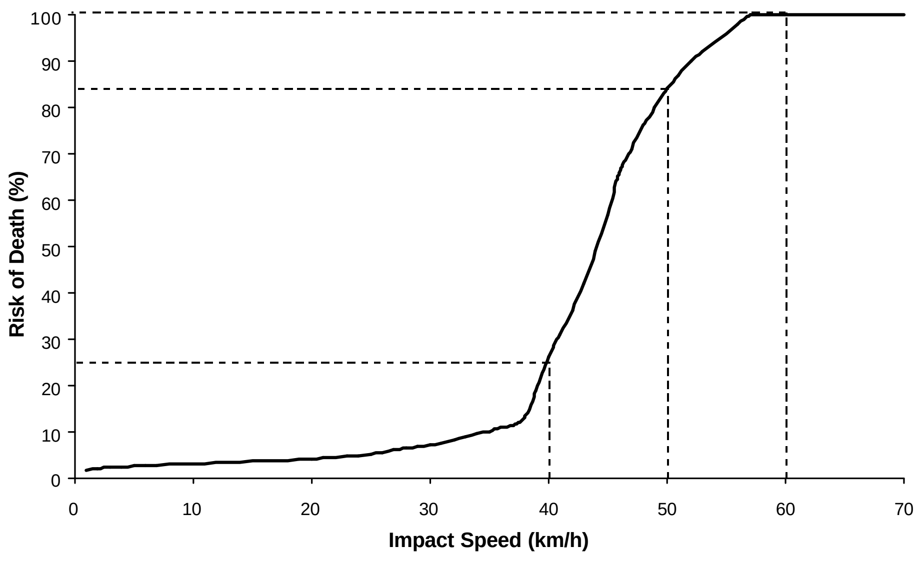

Figure 1.3: Risk of pedestrian death as a function of vehicle impact speed.

(source: Anderson, McLean, Farmer, Lee & Brooks, 1997)

This figure shows that the risk of death to a pedestrian struck at 30 km/h is less than 10 percent, at 40 km/h about 25 percent, while for a pedestrian struck at 50 km/h the risk of death rises steeply to over 80 percent. At a 60 km/h and above collision speed, the risk of death to a pedestrian is clearly 100 percent. The safety benefits of reducing or moderating vehicle speeds in high pedestrian activity areas is evident. There are, of course, safety benefits from more moderate speeds for all road users. The risk of death or long term injury is substantially reduced by small reductions in speed, with society's vulnerable groups, especially the young and the elderly, likely to benefit most.

Corben and Diamantopoulou (1996) investigated arterial road locations with high concentrations of pedestrian casualty crashes and identified vehicle speeds excessive for the conditions as a key factor in both the incidence and severity of pedestrian crashes. In addition, the critical role of excessive speeds in pedestrian crash outcomes was illustrated by Anderson et al (1997). They showed that small differences in travel speed can result in large differences in impact speed because braking distance is proportional to the square of the initial speed.

This strongly suggests that to reduce pedestrian crash and injury risk, an innovative and more comprehensive approach is needed and that moderating excessive vehicle speeds to uniformly lower levels in environments where there is a high pedestrian activity, offers an acceptable, potentially cost-effective solution. Further, it is desirable that arterial road travel times not be seriously affected. Corben and Duarte (2000) reviewed some philosophies and practices in Denmark and The Netherlands, both of which are known for their innovative and enlightened approaches to pedestrian safety and amenity, and considered the possible application of these philosophies and practices in Victoria and elsewhere in Australia.

In essence, the Dutch philosophy is not to provide more road space to vehicles than is needed, especially if this is at the expense of other activities such as residential or shopping amenity. The Dutch road safety policy 'Towards Safer Roads' (Transport Research Centre [AVV], 1996) noted that safety returns are diminishing and safety targets set for 2010 will not be met without new and innovative policies. "Towards Safer Roads" was inspired by the Dutch not wanting the next generation to inherit a road system that causes thousands of deaths and injuries each year. The new policy recommended "a more structural and preventative approach" based on the concept of sustainable road safety with "man as the reference standard". It also recommended that the traffic system be adapted to the limitations of human capacity, through proper road design, improved vehicle features, and by educating, informing and controlling road users. Three key safety principles were noted in the policy as being vital to achieving sustainable safety and to reducing implicit injury risk in advance. These are:

- functional use of the road network, by preventing unintended use of roads,
- homogeneous use, by preventing large differences in vehicle speed, mass and direction of movement, and
- predictable use, thereby avoiding uncertainty among road users.

While the philosophies and principles used by the Danes for improving pedestrian safety are very similar to those expressed by the Dutch, these have not been as comprehensively documented. As with the Dutch philosophies, the Danish practice recognises that densely populated countries cannot sustain unconstrained growth in motorised traffic. Hence, they support strategies which emphasise both sustainability and safety.

Many pedestrian safety issues and challenges faced in The Netherlands and Denmark have close parallels in Victoria, especially Melbourne. Corben and Duarte (2000) contended that a concerted and innovative approach is required if real and lasting gains are to be made to pedestrian safety in Victoria's hazardous commercial environments. They argued that it is likely that some of the practices used in these countries could be selectively applied throughout Victoria and, indeed, elsewhere in Australia, to substantially reduce pedestrian crash and injury risk.

1.2 OBJECTIVES

This research was conducted as part of a larger study looking at the reduction of injuries in areas that are particularly hazardous to pedestrians. Stage 1 of the project involved a discussion of the pedestrian injury problem in Victoria, and provided a description of various countermeasure options that are available to ameliorate this problem. Stage 2 of this project involved the evaluation of some of these countermeasure options.

Corben and Duarte (2000) identified a wide range of countermeasure options with the potential to moderate vehicle speeds, thus reducing pedestrian crash or injury risk, without seriously affecting travel times. Three 'high-priority' options were selected for further evaluation. These were:

- 50 km/h Speed Zone,
- Gateway Treatments – such as road narrowing, change in pavement texture, roundabouts, etc.,
- Street-scape Improvements.

The broad objective of this study was to evaluate these countermeasure options on arterial roads in the Melbourne metropolitan region. The specific objectives were:

i Reduce serious pedestrian crashes, through the development of practical new approaches to moderating vehicle speeds, without seriously affecting travel times, thereby improving pedestrian safety in locations shown to be hazardous to pedestrians, and

ii Evaluate the effectiveness of recommended measures, so that the most cost-effective measures may be introduced at hazardous locations in Victoria's urban areas.

2 STUDY DESIGN

This project was designed to evaluate the effectiveness of a number of countermeasures on vehicle speeds in locations hazardous to pedestrians.

2.1 EVALUATION METHOD

This stage of the research involved the use of a 'before' and 'after' quasi-experimental design to investigate the effects of countermeasure treatments in strip shopping centres known to be hazardous to pedestrians. Speed profiles and vehicle travel times were compared before and following the implementation of speed moderating treatment(s) at one treatment site and one control site. Ideally, the effects of safety treatments on the incidence and severity of pedestrian crashes would be evaluated to determine the ultimate success of the approach under trial. However, to obtain statistically reliable results, it may be necessary for many years to elapse. Hence, examination of speed behaviour of drivers has been carried out in this study at two locations to shorten the time required to assess the safety (and other) impacts.

Experimental evaluations provide the most rigorous test of the effectiveness of treatment programs. 'Before' and 'after' methods have been widely used to assess changes in driving behaviour and crash frequency attributable to some type of treatment. While a 'before' and 'after' design is a useful technique to examine the effect of treatments at a particular site, it is not sufficient just to compare these changes in the periods before and after treatment implementation to determine the effects of the change. This is because this type of evaluation by itself lacks control of the effects of other factors and generalizability to other sites. Any attempt to measure the effects of treatments on driver behaviour must also take into account changes due to other programs or influences.

Use of measurements of driver behaviour at a control site in the analysis allows for adjustment of other factors that may have affected driver behaviour. This design ensures that observed effects are attributable to the treatment rather than other extraneous influences, through the use of appropriate control or untreated sites. Appropriately chosen control sites provide a measure of speed profiles associated with other influences, leaving any further changes associated with the treatments alone. The measure of the effect of treatments on speed profiles is made by comparing the before and after speed profiles at the treatment site adjusting for the parallel changes in speed profiles at the control site from the corresponding before and after treatment time periods. The essence of designing this type of evaluation is to increase the likelihood that measured effects are valid and can be attributed to the 'treatment' rather than the effect of any other factors. The advantage of using a 'control' site is that the effects of extraneous factors are automatically allowed for, without having to identify or, more likely, to assume what these factors might be, and subsequently attempting to measure them in order to use them as statistical controls. This evaluation format is known as a quasi-experimental design as it follows the format of a fully randomised treatment-control type experiment but differs in that the treatment sites are not chosen at random.

2.2 SITE SELECTION

Identification of locations which would be suitable for the trial of options for moderating vehicle speeds was undertaken in consultation with VicRoads and Local Government.

Identification of candidate locations included consideration of pedestrian crash histories, the physical features of the routes, and vehicle and pedestrian volumes along the routes.

Two sites were chosen for the study. Clarendon Street, South Melbourne between Park Street and Ballantyne Street was chosen as the treatment site (Figure 2.1), while High Street, Northcote, between Normanby Avenue and Separation Street was designated as the control site (Figure 2.2).

Figure 2.1: Treatment location (Clarendon Street, South Melbourne).

Figure 2.2: Control location (High Street, Northcote).

High Street was chosen in order to match the treatment site's physical characteristics and traffic layout as closely as possible. Both streets run through strip shopping centres where pedestrian safety is a known problem, and both have two lanes of traffic per direction, tram lines running in each direction, one parking lane, and are relatively wide arterial roads.

2.3 COUNTERMEASURE TREATMENTS

The countermeasure treatments selected for evaluation were: 50 km/h speed limit and physical measures aimed to improve pedestrian safety. Physical measures included painted pedestrian refuge between tram tracks, coloured crosswalks at intersections and pram crossings. A brief description of each treatment follows.

2.3.1 50 km/h Speed Limit

Speeding vehicles are a major concern in the traffic system and the contribution of speed to the severity of crash outcomes is well established. Excessive speed is reported to be an important contributory factor in many crashes. In the US it is estimated that speed contributes to around 12 percent of all crashes reported to the police, and to about one third of fatal crashes (Bowie & Walz, 1991). In Australia, too, approximately 20 percent of fatal crashes involve speeding vehicles (Haworth & Rechnitzer, 1993). The aim of changing the speed zone is to reduce vehicle speeds on the arterial road. Cameron (1992) reports that many western European countries (namely, Belgium, Denmark, Finland, Greece, Holland, Italy, Spain, Norway, Germany and Sweden) have set a consistent urban speed limit of 50 km/h, with 30 mph (48 km/h) being set in Great Britain. He further reported that there is evidence that the reduction in the general urban speed limit in Denmark from 60 km/h to 50 km/h was accompanied by a reduction in crashes and injuries (especially fatalities) in urban areas.

Similarly, Walz, Hoefliger and Fehlmann (1983) reported a 25 percent decrease in pedestrian fatalities as a result of a reduction in speed limit in the US. In Australia, McLean et al. (1994) predicted a 30 percent reduction in the incidence of pedestrian fatalities even with a 5 km/h reduction in speed limit from 60 km/h to 55 km/h. A 50 km/h speed limit was implemented in Clarendon Street – reduced from 60 km/h (Figure 2.3). This was introduced without any change in police enforcement or publicity support.

Figure 2.3: 50 km/h speed limit implemented along Clarendon Street

2.3.2 Physical Measures

European experience in Denmark and Norway has shown that urban speeds cannot be managed by speed limits alone, and must be implemented in conjunction with other safety and speed reduction measures. Physical measures were installed to improve pedestrian safety in general and to make motorists aware of a change in the road environment, to mark the extremities of the strip shopping centre, and create an image of the shopping precinct (Westerman, Black, Brindle, Lukovich & Sheffield, 1993). Fildes and Lee (1993) reported that there are safety benefits, particularly in urban settings, to be gained from clearly informing drivers of the transition from one environment to another. Physical measures are primarily used to direct pedestrians to the safest places to cross and provide a better level-of-service at traffic signals and in the centre of the road. In addition, they tend to influence driver behaviour and have the potential to bring about lower speeds by conveying to drivers that they are passing though an environment where road use by vehicles should be equitably shared with pedestrians. A description and discussion of the safety benefits of each physical measure implemented follows. More extensive discussion may be found in Corben, Triggs, Wilson and Diamantopoulou (1999), Cairney, Tziotis, Corben, Diamantopoulou, Deery and Wilson (1999), and Corben, Triggs, Diamantopoulou and Wilson (2000).

Pram Crossings

New pram crossings were installed to allow safe and accessible crossings at formal crossings along Clarendon Street. Improving the level-of-service to pedestrians at formal crossings will encourage greater use of, and compliance with, traffic signals by pedestrians and hence safer crossing movements than can otherwise occur. Pram crossings consist essentially of a ramp construction at formal pedestrian crossings to allow safe entry from the footpath to the road (and vice versa). Ramps allow easy access for wheelchairs, prams, scooters and older pedestrians with vision impairment and mobility difficulties to complete a safe crossing. Figure 2.4 shows an example of a pram crossing.

Figure 2.4: Pram crossing installed on existing pedestrian crossings at Clarendon Street

__Painted Median between Tram Tracks__

In order to address the risks associated with the linearly distributed nature of pedestrian crossing demand within strip shopping centres and along arterials in general, painted medians were installed throughout most of the length of the Clarendon Street site. The key feature of medians in hazardous arterial roads such as Clarendon Street is their ability to provide safe crossing opportunities and assist pedestrians over the entire length of the shopping strip, rather than in the limited way that localised treatments do (e.g. pedestrian signals). Medians assist pedestrians to cross a road by breaking a potentially complex task into two simpler tasks that can be dealt with sequentially. This is particularly beneficial for older pedestrians who experience difficulty crossing complex two-way roads. A median strip provides both a safe area for pedestrians to pause and allows pedestrians to cross busy roads in two stages (Oxley, Fildes, Ihsen, Charlton & Day, 1997). This can be achieved by delineating an area of the road where pedestrians are separated from vehicular traffic. They can be raised or flush with the pavement.

Painted pavement between the two inside rails of tram tracks can potentially provide a cost-effective measure to enhance pedestrian safety by providing a safe refuge, separating vehicles and pedestrians, and to influence speed perception. Figure 2.5 shows the painted median on Clarendon Street.

Figure 2.5: Painted median between tram tracks on Clarendon Street

__Coloured Crosswalks at Intersections__

Pavement treatments were used on the core zone area of the shopping centre in Clarendon Street where pedestrian densities and vehicle volumes are high, to reduce vehicle speeds and to make both drivers and pedestrians aware of the potential conflict area (Figure 2.6). This treatment, in effect, might help to bring about the perception by drivers of passing through a ‘gateway’ to a changed road environment. Schnull and Lange (1990) reported that changes of the road surface to rougher materials and/or contrasting colours in entrance areas led to a distinct speed reduction, especially of excessively high speeds.

By creating a street-scape that clearly signifies that changed conditions will be encountered, drivers can be encouraged to travel at speeds more compatible with the conditions. Street-scapes such as contrasting pavement crossings at the entrance of a shopping precinct convey the notion of a pedestrian-friendly environment and are likely to produce lower vehicle speeds.

Figure 2.6: Pavement treatments on Clarendon Street

2.4 SURVEY METHODOLOGY

The objectives of the survey were:

- to collect *free-flowing* speeds at several points within the shopping strips, and
- to collect information on travel times through the designated treatment and control shopping strip areas.

Surveys were conducted at both sites on three occasions. The first 'before' surveys were conducted in December, 1999 at each site. Two further surveys conducted were designed to represent two separate 'after' periods. The first 'after' survey occurred in March/April, 2000, and was timed to occur after the first stage of treatment. This first phase of the countermeasure treatment involved a traffic control measure in the form of speed zoning. The speed limit on Clarendon Street was reduced from 60 km/h to 50 km/h on February 25, 2000. Approximately one month was allowed after the countermeasure was installed, in order to provide for a settling-in period during which both drivers and pedestrians could become familiar with the lowered speed limit.

The second 'after' surveys occurred in May/June 2000, after a second set of countermeasures was implemented. These treatments involved physical measures, and consisted of the construction of new pram crossings, a painted pedestrian refuge between the tram tracks, and the installation of coloured crosswalks at signalised intersections. Again, approximately one month was allowed before surveying to provide for a settling-in period.

Surveys were conducted on Wednesday afternoons, typically over a four-hour period from about 1pm to 5pm, by Turnbull Fenner Traffic Engineers and Transport Planners. On all occasions the weather was fine. Wednesday afternoons were chosen following a review of crash records at these sites. This review showed that Wednesday afternoons were amongst the worst in terms of pedestrian crashes. Although it was impossible within the constraints of this project to determine whether the traffic dynamics were similar at other times, it was assumed that traffic was similar on other weekday mornings and afternoons at these sites.

The sample at both sites consisted of city-bound vehicles only, such that northbound vehicles were surveyed on Clarendon Street and southbound vehicles were surveyed at High Street. Two types of data were collected: vehicle speeds and travel times.

2.4.1 Speed Surveys

Vehicle speeds were collected in two ways. First, using travel time data (refer section 2.4.2), average speeds over the entire length of the shopping centre which had been treated were determined from the distance travelled and the time taken to travel that distance. Second, vehicle speeds were recorded at two mid-block locations at each site using laser guns supplied by the Victoria Police to record free-flowing speeds as vehicles entered and left the strip shopping centre. It was assumed that vehicle speeds at these locations would reflect a driver's perception of appropriate speeds to travel through a strip shopping centre. In other words, drivers would travel slower on entry to the shopping centre because they are aware of the hazardous location, and perhaps be influenced to drive faster on exit because they are leaving the hazardous location. Therefore, vehicle speeds were measured approximately one-third and two-thirds of the way through the study area on both Clarendon Street and High Street.

On Clarendon Street, the first speed measurement (entry point to the survey area) was taken by recorders positioned unobtrusively at Bank Street. Vehicle speeds were recorded for vehicles entering the survey site approximately two-thirds between Park Street and Bank Street. For the second speed measurement (exit point from the survey area), recorders stood at Market Street and collected vehicle speeds approximately mid-block between York Street and Market Street.

On High Street, recorders were positioned at comparable sites to those chosen on Clarendon Street for consistency in speed measurement. Vehicle speeds were recorded approximately one-third of the way through the study area near Beaconsfield Parade and collected vehicle speeds mid-block between Beaconsfield Parade and Darebin Road to collect a sample of vehicle speeds as vehicles entered the survey site. Like on Clarendon Street, vehicle speeds were also recorded as vehicles left the survey site on High Street. For this measurement, recorders stood near Kemp Street and collected vehicle speeds near Woolton Avenue. Although these sites were chosen for consistency across sites, there were some differences between sites. Of particular relevance here was the fact that the shopping centre on High Street extended well beyond the set survey site, while on Clarendon Street, the shopping centre clearly finished in the vicinity of the survey site boundary.

To ensure an unbiased sample set, the following categories of vehicles were included in the survey:

- Cars
- Motorcycles
- Four-wheel drive vehicles and vans
- Trucks (any type of heavy vehicle, from a small rigid truck to a semi-trailer – as defined in specifications provided by VicRoads)
- Trams

2.4.2 Travel Time Survey

Travel time information was collected along both treatment and control routes via the origin-destination survey technique. Vehicle number-plates were recorded at both extremes of the study area. The entry point on Clarendon Street was located at Park Street and the exit point was Ballantyne Street, such that number-plates of north-bound vehicles were recorded. Likewise, the entry point on High Street was located at Normanby Avenue and the exit point was Separation Street and number-plates of south-bound vehicles were recorded. At each location the last four characters of the number-plate of all vehicles travelling through the points were recorded along with the time that they passed. Number-plates and times were matched at both ends of the study area, with the travel time being estimated by calculating the difference between the entry and exit times. At both locations the time was recorded as the vehicle crossed the stop line. Only the last four characters of the number-plate were recorded to allow for accurate matching while maximising the size of the sample. Vehicles were classified in the same way as for the vehicle speed survey, although only travel time data for red and white cars were collected because it was impractical to sample all vehicles passing the survey point, and red and white cars make up a high proportion of the vehicle population.

3 RESULTS AND DISCUSSION

The evaluation method involved a quasi-experimental design, that is, using measurements of driver behaviour at a control site as well as at a treatment site and adjusting the data for observed driver behaviour in the traffic system. It was anticipated that this design would ensure that any observed effects of treatment implementation at Clarendon Street could be attributed to the treatments themselves rather than other factors. For this type of evaluation to be successful, an appropriate control site needs to be selected. High Street was chosen as the most suitable site, based on the factors indicated in previous sections. During the analysis of the data, however, some problems became apparent in the data collection at the control site that raised some concerns about the validity of the quasi-experimental control analyses.

Although the authors believe in the concept of this design, that it ought to provide a rigorous test of the effectiveness of treatment programs, there were some concerns about the reliability of the data collected at the control site. For this reason, it was decided to present and discuss the findings in two ways. First, the results of the vehicle speed and travel times will be presented as they were adjusted for the control site. The concerns regarding the data on High Street will be discussed here. Second, the effect of treatment implementation on Clarendon Street will be discussed without adjusting the figures for the control site. Some general conclusions regarding the changes on Clarendon Street will be made, particularly in terms of the effect of treatment implementation on vehicle speeds and travel times, the proportion of vehicles travelling at speeds likely to cause severe injuries if a pedestrian is struck, and the relationship between speed and crash risk.

3.1 VEHICLE SPEEDS AND TRAVEL TIMES ADJUSTED FOR THE CONTROL SITE

In this section, the control-adjusted analysis of overall speeds, travel times, *free-flowing* speeds at selected locations within the survey sites and proportions of vehicles travelling at speeds associated with high injury risk to pedestrians will be presented. To make adjustments for changes at the control site (High Street), a multiple regression model was fitted to the vehicle speed and travel time data on the treated site (Clarendon Street) to test for a real effect of treatment implementation.

3.1.1 Average Speeds and Travel Times

Using the origin-destination survey technique, travel times were collected for vehicles passing through the survey site. Vehicle number-plates were collected and matched at both extremes of the study area, with the travel time calculated as the time difference between the recorded times. The times that vehicles entered and exited the survey site were recorded and average speeds were calculated from these data. The distance travelled was divided by the time taken to travel that distance and multiplied by 3.6 (i.e., to convert m/s into km/h). All vehicles with travel times of 3 minutes or less were included in the sample as it was assumed that these vehicles travelled through the survey site continually without stopping for reasons other than normal traffic flow interruptions. While it was not possible to determine if vehicles had stopped at traffic lights or not (therefore affecting the average vehicle speed), the purpose of the study was to evaluate the effect of treatments on average vehicle speed. Therefore, the effect of traffic lights on vehicle speeds was not an important issue in this context. Furthermore, it is expected that the effect of traffic lights would be the same before and after treatment installation.

Average vehicle speed data provide some indication of overall average speeds throughout the site, however, they do not provide actual speed measurements at selected locations. These data, nevertheless, show some interesting differences in average speeds between survey times on Clarendon Street. Table 3.1 summarises these data for the treatment and control sites.

Table 3.1: Average calculated vehicle speed (km/h) travelling through survey sites (treatment and control sites) during each survey time period.

Site	**Average calculated vehicle speed (km/h) before treatments installed**	**Average calculated vehicle speed (km/h) after FIRST treatment installed**	**Average calculated vehicle speed (km/h) after ALL treatments installed**
Clarendon Street (treatment site)	28.30	28.50	20.80***
High Street (control site)	30.97	29.72	29.83

*** $p<0.001$

On Clarendon Street, there was a slight increase of 0.20 km/h in average vehicle speed from before treatment installation to after installation of the 50 km/h speed zone. By contrast, on High Street there was a slight decrease in average vehicle speeds of 1.25 km/h during this time period. The control-adjustment analysis revealed that the expected average speed should have been 27.2 km/h on Clarendon Street, i.e., reduced by 1.14 km/h. After taking into consideration the changes on High Street, the net change in average speed of vehicles on Clarendon Street was a small and insignificant net 1.45 km/h increase. Thus, it can be concluded that installation of the 50 km/h speed zone had no measurable effect on average vehicle speeds throughout the survey site. It should be noted that the introduction of the 50 km/h speed zone was not accompanied by any change in Police enforcement or publicity.

More importantly, a substantial reduction of 7.5 km/h in average vehicle speeds was found on Clarendon Street after all treatments had been installed compared to before treatments were installed. By contrast, on High Street, there was very little difference in average vehicle speeds comparing before treatment installation and after all treatments were installed (a 1.14 km/h reduction). The control adjustment analysis revealed that a reduction of only 1.04 km/h was required to conclude that treatment installation resulted in reductions in vehicle speed. Thus, after taking into consideration the small changes on High Street, the net change in average speed of vehicles on Clarendon Street was a large reduction of 6.86 km/h, $p < 0.001$. Likewise, the comparison of vehicle speeds after installation of the 50 km/h with after installation of all treatments, revealed that a reduction of only 0.11 km/h was required to reach the conclusion that treatment installation had a real effect on vehicle speed. The net reduction of 8.31 km/h in average speed provided strong evidence of an effect of treatment installation on moderating average vehicle speed throughout the survey site, $p < 0.001$.

This is an important finding. The main objective of this study was to evaluate countermeasure options designed to moderate vehicle speeds in areas where there is high pedestrian activity and substantial reductions in average vehicle speeds through the survey site were apparent. Surprisingly, installation of the 50 km/h speed zone by itself did not affect overall speeds, however, it should be noted that these average speeds were generally far below this limit. It seemed, however, that installation of all treatments resulted in large reductions in overall vehicle speeds. This finding supports earlier suggestions that traditional countermeasures alone have limited success in reducing pedestrian casualty crashes, however, an innovative approach that combines a range of countermeasure applications can moderate vehicle speeds (Newstead et al., 1997; Corben & Duarte, 2000). However, there was no specific supporting enforcement or publicity with the introduction of the 50 km/h speed zone. More will be said on this in a later section.

These calculations of average speed are coarse indicators of vehicle speeds, and do not adequately control for the possibility that vehicles had stopped for a short period of time for traffic-related reasons (such as banking up of traffic at lights, stopping at tram stops for passengers to alight, etc.). Nevertheless, if it is assumed that traffic signal phasing had not changed during the survey time periods, these data provide strong evidence of the effect of treatment implementation on overall vehicle speeds through the survey site. While these data suggest that there was very little change in average speeds on High Street during all survey time periods, a substantial reduction was found on Clarendon Street. In summary, it would appear that significant reductions in average vehicle speed occurred on Clarendon Street as a result of treatment implementation.

The travel time data for both treatment and control sites during all survey time periods are shown in Table 3.2. Average travel times remained fairly stable from before treatment installation to installation of the 50 km/h speed zone, increasing by only 0.01 min. (i.e., from 1.80 to 1.81 min.). Taking into consideration the changes on High Street where there was also a small increase in travel times (0.08 min.) the expected average travel time should have been 1.86 min. on Clarendon Street after installation of the first treatment. That is, average travel time should have increased by a further 0.05 min. After taking into consideration the changes at the control site, average travel times on Clarendon Street after installation of the 50 km/h speed zone resulted in a net reduction of 0.06 min., however, this reduction was not significant.

By contrast, travel times increased from installation of the 50 km/h speed zone to installation of all treatments on Clarendon Street by 0.6 min. Taking into consideration the small reduction in travel time on High Street from installation of 50 km/h speed zone to installation of all treatments, a net 0.61 min. increase in travel time on Clarendon Street was found, $p < 0.001$.

As for the comparison of travel times from before treatment installation to installation of all treatments, average travel times increased by 0.61 min. on Clarendon Street and by 0.08 min on High Street. The analysis showed that the expected average travel time should have only increased by 0.06 min. to reach a conclusion that treatment implementation affected travel times. After taking into account the small changes at the control site, the net change in average travel time on Clarendon Street was a net 0.54 min. increase, $p < 0.001$.

Table 3.2: Average travel times of vehicles (min.) at survey sites (treatment and control sites) during each survey time period.

Site	Average travel time (min.) before treatments installed	Average travel time (min.) after FIRST treatment installed	Average travel time (min.) after ALL treatments installed
Clarendon Street (treatment site)	1.80	1.81	2.41***
High Street (control site)	2.25	2.33	2.32

*** $p<0.001$

Again, this is an important finding. With any moderation of vehicle speeds in areas where there is high pedestrian activity, it is highly likely that travel time will increase also. One aim of this study was to develop approaches to moderate vehicle speeds without seriously affecting travel times and to evaluate the changes in traffic dynamics after implementation of treatments. After adjusting for changes at the control site, where travel times increased slightly from the first survey time period to the last, travel times on Clarendon Street increased to a greater extent. Interestingly, travel times remained fairly stable from before treatment installation to after installation of the 50 km/h speed zone, however, only increased significantly after installation of all treatments. This provides further evidence that installation of the 50 km/h speed zone alone did not greatly affect speed and travel behaviour on Clarendon Street, however, installation of all treatments resulted in more moderate overall vehicle speeds throughout the survey site, as well as increased travel time. This increase was less than one minute, however.

3.1.2 Vehicle speed measurements at locations within the survey site

3.1.2.1 Combined measures of vehicle speeds

Vehicle speeds were measured at two locations in both the control and treatment sites. Vehicle speeds were recorded approximately one-third and two-thirds along the study area to detect speeds as vehicles entered and as they left the survey site. These locations were chosen to ensure collection of a sample of *free-flowing* vehicles at mid-block locations. Initially, the two measures of vehicle speeds were combined to examine the overall effect of treatment implementation on speeds of free-flowing traffic. Subsequent analyses examined the effect of treatment implementation on vehicle speeds at the separate locations (i.e., as vehicles entered and left the survey site). It should be noted here that data collected in the third survey time period on High Street at location 2 (speed measurement of vehicles as they left the survey area) were inconsistent and incomplete due to unforeseen traffic and technical circumstances. These included traffic congestion after a crash involving a tram upstream from the survey site, a short period where no data was collected due to technical problems, and possible contamination of the data due to Police presence after a technical problem with the laser speed measurement device and consequent probable detection by drivers of speed measurements. Furthermore, close inspection of the ‘exit’ points where free-flowing speeds were measured revealed differences between the treatment and control sites. On Clarendon Street, the exit location is clear of the main commercial activity whereas on High Street commercial activity extends well beyond the 'exit' point. This may, in part, explain differences in exit speeds at the two locations.

Because of other road safety measures conducted in the immediate area of the survey site on High Street after the last survey was completed, it was not possible to repeat the data collection task to overcome the irregularities found in the final data collection phase. Given the contamination of the data in the third survey time period on High Street, all data collected at location 2 (as vehicles exited the survey site) during the third survey were excluded from this analysis. Thus, only speed measurements at location 1 (as vehicles entered the survey site) formed the sample for the last data set on High Street.

Average vehicles speeds measured as vehicles entered and left the survey site during the three survey time periods for both the control and treatment sites are shown in Table 3.3. The effect of treatment implementation on overall vehicle speeds on Clarendon Street was adjusted for the changes in vehicle speeds over survey time periods on High Street.

Measurements of vehicle speeds were considerably greater than average speeds calculated from travel time data throughout the survey site. This may, however, be explained by the locations chosen to measure vehicle speeds. As indicated earlier in this section, the locations were selected to capture *free-flowing* traffic. As a result, these measures may have been biased in terms of targeting faster travelling vehicles, rather than examining vehicle speeds on sections of the road in which vehicles travelled slower (possibly because of bank-up of traffic at signalised intersections, tram stops, etc.). In addition, in an attempt to measure free-flowing traffic only at these locations, the data collectors disregarded vehicles that appeared to be slowing down to park, turn into a side street, or perform other traffic manoeuvres.

Table 3.3: Average measured vehicle speeds during the three survey times (treatment and control sites).

Site	Average vehicle speed (km/h) – Survey 1	Average vehicle speeds (km/h) – Survey 2	Average vehicle speeds (km/h) – Survey 3
Clarendon Street (treatment site)	44.95	44.28**	43.65*
High Street (control site)	46.17	44.72	43.03

* $p<0.05$,
** $p<0.01$

This analysis revealed that, despite finding a reduction of 0.7 km/h in average free-flowing vehicle speeds on Clarendon Street (at the two specific locations) from before treatment installation to after installation of the 50 km/h speed zone, there was also a substantial reduction of 1.45 km/h in average free-flowing vehicle speeds on High Street. Taking into consideration the changes on High Street, the expected average vehicle speed should have been 42.87 km/h after the first treatment had been installed. That is, the average speed should have been reduced by a further 1.41 km/h. The analysis revealed a relative net increase of 0.78 km/h in average speeds of vehicles at the two locations studied on Clarendon Street, $p < 0.05$. Likewise, the comparison of average vehicle speeds between installation of the 50 km/h speed limit and installation of all treatments revealed that there was a reduction of 0.63 km/h on Clarendon Street. However, considering that there was a reduction of 1.69 km/h on High Street, the expected average vehicle speed should have been 41.97 km/h. Again, the analysis revealed a relative net increase of 1.06 km/h in average measured speeds of vehicles on Clarendon Street, $p < 0.01$.

Overall, the comparison between before implementation of treatments and after all treatments were installed revealed that, despite the reduction of 1.3 km/h on Clarendon Street, there was a substantial reduction of 3.14 km/h in average vehicle speeds on High Street too. Thus, taking into consideration the changes on High Street, the expected average speed on Clarendon Street should have been 41.89 km/h. This analysis revealed that, in effect, there was a net increase of 1.84 km/h in average vehicle speeds on Clarendon Street, $p < 0.001$. Therefore, after adjusting vehicle speeds for changes at the control site it cannot be concluded that treatment installation on Clarendon Street resulted in speed reductions. In summary, this analysis demonstrated that, relative to changes on High Street, there was an increase in measured *free-flowing* vehicle speeds on Clarendon Street after installation of treatments.

3.1.2.2 Proportion of vehicles travelling at speeds unsafe for pedestrians

Given the importance not only to reduce average vehicle speeds, but also to reduce the number of vehicles travelling at fast speeds (those most likely to result in a severe injury outcome if a pedestrian collision occurs), the proportions of vehicles travelling at high speeds before and after implementation of the treatments were compared. Figure 3.1 shows the proportion of vehicles travelling at 60 km/h or over, at 50 km/h or over and at 40 km/h or over on both Clarendon Street and High Street at the two (combined) selected speed measurement locations. The proportions of vehicles travelling at high speeds were compared within and across treatment and control sites.

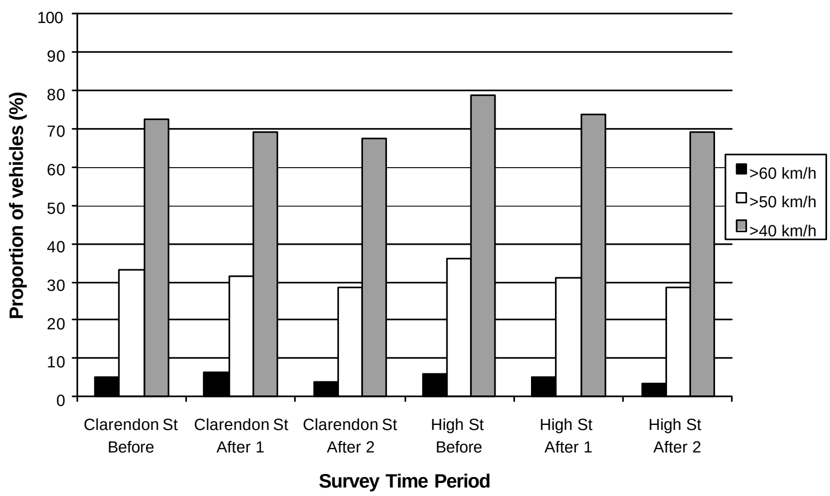

Figure 3.1: Proportion of vehicles travelling at fast speeds during each survey time period (treatment and control sites).

Around 5 percent of vehicles travelled at 60 km/h or over on Clarendon Street before treatments were installed. This proportion rose to just over 6 percent after installation of the 50 km/h speed zone, but dropped again to just over 4 percent after all treatments were installed. In comparison, on High Street close to 6 percent of vehicles travelled at these speeds during the first survey time period, but this proportion decreased slightly after installation of the 50 km/h speed zone to 5 percent. Furthermore, after installation of all treatments, only 3.3 percent of all vehicles travelled at fast speeds during the last survey time period. The proportions of vehicles travelling along the untreated site at or over 60 km/h at these two locations on Clarendon Street, almost certain to kill a pedestrian struck at these speeds, before and after installation of treatments were compared, taking into consideration the changes on High Street. The proportion of vehicles travelling at 60 km/h or over after installation of the 50 km/h speed zone should have been reduced by 0.75 percent. Thus, after taking into consideration the reductions on High Street, there was effectively a difference in proportion of vehicles travelling at or over 60 km/h from 5 percent before treatment installation to 7.3 percent after treatment installation on Clarendon Street, $p < 0.01$.

The comparison of changes between installation of the 50 km/h and installation of all treatments revealed that, considering the changes on High Street, there was no significant change in proportion of vehicles travelling fast after installation of all treatments. In contrast, the comparison of changes between before treatment installation and after all treatments were installed revealed that, despite there being an observed reduction of 1 percent in speeding vehicles on Clarendon Street, there was also a reduction of 2.6 percent on High Street. Taking these changes into consideration, there was a relative net increase of 2.3 percent of speeding vehicles, $p < 0.05$

The proportion of vehicles travelling at or over 50 km/h on Clarendon Street, remained stable from before installation of treatments (33%) to after installation of the 50 km/h speed zone (32%). However, a larger reduction of 5 percent was found on High Street. The comparison, therefore revealed a relative net increase of 3.6 percent of vehicles travelling at or above 50 km/h on Clarendon Street after installation of the 50 km/h speed zone, $p < 0.05$. The comparison of changes in the proportion of vehicles travelling at or above 50 km/h from installation of the 50 km/h speed zone and installation of all treatments revealed a slightly larger reduction on Clarendon Street, compared to High Street, (3.2% vs. 2.3%). The analysis also revealed, however, that there was a non-significant net decrease of 1 percent of vehicles travelling at fast speeds on Clarendon Street (i.e. from 31.6 percent to 30.6 percent).

Overall, the comparison of vehicles travelling at or above 50 km/h from before installation of treatments to after installation of all treatments revealed an observed reduction of 5 percent on Clarendon Street, however, a larger reduction of close to 8 percent was observed on High Street. Taking into account these changes, there was a relative increase of 2.5 percent from 33.3 percent to 35.8 percent on Clarendon Street, however, this was not statistically significant.

The majority of vehicles travelled at 40 km/h or above on both Clarendon and High Streets. As for faster travelling vehicles, the proportion of vehicles travelling at or above 40 km/h dropped over survey time periods at both the control and treatment sites. On Clarendon Street, almost 73 percent of vehicles travelled at these speeds before installation of treatments and this dropped to 69 percent after installation of the 50 km/h speed zone and marginally to 68 percent after all treatments were installed. Again, however, the reductions on High Street were of greater magnitude than on Clarendon Street, dropping from 79 percent during the first survey time period to 74 percent during the second and to 69 percent during the last survey time period. Like before, the control-adjusted analysis revealed a non-significant relative increase of 1.1 percent from before treatment installation to installation of the 50 km/h speed zone and a relative increase of 3.1 percent from installation of the 50 km/h speed zone to installation of all treatments, $p < 0.05$. There was an overall relative increase in the proportion of vehicles travelling at or above 40 km/h on Clarendon Street of 4.4 percent (i.e. from 72.7 percent to 77.1 percent) from before treatment installation to after all treatments were installed, $p < 0.05$.

In summary, these results indicated that treatment installation on Clarendon Street did not effectively result in moderating speeds of fast travelling vehicles. Although there were observed reductions in the proportion of vehicles travelling at fast speeds on Clarendon Street, there were also reductions on High Street (often of greater magnitude than on Clarendon Street). The observed reductions on High Street were somewhat surprising, given that there were no treatments installed here and that the unreliable data were excluded from this analysis. It can only be assumed that travel behaviour changed at this site for reasons that the authors are unaware of and this raises questions about the validity of the control site selected for this evaluation.

3.1.2.3 Measures of vehicle speed as vehicles entered the survey site

For any treatments aimed to moderate vehicle speeds in areas of high pedestrian activity, it is intuitively sensible to target driver behaviour as vehicles enter the area along with moderating vehicle speeds as they travel through the area. Thus, a separate analysis of measured vehicle speeds was undertaken by examining the changes in vehicle speeds as vehicles entered the survey site, and adjusting the data for changes at the control site. Given the contamination of the data in the last survey on High Street at location 2 (as vehicles left the survey site) and the decision to exclude these measurements of vehicle speed, it was not meaningful to examine the effect of treatment implementation on vehicle speeds as vehicles left the survey site, adjusting for changes at the control site. Therefore, this analysis was not performed.

The effect of treatment implementation on vehicle speeds as they entered the survey site on Clarendon Street was adjusted for the changes in vehicle speeds over survey time periods on High Street. Table 3.4 shows average vehicle speeds at this location during each survey time period at both sites.

Table 3.4: Average measured vehicle speeds as vehicles entered the survey site during the three survey times (treatment and control sites).

Site	Average vehicle speed (km/h) – Survey 1	Average vehicle speeds (km/h) – Survey 2	Average vehicle speeds (km/h) – Survey 3
Clarendon Street (treatment site)	41.04	39.98	39.15
High Street (control site)	45.69	44.48	43.03

The comparison of speeds as vehicles entered the survey site on Clarendon Street between before treatment installation to installation of the 50 km/h speed zone showed that average speeds reduced by 1.06 km/h (i.e. from 41.04 km/h to 39.98 km/h). Taking into consideration the changes on High Street, the expected average speed on Clarendon Street should have been 39.95 km/h, a further 0.03 km/h from the observed 39.98 km/h. In effect, there was a relative small and non-significant increase in average speed of 0.14 km/h on Clarendon Street. Likewise, speeds as vehicles entered the survey site reduced by 0.83 km/h after all treatments had been installed compared to only when the first treatment was installed. However, there was a reduction of 1.45 km/h in speeds as vehicles entered the survey site on High Street also. The expected average speed on Clarendon Street should have been 38.67 km/h (a reduction of 1.31 km/h instead of 0.83 km/h). In effect, there was a (non-significant) increase in average speed on Clarendon Street of 0.63 km/h.

Overall, average speeds as vehicles entered the survey site on Clarendon Street decreased by 1.89 km/h after all treatments had been installed compared to before treatment installation. Considering, however, the substantial reduction of 2.66 km/h in average vehicle speeds on High Street, the control-adjusted analysis revealed that the expected average vehicle speed as vehicles entered the survey site on Clarendon Street should have been 38.64 km/h after all treatments had been installed. That is, average speed should have been reduced by 2.39 km/h instead of only 1.89 km/h. This adjustment resulted in a net increase in average speed on 0.78 km/h, however, this again did not reach significance.

In summary, although there was an overall reduction in vehicle speeds as vehicles entered the survey site on Clarendon Street after treatment installation, considering the substantial reductions found at the control site, it cannot be concluded that the reductions on Clarendon Street were the result of treatment installation. Indeed, after taking into the account the changes on High Street, the net change in average vehicle speeds on Clarendon Street increased slightly.

3.1.2.4 Summary

The most important finding in this analysis was that there was a considerable overall reduction in average vehicle speeds of around 8 km/h throughout the survey site on Clarendon Street, after adjusting for data on High Street. This measurement provided a coarse indicator of average vehicle speeds over the full length of the survey site and it is possible that some vehicles had stopped for a short period of time for traffic-related reasons. Nevertheless, they do provide strong evidence of the effect of treatment implementation on overall vehicle speeds through the survey site.

While only small speed reductions were found at specific locations within the survey site on Clarendon Street (around 1 – 2 km/h), after adjusting for changes at the control site, there was an increase in vehicle speeds here relative to the changes on High Street. Interestingly, there was a large difference between calculated average speed throughout the survey site and measured speed at specific locations within the site that targeted free-flowing traffic. For these reasons, it may be assumed that large reductions (possibly even greater than 8 km/h) would have been found at other locations within the survey site on Clarendon Street and may be attributable to treatment implementation. However, as speed measurements are not available at other points within the survey site, this is largely speculative.

The findings that vehicle speeds and proportions of speeding vehicles decreased on High Street as well as on Clarendon Street (sometimes to a greater extent) were surprising, considering that no treatments were installed at High Street and that the contaminated data were excluded from the analysis. As indicated earlier, control sites are usually chosen to reflect stability in the traffic system as a whole and it was unexpected to find changes in speed behaviour at this site. It is unusual to find even small variations in vehicle speeds, particularly in the short space of time between the first and last surveys (around 6 months) and that there had been no countermeasure applications aimed to moderate vehicle speeds here. These findings raised questions regarding the validity of the control site and the sampling exercise. To the knowledge of the authors there was no overall change in speed behaviour in the Melbourne metropolitan area, nor was there any campaign launch aimed to target speed behaviour. Moreover, there seemed to be no forthcoming explanations as to why speed behaviour had changed on High Street. For instance, there was no apparent modification or difference on High Street that could explain the change in speed behaviour. With this in mind, it could be that the High Street data were flawed in some way. It may be that the sampling exercise was limited in some way. At each site, travel time data and vehicle speed data were only collected for four hours at each survey time period. Furthermore, sampling was generally only conducted between the hours of 1 pm and 5 pm on Wednesdays. Perhaps if sampling had been more extensive, with data collected for longer, during morning hours as well as afternoon hours, and on a selection of days of the week instead of only on Wednesdays, the data may have been more indicative of general trends in speed behaviour. Furthermore, while data collected at location 2 (as vehicles exited the survey site) were excluded because of apparent contamination (tram crash, short-term technical difficulties with speed measuring equipment, etc), it may be that these factors influenced traffic movements at location 1 too (as vehicles entered the survey site).

Considering these uncertainties regarding the reliability of the control data, an alternative approach is to assume that there was no system-wide change in speed behaviour in the Melbourne metropolitan area and examine the changes in speed behaviour and travel times on Clarendon Street without adjusting for control data. In the following section, a detailed evaluation of treatment implementation, based on this assumption is presented for comparison with earlier results.

3.2 VEHICLE SPEEDS AND TRAVEL TIMES ON CLARENDON STREET

This section presents the evaluation of the effect of treatment implementation on Clarendon Street *without* adjusting the data for a control site. Unlike the results of Section 3.1, it is assumed here that speed behaviour in the road-traffic system, as a whole, did not change through the study period. As for the control-adjusted analyses, examination of overall speeds, travel times, measured speeds at selected locations within the survey site and proportions of vehicles travelling at excessive speeds will be presented. The results from surveys on High Street are presented in Appendix A.

3.2.1 Average Speeds and Travel Times

Travel times were collected for vehicles passing through the survey site and data were examined for vehicles that took 3 minutes or less to travel through the survey area. Average speeds calculated from the travel time data are shown in Table 3.5.

An effect of treatment implementation was found for average vehicle speeds here, $F(2,379) = 27.91$, $p < 0.001$. Little difference was found for average vehicle speed before treatments were installed and after the first treatment, but a significant reduction of 7.5 km/h to 20.8 km/h after all treatments were installed was found, $p < 0.001$. Significant effects of treatment installation on average vehicle speed were found for cars and vans/four-wheel-drive (4WD) only. An effect of treatment implementation was found for average speeds of cars, $F(2,210) = 18.08$, $p < 0.001$. A reduction of 8.8 km/h was found after installation of all treatments, p-values < 0.001. Similarly, an effect of treatment implementation was found for average speeds of vans/4WD, $F(2,110) = 11.83$, $p < 0.001$. While average speeds increased slightly but not significantly after installation of 50 km/h speed limit, a reduction of 7.1 km/h after installation of all treatments was found, p-values < 0.01. Even though average speeds of trucks decreased by 7.2 km/h, this reduction was not significant, probably due to small sample sizes. Comparisons of average vehicle speeds of trams and motorcycles were not possible due to a lack of data on these vehicle types during some survey time periods.

Table 3.5: Average speed of vehicles travelling through the survey site on Clarendon Street before treatments, after first treatment, and after all treatments were installed.

Vehicle Classification	**Average calculated vehicle speed (km/h) before treatments installed** *n = 159*	**Average calculated vehicle speed (km/h) after FIRST treatment installed** *n = 162*	**Average calculated vehicle speed (km/h) after ALL treatments installed** *n = 61*
Cars	29.69	29.59	20.94***
Vans/4WD	27.07	29.32	19.97**
Trucks	25.40	24.65	18.18
Trams	22.55	17.43	n/a
Motorcycles	n/a	47.00	n/a
All Vehicles	**28.30**	**28.50**	**20.80*** **

** p<0.01
*** p<0.001

As indicated in the previous analysis, these measurements are coarse indicators of vehicle speeds and do not fully control for the possibility that vehicles had stopped for a short period of time for traffic-related reasons. Nevertheless, they do provide strong evidence of the effect of treatment implementation on overall travel speeds. It appears that significant reductions in average vehicle speed occurred as a result of implementation of all treatments.

Travel times of all vehicles during the three survey time periods on Clarendon Street are shown in Table 3.6.

An overall effect of treatment installation on travel times was found, $F(2,379) = 44.82$, $p < 0.001$. Travel times after installation of the 50 km/h speed zone did not alter significantly from those before treatment installation, however, the increase of 0.6 min. after installation of all treatments was significant, p-values < 0.001. Installation of all treatments resulted in increased travel times of approximately 0.6 min for cars, $F(2,210) = 32.75$, $p < 0.001$, approximately 0.6 min. for vans/4WD, $F(2,110) = 20.75$, $p < 0.001$, and an increase of 0.7 min. for trucks, $F(2,38) = 5.05$, $p < 0.05$. For cars, vans/4WD and trucks there was no substantial increase in travel time between before treatments and after installation of the 50 km/h speed zone, however, significant increases were found for the second after survey period and other survey periods, p-values < 0.001. No comparisons for travel times of trams and motorcycles were made due to a lack of these vehicles travelling through the survey site during some survey periods.

Table 3.6: Average travel times of vehicles (min.) through the survey site on Clarendon Street before treatments, after first treatment, and after all treatments were installed.

Vehicle Classification	**Average travel times (min.) before treatments installed** *n = 159*	**Average travel times (min.) after FIRST treatment installed** *n = 162*	**Average travel times (min.) after ALL treatments installed** *n = 61*
Cars	1.70	1.73	2.34***
Vans/4WD	1.89	1.74	2.46***
Trucks	1.97	2.06	2.67*
Trams	2.37	2.74	n/a
Motorcycles	n/a	1.05	n/a
All Vehicles	**1.80**	**1.81**	**2.41*** **

* p<0.05
*** p<0.001

Treatments were installed with the aim to moderate vehicle speeds without seriously affecting travel times. This analysis showed that travel time did change as a result of the first treatment installation, but the increase in travel time was only apparent when all treatments were installed. The small increase of 0.6 min. may be considered minor and it is doubtful whether an increase of less than one minute would greatly affect traffic flow for motorists or, indeed, be noticed by them. Furthermore, the benefits of moderating vehicle speeds to pedestrians may far outweigh the small impact to motorists of slowing traffic movement by less than one minute.

3.2.2 Vehicle speed measurements at locations within the survey site

This section presents the speed survey results for Clarendon Street. Measurements of vehicle speeds were collected for all vehicles travelling through the site during survey times at two mid-block locations. The effect of treatment implementation will be examined in terms of overall *free-flowing* speed by combining measurements from the two locations within the survey site. This will then be examined at specific speed locations, that is, as vehicles entered and exited the survey site.

3.2.2.1 Combined measures of vehicle speeds

Speed measurements at both locations on Clarendon Street were combined and average measured vehicle speeds are presented in Table 3.7.

Table 3.7: Average vehicle speeds on Clarendon Street before treatments, after first treatment and after all treatments were installed.

Vehicle Classification	**Average vehicle speed (km/h) BEFORE treatments installed** *n = 2868*	**Average vehicle speeds (km/h) AFTER FIRST treatment installed** *n = 3304*	**Average vehicle speeds (km/h) AFTER ALL treatments installed** *n = 2145*
Cars	45.45	44.91	44.31**
Vans/4WD	44.06	43.12	43.33
Trucks	39.52	39.47	38.81
Trams	29.57	31.91	30.15
Motorcycles	53.29	47.17*	44.14*
All Vehicles	**44.95**	**44.28***	**43.65*****

* $p<0.05$
** $p<0.01$
*** $p<0.001$

An overall effect of treatment implementation on measured vehicle speeds on Clarendon Street was found, $F(2,8314) = 10.65$, $p < 0.01$. Before treatment implementation, the average vehicle speed on Clarendon Street was close to 45 km/h. After installation of the 50 km/h speed zone, average vehicle speeds reduced significantly by 0.67 km/h to 44.28 km/h, $p < 0.05$. This trend continued after installation of all treatments, with a further mean reduction in vehicle speed of 0.63 km/h, $p = 0.059$. Overall, a mean reduction of 1.3 km/h was found from before treatment implementation to after all treatments had been installed, $p < 0.001$.

The majority of vehicles were cars and an overall effect of treatment implementation was found for vehicle speeds of cars, $F(2,6528) = 6.47$, $p < 0.01$. While the mean reduction of 0.54 km/h from before treatment installation to after installation of the 50 km/h speed zone did not reach significance, the mean reduction of 1.14 km/h from before treatment installation to after installation of all treatments was significant, $p < 0.01$. An overall effect of treatment implementation was also found for average speeds of motorcycles, $F(2,74) = 3.74$, $p < 0.05$. On average, motorcycles travelled at fairly high speeds before implementation of treatments, but decreased by 6.12 km/h after implementation of 50 km/h speed limits, and by a further 3.03 km/h after implementation of all treatments. The overall mean reduction of 9.15 km/h was significant, $p < 0.05$. With regard to vans/4WD and trucks, there was no effect of treatment implementation on average speeds for these vehicles, even though mean reductions of around 0.7 km/h were found. By contrast, average speeds of trams increased by 2.34 km/h after installation of the 50 km/h speed zone, but decreased again by 1.76 km/h. These changes were not significant, however, probably due to the small sample sizes.

These findings have shown that treatment implementation affected mean vehicle speeds in general at Clarendon Street. The overall reduction of 1.3 km/h was a significant reduction. Like in the control-adjusted analysis, there was a large reduction of around 8 km/h in average vehicle speeds throughout the survey site and smaller reductions at specific sites that targeted speeds of free-flowing vehicles. Again, it may be assumed that even larger reductions in vehicle speeds would have occurred at other locations within the survey site and can be attributed to the general effect of the installation of treatments.

3.2.2.2 Proportion of vehicles travelling at speeds unsafe for pedestrians

Again, a comparison of the proportion of vehicles travelling at high speeds (i.e., speeds that are likely to cause death or other severe injuries to struck pedestrians) before and after treatment implementation on Clarendon Street was made. Figure 3.2 shows the overall proportion of vehicles travelling over 60 km/h, over 50 km/h and over 40 km/h before treatment installation, and after first and second treatment implementation.

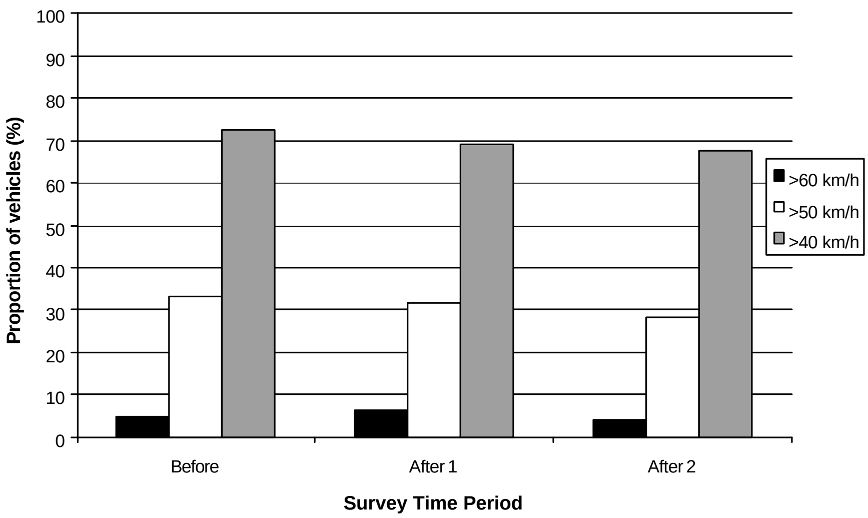

Figure 3.2: Proportion of vehicles travelling over 60 km/h, over 50 km/h and over 40 km/h on Clarendon Street before treatments, after first treatment and after all treatments were installed.

Only small proportions of vehicles travelled at or over 60 km/h during all survey time periods. Before implementation of treatments, almost 5 percent of vehicles travelled at or faster than 60 km/h. This rose to just over 6 percent after installation of the 50 km/h speed zone, $p < 0.05$. After installation of all treatments, only 4.1 percent of vehicles travelled at these speeds, however, this reduction did not reach significance. The proportions of vehicles travelling at or above 60 km/h are relatively low. In terms of raw numbers, these figures revealed that over the survey times of 4 hours, 143 vehicles before implementation of treatments and 205 vehicles after installation of the 50 km/h speed zone travelled at these speeds. In comparison, this number dropped considerably to 87 vehicles (or one vehicle every three minutes) travelling at or above 60 km/h after installation of all treatments.

The comparison of the proportions of vehicles travelling 50 km/h or over revealed an overall reduction of 4.9 percent from before treatment implementation to after all treatments were installed, $p < 0.01$. There was a reduction of 1.7 percent from 33.3 percent before installation of treatments to 31.6 percent after installation of the 50 km/h speed zone, $p < 0.05$. The proportion of vehicles travelling at these speeds was reduced by a further 3.2 percent to 28.4 percent after installation of all treatments, p-values < 0.05. Again, this comparison revealed that close to 1000 vehicles per 4 hours before implementation and after installation of the 50 km/h speed zone travelled at these speeds, but this decreased to just over 600 vehicles after implementation of all treatments. This translates to a reduction from 4 vehicles every minute to 2.5 vehicles every minute (or 240 vehicles to 150 vehicles every hour) that are travelling at or above 50 km/h after installation of all treatments. At impact speeds of 50 km/h or higher, probability of death to a struck pedestrian exceeds 85%.

While the majority of vehicles travelled over 40 km/h in all survey time periods, the installation of treatments affected the proportion of vehicles travelling at these speeds. Before treatments were installed, close to 73 percent of vehicles travelled at or over 40 km/h. This proportion decreased by 3.6 percent to just over 69 percent after installation of the 50 km/h speed zone, $p < 0.001$, and decreased by another 1.6 percent to 67.5 percent after all treatments were installed, p-values < 0.05. Over 2000 vehicles travelled at these speeds per 4 hours before treatment installation and surprisingly rose to around 2280 vehicles after installation of the 50 km/h speed zone. After installation of all treatments, however, less than 1500 vehicles travelled at or over 40 km/h. This translates to a reduction from almost 10 vehicles every minute before treatment installation to only 6 vehicles every minute (i.e., 600 vehicles to 360 vehicles per hour) after all treatments were installed that travelled at or above 40 km/h.

The finding that the proportion of vehicles travelling at speeds that are unsafe for pedestrians dropped after installation of treatments was a valuable finding. The proportion of vehicles travelling at or above 60 km/h was not large and consequently the observed reductions were not significant. However, substantial reductions in vehicles travelling at or above 50 km/h and 40 km/h were observed. In real terms, this finding means that fewer vehicles travelled at speeds that are highly likely to kill or seriously injure a pedestrian struck at or near these speeds. In summary, it appeared that installation of treatments resulted in a reduction of the proportion of vehicles travelling fast, effectively, reducing the risk of death or serious injury to pedestrians substantially.

3.2.2.3 Speeds as vehicles entered the survey site

Average vehicle speeds as vehicles entered the survey site were analysed separately from those as vehicles exited the survey site to examine any differences in the behaviour of drivers at each location. Table 3.8 shows the average vehicle speeds as vehicles entered the survey site on Clarendon Street.

An overall effect of treatment implementation on vehicle speeds was found as vehicles entered the survey site, $F(2,3940) = 10.94$, $p < 0.001$. There was a mean reduction in vehicle speed of 1.06 km/h between before treatment implementation and after installation of the 50 km/h speed zone, $p < 0.01$, and a mean reduction of 1.89 km/h from before treatment implementation to after all treatments were installed, $p < 0.001$. The mean reduction in vehicle speed of 0.83 km/h between first and second treatment implementation did not reach significance.

Table 3.8: Average vehicle speeds as vehicles entered the survey site on Clarendon Street before treatments, after first treatment and after all treatments were installed.

Vehicle Classification	**Average vehicle speed (km/h) BEFORE treatments installed** *n = 1365*	**Average vehicle speeds (km/h) AFTER FIRST treatment installed** *n = 1737*	**Average vehicle speeds (km/h) AFTER ALL treatments installed** *n = 841*
Cars	41.40	40.48	39.61***
Vans/4WD	40.58	39.27	39.36
Trucks	36.13	35.08	36.92
Trams	25.75	25.48	27.18
Motorcycles	47.38	43.47	38.25
All Vehicles	**41.04**	**39.98****	**39.15*****

** p<0.01
*** p<0.001

Cars, vans/4WD and motorcycles travelled more slowly as they entered the survey area after the first and second treatment installation compared to before treatment installation. A significant effect of treatment implementation was found for vehicle speed of cars only $F(2,3103) = 7.55$, $p < 0.001$, even though this reduction of 1.79 km/h was comparable to that of vans/4WD (1.22 km/h) and substantially smaller than the reduction of 9.13 km/h for motorcycles. These reductions were not significant due to small sample sizes in these vehicle classifications. Average vehicle speeds of trucks and trams increased slightly but not significantly by, 0.79 km/h and 1.43 km/h, respectively.

As for the overall analysis of vehicle speeds, the proportion of vehicles travelling at fast speeds was examined. Figure 3.3 shows the proportions of vehicles travelling at or above 60 km/h, 50 km/h and 40 km/h as they entered the survey site.

Inspection of the proportion of vehicles travelling at 60 km/h or faster measured as vehicles entered the survey site shows that only small proportions of vehicles travelled at these speeds at each survey time as they entered the survey site. Just under 1 percent of vehicles travelled over 60 km/h before treatments and this proportion rose to over 2 percent after installation of the 50 km/h speed zone, $p < 0.05$. This proportion dropped slightly, but not significantly, to 1.5 percent after all treatments were installed. While these proportions are relatively low, in terms of raw number, these figures revealed that, within the 4 hours survey time, 12 vehicles before implementation of treatments, 41 vehicles after installation of the 50 km/h speed limit, and 13 vehicles after installation of all treatments travelled at or above 60 km/h. In summary, it cannot be concluded that treatment implementation had any effect on the speed behaviour of drivers of fast travelling vehicles.

Twenty percent of vehicles travelled at 50 km/h and over as they entered the survey site before implementation of treatments. This proportion decreased to approximately 15 percent (a 25% reduction) after installation of the 50 km/h speed zone, $p < 0.05$, and decreased again to under 13 percent (an overall 35% reduction) after installation of all treatments. This 7.4 percent decrease from before installation of treatments to after all treatments were installed was significant, $p < 0.001$. Again, in terms of raw numbers, this relates to an overall decrease of 153 vehicles over the 4 hour survey time (just over one vehicle per minute) travelling at speeds above the set speed limit which are likely to kill or seriously injure a pedestrian struck at or near these speeds.

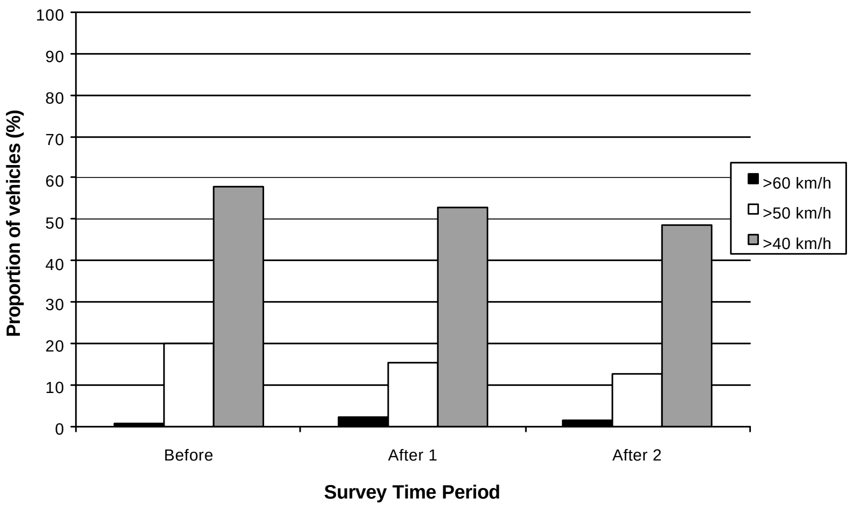

Figure 3.3: Proportion of vehicles travelling over 60 km/h, over 50 km/h and over 40 km/h on Clarendon Street before treatments, after first treatment and after all treatments were installed as they entered the survey site.

Likewise, the proportion of vehicles travelling over 40 km/h decreased from 58 percent before implementation of treatments to 53 percent after installation of the 50 km/h speed zone, $p < 0.01$, and decreased further to 48 percent after all treatments were installed, $p < 0.001$. Again, in terms of raw numbers, approximately 1300 vehicles over 4 hours travelled at or above 40 km/h before implementation and after installation of the speed limit over 4 hours, however, this decreased to approximately 1000 vehicles after implementation of all treatments. In other words, there was a reduction of just over 5 vehicles per minute before treatment installation to 4 vehicles per minute after installation of all treatments travelling at or above 40 km/h.

In summary, it appears that treatment implementation did not have any effect on the small proportion of drivers that travelled at fast speeds of 60 km/h and above. It is possible that the sample of vehicles travelling at 60 km/h was too small to find a significant effect, or it could be that these drivers require more substantive countermeasures to reduce travel speeds. However, treatment implementation did result in a substantial reduction of vehicles travelling at or above 50 km/h and 40 km/h, both after installation of the 50 km/h speed zone and after all treatments were installed.

3.2.2.3 Speeds as vehicles exited the survey site

Vehicle speeds at location 2 (as they exited the survey site) are shown in Table 3.9. Vehicle speeds as vehicles exited the survey site were markedly higher than as they entered. On average, vehicles travelled approximately 8 km/h faster as they left the shopping precinct, compared to their entry speed. This was not unexpected as vehicles often travel more slowly as they enter shopping areas and increase as they leave. Throughout shopping centres there is usually an increase in activities by road users in shopping precincts, traffic movements are more varied (e.g., vehicles parking, entering and exiting traffic flow) and traffic is often more congested.

Table 3.9: Average vehicle speeds as vehicles exited the survey site on Clarendon Street before treatments, after first treatment and after all treatments were installed.

Vehicle Classification	**Average vehicle speed (km/h) BEFORE treatments installed** *n = 1503*	**Average vehicle speeds (km/h) AFTER FIRST treatment installed** *n = 1567*	**Average vehicle speeds (km/h) AFTER ALL treatments installed** *n = 1304*
Cars	49.09	49.85	47.42**
Vans/4WD	47.66	47.66	45.55*
Trucks	42.26	42.91	39.76
Trams	31.57	37.32	32.88
Motorcycles	58.40	51.56	52.00
All Vehicles	**48.50**	**49.04**	**46.55****

* p<0.05,
** p<0.001

With respect to average vehicle speeds measured as vehicles left the survey area, a significant effect of treatment implementation on vehicle speeds was found, $F(2,4371) = 37.38$, $p < 0.001$. Vehicle speeds decreased by 1.95 km/h from before treatment installation to installation of all treatments, $p < 0.001$. Surprisingly, vehicle speeds increased marginally after installation of the 50 km/h speed zone compared to before implementation, but decreased significantly after implementation of other treatments, a mean reduction of 2.49 km/h, $p < 0.001$.

A significant effect of treatment implementation was found for vehicle speeds of cars, $F(2,3422) = 23.78$, $p < 0.001$, vans/4WD, $F(2,674) = 4.51$, $p < 0.05$, and trams, $F(2,69) = 5.24$, $p < 0.001$. On average, car vehicle speeds increased slightly, but not significantly so, after installation of the 50 km/h speed zone, compared to before measurements. Implementation of further treatments resulted in vehicle speed reductions for cars of 1.67 km/h compared to before treatments were installed, and by 2.43 km/h compared to after the first treatments, both p-values < 0.001. Average vehicle speeds of van/4WDs remained the same between before implementation and after the first treatment, but decreased 2.11 km/h after implementation of all treatments, $p < 0.05$. Similarly, average vehicle speeds of trucks increased slightly after the first treatment compared to before, and decreased slightly after installation of all treatments, but these changes were not significant. Average vehicle speeds of motorcycles decreased substantially from before implementation to after implementation of all treatments, 6.4 km/h, however, because of small sample sizes this reduction was not significant.

As for the combined vehicle speed data, the proportion of vehicles travelling fast was examined as vehicles left the survey site and are shown in Figure 3.4.

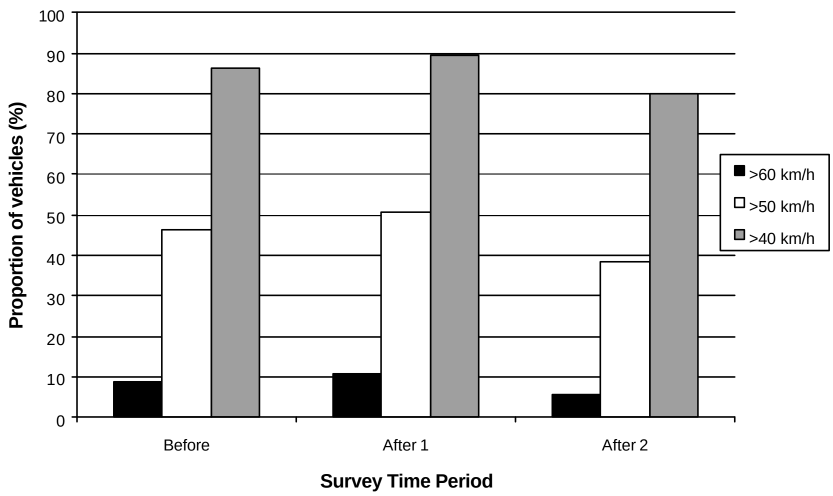

Figure 3.4: Proportion of vehicles travelling over 60 km/h, over 50 km/h and over 40 km/h on Clarendon Street before treatments, after first treatment and after all treatments were installed as they exited the survey site.

Compared to the proportion of speeding vehicles as they entered the survey site, here a greater proportion of vehicles travelling 60 km/h or above was found. Close to 9 percent of vehicles (a total number of 131 over 4 hours) travelled at these speeds before treatments were installed. Extrapolation of these results indicates that, on average, every two minutes one vehicle travels through this site within the shopping centre at a speed almost certain to kill any pedestrian struck at or near this speed. The number of vehicles travelling at these speeds remained at a similar proportion and number after installation of the 50 km/h speed zone. More importantly, however, the proportion of speeding vehicles dropped significantly to under 6 percent (a total of 74 vehicles over 4 hours) after installation of all treatments, p-values < 0.001. This means that a substantial number of vehicles (one vehicle, on average, every 3-4 minutes) were travelling at or above 60 km/h. While a small but substantial proportion of vehicles still travelled at or above 60 km/h as they left the shopping precinct however, compared to before installation of treatments, this number had halved.

Likewise, the proportion of vehicles travelling at 50 km/h here was higher than that as vehicles entered the survey site. Approximately 46 percent of vehicles travelled at 50 km/h or above before implementation and this proportion rose slightly, but not significantly to 51 percent of vehicles after implementation of the 50 km/h speed zone. Only 39 percent of vehicles travelled at these speeds after installation of all treatments. This reduction of 7.8 percent of vehicles travelling 50 km/h or above after installation of all treatments, compared to the before survey time was significant, $p < 0.001$. Like vehicles travelling at or above 60 km/h, these results show that over 700 vehicles per four hours (on average, three vehicles every minute) travelled at or above 50 km/h before implementation of treatments. After implementation of treatments this number decreased to approximately 500 vehicles per four hours (on average, two vehicles every minute).

Although the proportion of vehicles travelling 40 km/h and over increased slightly, but not significantly, from 86 percent before treatments to 89 percent after installation of the speed limit, this proportion decreased significantly to under 80 percent after all treatments were installed, p-values < 0.001.

3.2.2.4 Summary

Assuming that speed behaviour in the Melbourne metropolitan system on the whole has not changed, this evaluation has demonstrated that the installation of treatments on Clarendon Street, which aimed to moderate vehicle speeds without seriously affecting travel times, has been successful. Interestingly, speed behaviour remained fairly stable after installation of the 50 km/h speed zone, but decreased after installation of all treatments. One interpretation of this finding may be that traditional countermeasures, such as speed zoning alone, have limited success in reducing the frequency and severity of pedestrian crashes (Corben et al., 1996; Newstead et al., 1997) and that innovative approaches offer a potential solution to moderate vehicle speeds in areas where there is high pedestrian activity. However, it should be remembered that the installation of the 50 km/h speed zone at this location was not supported by enforcement or publicity. Perhaps if the speed zoning change had been accompanied by any changes in special enforcement and publicity, a measurable effect might have been possible and a reduction in vehicle speeds may have been observed. Unlike the recent introduction of 50 km/h in residential streets, for 50 km/h speed zoning to be successful in strip shopping centres, there may need to be support from police enforcement and publicity. In addition, the circumstances of this trial are somewhat different to the introduction of 50 km/h speed zoning in residential streets where average speeds tend to be considerably higher than in strip shopping centres (here, average free-flowing speeds were around 44 km/h).

At a broad level, it would appear that average speeds were largely unaffected by the 50 km/h speed zoning. This is not surprising in that average free-flowing speeds at both entry to and exit from the survey site were already below 50 km/h (41 km/h and 49 km/h, respectively). However, if the aim of the treatments is to target those drivers that are exceeding the speed limit (i.e., those travelling at or above 50 km/h), the findings show a real effect of treatment implementation. On entry to the shopping centre, the proportion of drivers travelling at or over 50 km/h fell from 20% before treatments to 15% after installation of the 50 km/h speed limit (equivalent to a 25% reduction in the proportion of vehicles posing a serious threat to pedestrians). No significant changes in the proportion of vehicles travelling at these speeds, however, were observed at the exit location. Overall, there is evidence that the 50 km/h speed zoning has tended to reduce the number of drivers travelling at or above 50 km/h, at least on entry to the shopping centre. Thus, pedestrian exposure to threatening speeds has been substantially reduced by the installation of all treatments.

More importantly, installation of all treatments resulted in a large reduction of 7.5 km/h in average calculated vehicle speed throughout the survey site. Although this was a coarse measurement of speed behaviour, this analysis showed clearly that speed behaviour throughout the survey site changed as a result of treatment implementation. Furthermore, it appears that travel times were not seriously affected by treatment implementation, with average increases of around 30 to 40 seconds only observed.

While this large reduction in overall speed behaviour was encouraging, smaller reductions in vehicle speeds at selected locations in the order of 1 km/h were found. However, as stated previously, the locations selected to measure speeds focused on free-flowing traffic. These measurements, therefore, may have been biased towards faster travelling vehicles and it is conceivable that larger reductions may have been found at other locations within the survey site. Also, average speeds at these locations of free-flowing traffic were already below 50 km/h before any treatments were implemented.

The proportional data showed that treatment installation did not significantly reduce the proportion of vehicles travelling at or above 60 km/h, however, this may be related to the small sample size. By contrast, there was a significant reduction in the proportion of vehicles travelling at or above 50 km/h and 40 km/h. In terms of raw numbers, this meant that the number of vehicles travelling at or above 60 km/h dropped from one vehicle every two minutes to one vehicle every three minutes. Similarly, the number of vehicles travelling at or above 50 km/h dropped from 4 vehicles to just over 2 vehicles every minute. While the majority of vehicles travelled at or above 40 km/h, treatment installation resulted in a reduction from 10 vehicles to 6 vehicles every minute travelling at speeds with a sizeable probability of causing fatal or serious injuries to pedestrians (refer Figure 1.3).

Treatment implementation appeared to affect speed behaviour as vehicles entered the survey site and to a lesser extent as they left the survey site. Reductions in free-flowing speeds of almost 2 km/h were found at both sites, despite the faster average speeds of around 7 km/h as vehicles left the shopping precinct compared to entry speed. Installation of the 50 km/h speed zone resulted in a reduction of 1 km/h as vehicles entered the shopping precinct, but had no effect of vehicle speeds as vehicles left the site. It seems therefore that drivers were more aware of the reduced speed limit as they approached the shopping precinct and drove accordingly as they entered the area, compared to leaving the area. Intuitively, it makes sense to target speed behaviour as vehicles enter an area, rather than as they leave, and this evaluation demonstrates an effect of this treatment on approaching vehicles. More importantly, however, it seemed that installation of all treatments resulted in drivers maintaining lower speeds throughout the shopping precinct to the exit point. Indeed, the estimates of risk reduction to pedestrians associated with reductions in vehicle speeds would strongly support installation of these treatments. The reductions of average speeds as vehicles entered and left the survey site were expected to result in large reductions in fatal, serious casualty and casualty pedestrian crashes.

The proportional data at each location supported the overall findings. While little difference was found in the proportions of vehicles travelling at or above 60 km/h at both locations, there was a significant reduction in the proportion of vehicles travelling at or over 50 km/h and 40 km/h as vehicles entered and left the shopping precinct. Greater proportions of vehicles travelling at these speeds were found as vehicles left the shopping precinct, compared to when they entered, however, treatment installation resulted in reductions at both sites.

3.3 RELATIONSHIP BETWEEN IMPACT SPEED AND PEDESTRIAN DEATH/INJURY RISK

As noted in the introduction, the severity of a pedestrian crash depends largely on the collision speed of the vehicle, especially in the range of the speeds usual on arterial roads in Melbourne. It is therefore a useful exercise to relate the findings of vehicle speed reductions in this study to pedestrian injury risk. In order to do this, a number of previous studies that provide estimates of this relationship were consulted. Figure 3.5 shows the relationship between impact speed and the probability of pedestrian death or serious injury, estimated in a number of previous studies (Ashton & Mackay, 1979; Pasanen & Salmivaara, 1993; Anderson et al., 1997).

Anderson et al. (1997) estimated the likely effect of reduced travel speeds on the incidence of fatal pedestrian collisions. They based their estimates on the results of detailed investigations of fatal pedestrian crashes in Adelaide and predicted that small reductions in travelling speed are likely to result in large reductions in impact speed in pedestrian collisions, often to the extent of preventing the collision altogether. Anderson et al. calculated that the probability of death if a pedestrian is struck at an impact speed of 60 km/h is 100%. Likewise, the probability of death if struck at 50 km/h and 40 km/h is 84% and 26% respectively.

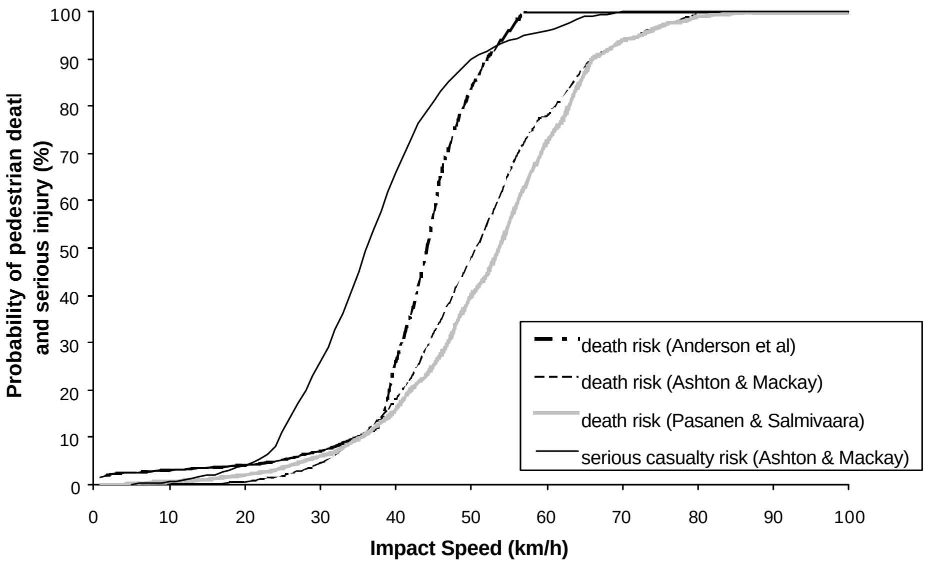

Figure 3.5: Probability of pedestrian death and serious injury by impact speed.

Similarly, Ashton and Mackay (1979) examined a number of variables, of which impact speed was one, on pedestrian injury and death risk. They also derived their estimations from data obtained in at-the-scene pedestrian crashes. Unlike Anderson et al., Ashton and Mackay argued that the probability of death with an impact speed of 60 km/h is lower, at 78%. Ashton and Mackay's estimates also differed from those of Anderson et al. for impact speeds of 50 km/h and 40 km/h. Here, their estimates are also lower than Anderson et al's. They estimated that the probability of death with impact speeds of 50 km/h is 48% and with impact speeds of 40 km/h is 18%.

Ashton and Mackay also provided some estimates of the probability of serious injury, given variations in impact speed. Overall, the probability of sustaining a serious injury is greater than a fatal outcome in similar impact speed conditions. They estimated that if a pedestrian is struck at 60 km/h, the likelihood of a pedestrian sustaining a serious injury is 96%. If struck at 50 km/h, the probability of sustaining a serious injury is estimated to be 90%, and if struck at 40 km/h it is estimated to be 66%.

Last, Pasanen and Salmivaara (1993) examined the influence of collision speed on the probability of death in Finland and reported similar estimates to Ashton and Mackay. They estimated the probability of pedestrian death if struck at 60 km/h, 50 km/h and 40 km/h to be 73%, 40%, and 16 %, respectively.

All of these studies show that the probability of pedestrian serious injury or death increases slowly as the impact speed increases from zero. As the impact speed increases further, however, the probability of serious injury and/or death increases rapidly. Ashton and Mackay estimated that the probability of serious injury for a pedestrian reaches 100% at an impact speed of 70 km/h. They, and Pasanen and Salmivaara, estimated that the probability of death reaches 100% at an impact speed of 80 to 88 km/h. Anderson et al.'s estimates are more conservative, estimating that the probability of death reaches 100% at an impact speed of 57 km/h.

While these studies are generally not directly comparable due to differences in the populations considered, vehicle fleets over time, and in the methods used to describe the injuries and crash scenarios, there is some merit in presenting all available estimates to draw some meaningful conclusions regarding the present findings.

In addition to estimating the risk of death and/or injury with variations in impact speed by examining crash data, Nilsson (1984) developed a mathematical model to describe the relationship between speed and safety. Nilsson found that the risk of all casualty crashes changed by the second power of the relative change in speeds, serious injury crashes (including fatal crashes) by the third power and fatal crashes by the fourth power of the relative speed change. Nilsson's model is defined below.

Let ν_0 be the initial speed of the vehicle.
Let ν_1 be the speed of the vehicle after implementation of a treatment (for example).

Let y_0 be the number of (pedestrian) crashes of a given severity, at the time of the initial speed.
Let y_1 be the number of (pedestrian) crashes of a given severity, after implementation of a treatment (for example).

Then the number of **fatal** (pedestrian) crashes after implementation of a treatment is given by:

$$y_1 = \left(\frac{\nu_1}{\nu_0} \right)^4 y_0$$

The number of **serious casualty** (pedestrian) crashes after implementation of a treatment is given by:

$$y_1 = \left(\frac{\nu_1}{\nu_0} \right)^3 y_0$$

And the number of **casualty** (pedestrian) crashes after implementation of a treatment is given by:

$$y_1 = \left(\frac{\nu_1}{\nu_0} \right)^2 y_0$$

It should be noted here that Nilsson's laws are applicable for vehicle speeds travelling at and above 70 km/h.

3.3.1 Average Speeds

Mean speeds over the full length of the survey site on Clarendon Street fell from 28.3 km/h to 20.8 km/h. Table 3.10 shows the associated reductions in pedestrian fatal and serious injury crashes predicted by the various previous studies (Anderson et al., 1997; Ashton & Mackay, 1979; Pasanen & Salmivaara, 1993). Nilsson's laws were not applied to these data, as these laws are more applicable for higher travel speeds.

Table 3.10: Associated reductions in probability of fatal pedestrian crashes for mean speed reductions on Clarendon Street.

	Impact speed of 28.3 km/h	**Impact speed of 20.8 km/h**	**OVERALL REDUCTION OF 7.5 km/h**
Probability of fatal pedestrian crashes (%) as predicted by Anderson et al. (1997)	6.4	4.2	2.2
Probability of fatal pedestrian crashes (%) as predicted by Ashton & Mackay (1979)	3.1	0.7	2.4
Probability of fatal pedestrian crashes (%) as predicted by Pasanen & Salmivaara (1993)	5.0	2.2	2.8
Probability of serious injury pedestrian crashes (%) as predicted by Pasanen & Salmivaara (1993)	20.0	4.6	15.4

In terms of the relationship between this reduction and pedestrian risk, the following may be predicted:

- A fall in the probability of pedestrian fatal crashes. The reduction of 7.5 km/h average travel speed (from 28.3 km/h to 20.8 km/h) is expected to result in a reduction of between 2.2% and 2.8% in probability of fatal pedestrian crashes.

- A fall in the probability of pedestrian serious injury crashes. The reduction of 7.5 km/h average travel speed is expected to result in a reduction of 15.4% in probability of serious injury pedestrian crashes

- Reductions in likely braking distance of around 10 m (from approximately 20 m to 10 m), thereby actually preventing some collisions. McLean et al. (1994) noted that braking distance is proportional to the square of the initial speed.

3.3.2 Spot measures of vehicle speed

3.3.2.1 Combined measures of vehicle speeds

Mean travel speeds on Clarendon Street (combined entry and exit speeds) fell from 44.95 km/h to 43.65 km/h (a statistically significant reduction of 1.3 km/h). As these speeds are higher than average speeds over the full length of the survey site, Nilsson's speed and safety relationship model was also applied to these data to examine risk reduction in pedestrian crashes as a result of the reductions in vehicle speeds. Table 3.11 presents the estimated reductions in crash risk of pedestrians expected to occur as a result of the reductions found in spot measures of vehicle speeds on Clarendon Street after installation of the 50 km/h speed zone and after all treatments had been installed.

Table 3.11: Expected reductions in pedestrian crashes on Clarendon Street due to changes in average spot speed measurements (entry and exit locations).

	Net reduction in average speed	**Expected reduction in pedestrian crashes (%)**		
		Fatal	**Serious casualty**	**Casualty**
Before vs. After all treatments installed	-1.30 km/h (a 2.9% reduction)	11.1	8.4	5.7
Before vs After 50 km/h speed zone installed	-0.67 km/h (a 1.5% reduction)	5.8	4.4	3.0
After first vs. After all treatments installed	-0.63 km/h (a 1.4% reduction)	5.6	4.2	2.8

In terms of the relationship between this reduction and pedestrian risk, the following may be predicted:

- Installation of the 50 km/h speed zone has the potential to reduce fatal crashes by 5.8%, serious injury crashes by 4.4%, and casualty crashes by 3%.
- Installation of all treatments has the potential to reduce fatal crashes by 11.1%, serious injury crashes by 8.4% and casualty crashes by 5.7%.

3.3.2.2 Speeds as vehicles entered the survey site

The estimation of risk reduction in pedestrian crashes as a result of the reductions in vehicle speeds as vehicles entered the survey site is shown in Table 3.12 (Nilsson, 1984).

Table 3.12: Expected reductions in pedestrian crashes on Clarendon Street due to changes in average vehicle speeds as vehicles entered the survey site.

	Net reduction in average speed	Expected reduction in pedestrian crashes (%)		
		Fatal	**Serious casualty**	**Casualty**
Before vs. After all treatments installed	-1.89 km/h (a 4.6% reduction)	17.2	13.2	9.0
Before vs After 50 km/h speed zone installed	-1.06 km/h (a 2.6% reduction)	9.9	7.6	5.1
After first vs. After all treatments installed	-0.83 km/h (a 2.1% reduction)	8.1	6.1	4.1

In terms of the relationship between this reduction and pedestrian risk, the following may be predicted:

- Installation of the 50 km/h speed zone has the potential to reduce fatal crashes by 9.9%, serious injury crashes by 7.6%, and casualty crashes by 5.1%.
- Installation of all treatments has the potential to reduce fatal crashes by 17.2%, serious injury crashes by 13.2% and casualty crashes by 9%.

3.3.2.3 Speeds as vehicles exited the survey site

The estimation of risk reduction in pedestrian crashes as a result of the reductions in vehicle speeds as vehicles left the survey site is shown in Table 3.13 (Nilsson, 1984).

Table 3.13: Expected reductions in pedestrian crashes on Clarendon Street due to changes in average vehicle speeds as vehicles exited the survey site.

	Net reduction in average speed	Expected reduction in pedestrian crashes (%)		
		Fatal	**Serious casualty**	**Casualty**
Before vs. After all treatments installed	-1.95 km/h (a 4.0% reduction)	15.1	11.6	7.9
After first vs. After all treatments installed	-2.49 km/h (a 5.1% reduction)	18.8	14.5	9.9

In terms of the relationship between this reduction and pedestrian risk, the following may be predicted:

- It is estimated that there would be no reductions in fatal, serious injury or casualty pedestrian crashes as a result of installation of the 50 km/h speed zone.
- Installation of all treatments has the potential to reduce fatal crashes by 15.1%, serious injury crashes by 11.6% and casualty crashes by 7.9%.

3.3.3 Proportion of drivers travelling at greater than specified speeds.

The proportion of drivers travelling at or above given speeds fell. These are described below in terms of the estimated risk of death by impact speed by Anderson et al. (1997) and estimated risk of serious injury by Ashton and Mackay (1979).

- ≥60 km/h impact speed – the proportion fell from 5% to 4% (i.e. a 20% reduction). Any vehicle travelling at or above 60 km/h is almost certain to kill or seriously injure a struck pedestrian (Ashton & Mackay, 1979; Anderson et al., 1997).
- ≥50 km/h impact speed – the proportion fell from 33% to 28% (i.e. a 15% reduction). Any striking vehicle travelling at or above 50 km/h has a probability of up to 84% of killing a pedestrian and 90% of resulting in a serious injury pedestrian crash (Ashton & Mackay, 1979; Anderson et al., 1997).
- ≥40 km/h impact speed – the proportion fell from 73% to 68% (i.e. an 8% reduction). Any striking vehicle travelling at or above 40 km/h has a probability of up to 26% of killing a pedestrian and a 66% probability of resulting in a serious injury pedestrian crash (Ashton & Mackay, 1979; Anderson et al., 1997).

4 SUMMARY AND CONCLUSIONS

This section attempts to draw some conclusions regarding the aims and findings of this study. Pedestrian crashes in high activity/commercial centres represent a long-standing problem. A number of countermeasure options are available for reducing the risk of death or serious injury to pedestrians including reducing vehicle and/or pedestrian volumes, and separating vehicles and pedestrians either in time or space. The remaining alternative is to moderate vehicle speeds in high activity pedestrian areas.

A previous study (Corben & Duarte, 2000) identified a number of innovative countermeasures which have the potential to moderate vehicle speeds and therefore reduce the probability and severity of crashes. Through an extensive review of some philosophies and practices in Denmark and The Netherlands, Corben and Duarte argued that an innovative and comprehensive approach to moderate vehicle speeds in high density pedestrian areas offers an acceptable and potentially cost-effective solution to the pedestrian problem in these areas.

To this end, the current study, which was conducted to investigate the effects of countermeasure treatments in strip shopping centres, utilised a 'before' and 'after' quasi-experimental design. Countermeasure treatments included installation of a 50 km/h speed zone and installation of physical measures such as painted pedestrian refuges between tram tracks, pram crossings and coloured crosswalks at intersections. While surveys were conducted only on one weekday afternoon, the findings can provide some indication of the gains possible under these day-time circumstances in terms of predicted reductions in the incidence and severity of pedestrian crashes as a result of the introduction of these countermeasures.

The specific objectives of this study were to: reduce serious pedestrian crashes through the development of practical new approaches to moderating vehicle speeds without seriously affecting travel times; and to evaluate the effectiveness of recommended measures so that the most cost-effective measures may be introduced at hazardous locations in Victoria's urban areas. A total of six surveys were conducted, three at a control site and three at a treatment site. The first set of surveys were completed before installation of any treatments, while the second set of surveys were completed after installation of the 50 km/h speed zone and the last surveys completed after installation of all other physical countermeasures.

It was anticipated that the use of a control site would provide a rigorous test of the effectiveness of treatment programs, however, some concerns were raised regarding the suitability of the site and data collection methods. For these reasons, the results were presented both with and without control-adjustment analyses.

Average vehicle speeds calculated from travel time data provided the most encouraging results, even when the data were adjusted for changes at the control site. It seemed that installation of treatments resulted in sizeable reductions in average vehicle speed throughout the shopping precinct. These reductions in average vehicle speeds were observed after all treatments were installed, compared to before treatment installation. Installation of the 50 km/h speed zone did not affect overall speed behaviour.

The findings from speed measurements at specific locations within the shopping centre were somewhat disappointing, particularly after controlling for changes at the control site.

This finding, however, may be explained by the locations chosen to measure free-flowing traffic and unexpected changes at the control site. Nevertheless, if it is assumed that no overall changes in speed behaviour occurred in the Melbourne metropolitan area during the time that the surveys took place, the unadjusted data provided some evidence that treatment implementation resulted in reducing vehicle speed on Clarendon Street. At these locations there was an overall reduction of 1.3 km/h on Clarendon Street.

The finding that proportions of vehicles travelling at threatening speeds decreased as a result of treatment implementation also provided strong evidence of the benefits to pedestrians. Again, reductions in the proportion of vehicles travelling at such speeds were found at the control site and therefore it was difficult to determine whether the changes on Clarendon Street were due to treatment implementation. However, if it is assumed that no overall speed behaviour changes occurred in Melbourne, the observed reductions in proportion of fast travelling vehicles at locations where free-flowing traffic was targeted, substantiate the suggestion that treatment implementation affected speed behaviour on Clarendon Street. While there was only a minor effect of treatment implementation on travel speeds of vehicles travelling at or over 60 km/h, there was a reduction of 5 percent in vehicles travelling at or above 50 km/h after all treatments were installed, compared to before treatment installation. In terms of real numbers of vehicles, this means a reduction from 4 vehicles to 2.5 vehicles every minute, or 240 to 150 vehicles every hour, that travelled through the shopping precinct at speeds which pose a high risk of death or serious injury to a pedestrian if struck (at 50 km/h or above).

Similar reductions of approximately 2 km/h were found as vehicles entered and left the shopping precinct, although vehicles tended to travel at faster speeds as they exited. It appeared that speed behaviour changed as drivers approached the shopping precinct after installation of the 50 km/h speed zone, but did not as vehicles left the area. This finding would suggest that 50 km/h speed limits were successful in reducing vehicle speed as vehicles approached the shopping precinct, but were unsuccessful in maintaining these reductions as vehicles left the area. By contrast, installation of all treatments seemed to change speed behaviour at both locations, suggesting maintenance of reduced speeds.

In terms of the effect of treatment implementation on travel times, the findings suggest that travel times did increase marginally on Clarendon Street. With any moderation in vehicle speeds, it is likely that travel time will increase also. The treatments were installed primarily with the aim of moderating vehicle speeds in order to reduce the risk to pedestrians but also to disrupt traffic dynamics and travel times as little as possible. While travel times remained fairly stable after installation of the 50 km/h speed zone, travel times were affected by installation of all treatments. However, considering the large expected safety benefits to pedestrians, the impact that less than one minute extra travel time would have on drivers seems minimal, and unlikely to be noticed.

The findings were related to pedestrian death and injury risk, utilising previous studies examining the relationship between impact speed and the risk of death and serious injury to pedestrians. The reduction of 7.5 km/h in average speeds over the full length of the survey site were estimated to result in a fall in the probability of fatal pedestrian crashes (2-3%) and serious injury pedestrian crashes (15%). The reduction of 1.3 km/h in measured speeds at locations within the survey site were estimated to result in a fall in the probability of fatal pedestrian crashes (11%), serious injury crashes (8%), and casualty crashes (6%). In addition, reductions in the proportion of vehicles travelling at or above given speeds were found. There was an expected reduction in fatal pedestrian crashes of 17% as vehicles entered the shopping precinct and 15% as they exited, an expected reduction in serious casualty crashes (13% on entry and 12% on exit), and casualty crashes (9% on entry and 8% on exit). Reductions of 20%, 15% and 8% of vehicles travelling at or above 60 km/h, 50 km/h and 40 km/h, respectively were found.

The findings of this evaluation are based on an assumption that speed behaviour of motorists in shopping centre environments elsewhere in Melbourne did not change during the study period. If this assumption is invalid, then the effects of the treatment program are inconclusive and only the unadjusted results can be reported. The authors of this report have *not* been able to identify evidence of a general reduction in speeds in Melbourne and, therefore, believe that the control data may have been affected by other local influences rather than system-wide influences. It was, however, impossible to be definitive about this. In addition, it is acknowledged that the WalkSafe program co-ordinated by VicRoads, Victoria Police, the TAC and local government was implemented in the City of Port Phillip in 2000. This program aims to reduce the incidence and severity of pedestrian crashes in urban areas by combining and co-ordinating the traditional elements of engineering, enforcement and promotions/publicity. Although the campaign on Clarendon Street did not begin until after the surveys were completed, there was an intensive campaign targeted for Carlisle Street. It is possible that local residents and businesses were aware of the promotions and publicity for Carlisle Street and modified their behaviour in some way. Nevertheless, this evaluation highlighted a number of important findings on Clarendon Street:

- If it is accepted that speed behaviour did not change in the Melbourne metropolitan region throughout the study period, this evaluation demonstrated real reductions in vehicle speeds on Clarendon Street as a result of treatment implementation.

- Overall reductions of 7.5 km/h in average vehicle speed throughout the shopping precinct was associated with predicted reductions of 2-3% in fatal pedestrian crashes and of 15% in serious injury pedestrian crashes. The smaller reductions of 1.3 km/h at locations where free-flowing traffic was measured were associated with expected reductions of 11% in fatal pedestrian crashes, 8% in serious injury crashes and 6% in casualty crashes.

- There was only marginal change in speed behaviour after installation of the 50 km/h speed zone, however, larger reductions in average and measured speeds throughout the shopping precinct as a result of installation of all treatments. This supports the suggestion that traditional countermeasures such as reducing speed limits by themselves have limited success in reducing pedestrian casualty rates. An innovative approach that combines a range of countermeasure applications is more likely to be successful in moderating vehicle speeds in areas of high pedestrian activity.

- While travel times increase marginally, considering the large expected reductions in the crash risk of pedestrians, it would seem that the benefits far outweigh the cost of less than one minute to motorists.

- Although the treatments evaluated in this project were not particularly aggressive and that treatment costs were relatively low, significant reductions in vehicle speeds were still found. Any installation of more aggressive countermeasures could be expected to result in larger reductions and, therefore, provide even greater safety benefits for pedestrians.

- It would appear that small gains in speed reduction can lead to dramatic gains in road trauma. The benefits of speed reduction can be related, not only to pedestrian safety, but there are general benefits to other road users including cyclists, motorcyclists and vehicle occupants.

Considering the high safety effects possible for pedestrians for relatively small changes in speed and travel times, this is a potentially important area of countermeasure development to pursue. It would be desirable to evaluate a range of approaches with potential to moderate vehicle speeds. For instance, an evaluation of the effectiveness of more aggressive countermeasures may reveal even greater benefits for pedestrian safety. In addition, there is considerable scope for evaluating these types of treatments in rural cities and towns.

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APPENDIX A

A.1 VEHICLE SPEEDS AND TRAVEL TIMES ON HIGH STREET

As for the vehicle speed data on Clarendon Street, vehicle speeds on High Street were examined in detail. First, average vehicle speeds measured at both locations were combined to assess the overall effect of survey time on average vehicle speeds and proportion of vehicle travelling at excessive speeds. Second, average vehicle speeds were examined at each location, i.e., as vehicles entered and existed the survey site.

A.1.1 Average Speeds and Travel Times

Travel times were collected for vehicles passing through the survey site and data were examined for vehicles that took 3 minutes or less to travel through the survey area. Average speeds calculated from the travel time data are shown in Table A.1.

Table A.1: Average speed of vehicles travelling through the survey site during the three survey times (High Street).

Vehicle Classification	**Average calculated vehicle speed (km/h) Survey 1** *n = 246*	**Average calculated vehicle speed (km/h) Survey 2** *n = 171*	**Average calculated vehicle speed (km/h) Survey 3** *n = 199*
Cars	31.15	30.43	30.46
Vans/4WD	31.43	28.78	29.00
Trucks	29.81	30.36	27.75
Trams	24.60	25.15	24.93
Motorcycles	30.95	44.60	42.70
All Vehicles	**30.97**	**29.72**	**29.83**

Overall, there was no effect of survey time on average vehicle speed. On average, vehicles travelled at approximately 30 km/h through the survey site during all survey times. Only motorcycles travelled significantly faster during the second and third survey times compared with the first survey time, $F(2,2) = 56.44$, $p < 0.05$.

Travel times of all vehicles during the three survey time periods on High Street are shown in Table A.2. Overall, there was no effect of survey time on average travel times. On average, vehicles took 2.3 minutes to travel through the survey site during all survey times. Only motorcycles took less time to travel through the survey site in the second and third survey time periods compared with the first, $F(2,2) = 92.60$, $p < 0.05$.

Table A.2: Average travel times of vehicles (min.) through the survey site during the three survey times (High Street).

Vehicle Classification	**Average travel times (min.) before treatments installed** *n = 246*	**Average travel times (min.) after FIRST treatment installed** *n = 171*	**Average travel times (min.) after ALL treatments installed** *n = 191*
Cars	2.23	2.29	2.28
Vans/4WD	2.24	2.36	2.38
Trucks	2.37	2.28	2.45
Trams	2.73	2.67	2.67
Motorcycles	2.15	1.50	1.60
All Vehicles	**2.25**	**2.33**	**2.32**

A.1.2 Vehicle speed measurements at locations within the survey site

Speed measurements as vehicles entered and exited the survey site were combined and examined (Table A.3).

Table A.3: Average vehicle speeds during the three survey times (High Street).

Vehicle Classification	**Average vehicle speed (km/h) – Survey 1** *n = 3487*	**Average vehicle speeds (km/h) – Survey 2** *n = 3793*	**Average vehicle speeds (km/h) – Survey 3** *n = 1868*
Cars	46.74	45.41	43.51
Vans/4WD	45.54	43.49	41.25
Trucks	42.82	40.50	41.89
Trams	33.19	35.57	30.90
Motorcycles	51.64	47.56	46.71
All Vehicles	**46.17**	**44.72**	**43.03**

Surprisingly, at this site, an overall effect of survey time was found on vehicle speeds, even though no treatments had been installed, $F(2,9145) = 66.59$, $p < 0.001$. On average, vehicle speeds decreased significantly by 1.45 km/h from the first to the second survey time, $p < 0.001$, and decreased by another 1.69 km/h in the last survey time period, p <

0.001. In total, a reduction of 3.14 km/h between the first and last survey time periods was found, $p < 0.001$.

Vehicle speeds during the third survey time period were substantially lower than during previous survey time periods. This finding may be explained by a number of inconsistencies in traffic flow and data collection during this time. There was a substantial amount of traffic congestion after a crash involving a tram, particularly at Location 2 (as vehicles exited the survey site), a short period where no data was collected due to technical problems, and possible contamination of the data due to temporary Police presence and consequent detection of speed measurements.

Significant effects of survey time were found for cars, vans/4WD and trams, $F(2,7262) = 58.26$, $p < 0.001$, $F(2,1253) = 14.43$, $p < 0.001$, and $F(2,157) = 3.70$, $p < 0.05$, respectively. Average vehicle speeds of cars decreased significantly by 1.33 km/h from the first to the second survey time, $p < 0.001$ and further by 1.9 km/h in the last survey time, p-values < 0.001. A total reduction of 3.23 km/h was found for cars. Similarly, a total reduction of 4.29 km/h was found for average vehicle speeds of vans/4WDs from the first survey time to the last, $p < 0.001$, with a reduction of 2.05 km/h in the second survey time compared to the first, $p < 0.01$, and a further reduction of 2.24 km/h in the last survey time, $p < 0.05$. While average speeds of trams were lower overall compared to other vehicle groups and increased slightly but not significantly so from the first to the second survey time, a reduction of 2.29 km/h was found from the second survey time to the last, $p < 0.05$. Despite slight reductions in average vehicle speeds of trucks and motorcycles, no overall effect of survey time was found (possibly due to small sample sizes in these groups).

A comparison of the proportion of vehicles travelling at high speeds at each survey time was made at High Street. This is shown in Figure A.1.

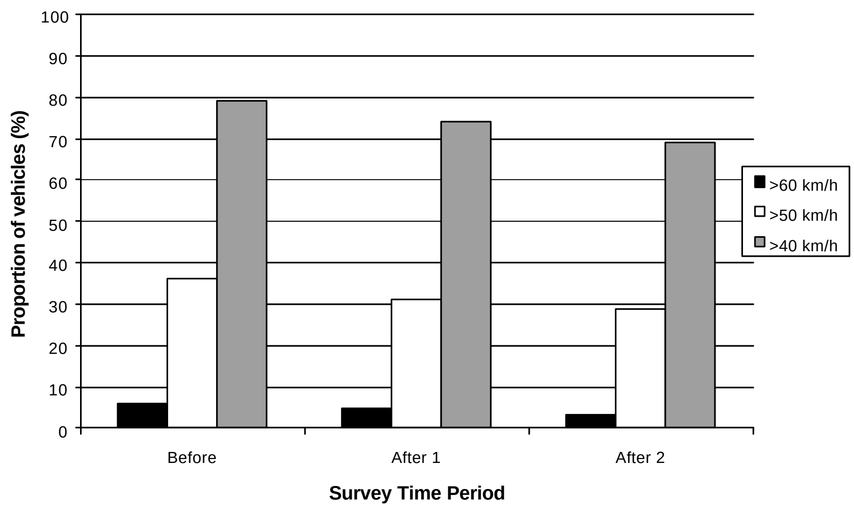

Figure A.1: Proportion of vehicles travelling over 60 km/h, over 50 km/h and over 40 km/h during the three survey times (High Street).

The proportion of vehicles travelling at or above 60 km/h, 50 km/h and 40 km/h here were similar to that found on Clarendon Street at each survey time period. For those vehicles travelling 60 km/h or over, almost 6 percent travelled at these speeds during the first survey time, but this proportion decreased to 5 percent during the second survey time period, $p < 0.05$. Although a further reduction to 3 percent of speeding vehicles was found during the last survey time period, this was not a significant reduction. Similarly, the proportion of vehicles travelling at or above 50 km/h decreased from 36 percent during the first survey time to 31 percent during the second survey, $p < 0.05$, and further to 29 percent during the third survey time period, p-values < 0.05. The majority of vehicles travelled at speeds at or above 40 km/h during all survey time periods, but, again, an effect of survey time period was found on the proportion of vehicles travelling at these speeds. Almost 80 percent of vehicles travelled at or faster that 40 km/h during the first survey time period, but this decreased to 74 percent during the second survey time period, $p < 0.001$, and further to 69 percent during the third survey time period, p-values < 0.05. Comparisons of raw numbers have not been made here due to the lack of data included from the second measurement location in the last survey time period.

A.1.2.1 Speeds as vehicles entered the survey site

To gain a better understanding of traffic movements at specific locations on High Street, separate analyses of vehicle speed data were made. In this section, average vehicle speeds as vehicles entered the survey site are examined. Table A.4 provides a summary of average measured vehicle speeds for all vehicle groups as they entered the survey site on High Street during each survey time period.

Table A.4: Average vehicle speeds as vehicles entered the survey site during the three survey times (High Street).

Vehicle Classification	**Average vehicle speed (km/h) – Survey 1** *n = 1988*	**Average vehicle speeds (km/h) – Survey 2** *n = 1868*	**Average vehicle speeds (km/h) – Survey 3** *n = 1868*
Cars	46.34	45.16	43.51
Vans/4WD	44.92	43.42	41.25
Trucks	42.12	40.17	41.89
Trams	28.72	33.06	30.90
Motorcycles	58.20	47.00	46.71
All Vehicles	**45.69**	**44.48**	**43.03**

Surprisingly, at this control site, vehicle speeds as vehicles entered the survey site decreased across survey periods even though there were no treatments installed here, $F(2,5721) = 33.74$, $p < 0.001$. On average, vehicle speeds measured in the last survey were 1.45 km/h lower than the previous survey, $p < 0.001$ and 2.66 km/h lower than measured in the first survey, $p < 0.001$. This trend was evident for cars and vans/4WDs. Cars travelled more slowly as time progressed, $F(2,4614) = 32.43$, $p < 0.001$, with an average reduction of 2.83 km/h from the first to the last survey, $p < 0.001$. Vans/4WDs also travelled more slowly as time progressed, $F(2,720) = 6.84$, $p < 0.01$, with a larger reduction in vehicle speed of 3.67 km/h, $p < 0.01$. Average vehicle speeds of trucks did not differ across survey times, while average speeds of trams increased over time (this difference, however, was not significant due to small sample sizes). Likewise, while average vehicle speeds of motorcycles decreased 11.5 km/h, this reduction was not significant because of small sample sizes.

As for the overall analysis of vehicle speeds, the proportion of vehicles travelling at or above 60 km/h, 50 km/h and 40 km/h was examined. Figure A.2 shows the proportions of vehicles travelling at these speeds as they entered the survey site.

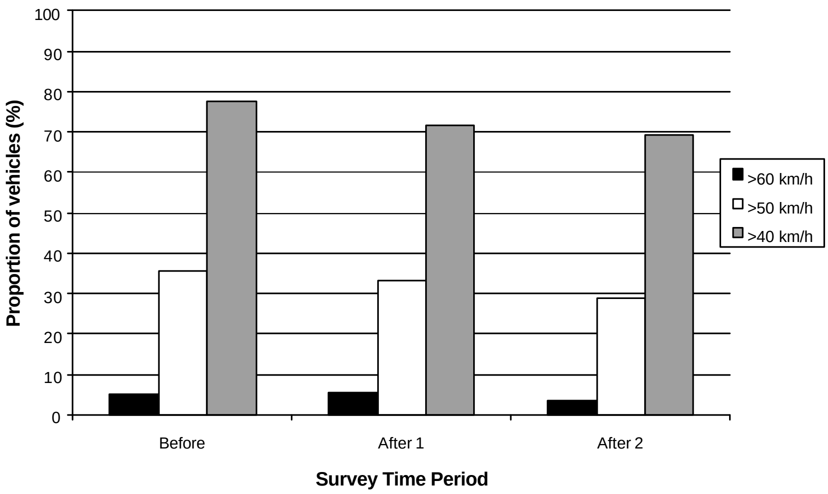

Figure A.2: Proportion of vehicles travelling over 60 km/h, over 50 km/h and over 40 km/h during the three survey times as they entered the survey site (High Street).

As vehicles entered the survey site, only a small proportion travelled at 60 km/h or above. This decreased from around 5 percent during the first two surveys to just over 3 percent during the last survey time, p-values < 0.001. A greater decrease in proportion of vehicles travelling at these speeds was noted as vehicles left the survey site. During the first survey time, close to 7 percent of vehicles travelled at high speeds. This proportion decreased significantly to 4 percent in the first-after survey time, $p < 0.001$, and decreased further to 2 percent in the last survey time, p-values < 0.001.

A similar trend was noted for vehicles travelling 50 km/h and over (Figure 3.5). Approximately one-third of all vehicles travelled at 50 km/h or over as they entered the survey site during the before and first after surveys. This proportion decreased to 29 percent during the last survey time, $p < 0.001$. The proportion of vehicles travelling 50 km/h or over as they left the survey site, decreased from 37 percent in the before survey time to 29 percent during the first after survey time, $p < 0.001$, and further to 17 percent in the last survey, p-values < 0.001.

The majority of vehicles in the before survey time (78 percent) travelled at 40 km/h or over as they entered the survey site. This proportion decreased to 72 percent during the first after survey time, $p < 0.001$, and to 69 percent during the last survey time, $p < 0.001$.

A.1.2.2 Speeds as vehicles exited the survey site

Vehicle speeds at Location 2 (as they exited the survey site) on High Street are shown in Table A.4. There was an overall effect of survey time period on vehicle speeds at this location, $F(2,5127) = 453.09$, $p < 0.001$. Average vehicle speeds decreased significantly by 1.82 km/h from the first to the second survey, $p < 0.001$, and decreased by a further 8.27 km/h in the last survey time period, p-values < 0.001.

Table A.4: Average vehicle speeds as vehicles entered the survey site during the three survey times (High Street).

Vehicle Classification	**Average vehicle speed (km/h) – Survey 1** *n = 1988*	**Average vehicle speeds (km/h) – Survey 2** *n = 1868*	**Average vehicle speeds (km/h) – Survey 3** *n = 1868*
Cars	47.29	45.67	36.94
Vans/4WD	46.29	43.56	37.29
Trucks	43.90	40.78	33.73
Trams	37.66	37.86	32.93
Motorcycles	48.00	47.83	21.22
All Vehicles	**46.80**	**44.95**	**36.68**