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Accident Research Centre

BENEFIT/COST ANALYSIS OF ROAD TRAUMA COUNTERMEASURES: RURAL ROAD AND TRAFFIC ENGINEERING PROGRAMS

A report for

Monash University Accident Research Centre

by

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Abstract:

This report represents the results of a study which examined the safety effect of providing sealed shoulders, overtaking lanes, and edge lining on rural highways in Victoria. For shoulder sealing, a statistically significant reduction in casualty accident frequencies was found, equivalent to a 43 per cent reduction on a per vehicle kilometre basis. Comparing economic benefits and costs, a benefit/cost ratio was determined of 2.9 x (AADT in thousands), where AADT is Annual Average Daily Traffic. The study was unable to find any statistically significant effect of overtaking lanes or edge lining on accidents.

Key Words:

Benefit/costs, countermeasures,
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SUMMARY

This report presents the results of a MUARC project which sought to determine the safety effect of three rural road programs, namely sealed shoulders, overtaking lanes, and edge lining.

Data were obtained on the location, condition and cost of recently installed projects in each of these activities on two lane-two way roads (i.e. one lane in each direction) in Victoria. Accident data were obtained for these sites, and a before and after comparison, using control sites, was undertaken.

Most **shoulder sealing** programs examined involved a low cost sealing of an existing shoulder, typically involving an interim bituminous sealing treatment, followed a year or so later with a reseal in conjunction with a pavement reseal. The shoulder width is typically between 600 and 1200 mm, with 600 or 800 mm being the most common. The results for this type of treatment indicate that:

- shoulder sealing was associated with a statistically significant reduction in casualty accident frequencies at sites where it was installed on 2-lane 2-way rural highways in Victoria,
- casualty accidents were reduced by 43 per cent, on a per vehicle kilometre basis, at such sites,
- this is equivalent to a reduction of 0.073 casualty accidents per million vehicle kilometres,
- the breakeven point (the point at which it is economically worthwhile) to install sealed shoulders is at a traffic flow of about 350 veh/d,
- the benefit/cost ratio of shoulder sealing can be calculated from:

$$\text{benefit/cost ratio} = 2.9 \times (\text{AADT in thousands})$$

where AADT is Annual Average Daily Traffic

- for example, if the AADT is 4,000 veh/d, a benefit/cost ration of about 11.6:1 could be expected,
- the main accident reductions are in rear end, overtaking - out of control, off carriageway to left, and off carriageway to right into fixed object crashes.

The study was unable to find any statistically significant effect of **overtaking lanes** or **edge lining** on accidents. In the former case, this was mainly because of a small number of suitable sites and a short "after" period. In the latter case it was again because of a shortage of sites, and also the absence of a suitable control situation. More work in these areas is recommended.

1. INTRODUCTION

1.1 BACKGROUND

In 1991, the Monash University Accident Research Centre (MUARC) conducted a project with the aim of estimating the economic benefits and costs of road trauma countermeasures which could be introduced or accelerated in Victoria.

That project identified a number of opportunities, including several which involved road and traffic programs on rural highways. Foremost amongst these were the provision of sealed shoulders, while other examples included the construction of overtaking lanes and improved delineation.

As a consequence of this earlier study, it was decided to undertake a further research study with the aim of establishing the economic benefits and costs of these measures in Victoria.

The need for this further study arose from the nature of the work undertaken in the earlier study. That study took a very "broad brush" approach, and examined a large number of road trauma countermeasures; there was very limited scope for original research. In the road and traffic area in particular, the effectiveness measures were based largely on results published in the literature. While these results, as mentioned above, were encouraging it was nevertheless considered important that they be examined further with specific reference to Victorian experience in recent years.

1.2 ROAD AND TRAFFIC FACTORS IN RURAL ROAD SAFETY

It is generally considered that the road traffic system comprises three elements, the human, the vehicle and the road. Crashes and other problems are the results of breakdowns in the system, either of one of these elements or (more commonly) at the interface between them.

Various studies have examined the contribution of the respective elements, and in general have shown that road and traffic factors contribute to a significant proportion of crashes. In her classic work in the UK, Sabey (1980) considered that they were the sole cause of 3 per cent of crashes, and contributed to a further 25 per cent. A study in Adelaide (McLean and Robinson, 1979) concluded that road layout (design and construction) was "definitely" relevant in 14 per cent of crashes and "possibly" relevant in a further 10 per cent. Traffic control (signals, signs, geometry, markings, etc) were "definitely" relevant in 20 per cent of cases and "possibly" relevant to a further 17 per cent. In their recent study of fatal crashes involving heavy vehicles on NSW highways, Sweatman et al (1990) concluded that poor road alignment was associated with 48 per cent of crashes, a roadside object with 33 per cent, a road shoulder with 24 per cent, and poor delineation with 21 per cent.

In Victoria, some 20 per cent of casualty crashes and 33 per cent of fatal crashes occur on the open road in rural areas (Armour and Cinquegrana, 1990). The most common type of crash is one involving a single vehicle leaving the road and hitting a fixed object. A detailed investigation of rural single vehicle crashes conducted by Armour and Cinquegrana (op cit, p 89) concluded that roadside objects were considered to have affected the severity of 27 per

cent of crashes and the presence or condition of unsealed shoulders was considered to have contributed to 30 per cent of crashes. Narrow lanes, curves, unsealed shoulders, and low skid resistance pavements were shown to have been associated with increased crash rates. By comparison, driver fatigue was considered to have been a factor in 33 per cent of crashes, and excessive or inappropriate speed in 25 per cent. (More than one factor could, of course, have been present in any one crash; detailed analysis of the results of this survey are presented in Armour, Carter, Cinquegrana and Griffith, 1989.)

These results serve to highlight the significance of the road trauma problem on rural roads, and the potential role for good traffic engineering and road design to contribute towards a reduction of the problem.

1.3 THE PRESENT STUDY

As noted above, the present study aims to establish the economic benefits and costs of three categories of rural road safety measure in Victoria, namely sealed shoulders, overtaking lanes, and edge lining. Originally, it was proposed to consider only sealed shoulders, but in discussion with Vicroads personnel about methodology and data sources it appeared that information about the other two measures could be collected simultaneously with little or no extra effort, so it was decided to include these within the ambit of the project.

In essence, the study involved four stages:

- A review of previous studies was undertaken, with the aim of guiding the work into promising areas as well as providing a basis of comparison of results.
- Field studies were conducted in Vicroads rural regions to establish the nature, extent, location and cost of relevant works. Data were sought for rural Victorian State Highways for the period July 1983 to June 1991. Control sections were identified for comparison purposes.
- Crash data for the treated sections and the control sections were extracted from the Victorian Road Accident Data Base.
- The data were analysed with the aim of determining both the effectiveness (in terms of the effects on crash frequency and crash rates) and the economic return (in terms of comparisons of benefits and costs) of the three types of treatment.

The study output includes:

- information on the safety effectiveness of the treatments (sealed shoulders, edge lining, and overtaking lanes) on rural highways in Victoria; and
- an economic appraisal of the returns from investment in such programs.

2. PREVIOUS STUDIES

2.1 SEALED SHOULDERS

A road shoulder serves a number of functions, including (Armour and McLean, 1983):

- a structural element of the total pavement, providing lateral support to the traffic lanes,
- allow construction-related edge effects to be located away from the trafficked section of the pavement,
- allow drainage of water away from the trafficked section of the pavement,
- increase the "effective" width of the traffic lanes, and so increase lateral clearances,
- provide a recovery area for errant vehicles,
- provide space for slower vehicles to allow faster vehicles to overtake,
- allow moving vehicles to overtake vehicles disabled in the traffic lane,
- allow moving vehicles to overtake vehicles turning right from the traffic lane, and
- allow a stopped vehicle to stand clear of the traffic lanes.

It can be seen that this is a mix of structural, operational and safety purposes. Furthermore, each of these may be affected by shoulder width, design, and type. For the purposes of this study, our main interest is in the safety effects of shoulder type, in particular the effects of shoulder sealing. However, there is an extensive literature on the other aspects (see for example Armour and McLean, 1983; Transportation Research Board, 1987a,b; Zegeer, Deen and Mayes, 1981; Carney, 1986; Zegeer and Deacon, 1987; Zegeer et al, 1988).

In a review of the then-available literature, Armour and McLean (1983) concluded that:

- paved shoulders have better safety records than unpaved shoulders for a wide range of traffic volumes and shoulder widths,
- the addition of paved shoulders to roads without shoulders has good potential for safety benefits, and
- the accident savings from improved shoulder design mainly result from reductions in run-off-the-road and opposite-direction crashes.

The provision of shoulders does not appear to reduce rear-end or stationary vehicle crashes.

This leads to the conclusion that the "stand clear" function of shoulders is not producing safety benefits; this may reflect the fact shoulder seals have insufficient width to adequately provide this aspect, for which a shoulder width of, say, 2.4 m is required.

The primary effect of sealed shoulders is to provide a greater recovery and manoeuvring space (National Association of Australian State Road Authorities, 1988, p 28). They also reduce the potential for vehicles which stray from the sealed pavement to lose control in loose shoulder material (Burns, et al, 1984; Catchpole, 1990, p 206). Armour (1984a) found this to be a contributing factor in over 50 per cent of fatal run-off-the-road crashes in New South Wales, while Catchpole (1990) concluded that at least 19 per cent of *single vehicle* crashes at sites with sealed pavements and unsealed shoulders involved a driver losing control of the vehicle in the shoulder.

In a recent major study of rural single vehicle crashes in Victoria, Armour and Cinquegrana (1990, p 85) found that the presence or condition of unsealed shoulders was considered to have contributed to 33 per cent of the crashes investigated. The major conclusion of their study was that specific funding be made available for a program of shoulder sealing on rural highways (op cit, p 89); trial applications of tactile thermoplastic edge lining were also recommended.

A number of recent Australian and American studies have shown the safety benefits of sealed shoulders:

- Armour (1984b, p 60) in a comprehensive review of Australian conditions found that roads with sealed shoulders had a fatal crash rate 60-70 per cent lower than roads with unsealed shoulders. There was some evidence that the benefits were greater on road sections with curves or grades; the ratio of crash rates for roads with unsealed and sealed shoulders was about 3:1 for straight, flat road sections and 4:1 for grades or curves.
- Pak-Poy and Kneebone (1988, p 72) used Armour's results to estimate the benefit:cost ratio for sealing shoulders under different circumstances. They assumed a 2 m shoulder width, a 5-year life, and a (then) present value cost for construction and maintenance of \$25,000 per km. They showed that for all combinations of road geometry (straight, grades, curves) and for traffic flows as low as 1000 veh/d, sealed shoulders produced benefit:cost ratios in excess of 2:1.
- A study in Texas (Rogness, Fambro and Turner, 1982; Turner, Fambro and Rogness, 1981) found that the addition of shoulders to a 2 lane rural road reduced the total number of crashes. At low volumes (AADT 3000 veh/d) there were significantly fewer single vehicle (run-off-the-road and hit-fixed-object) crashes, indicating the effectiveness of the sealed shoulder in providing recovery space. At moderate volumes (3000-5000 veh/d) the addition of sealed shoulders reduced both the total number of crashes and their severity, suggesting that the shoulders were being used for both crash avoidance and recovery. At higher volumes (5000-7000 veh/d), again crash frequency was reduced, but there was increased severity of those that did occur; this was

attributed to "increased operating speeds after the shoulder was added to roadways in this volume category" (Rogness, Fambro and Turner, 1982). The study concluded that full-width shoulders (i.e. a width approximating that of the through lane) on 2-lane roads were effective in reducing crashes, but were probably not cost-effective for roads carrying less than 3000 veh/d.

- A detailed review of the safety effects of road cross-section design for 2-lane roads in the US (Zegeer, et al, 1987; 1988) included consideration of the effects of "stabilised" shoulders. This study was based on a large sample of roads (1801 rural road sections covering 7700 km) and detailed equations incorporating a number of traffic and roadway variables were developed. The results indicated that sealed shoulders were only marginally better than unsealed shoulders for similar road and traffic conditions. (For example, a road carrying 3000 veh/d in rolling terrain with a moderate roadside hazard ranking was about 8 per cent safer with 1.8 m sealed shoulders compared with 1.8 m unsealed shoulders.)
- A Texas study (Woods, Rollins and Crane, 1989) examined the safety effects of various shoulder configurations and concluded that while shoulder width had no statistically significant effect, "a significant difference in accident rates for driveable and non-driveable shoulders were present ... these results were consistent for total, fatal, injury and for all AADT levels with the exception of instances where sample sizes were too small to accurately test the relevant hypothesis" (op cit, p 4). The study concluded that sealed shoulders (1.8 - 3.0 m wide) were cost-effective in safety terms for volumes in excess of 1500 veh/d on rural 2-lane roads.
- In a review of US experience, Skinner (1986) suggested that run-off-the-road and opposite-direction crashes could be reduced by 5-15 per cent with sealed shoulders, depending primarily on lane width. The greatest benefit occurred on roads with narrow lanes (2.4m - 2.7m).
- A major review of the safety effects of road geometric design was conducted by the Transportation Research Board (1987a). It concluded that sealed shoulders on 2-lane rural highways were cost-effective for traffic volumes in excess of 2000 veh/d.

In summary, the literature shows that there are clear safety benefits from sealed shoulders on 2-lane rural roads. The benefit results mainly from reductions in single vehicle run-off-the-road crashes (which may be due to reducing or eliminating loss of control when a vehicle strays onto an unsealed shoulder, and also increased recovery space) and multi-vehicle opposite-direction crashes (which may be due to the above, together with increased avoidance space). The literature indicates that sealed shoulders are cost-effective at quite low traffic volumes; an Australian study (Pak-Poy and Kneebone, 1988) suggested that they were cost-effective at volumes as low as 1000 veh/d, and even American data suggests that the practice is cost-effective for volumes in the range 1500-3000 veh/d.

Although not directly related to this study, it is relevant to point out that the Australian Road

Research Board has also conducted research into shoulder usage (Charlesworth, 1985). This research showed, inter alia, that less than one-quarter of vehicles stopped on shoulders were there as a result of an emergency, i.e. most shoulder usage was discretionary. This suggested that the provision of continuous full-width sealed shoulders may not be necessary, and that reduced width shoulders may provide high safety benefits without the additional earthworks and pavement cost of wider shoulders.

In addition to safety benefits, sealed shoulders may have an effect on shoulder maintenance costs, although the evidence is ambivalent. Eakins (1980, p 98) claimed that there would be reduced maintenance costs since "sealing of shoulders increases the strength of pavement materials by protecting them from moisture ingress. Revelling by wind currents from passing vehicles is also eliminated." In a survey of Australian shoulder design practice, Armour (1986b) found that there was virtual unanimity that sealed shoulders reduced maintenance costs, with about two-thirds of respondents reporting "substantial" maintenance cost reductions. Although the data are very old, Eakins (1980, p 98) suggested that reductions of the order of \$600 per km per year might be expected.

2.2 OVERTAKING

Armour (1984a) found that overtaking is involved in about 10 per cent of rural casualty crashes in Australia. This is much higher than the 3-4 per cent of such crashes in the US (Knasbasis, 1986), probably reflecting the much greater length and usage of multi-lane roads in that country.

On a 2-lane rural road, overtaking vehicles must overtake slower vehicles by entering the opposing lane. Therefore an overtaking opportunity requires a sufficiently large gap in the on-coming traffic for an overtaking manoeuvre, plus the distance travelled by that vehicle, plus a safety margin (Hoban, 1987). The road alignment (horizontal and vertical geometry) must allow sight distances of this magnitude if overtaking is to occur. However, as traffic volumes increase, opposing traffic will limit overtaking opportunities.

In these circumstances, overtaking lanes can be very effective in improving traffic operations by breaking up bunches and reducing delays caused by inadequate overtaking opportunities over substantial lengths of road. In moderate traffic (say 4,000 to 8,000 vehicles per day), judiciously placed overtaking lanes comprising around 10 per cent of the length of a road can provide much of the benefit of full duplication at a fraction of the cost (Hoban, 1982, 1989).

Several studies have assessed the safety effects of overtaking lanes, mostly in the United States:

- A Californian study in the 1970's reported by Kaub and Berg (1988) examined 19 projects involving the conversion of a 2-lane rural highway to a 3-lane configuration incorporating an overtaking lane. Before and after comparisons indicated that fatal crashes were reduced by about 60 per cent, personal injury crashes by about 20 per cent, and property damage crashes by about 20 per cent. Commenting on the same study, Harwood, Hoban and Warren (1988) noted its conclusion that the overall crash rate reduction in level or rolling terrain was 42 per cent.

- A study of 66 sites with overtaking lanes across 12 US States found that such sites had a 28 per cent lower overall crash rate, and a 41 per cent lower fatal crash rate than untreated 2-lane highways, but that these differences were not statistically significant (Harwood, St John and Warren, 1985).
- The same study also undertook a matched-pair comparison of 13 sites with overtaking lanes and 13 comparable untreated sites. In 11 cases, the treated sites had a lower crash rate, and the total crash rate for the treated sites was, on average, 38 per cent less, and this difference was statistically significant at the 95 per cent confidence level. Treated sites had a non-statistically significant 29 per cent lower fatal crash rate.
- Based upon the aforementioned Californian study, Kaub and Berg (1988) estimated if overtaking lanes were constructed on all US 2-lane primary highways, the total cost (based upon prescribed cost of a fatal, injury or property damage crash) of overtaking-related crashes on such highways would be reduced by an estimated 38 per cent.
- In a review of low cost operational and safety improvements for 2-lane roads conducted for the US Federal Highway Administration, Harwood and Hoban (1986) advised that, relative to a conventional 2-lane highway, a section of road with an overtaking lane would be expected to have a 25 per cent lower total crash rate and a 30 per cent lower fatal and injury crash rate.

These results suggest that overtaking lanes can show significant safety benefits, as well as the operational benefits for which they are constructed. If the Kaub and Berg estimate reported above for the US is accepted (i.e. that the construction of overtaking lanes on all 2-lane highways would reduce the total cost of overtaking crashes by 38 per cent) and combined with the earlier observation that overtaking is involved in about 10 per cent of Australian rural casualty crashes, then it would follow that the cost of rural casualty crashes could be reduced by about 4 per cent as a result of a comprehensive program of overtaking lane construction. These benefits are of course additional to any travel time or vehicle operating cost savings which are produced, and which are used as the economic justification of overtaking lane construction (Hoban, 1982).

2.3 EDGE LINING

Roadway delineation is used to:

- control the placements and movements of vehicles by supplying visual information to the driver that identifies the safe and legal limits of the travelled way,
- regulate the direction of travel, lane changing and overtaking,
- mark lanes or zones where manoeuvres such as turns or parking are permitted, required or restricted,

- improves lane discipline, particularly during night time driving, and
- aid in identifying potentially hazardous situations such as obstacles and pedestrian crossings (Freedman, et al, 1988, p 1).

Delineation is thus of critical importance to the safe and efficient operation of the road system. Most of the information which the driver uses to control a vehicle is visual. Good delineation assists the driver to locate the vehicle on the roadway and to make path selection and control decisions.

Delineation may be considered as (Good and Baxter, 1985, 1986; Johnston, 1982):

- short range delineation, which enables the driver to keep the vehicle within the traffic lane, and
- long range delineation, which assists the driver to plan the immediate forward route driving task, in terms of speed and course selection.

The importance of good delineation is likely to increase in the years ahead as the driving population ages. Older drivers have a reduced visual capability and hence rely to a greater extent on correct delineation of the road ahead (Transportation Research Board, 1988).

Delineation may be especially important on roads with a high proportion of truck traffic. Sweatman et al (1990) found that in 21 per cent of fatal heavy vehicle crashes on the Hume and Pacific Highways in NSW, poor delineation was considered to be a factor. Lumenfeld (1988) has noted that most reflective devices are designed essentially for car headlight height and car driver eye height, and as a result "the advantage that a driver of a large truck has in forward vision during the day becomes a disadvantage at night. Truck drivers who need increased sight distance actually have less."

Delineation devices include (Sanderson and Fildes, 1984; Hoque and Sanderson, 1988):

- guide posts and post mounted delineators (PMDs),
- centre lines and edge lines,
- raised reflective pavement markers (RRPMs),
- chevrons,
- bridge width markers,
- electronic signing, and
- novel delineation devices.

For the present study, the only delineation device considered was solid edge lining.

Edge lines are used to delineate the outer edge of the lane for the following purposes (Pak Poy and Kneebone, 1988, p 24):

- to make the driving task more comfortable and simplify the driving task,
- to reduce the crash rate, and

- to reduce pavement edge wear.

Edge lines have been shown to give a marginal advantage in driving performance (Johnston, 1982, 1983). Schwab and Cappelle (1980) have noted that "delineation of the outside edge of the travelled lane is highly desirable, especially for roads wider than 6 m ... there is substantial evidence that delineation provides important guidance information to motorists, especially when visibility decreases due to adverse weather or night time conditions." They also noted that edge lines are as effective, if not more so, on straight alignments as on curves. Triggs (1980) found that their main advantage is in short-term lane positioning; this is consistent with the findings of Johnston (1982) who found that the variance in lateral clearance was reduced following the installation of edge lines.

Pavement edge delineation has received considerable attention because of the high percentage of rural road crashes involving a single vehicle running off the road. Armour (1986a) for example found that 55 per cent of serious casualty crashes on Victorian rural roads in the period 1977-84 were of this type. Pak-Poy and Kneebone (1988, p 24) have noted that in rural areas in Victoria in the late 1970s, 76 per cent of night time alcohol related crashes were run-off-the-road type (especially on curves), highlighting the need to consider the effects of delineation on alcohol-impaired drivers as well as sober drivers.

Various studies have demonstrated the safety benefits of edge lines:

- Moses (1986) reported that following the installation of wide edge lines on rural highways in Western Australia, total crashes on those roads fell by 8 per cent, but out of control single vehicle crashes fell by 34 per cent.
- Jackson (1981) reported reductions in total crashes of between 13 and 30 per cent, and reductions in night time crashes of between 37 and 42 per cent following the installation of edge lines at sites in Britain.
- Catchpole (1990, p 204) in a study of the factors associated with fatal crashes in Australia found that single vehicle crashes were under-represented but multi-vehicle crashes were over-represented on rural roads where edge lines were present.
- Nairn (1987, p 47) suggests that crashes may be reduced by 15 per cent (straight roads) to 45 per cent (curves) following the installation of edge lines.
- On the other hand, Willis, Scott and Barnes (1984) in an English study were unable to conclude whether the installation of edge lines had any effect, although they acknowledged that other studies had shown a positive effect on crash reduction.

Edge lines are typically 100 mm wide, although both 150 mm and 200 mm edge lines have been used. It appears that the wider line may have safety advantages. A US study in Washington State showed reductions of 19 per cent for all crashes and 32 per cent for injury crashes with 200 mm edge lines compared with the standard 100 mm installation. Studies by Nedas, Belcar and Macy (1982) and Cottrell (1987) have shown that the 200 mm edge line had a positive effect on driver performance on curves.

As noted above, edge lines may also be installed to reduce shoulder and pavement maintenance costs; since edge lines tend to reduce the incidence of vehicles leaving the paved surface, they reduce wear at the edge of the sealed pavement and on the shoulder itself. Armour (1986b) in a survey of shoulder design practice on Australian roads found that 49 per cent of respondents who used edge lines on unsealed shoulders considered that the edge lines reduced maintenance costs.

3. STUDY METHODOLOGY

3.1 INTRODUCTION

As noted in Section 1, the objective of this study was to attempt to establish the economic benefits and costs of three categories of rural road safety measures in Victoria, namely sealed shoulders, overtaking lanes and edge lining. The emphasis was on sealed shoulders, and the other two categories were included only because it was seen that the data to analyse these could be collected simultaneously and at little extra effort.

In essence therefore, the study aimed to firstly reconcile accident data and road condition data, and then assess whether changes in specified road conditions were associated with accident reductions on the road sections treated.

The method used to undertake this work is reported in this Section. Results are presented in Section 4.

3.2 INITIAL DISCUSSIONS

The parameters and limits of the study were established after detailed discussions with Vicroads personnel. These discussions established that road information of the sort required would necessitate visits to Regional Offices of Vicroads. The projects to be investigated are under Regional control, and information about the extent of such works is not collated at Vicroads' Head Office.

These discussions also established that accident information would be available from the Victorian Road Accident Data Base in the form and detail required, although it may be necessary in some cases to examine the original Police accident report form (held on microfiche) to establish the exact location of some crashes.

It was also established that information on traffic flows on rural roads is kept by Vicroads. This information was subsequently obtained, and an estimate of the 1992 AADT at each shoulder sealing site and overtaking lane site was obtained.

As a result of these discussions, the following parameters were established for the study:

- The study would be confined to State Highways, partly because most of the projects of interest were on these routes, and partly because collecting data on other roads would require visits to Local Government offices.
- The delineation aspect would be limited to edge lining, as there was some hope that information on this type of work may be available, whereas information on the installation of other delineation devices would be either unavailable or very difficult to establish.
- Accident data would be limited to the period from 1983, since the accident

data base changed at that date.

3.3 REGIONAL VISITS

Following the initial discussions referred to in Section 3.2, the relevant Vicroads Regional Managers were contacted by Vicroads' Director - Road Safety, their cooperation in the Study invited, and were told to expect a visit from the Principal Researcher. Consequently, Operations Managers were contacted at the following offices:

- North-West Metropolitan
- South-East Metropolitan
- Traralgon
- Benalla
- Bendigo
- Ballarat
- Horsham
- Geelong

Although the records kept and the construction practices varied a little from Region to Region, the following discussion describes both the data sources and the information obtained.

Shoulder Sealing

There has been an active program of shoulder sealing on the busier State Highways over recent years. Practice varies a little, but typically the work is undertaken as part of pavement resealing activities. A common practice is to "tickle up" the shoulder (i.e. routine grading, perhaps with additional material and/or cement stabilisation) and apply an interim treatment primer seal or prime and seal. This work is undertaken a year or so in advance of scheduled pavement resealing, and when the latter occurs, a full width (i.e. pavement plus shoulder) seal is applied.

A typical configuration might be to have a 7.4 metre pavement, and to seal 0.6 - 0.8 m on each side to give a 8.6 or 9.0 m pavement. Edge lines would be painted to give either a 3.7 m lane (i.e. lined at the edge of the full depth pavement) or a 3.5 m lane (i.e. attempt to keep traffic away from the thinner shoulder).

Information about shoulder sealing activities was readily available in most Regions from the Bituminous Sealing Records. These show, in pictorial fashion, the sealing activities along each highway, and detail the type of work (e.g. primer seal, reseal, interim treatment seal, prime only, etc), width and chainages. In most cases, dates are for the financial year in which the work was done.

This information was collated and transferred to a record sheet.

Overtaking Lanes

There has been an extensive program of providing overtaking lanes on 2-lane rural highways (i.e. one lane in each direction) in Victoria in recent years. Typically these are quite short in length - perhaps 1 km - providing overtaking opportunities in one direction only. In a few cases, they are provided in pairs, with contiguous lanes providing overtaking in opposite directions.

Information about these lanes was readily available, since, as a major item on a Region's works program, they were identifiable in works and budget records.

As before, this information was extracted and transferred onto a record sheet.

Edge lining

Unfortunately, it was not possible to obtain comprehensive records about new edge lining. Although both the Regional Offices and the Roadmarking Operations Office in Melbourne had records of works undertaken, it was not possible to identify whether this was *new* work, i.e. installation of edge lines where none existed previously.

Therefore, the only edge lining work considered in this study was for highways where the Operations Manager or staff could recall that the work was a new installation. Three highways were thus identified - the Ouyen Highway, the Sturt Highway, and the Calder Alternate Highway (the full length in each case).

Costs

Although actual costs will vary somewhat from site to site, for evaluation purposes in the context of the present study, the following cost estimates were adopted:

Shoulder sealing: \$1.00 per m² for shoulder preparation, \$2.00 per m² for interim seal, and \$1.50 per m² for reseal. These costs include preparation, materials and labour. They make no allowance for any earthworks or culvert works, etc, but these are not relevant to the present study, which is concerned only with sealing of existing shoulders.

Overtaking lanes: information obtained from work records kept in the Regions.

Edge lining: Although the cost of edge lining varies with the plant used, a typical figure is \$175 per line km (i.e. \$350 per km for an edge line on both sides).

Regional Operations Managers were also asked about the effect of shoulder sealing on subsequent maintenance. In general, all reported a positive effect on maintenance. One suggested that costs were reduced by about 25 per cent, as the interval between grader passes could be increased from about 4 weeks to 5-6 weeks. In general however, most reported that they were not using fewer resources of personnel or plant, but that they were able to be deployed more effectively.

For the purposes of evaluation in this report therefore, no allowance was made for any maintenance cost savings associated with shoulder sealing.

3.4 SITE VISITS

Although much information could be obtained in the various Regional Offices, it was necessary to actually visit the site of each project to establish what work had actually been undertaken. This was particularly so with shoulder sealing, as the bituminous sealing records merely recorded the width of the seal, not its final configuration. On the basis of the site visits, about half of all candidate shoulder sealing sites were eliminated because the work did not involve a sealed shoulder; the work undertaken may have been a third lane as part of an intersection treatment, a wide pavement without sealed shoulders, etc.

For the purposes of this study, a shoulder was considered only if there was an edge line, and at least 600 mm of seal was provided outside the edge line.

Inspection of overtaking lanes was not as critical (although in one case, the direction of travel was the opposite of that indicated in the office), while no purpose would have been achieved by inspecting the edge lining sites.

The second reason for a site inspection at shoulder sealing and overtaking lane sites was to identify a suitable control section. Control sections were necessary to enable a comparison of the accident history of both treated and untreated sites. (This is a standard approach in accident evaluation, as it allows for any underlying trend in accident frequency which may otherwise (erroneously) be attributed to the countermeasure in question in a simple before and after analysis.)

Control sections were generally adjacent or very close to the analysis site. The main criteria were that they were similar in design standard, alignment, terrain, roadside conditions, traffic flow, etc. In almost all cases they also had painted edge lines. Control sections were of the same length as the analysis site, and, since they could be reasonably considered to have the same traffic flow, they had the same accident exposure (in vehicle kilometres).

For sealed shoulders, a single control section was identified, using the above criteria.

For overtaking lanes, the criteria were more precise. The influence of an overtaking lane on accidents could be expected to include not only the overtaking lane itself, but a certain distance downstream (as the traffic is less bunched) and a certain distance upstream (as traffic behaviour is influenced by advance warning signs indicating the presence of an overtaking lane ahead). Accordingly, two control sections were used, one ending 2 km upstream of the start of the overtaking lane (most overtaking lanes in Victoria have an advance warning sign 2 km in advance of start of the overtaking section), and one downstream. In general, this was 5 km downstream of the end of the overtaking section, but this was not always possible because of the presence of a town, another overtaking lane, a divided road section, etc.

Site information included lane and shoulder widths for the site and control, and the kilometre readings at the start and end of each analysis and control section (taken to the nearest tenth

of a kilometre, according to the kilometre markers at the roadside).

In retrospect, an important additional piece of information which it would have been helpful to collect while in the field was the kilometre readings (i.e. precise location) of nearby intersections. This information was necessary in the analysis of the accident data (see below), and special steps had to be taken to collect it.

3.5 VICTORIAN ROAD ACCIDENT DATA BASE

Accident data for each highway were extracted from the Victorian Road Accident Data Base, held by Vicroads for the period January 1983 - December 1991. The information extracted at this stage included a wide range of road, vehicle and site information. Data excluded at this stage were accidents which occurred in towns (identified as speed zone less than 100 km/h or urban map types), and intersection accidents involving vehicles on different roads (DCA code 11X). They were excluded because the types of measure considered here (sealed shoulders, overtaking lanes, edge lines) were not directed at either urban accidents or intersection accidents. (However, accidents which occurred at intersections were not excluded, if the vehicles involved were all on the highway; the presence of the intersection in such a case may be incidental).

This data were loaded onto a floppy disk and made available for analysis at the Monash University Accident Research Centre.

Because this data referred to the whole highway, it was necessary to identify those parts of each highway in which an analysis site or control site was located. Thus a subset of the data records, covering only those highway sections of interest was prepared, and a hard copy printed. The information on this hard copy was:

- microfiche run and frame number
- accident number
- location type (mid block or intersection)
- Road Reference Point identifier
- Kilometre distance (roughly corresponds with km post)
- DCA code (accident type)
- Severity (fatal, serious injury, other injury, non-injury)
- Accident date
- Highway route number
- Distance from nearest intersection (road reference point)
- Direction to road reference point
- Name of road reference point

The "kilometre distance" variable could not be used to identify the precise location of the crash, as this variable was coded in such a way that all accidents between two road reference points (mostly intersections) had the same kilometre distance. To obtain precise location details, it was necessary to use the distance and direction to the nearest road reference point. However, in many cases, this was not coded, and so it was necessary to go back to the original police accident report form on microfiche and enter this information manually.

To correlate the location information on this accident data set with the location of the analysis and control sites, it was necessary to reconcile the kilometre posts at the roadside with the kilometre distances of the road reference points. Discussion with people in Vicroads' mapping section indicated that the kilometre posts and the readings shown on the Vicroads Country Directory maps were not necessarily identical. Since the site information had been obtained with respect to the kilometre post readings, it was therefore necessary to go back to the field to obtain kilometre readings at key intersections against the kilometre post readings. Distances between intersections, and thus kilometre readings at other road reference points, could then be obtained by scaling off maps. In most cases, the Vicroads Country Directory was used, although for some highways it was necessary to go to more detailed maps held by Vicroads.

In this way, the "kilometre distance" reading in the above data list was replaced, for each accident, by a precise location of the accident.

3.6 DATA FILES

Based on the information collected in the phases described above, three data files were prepared for analysis using purpose-written Basic programs on a PC. These files and the information contained in each were:

Accident Data:

- location (km distance along the highway)
- DCA code
- accident severity
- year and month of accident

Sealed Shoulder Data

- highway/site number
- km at start of analysis site
- km at end of analysis site
- year of construction (financial year)
- width of sealed shoulder (site)
- estimate of AADT
- km at start of control site
- km at end of control site

Overtaking Lane Data

- highway/site number
- year of construction
- km at start of upstream control
- km at end of upstream control
- km at start of overtaking lane
- km at end of overtaking lane

km at start of downstream control
km at end of downstream control
AADT

The following highways were represented in the accident files:

Calder Highway
Glenelg Highway
Goulburn Highway
Henty Highway
McIvor Highway
Midland Highway
Northern Highway
Princes Highway East
Princes Highway West
South Gippsland Highway
Western Highway

Data were collected for a total of 44 sections of sealed shoulder. However, not all of these could be used in analysis, mainly because of the difficulty in identifying a suitable control site. In some cases, especially where long sections of highway had been provided with sealed shoulders, the nearest available control site was many kilometres away, where traffic and terrain conditions were quite different. In the interests of rigour and proper research technique, these sites were eliminated. A total of 36 sites with sealed shoulder were thus used. Table 3.1 shows details of each site, including its location, length, year in which the treatment was undertaken, shoulder width, and the before and after casualty crash frequencies for the site and its corresponding control section.

Similarly, data for 28 overtaking lanes were collected. In this case, even fewer could be used for analysis, because of the presence of another overtaking lane or a radical change in road environment (e.g a town) in the upstream or downstream control zone. Only 16 sites were therefore available for this analysis. Table 3.2 shows details of each site, including its location, year of construction, and the before and after casualty crash frequencies for the site and the upstream control section (generally this was 2 km in advance of the start of the overtaking lane).

With the edge lining, data were available for three highways, as mentioned above, namely the Ouyen Highway, the Sturt Highway, and the Calder Alternate Highway.

Site No.	Start km	End km	Year Widened	Shoulder Width	Crashes Site B/A*	Crashes Control B/A*
Calder Hwy						
1	131.6	133.5	89/90	0.9	3/0	5/2
Glengelg Hwy						
1	124.6	128.7	87/88	0.6	4/4	3/6
2	130.5	132.8	87/88	0.7	0/1	0/1
3	136.1	139.4	88/89	1.5	0/1	2/2
Goulburn Valley Hwy						
1	161.2	162.4	89/90	2.4	4/0	2/0
Henty Hwy						
1	166.2	168	88/89	0.9	0/0	0/0
2	175	178	89/90	0.8	2/0	1/0
Melvor Hwy						
1	121.5	123.9	89/90	1.2	3/0	2/0
Midland Hwy (Section 1)						
1	61.3	64.6	88/89	1.2	4/0	3/1
2	64.6	68.5	87/88	0.9	2/3	2/2
3	68.5	69.9	88/89	0.9	4/0	3/0
Northern Hwy						
1	93.5	94.9	87/88	0.8	1/3	1/1
Western Hwy						
4	162.4	163.8	87/88	0.6	3/1	2/0
5	171.0	176.6	86/87	0.7	3/4	2/3
6	181.7	183.6	89/90	2	5/1	2/0
7	191.0	192.0	89/90	0.7	2/1	0/0
8	214.8	216.4	88/89	0.6	1/0	1/0
9	233.0	236.2	88/89	0.9	4/1	2/1
10	240.1	243.0	85/86	0.7	0/4	2/7
11	243.0	244.7	86/87	0.7	2/1	1/2
12	249.4	253.1	89/90	1.1	2/2	4/2
13	253.1	254.4	89/90	0.9	3/0	1/2
14	254.4	256.7	89/90	1.2	4/0	2/3
15	256.7	258.4	88/89	1	1/2	0/4
16	260.7	263.0	88/89	0.6	2/0	1/4
17	263.0	264.3	89/90	1	0/0	0/0
18	266.3	268.6	88/89	0.9	1/0	1/4
19	270.0	272.0	88/89	1.2	1/0	1/0
20	273.4	283.1	86/87	0.6	5/4	6/5
21	290.5	292.3	85/86	0.9	2/4	0/2
22	302.9	305.1	89/90	1.2	3/2	3/1
23	314.8	316.1	86/87	0.7	0/1	2/1
24	364.4	365.4	88/89	0.8	0/0	0/1
25	365.4	366.4	89/90	0.8	1/0	0/0
26	371.9	374.6	85/86	0.6	0/3	1/2
27	377.3	380.0	85/86	0.8	1/1	0/2

* Casualty crashes only. "Before" is from 1/1/83 to end of financial year preceding widening. "After" is from start of financial year following widening to 31/12/91.

TABLE 3.1 DATA SUMMARY - SHOULDER SEALING SITES

Site No.	Year Constructed	Start km	End km	Crashes Site B/A*	Crashes Control B/A*
Goulburn Valley Hwy					
3	87/88	166.8	166.4	0/0	0/0
Northern Hwy					
1	88/89	67.3	68.6	1/0	2/1
2	87/88	95.6	96.6	3/0	0/0
3	87/88	97.3	96.2	4/0	0/0
Princes Hwy East					
1	87/88	170.9	172.7	1/1	3/2
3	88/89	178.0	177.4	0/0	1/1
4	88/89	178.6	179.5	2/0	0/0
5	89/90	191.6	190.7	0/0	0/0
6	88/89	200.3	199.4	2/1	1/0
7	88/89	200.7	201.6	2/1	2/0
9	88/89	251.7	250.7	0/0	1/0
11	87/88	341.5	342.5	2/0	0/0
Princes Hwy West					
1	88/89	95.6	94.9	0/2	0/0
South Gippsland Hwy					
3	89/90	122.8	123.5	1/1	0/0
Western Hwy					
1	88/89	134.5	135.5	0/0	1/0
5	88/89	222.8	223.8	2/0	1/0

* Casualty crashes only. "Before" is from 1/1/83 to end of financial year preceding construction. "After" is from start of financial year following construction to 31/12/91. Control site is upstream control, usually 2km prior to start of overtaking lane.

TABLE 3.2 DATA SUMMARY - OVERTAKING LANE SITES

4. ANALYSIS AND RESULTS

4.1 STATISTICAL TESTS

Sealed Shoulders

Using the accident files and the sealed shoulder files described in Section 3.6, accident data was tabulated into one of four sets: analysis site and control site: before and after.

The date of construction of the sealed shoulder section was of course the demarcation between before and after. However, since this was only known in terms of the financial year in which the work was undertaken, accident data for that whole financial year were excluded. Apart from this practical consideration, this is probably prudent for another reason, namely that it excludes accidents which occurred during the construction period or in the settling-in period immediately after construction.

Accident data were tabulated also according to severity (on the 4-point scale noted in Section 3.5). However, since data on non-injury accidents are generally regarded as less reliable, these were excluded from the analysis.

The results, showing casualty accidents before and after for the site and the control were as follows:

	Site	Control	Total
Before	73	58	131
After	44	61	105
Total	117	119	236

These results can be analysed using a chi-squared test, in the manner used in other MUARC studies (Corben, Ambrose and Foong, 1990) and as advocated by Tanner (1958) for analysis of before and after accident frequencies involving the use of control sites.

The null hypothesis is that the two data sets (analysis site and control site) are from the same distribution, and the "expected" value in any cell can be found by proportion. For example, the "expected" site/before frequency in the above table is $117 \times 131 / 236 = 64.9$. The table of "expected" accident frequencies is thus:

	Site	Control	Total
Before	64.9	66.1	131
After	52.1	52.9	105
Total	117.0	119.0	236

Application of the usual chi-squared test, with $(n-1)(r-1) = 1$ degree of freedom reveals a chi-squared statistic of 4.50, which is significant at the 4 per cent level, i.e. there is only a 4 per cent chance that the above data are drawn from the same distribution.

On this basis, it can be confidently asserted that the data show that sealed shoulders have a positive effect on accidents on 2-lane 2-way rural highways.

Overtaking Lanes

As discussed in Section 3, analysis of overtaking lanes requires an assessment of the extent to which such lanes may affect traffic behaviour and thus accidents both upstream and downstream of the overtaking lane itself. Accordingly, the data were grouped into four sets: upstream control, overtaking lane, downstream control, and an "influence zone", taken as the length of road between the end of the overtaking lane and the start of the downstream control.

The downstream control was taken as 3 km (except that in a couple of cases, a slightly shorter distance was used because of the need to avoid towns, etc in the control zone). On this basis, the results were:

	Upstream	Lane	Influence	Downstream
Before	12	20	62	19
After	4	6	38	9

Three tests (as above) were performed on this data. First, the upstream control and the downstream control were compared. This analysis showed that these two were similar to a highly significant extent (> 85% level). This means that the control sections are robust, and that any effect of the overtaking lane has dissipated by 3 km downstream.

The second analysis was between the control zones (adding the upstream and downstream frequencies gives the best estimate of the control frequencies) and the overtaking lane itself. This revealed that although the overtaking lane gave a lower accident frequency than the control zone, it was only significant at about the 40 per cent level.

The third analysis was between the control zones and the influence zone immediately downstream of the overtaking lane. However, this also showed only a minor influence, with about a 30 per cent probability that this difference occurred by chance. Thus there is no statistically significant effect of the lane on accident frequencies immediately downstream.

On the basis of these analyses therefore, it is not possible to draw any conclusions about the influence of overtaking lanes on accident frequency. There is some indication that accidents may be reduced on the overtaking lane itself, but this is not statistically significant.

It should however be noted that the accident frequencies are quite small, and for this reason further analysis using more sites and/or waiting for a longer "after" period is recommended.

Edge lining

As noted in Section 3.3, only 3 road segments were identified which had new edge lining installed, namely the Ouyen Highway, the Sturt Highway and the Calder Alternate Highway.

In these cases, since the data were for the highway as a whole, control sites on the same highway were not possible. A suitable control therefore was to take the full data set for all

highways for which data were used in this study, since these represented Victoria-wide experience over the same period.

Before and after data for these three highways and the remaining highways as a whole were extracted, as follows (n.b. these are total reported accidents, not just casualty accidents):

		Before	After
Ouyen Highway	- site	62	8
	- control	9127	2041
Sturt Highway	- site	210	377
	- control	4071	6809
Calder Alt Hwy	- site	26	34
	- control	5837	5608

Analysis of these results indicated that in no case was there any statistical confidence that the accident experience on the highway concerned was any different from that of the state as a whole. Indeed, the one with the largest confidence level (and then only about 25 per cent) was the Calder Alternate Highway, and in this case it suggested that this highway had experienced an increased number of accidents by comparison with the control highways. However, this is perhaps not surprising, in that this particular road segment skirts the City of Bendigo, and was declared a State Highway, so it may be reasonable to expect that it is experiencing a higher rate of traffic growth than rural highways elsewhere in the state.

Overall then, the data set for edge lining, together with the difficulty of identifying a reliable and meaningful control site, means that there is nothing that can be said, one way or the other, about the influence of edge lining on accidents, on the basis of the analysis performed here.

4.2 EFFECT ON ACCIDENT RATES

In the light of the analysis in Section 4.1 which showed that sealed shoulders experience a statistically significant reduction in accidents, the effect on accidents can be estimated. The most appropriate way of doing this, given that the before and after periods cover several years, is to relate accident frequency to accident exposure measured in vehicle kilometres of travel (VKT).

VKT was estimated for each site and control, based upon estimated of 1992 AADT provided by Vicroads. Vicroads further estimate that traffic on rural highways increased at the rate of 2.5 per cent per year during the 1980s. Hence it was possible to estimate the VKT for each site in each year, and thus for the before and after periods.

Comparing site and control accident rates (casualty accidents per million VKT) before and after the construction of sealed shoulders indicated that, compared with the control sites, the sites with sealed shoulders experienced a 43 per cent lower accident rate after the shoulder

was sealed. It is interesting to note that this is within the band of results reported in the literature (see Section 2.1), and thus appears to be reasonable.

Again comparing analysis and control sites in the before and after periods, this 43 per cent reduction translates to a casualty accident reduction of 0.073 casualty crashes per million VKT. (To put this figure in perspective, a road with an AADT of 2700 veh/d carries about 1 million VKT annually. If about 14 km of this road had sealed shoulders provided, a reduction of about one casualty crash per year on that section would be expected - from about 2.3 crashes (on average) to about 1.3 crashes. If the road had, say, double that amount of traffic, the number of kilometres necessary to achieve a reduction of one casualty crash per year would be about 7 km, *ceteris paribus*.)

4.3 EFFECT OF SHOULDER SEALING ON ACCIDENT PATTERNS

For each accident in the analysis, the DCA code was extracted. Obviously, the numbers of accidents in any one code will be small, because the accident numbers are comparatively small. However, the results for the effects of shoulder sealing on accidents are of interest. The main accident types showing large proportional reductions in the analysis sites were as follows:

- DCA 130 rear end
- DCA 151 overtaking, out of control
- DCA 170 off carriageway to left
- DCA 171 off carriageway to left into fixed object
- DCA 181 off carriageway on right hand bend into fixed object

These accident types are all of the sort that might be expected to be favourably affected by shoulder sealing, and the fact that accidents were reduced in each of these cases gives strong reassurance that the shoulder sealing program is working as intended.

4.4 ECONOMIC EVALUATION

As pointed out in Section 1, this project had its origin in an investigation of the economic benefits of road and traffic accident countermeasures. It is necessary therefore to determine the economic worth of shoulder sealing. (As noted in Section 4.1, the analysis here is inconclusive about the safety implications of overtaking lanes and edge lining, so no economic evaluation is possible).

As pointed out in Section 3.3, most recent shoulder sealing programs in Victoria have involved a low cost sealing of an existing shoulder, typically involving an interim bituminous sealing treatment, followed a year or so later with a reseal in conjunction with a pavement reseal. The shoulder width is typically between 600 and 1200 mm, with 600 or 800 mm being the most common. The results presented below are for this type of treatment on 2-lane 2-way rural roads.

The economic evaluation of shoulder sealing is based on the following set of assumptions or

conditions:

- a reduction of 0.073 casualty crashes per million VKT (see Section 4.2), and this reduction is maintained over the life of the project and is independent of AADT,
- traffic flow increases at the rate of 2.5 per cent per annum (see Section 4.2),
- the project life is 10 years (Vicroads, 1992, p 10),
- the discount rate for calculating the present value of future benefits is 4 per cent per annum (Vicroads, 1992, p 10; this is the rate currently recommended by the Victoria Treasury Department),
- there is no benefit from savings in maintenance cost (this is probably a conservative assumption),
- the value of a saving of a single casualty accident is \$90,000 (Vicroads, 1992, p 10), and
- the capital cost of the project (including reseal in the second year and edge lining after both the initial interim seal and again after the reseal) is \$7,900 per kilometre, based on (see Section 3.3 above):
 - 800 mm widening on both sides
 - \$1.00 per m² shoulder preparation
 - \$2.00 per m² initial treatment
 - \$1.50 per m² reseal
 - 2 applications of edge lining @ \$350 per kilometre

On this basis, per 1000 AADT, per one kilometre of road, the results are as follows:

- cost: \$7,900
- benefit: \$22,830

The net present value of providing a 800 mm seal on both shoulders of 1 km of road carrying 1000 veh/d is thus \$14,930. For roads carrying different volumes, the net present value is given by:

$$\text{NPV} = \$22,830 \times (\text{AADT in thousands}) - \$7900$$

For example, if AADT = 4000 veh/d, the NPV is \$83,420.

The breakeven point (i.e. the point at which benefits begin to exceed costs, with a net present value of zero or a benefit/cost ratio of 1.0) is about 350 veh/d. That is, it is economically worthwhile to provide an 800 mm sealed shoulder on any 2-lane rural road carrying more than about 350 veh/d. Whether that is a good use of funds depends of course on priorities:

other projects with a higher net present value should presumably take priority. However, if the projects otherwise undertaken by the road authority have a calculable benefit/cost ratio or net present value, the relative priority of shoulder sealing can readily be calculated. For example, if other activities show a B/C ratio of (say) 5, then shoulder sealing would be a candidate project at an AADT of about 1700 veh/d.

Since the cost will not vary with AADT, but the benefit is assumed to increase linearly with AADT, the benefit:cost ration can be readily calculated as:

$$\text{B/C ratio} = 2.9 \times (\text{AADT in thousands})$$

For example, if AADT is 4000 veh/d, the B/C ratio is 11.6

These results are well-founded, and are quite consistent with results found in other studies in Victoria and elsewhere. They provide strong support for the argument that a higher level of attention to shoulder sealing on 2-lane 2-way rural roads is a highly cost effective road safety measure. There are likely to be maintenance cost advantages in addition to these accident cost savings.

While the above results may be considered as a "best" estimate, in reality they are of course subject to the assumptions and data used. To assess the sensitivity of the results to various changes in assumption, the following variations were considered:

- If the assumption of a 2.5 per cent per annum increase in traffic flow is removed, and traffic is assumed to remain constant over the life of the shoulder seal (10 years), this reduces the benefit by approximately 11 per cent, i.e.

$$\text{NPV} = \$20,320 (\text{AADT in thousands}) - \$7900$$

and

$$\text{B/C ratio} = 2.6 \times (\text{AADT in thousands})$$

- The value of a casualty crash was taken as \$90,000, as described above. This was considered at the time to be the best estimate of the value of a casualty crash, and hence the appropriate value to use to assess the benefits of crash reduction programs. Recently, new research on the value of crash reductions has been published (Andreassen, 1992), and this may be used as a means of corroborating the evaluation. Andreassen's estimates for the cost of a casualty crash per person were \$625,065 (death), \$107,267 (hospital admission) and \$7,003 (medical treatment) - all in 1991 dollars. These do not translate directly to the current study because they relate to costs per person, not costs per crash. However, if we adopt the conservative assumption that these are the same (equivalent to saying that there is only one person killed or injured per crash), and if we weight Andreassen's costs in proportion to the number of fatal, serious injury and other injury crashes found in the sample (totalling both treated shoulder sites and their control sites - this being the best estimate of the proportion of crashes in the three categories for the rural roads under consideration), the result is an average cost per crash of \$126,400. This is more than the \$90,000

value used in the analysis, indicating that the benefit-cost results are indeed conservative.

- For the purposes of the above calculations, a shoulder width of 800 mm was used. The data did not allow analysis of the effect of different width of sealed shoulders on crashes, although this would be a valuable result if it could be obtained. However, if we ignore the effect (if any) of sealed width on crash rates, the effect of varying the width of seal on the economic performance can be tested by varying the assumptions listed above.

5. CONCLUSIONS

Shoulder Sealing: The results of the analysis of the effect of shoulder sealing on State Highways in Victoria indicate that:

- shoulder sealing is associated with a statistically significant reduction in casualty accident frequencies at sites where it has been installed on 2-lane 2-way rural highways,
- at these sites, casualty accidents were reduced by 43 per cent, on a per vehicle kilometre basis, at such sites,
- this is equivalent to a reduction of 0.073 casualty accidents per million vehicle kilometres,
- the breakeven point (the point at which it is economically worthwhile) to install sealed shoulders is at a traffic flow of about 350 veh/d,
- the benefit/cost ratio of shoulder sealing can be calculated from:
$$\text{benefit/cost ratio} = 2.9 \times (\text{AADT in thousands})$$
where AADT is Annual Average Daily Traffic
- for example, if the AADT is 4,000 veh/d, a benefit/cost ration of about 11.6:1 could be expected,
- the main accident reductions are in rear end, overtaking - out of control, off carriageway to left, and off carriageway to right into fixed object crashes.

Overtaking Lanes and Edge Lines. The study was unable to find any statistically significant effect of these treatments on accidents. In the former case, this was mainly because of a small number of suitable sites and a short "after" period. In the latter case it was again because of a shortage of sites, and also the absence of a suitable control situation. More work in these areas is recommended.

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