TOPIC 3
SAFETY ANALYSIS
AND POLICY (SIG)

THE SAFETY BENEFITS OF SEALING THE SHOULDERS OF RURAL ROADS

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Abstract

This paper presents the results of a project which sought to determine the safety effect of sealing shoulders on rural roads in Victoria, Australia. Data were obtained on the location, condition and cost of recent shoulder sealing projects on two-lane-two-way roads. Accident data were obtained for these sites, and a before and after comparison, using control sites, was undertaken.

INTRODUCTION

In Victoria, Australia, some 20 per cent of casualty accidents and 33 per cent of fatal accidents occur on the open road in rural areas (Armour and Cinquegrana 1990). The most common type of accident is one involving a single vehicle leaving the road and hitting a fixed object.

A detailed investigation of such accidents conducted by Armour and Cinquegrana (1990: 89) concluded that roadside objects were considered to have affected the severity of 27 per cent of accidents and the presence or condition of unsealed shoulders was considered to have contributed to 30 per cent of accidents. Narrow lanes, curves, unsealed shoulders, and low skid resistance pavements were shown to have been associated with increased accident rates. By comparison, driver fatigue was considered to have been a factor in 33 per cent of accidents, and excessive or inappropriate speed in 25 per cent.

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.

THE PRESENT STUDY

The present study sought to establish the economic benefits and costs of sealing shoulders on rural roads in Victoria. It was initially carried out for the Monash University Accident Research Centre (MUARC) (Ogden 1992) as part of a road safety research program funded by the Victorian Department of Justice, the Transport Accident Commission, the Royal Automobile Club of Victoria and VicRoads (the State road and traffic agency).

In essence, the study involved four stages, as follows:

- 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 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.
- Accident 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 accident frequency and accident rates) and the economic return (in terms of comparisons of benefits and costs) of the treatment.

The study output includes:

- information on the safety effectiveness of sealed shoulders on rural highways in Victoria; and
- an economic appraisal of the returns from investment in such programs.

PREVIOUS STUDIES

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 (n.b. traffic in Australia drives on the left), 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 accidents.

The provision of shoulders does not appear to reduce rear-end or stationary vehicle accidents. 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, 2.4m is required.

Thus the primary safety effect of sealed shoulders is to provide a greater recovery and manoeuvring space (National Association of Australian State Road Authorities 1988: 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: 206). Armour (1984a) found this to be a contributing factor in over 50 per cent of fatal run-off-the-road accidents in New South Wales, while Catchpole (1990) concluded that at least 19 per cent of *single vehicle* accidents at sites with sealed pavements and unsealed shoulders involved a driver losing control of the vehicle in the shoulder.

A number of recent Australian and American studies have shown the safety benefits of sealed shoulders (Armour 1984b; Pak-Poy and Kneebone 1988; Rogness, Fambro and Turner 1982; Turner, Fambro and Rogness 1981; Woods, Rollins and Crane 1989; Skinner 1986; Transportation Research Board 1987a). In particular:

- Armour (1984b: 60) in a comprehensive review of Australian conditions found that roads with sealed shoulders had a fatal accident 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 accident rates for roads with unsealed and sealed shoulders was about 3:1 for straight, flat road sections and 4:1 for grades or curves.
- An American 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 accidents (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 accidents (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 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, ie most shoulder usage was discretionary. This suggested that the provision of continuous full-width sealed shoulders may not be necessary, and that narrow shoulders may provide high safety benefits without the additional earthworks and pavement cost of wider shoulders.

In addition to safety benefits, sealed shoulders are generally considered to have an effect on shoulder maintenance costs. Eakins (1980: 98), for example, 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: 98) suggested that reductions of the order of $600 per kilometre per year might be expected.

STUDY METHODOLOGY

Site identification

There has been an active program of shoulder sealing on the busier State Highways in Victoria over recent years, carried out by the Victorian state road authority, VicRoads. 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 (ie 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 (ie 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 (ie lined at the edge of the full depth pavement) or a 3.5 m lane (ie attempt to keep traffic away from the thinner shoulder).

Information about shoulder sealing activities was readily available in most VicRoads Regions from the Bituminous Sealing Records. These show, in pictorial fashion, the sealing activities along each highway, and detail the type of work (eg 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.

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, based upon examination of VicRoads records:

- $1.00 per m^2 for shoulder preparation,
- $2.00 per m^2 for interim seal, and
- $1.50 per m^2 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.

VicRoads 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 routine shoulder maintenance 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.

Site visits

Although much information could be obtained in the various VicRoads Regional Offices, it was necessary to visit the site of each project to establish what work had actually been undertaken. Usually, the aforementioned 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 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.

The second reason for a site inspection 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. 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).

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).

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 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. These were excluded because sealed shoulders 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).

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. The information on this file was:

- microfiche run and frame number
- accident number
- location type (mid block or intersection)
- road reference point identifier
- kilometre distance (roughly corresponds with kilometre post)

- DCA code (Definitions for Coding Accidents: description of 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 accident, 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.

Data files

Based on the information collected in the phases described above, an accident data file and a road inventory data file for sections of road with sealed shoulders were assembled. The data on these files comprised:

- Accident Data:
  - — location (km distance along the highway)
  - — DCA code (accident type)
  - — 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

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 several 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.

ANALYSIS AND RESULTS

Statistical tests

Using the accident files and the sealed shoulder files described above, 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, as outlined above. 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 (Table 1):

Table 1 Casualty accidents

	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 therefore the "expected" value in any cell can be found by proportion. For example, the "expected" site/before frequency in the above table is 117*131/236 = 64.9. The table of "expected" accident frequencies is thus (Table 2):

Table 2 "Expected" accident frequencies

	Site	Control	Total
Before	64.9	66.1	131.0
After	52.1	52.9	105.0
Total	117.0	119.0	236.0

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, ie 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.

Effect on accident rates

In the light of the above analysis which showed that sealed shoulders experience a statistically significant reduction in accidents, the effect can be quantified. 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). This implicitly assumes that accident risk is linearly related to traffic flow. This is not necessarily so. For example, Satterthwaite (1981) found that the single vehicle accident rate per vehicle kilometre tends to decrease with flow, the multi-vehicle rate tends to increase with increasing flow, and overall, the accident rate varies in a U-shaped pattern with flow rate. However, for this study, where most of the traffic flows were over a relatively narrow band between about 2,000–4,000 veh/d, the assumption of linearity was considered to be reasonable.

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 above), 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 accidents 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 accident per year on that section would be expected—from about 2.3 accidents (on average) to about 1.3 accidents. If the road had, say, double that amount of traffic, the number of kilometres necessary to achieve a reduction of one casualty accident per year would be about 7km, ceteris paribus.)

Effect on accident patterns

For each accident in the analysis, the accident type (DCA—see above) code was extracted. Obviously, the numbers of accidents in any one code will be small, because the accident numbers are comparatively small. 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.

Economic evaluation

As pointed out earlier, 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 accidents per million VKT, maintained over the life of the project and independent of AADT,
- traffic flow increases at the rate of 2.5 per cent per annum,
- 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: 10; this is the rate recommended at the time of the study 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), 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:
  - — 800 mm widening on each side
  - — $1.00 per m^2 shoulder preparation:
  - — $2.00 per m^2 initial treatment
  - — $1.50 per m^2 reseal
  - — two applications of edge lining @ $350 per kilometre

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

- present value of project cost: $7,900
- present value of benefits: $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:

$$\text{NPV} = \$22{,}830 \times (\text{AADT in thousands}) - \$7900 \quad (1)$$

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

The breakeven point (ie 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 ratio can be readily calculated as:

$$\text{B/C ratio} = 2.9 \times (\text{AADT in thousands}) \quad (2)$$

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, ie

$$\text{NPV} = \$20{,}320 \times (\text{AADT in thousands}) - \$7900 \quad (3)$$

and

$$\text{B/C ratio} = 2.6 \times (\text{AADT in thousands}) \quad (4)$$

- The value of a casualty accident 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 accident, and hence the appropriate value to use to assess the benefits of accident reduction programs. Subsequently, the results of research on accidents costs conducted by the Australian Road Research Board (Andreassen 1992) were published. This may be used as a means of corroborating the evaluation. Andreassen's estimates for the cost of a casualty accident 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 accident. 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 accident), and if we weight Andreassen's costs in proportion to the number of fatal, serious injury and other injury accidents found in the sample (totalling both treated shoulder sites and their control sites—this being the best estimate of the proportion of accidents in the three categories for the rural roads under consideration), the result is an average cost per accident 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 accidents, although this would be a valuable result if it could be obtained. However, if we ignore the effect (if any) of sealed width on accident rates, the effect of varying the width of seal on the economic performance can be tested by varying the assumptions listed above.

CONCLUSIONS

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:

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

  where AADT is Annual Average Daily Traffic
- for example, if the AADT is 4,000 veh/d, a benefit/cost ratio 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 accidents.

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