DEPARTMENT OF TRANSPORT AND COMMUNICATIONS
FEDERAL OFFICE OF ROAD SAFETY
DOCUMENT RETRIEVAL INFORMATION

Report No.	Date	Pages	ISBN	ISSN
CR71	April 1988	179	0-642-51147-0	OR = 0158-3077 CR = 0810-770X

Title and Subtitle

ROAD SAFETY BENEFITS FROM RURAL ROAD IMPROVEMENTS

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Abstract

This report describes the results of a literature review undertaken to determine the cost-effectiveness of a range of safety improvements for rural roads. Safety benefit to cost ratios have been determined for eleven categories of improvements to the road and roadside, including road delineation, signage, pavement resurfacing, shoulder and lane widening, overtaking lanes, geometric improvements, roadside hazard management, construction of medians and barriers, intersection treatments, railway crossing treatments, and new road construction.

Deficiencies in available research have been identified and recommendations on future research provided.

Keywords

NOTES:

(1) FORS Research reports are disseminated in the interests of information exchange.
(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government.
(3) The Federal Office of Road Safety publishes two series of research report
  (a) reports generated as a result of research done within the FORS are published in the OR series;
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ROAD SAFETY BENEFITS FROM RURAL ROAD IMPROVEMENTS

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87-345
87N1017

April, 1988

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PART A

OVERVIEW

1.0 INTRODUCTION

1.1 OVERVIEW

1.1.1 Background of Study

The Federal Government makes a considerable investment in improving roads on the grounds (inter alia) of increased convenience and enhanced safety for road users. Selecting the best design for the construction or reconstruction of a road requires consideration of a number of factors. One factor that is receiving increasing attention is the relative safety benefits of alternative road improvements.

The Federal Office of Road Safety (FORS) commissioned this study to assess the cost-safety relationship for various road improvements. The principal objective of the study was to rate and compare the cost-effectiveness with regard to safety of a range of road safety improvements. The safety effectiveness was to be identified from a literature review of Australian and overseas research. In this respect it goes beyond the scope of other previous literature reviews which have focused on determining the effectiveness of safety measures without attempting a comparison of such measures.

An important additional element of the study was to identify deficiencies in the available research and provide advice on the direction of future research.

In accordance with the Brief and discussions with FORS, the study concentrates on rural roads, where in general crash rates and crash severity are often highest, and encompasses both the road and road environment (i.e. roadside features). The study also emphasises road design features rather than traffic management strategies though the latter are considered because of their potential to offer significant reductions in crash rates at a relatively low cost.

The contribution to road safety of vehicle design or maintenance and driver behaviour or education is outside the scope of this study.

1.1.2 The Rural Road Safety Problem

Figures released by the Australian Bureau of Statistics show that road traffic crashes accounted for 2,942 deaths in Australia in 1985. The Department of Transport (Australia) estimates that road crashes in Australia cost the community about $2.7 billion each year in 1984 values (see Table 1.1)(1). This represents 2% of the Gross National Product (Federal Office of Road Safety, 1984).

Table 1.1

Total Crash Costs

Crash	Cost ($million)
Fatality	1,000
Injury	740
Property	970
TOTAL	2,710

Source: Federal Office of Road Safety (1984)

Fatalities and casualty crashes are seriously over-represented in rural areas. In Victoria crashes in rural areas account for about 47% of fatal crashes and 34% of crashes resulting in an admission to hospital (Armour, 1986).

Similar statistics apply to other states. In South Australia in 1986 5.5% of all reported crashes occurred on rural roads (excluding towns). Yet

(1) Subsequent to the preparation of this report, the Bureau of Transport and Communications Economics has produced revised crash costs based on 1985 figures. These have been adjusted by relevant factors to arrive at a total cost of road crashes in Australia for 1987 of $5,690 million. The corresponding total costs for crashes by category are; for those where a person received a fatal injury: $1,330 million; a person received another injury: $3,290 million; and where only property damage occurred: $1,070 million.

9.5% of all injury (including fatality) crashes occur on rural roads and 34% of all fatalities occurred on rural roads. Moreover Armour (1984) found from 1980 statistics that 11.5% of casualty crashes on rural roads throughout Australia resulted in a fatality.

1.2 STUDY OBJECTIVES

The principal objectives of the study were defined as:

- to identify, review, and from a cost-effectiveness viewpoint, rank known measures for modifying the road and road environment to enhance road safety;

- to identify areas of future research into improvements of the road environment that are likely to enhance safety.

A thorough search of Australian and international literature on road improvements was performed during the first stage of the study. The search encompassed all safety measures, regardless of their effectiveness in enhancing safety.

1.3 MEASURES ASSESSED

The following road improvement measures have been evaluated in this study:

- Road delineation
- Signage
- Pavement resurfacing
- Lane widening/shoulder improvements
- Overtaking lanes
- Geometric improvements
- Roadside hazard improvements
- Barriers and medians
- Intersection treatments
- Railway crossing treatments
- Construction of limited access roads.

2.0 RESEARCH APPROACH

2.1 LITERATURE REVIEW

Three data bases were systematically searched for information on the safety effects of road improvements:

- the Australian Road Research Board's (ARRB) ROADS data base which includes all ARRB documents published since 1960;
- the International Road Research Documentation data base (IRRD);
- the Literature Analysis System on Road Safety (LASORS) data base established by the Federal Department of Transport.

The first two data bases were searched by ARRB. The LASORS data base was searched by the South Australia Department of Transport. The combined searches resulted in documents from around the world being cited, but the predominant contributions were from Australia, The United States and Great Britain.

In addition other documents addressing road design or road safety issues were consulted.

A further source of information included road, traffic and safety authorities (primarily ARRB) who have researched the relationship between road improvements and safety effects. State authorities were requested to provide any relevant findings that may not have been published.

2.2 PREVIOUS REVIEWS

Several previous literature reviews on the subject of the safety benefits were consulted as part of this project. In particular the following major studies were found to be useful:

A rural road accident study undertaken in South Australia by the NH and MRC Road Accident Research Unit in conjunction with Nicholas Clark and Associates (1985) which included a literature review to identify measures that were effective in reducing crash rates. The study included driver behaviour, emergency first aid and use of restraints, but only a brief review of road engineering improvements was included.

A study undertaken on behalf of the Department of Transport by Nicholas Clark and Associates (1984) evaluated the safety effectiveness of low cost traffic engineering projects undertaken in South Australia and Western Australia as part of the MITERS program (Minor Improvements in Traffic Engineering for Road Safety). Before and after crash rates were compared to determine the cost effectiveness of improvements (reported as crashes avoided per $1,000 capital cost). The project concentrated on urban areas, but a few rural projects were studied.

The Texas Transportation Institute (1982) undertook an extensive literature review of the relationship of traffic control and roadway elements to highway safety. This very detailed, two-volume report was intended to provide factual research findings on the full range of roadway elements, but does not provide an aggregated assessment of the safety features discussed.

A review of the cost and safety effectiveness of highway design elements by Roy Jorgensen Associates (1978). The effectiveness of design features was assessed separately for various categories of roads (ranging from freeways to two-lane rural roads). Approximately 50 design features were found to have some type of safety relationship. However no attempt was made to rate features nor was an overall conclusion drawn regarding those features for which conflicting information on effectiveness was reported. However, quantitative relationships with safety were developed for pavement width, shoulder width and shoulder surface type for two-lane rural highways.

A literature review of road design in relation to road safety was undertaken in 1973 by Sinclair and Knight. Covering geometric design, materials, structures, intersections, interchanges, and access control, the report provides conclusions on the effect of each of the design parameters reviewed and describes those which most affect road safety. A method for applying the data to determine the cost-effectiveness of improvement for specific applications was outlined, but general cost-effectiveness measures were not developed.

The above reports provided useful information for this study, but lacked the detail required to quantitatively compare the cost-effectiveness of road safety features under comparable conditions (with the exception of the Nicholas Clark report which focused on urban roads). In this respect they differ fundamentally from this study in which the literature review is only the initial step in ultimately rating safety measures.

2.3 APPROACHES TO DETERMINING SAFETY BENEFITS

Studies to assess the safety benefits of road improvements vary in their approach, from the analysis of empirical data to computer simulation and laboratory experiments. The following categories are the most prevalent:

"Before/After" studies. This is a classic approach that requires little explanation. It also accounts for most of the studies reviewed for this document. Crash data for a specific period before and after the road improvement is implemented are compared to determine changes in annual crash rates. Typically crash statistics are collected for one year before and one year after construction but in some cases three year periods (a total of 6 years) have been studied. Longer periods (which have the advantage of providing a larger sample size) are normally not employed because changes in traffic and travel characteristics or road conditions would be more pronounced than over a shorter time span.

Theoretically before/after studies also include for control purposes the analysis of crash data on roads with similar characteristics but excluded from the improvement programme. Other factors which can influence crash rates and can change over time can therefore be accounted for.

Simulation studies. Typically in these studies the causes of crashes are defined and those causes then eliminated or modified (either as a manual or computer assisted exercise). The corresponding crash reductions can then be calculated.

A major deficiency with this approach is that the cause-effect relationship of crashes is often not easy to define. Factors causing crashes are complex and inter-related (encompassing driver behaviour, vehicle design and maintenance, and road condition parameters) and misleading reduction in crash rates can result.

Laboratory studies. These are less common and may include use of test tracks or films etc.

Whilst before/after studies have the potential to provide the most conclusive results, they are difficult to control. Thus simulation and laboratory studies are valuable, and have therefore been included in this study.

2.4 MEASURES OF SAFETY EFFECTIVENESS

One of the main problems in undertaking the project has been the very wide range of measures used to describe the effectiveness of the various measures. These ranged from subjective impressions that one measure was intuitively better than another to detailed statistical analyses. Even where satisfactory statistical conclusions have been drawn, there are many measures of effectiveness used.

The safety effectiveness measures typically utilised in the studies include:

Percent reduction in total or specific types of crashes. Although the most common measure, its direct application to this study was limited as it could not be converted to the absolute numbers necessary to derive the value of crashes eliminated. However the percent reduction figures were useful in verifying or modifying the findings of other studies for the same road improvement measure, or in some cases, where some additional information was provided, (such as traffic volume, road environment, length of road etc.) the percent reduction could be converted to an estimated absolute reduction by applying reasonable assumptions.

Reduction in number of crashes (total or by type) for the particular road (or location) and conditions studies. This provided useful base information but often excluded a description of factors that influence crash rates (particularly traffic volumes and the standard of road design and maintenance). Whether the section of road studied experienced an unusually high crash rate was also generally not explained.

Reduction in number of crashes per million vehicle-kilometre of travel on the road. This introduced the crash exposure level into the effectiveness rating. It is known that typically the frequency of crashes on a section of road increases with traffic volume (up to a level), and therefore roads with higher volumes can be expected to experience a higher reduction in crash numbers from a particular improvement than if constructed on a lower volume road. For a valid comparison of studies, volume is therefore a key piece of information, yet it was often omitted.

A benefit to cost ratio was reported in some cases. However caution must be exercised when this was determined for overseas studies as crash costs and road construction costs can vary significantly.

Similarly, economic measures used include:

Net present value (NPV)
Benefit Cost Ratio (BCR)
First Year Rate of Return (FYRR)
Internal Rate of Return (IRR)

RACV (1985) analysed this matter on behalf of the Federal Office of Road Safety and concluded that, for rural areas, the measure which gives the best economic return for funds expended is to compare Benefit Cost Ratios on a crash number basis. Figure 2.1 shows their comparison between the number and rate identification procedures for BCR and NPV selection criteria. BCR is the most common measure used for the economic aspects. However for the crash aspects there is a substantial body of research which uses crash rate procedures and rarely gives sufficient information (i.e. AADT's or distance) for conversion. There is little doubt that the RACV conclusions are appropriate for implementation selection but it is not so clear as to the best way to conduct research. However, for consistency, in this report crash numbers have been used where possible.

The costs of crashes estimated to be saved by the various measures have been estimated from the single year benefits by discounting future years benefits at 10% p.a. to give a net present value. The cost of implementation of the measure has been assumed all to occur in the first year and maintenance costs discounted in the same way as benefits. This gives a net present benefit (NPB) and a net present cost (NPC). The benefit cost ratio (BCR) is then BCR = NPB/NPC.

The approach to calculating the value or cost of a rural road crash is detailed in Section 2.6, and a summary of typical costs for road improvements is provided in Section 2.7. Crash costs and road construction costs are all 1987 values.

It could be argued that findings not supported or clarified by adequate information should not be included in a quantative assessment of road safety measures. However, to do so would severely limit the size of the data base for this study and therefore the validity of its conclusions. Therefore, within reason, all findings have been integrated into this study.

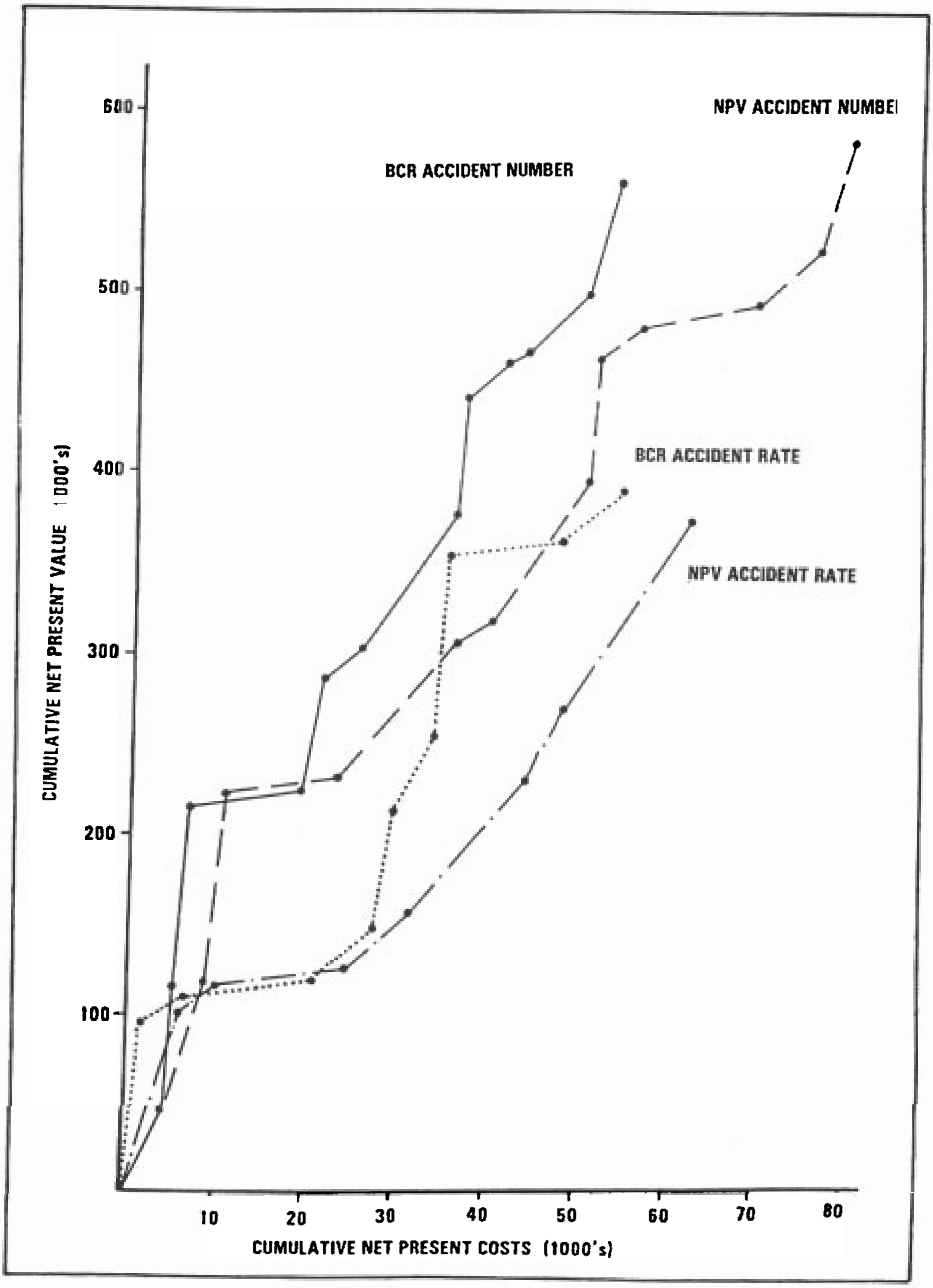


Figure 2.1

Hazardous Location Procedures in Rural Areas
Comparison of Number and Rate Identification Procedures
for BCR and NPV Selection Criteria

Source: RACV (1985)

2.5 LIMITATIONS OF CONCLUSIONS

The conclusions as assessed in Section 3.0 of this document are limited by the quality and detail of the studies reported in the literature. Very often inadequate detail was provided in the methodology employed.

The following factors which are particularly relevant in assessing the effectiveness of road safety measures have typically not been provided or are characteristic of the studies reviewed:

- The before/after analyses are typically based on crash statistics for one year prior to and one year after the road improvement, although some studies include 3 year before and 3 year after data. Crash frequencies are therefore usually low and changes in frequency even lower. This severely limits the statistical validity of the findings.

- Controls were often not employed in studies, and when employed, could not be expected to account for all other causes of changes in crash rates.

- The level of confidence (or statistical significance) in the results was often not determined or reported. The statistical significance of results has been quoted quantitatively where given in the references, or qualitatively where otherwise quoted by authors. (A lack of any reference to this matter indicates that this was not reported by the authors). However, it is perhaps unnecessary to require a 95% confidence limit on all data relationships to be sure that crash reductions are worth pursuing.

- A description of the road and associated conditions was usually not included. No independent assessment of the likely contribution of the features of the road to the crash rate was possible, and therefore an intuitive assessment of the role of the improvement in reducing crashes could not be made.

It appears that existing road conditions are important factors, as similiar (or identical) road improvements often resulted in very different levels of safety benefits, often on roads in close proximity to each other.

Traffic volumes, an important influence on crash rates (as described in Section 2.4), were usually not specified.

The range of findings for a particular improvement, often extending from no benefit whatsoever to a high cost-effectiveness rating, also highlights the importance of selecting the appropriate improvement for a particular set of road and traffic conditions.

2.6 RURAL CRASH COSTS

With few exceptions, crash reductions reported in the literature have not been assigned a monetary value. Furthermore, crash reductions have typically been reported for total crashes without categorising crashes by severity. Therefore it has been essential to make certain assumptions regarding the type and value of crashes occurring on rural roads.

Crash Type

Crashes on rural roads are typically more severe than those occurring on roads within metropolitan areas. This is illustrated by 1986 statistics compiled for South Australia by the Department of Transport, shown in Table 2.1. These statistics indicate that 36% of reported rural crashes were casualty crashes, compared to 21% for the metropolitan area, and almost 35% of all fatality crashes in the state occurred on rural roads. In Victoria Armour (1986) found that rural road crashes account for 47% of all fatalities.

The fatality rate for South Australian rural roads (10.0% of all rural road crashes) is slightly lower than a national average of 11.1% derived from 1980 data (Armour 1984a). Armour found that the proportion of rural state highway casualty crashes involving a fatality ranged from 8.4% in Tasmania to 17.0% in NSW. From the data available Armour was able to conclude that, as a guide, a fatality occurred in 11.5% of all casualty crashes on rural highways. This is not significantly different from the South Australian statistic.

Therefore, where changes in crash rates as a consequence of a particular road improvement have referred only to total crashes, a proportion of crashes within each category can be established from the above statistics i.e. whether property damage only, injury or fatality. For this purpose the statistics compiled for S.A. were employed recognising that the proportion of fatalities may be slightly understated.

Table 2.1

Summary of Crash Statistics for South Australia - 1986

Severity	Crashes on Rural Roads (Outside Towns)	Total Crashes for S.A.	Proportion Rural/Total
Fatal	88 (3.67%)	259 (0.60%)	33.98%
Admitted to/Treated at Hospital	696 (28.99%)	6315 (14.53%)	11.02%
Minor Injury	93 (3.87%)	2671 (6.15%)	3.48%
Property Damage Only	1524 (63.47%)	34206 (78.72%)	4.46%
TOTAL	2401 (100%)	43451 (100%)	5.53%

Source: Department of Transport, South Australia

Where only changes in injury/fatality crash rates have been reported in the literature the same ratio has been applied to derive an estimate of the change in property damage only crashes.

Average Crash Costs

Assigning costs to types of crashes is a complex task that by necessity entails numerous assumptions. It is also an area that is subject to continuous scrutiny and debate, particularly with regard to the economic value of life and suffering, and quality of life sacrifices of the community as a whole in contributing a proportion of the Gross National

Product to the prevention and consequences road crashes (Atkins 1982; Andreassend 1984; Blomquist 1982; Mishan 1982).

For the purpose of this study 1983 average costs developed by the Federal Department of Transport (the most recent costs available) have been adopted. These have been converted to 1987 values by applying an 8% inflation factor per annum to obtain the figures shown in Table 2.2.

Table 2.2

Australian Crash Costs

	1983 Average Cost	1987 Average Cost	Severity Index
Fatality Crash	$300,000	$408,000	157
Major Injury Crash	$67,000	$91,000	35
Minor Injury Crash	$8,000	$10,900	4
Property Damage Only Crash	$1,900	$2,600	1

Source: Federal Office of Road Safety (1984)

The severity index represents the cost multiple for each category of crash taking a property only crash as 1.

In considering individual crash locations, the statistical problems in having a very small data base of crashes can mean that a fatality may overinfluence decisions due to its very high severity factor. The crash severities used by the States are thus reduced in weighting as shown in Table 2.3 (RACV 1985). However, in this study a large data base (all rural crashes in Victoria for 4 years) has been used and the full cost-based severity index is considered valid.

The average cost of a rural road crash can be determined by applying these costs to the breakdown of rural crashes determined earlier. The computations are shown in Table 2.4, with the results that the cost of the average rural road crash is $43,427.

Table 2.3

Summary of Australian Crash Severity Weightings

	ACT	NSW	QLD	SA[2]	TAS	VIC	WA[3]
Fatal crash	16	3	4	60	3		12
Injury crash where a casualty is admitted to hospital	4	1.8	3	20	1	n/a	3
Injury crash where a casualty is not admitted to hospital	4	1.3	1	20	1	n/a	3
Property damage only	1	1[1]	1	1	1		1

Notes:
1 In NSW, this basic factor is tow-away crashes.
2 In SA the weightings are approximately based upon the crash costs included.
3 In WA the weights are not generally used.

Source: RACV (1985)

Table 2.4

Calculation of Cost of Average Rural Road Crash

Crash Severity	% of Crashes on Rural Roads (SA 1986)(1)	1987 Average Crash Costs	Cost Per 100 Rural Crashes	% of Average Crash Cost
Fatality	3.67	\$408,000	\$1,497,360	34.5
Admitted to/Treated at Hospital	28.99	\$91,000	\$2,638,090	60.7
Minor Injury	3.87	\$10,900	\$42,183	1.0
Property Damage Only	63.47	\$2,600	\$165,022	3.8
TOTALS	100%		\$4,342,655 or (\$43,427 per crash)	100%

(1) Refer Table 2.1.

2.7 SUMMARY OF COSTS FOR ROAD IMPROVEMENTS

Some typical costs for the following improvements in the rural environment, based on current National cost indicators and average for the National situation are given below in Table 2.5. The indicative life of each improvement and the annual maintenance costs are also included as a guide only, since these are very dependent on environmental factors and traffic volumes.

Table 2.5

Road Safety Improvement Costs (1987 Values)

Road Improvement Type		Costs $	Indicative Life Years	Indicative Maint. Costs (1)
Overtaking Lane (2)				
850 m long		87,000-133,000	10-20	5-10
1200 m long		127,000-197,000	10-20	5-10
Passing Bay (3)		10,000-15,000	10-20	10-20
Sealed Shoulders				
Plain seal only per kilometre	Width	1-3 coats		
	0.5	800-2,400	5-8)	15-30)
	1.0	1,600-4,800	)	)
	1.5	2,400-7,200	)	)
	2.0	3,200-9,600	)	)
	3.0	4,800-14,400	)	)
Full pavement per kilometre	0.5	11,000-13,000	10-20)	5-10)
	1.0	18,300-22,300	)	)
	1.5	25,500-31,500	)	)
	2.0	32,800-40,800	)	)
	3.0	47,300-59,300	)	)
Stopping Sight Distance (4)				
Per kilometre		30-220,000	30-50	2-5
Edge Lines (2 no.) Reflectorised				
Per kilometre				
2 no. width	100 mm	1,500-2,500	)	
	150 mm	2,500-3,500	2-5)	5-15
	200 mm	3,500-4,500	)	
Flexible Guard-Rail (5)				
Per kilometre		61-65,000	10-20	5-10
Concrete Barrier Crash Rail				
Per kilometre				
Double sided		110-130,000	30-50	0-2
Single sided		90-110,000	30-50	0-2

(Cont'd.)

Table 2.5

Cont'd.

Road Improvement Type	Costs $	Indicative Life Years	Indicative Maint. Costs (1)
Raised Reflective Pavement Markers Per kilometre	4,800	3-8	2-5
Reflectors on Posts Per kilometre			
Existing posts	120	5-10	2-5
Including posts	2,000	5-10	2-5

(1) Maintenance costs are quoted as an annual percentage of the capital cost.

(2) 3.7 m lane + 1.2 m shoulder, AADT 1100-2200, 80 km/h design speed and length of 850 to 1200 m, 2-coat seal + 300 mm base.

(3) 3.7 m lane, 120 m long.

(4) For clearing and excavation down to sight level in rolling terrain for design speeds to 100 km/hr and radii greater than 450 m.

(5) Double steel W beam with posts at 2.5 m and anchors.

3.0 SUMMARY OF RESULTS

3.1 ESTIMATED BENEFIT COST RATIOS

Table 3.1 provides a summary of Benefit Cost Ratios (BCR's) estimated for safety benefits only.

It is important to emphasise that the following summary is indicative only in view of the very wide range of measures used to describe crash savings. An attempt has been made to standardise the methodology in order to make comparison possible. However, this has involved a need to make a considerable number of assumptions about traffic flows, lengths of test sites, crash severities and average crash rates. These assumptions are shown in the main body of the text.

As detailed in Section 2.0, Benefit Cost Ratios (BCR's) are dependent on traffic flows. The higher the flow, the higher the benefit, although the relationship is not direct. RACV (1985) showed that when flow increased, crash numbers increased but crash rate per million vehicle km reduced. Thus no single BCR can be valid for all situations. For the reasons given in Section 2.0, this report compares BCR's on a crash number basis not a crash rate. The most common flows used for calculations are 2000, 5000 and 10000 AADT's.

BCR's will also increase for work done in high risk areas, i.e. at horizontal curves (less than 450m radius), at intersections, at gradients (greater than 2%) or crests and, especially, at combinations of these. BCR's *quoted below are generally for medium flow and risk situations.*

It has not been possible to give BCR's for a few improvements.

3.2 FURTHER RESEARCH

Further research is suggested in the main text where appropriate and the following section is a summary of the suggestions.

Table 3.1

Estimated Safety Benefit Cost Ratios

Improvement		BCR(1)
Low Cost		
Intersection signage		200:1 - 750:1
Warning signs		125:1 - 400:1
100 m edge line		10:1
150-200 mm edge line		10:1
Removal of trees		10:1
Raised Reflective Pavement Markers		8:1
Reflective guide posts		8:1
Installing breakaway poles		7:1
Intersection sight distances		5:1
Crash attenuators		?
Rumble strips		?
Medium Cost		
Resurfacing		9:1
Turnouts - tourist areas only		8:1
Turning lanes		5:1
Wide median		3:1
Median with barrier		0.8:1
Railroad crossings:	Flashing Lights	0.6:1
	Boom gates	0.5:1
	Both	0.4:1
Clear zone policy		?
Installing barrier on wide median		Negative
High Cost		
2 m paved shoulders		12:1
Overtaking lanes		3:1 - 6:1
Short 4 lane section		2:1 - 4:1
Stopping sight distance improvements		2:1
Increasing horizontal curvature to greater than 600 m		2:1
Replacement of crossroad by T intersections		GT 1:1
Superelevation and crossfall improvements		LT 1:1
New roads (e.g. 2 lane, limited access by-pass)		0.1:1
Vertical curves/gradients		?

(1) A "?" indicates that a BCR cannot be determined.

It is recommended that the measure by which studies and improvements are reported be standardised as far as possible. It is considered that the most appropriate measure is a Benefit Cost Ratio (BCR) based on crash numbers and severity index. It is very important that an appropriate AADT is given together with, if practical, an adjustment factor for varying AADT.

3.2.1 Suggested Further Research

(a) Road Delineation

Additional research to identify those locations likely to benefit most from delineation is required, as is research into the optimum combination of delineation treatments for particular locations and traffic conditions.

(b) Signage

The very high benefit to cost ratios associated with signage indicate that low volume roads that are usually not signed could also benefit. Therefore future research should be directed at such roads.

(c) Pavement Resurfacing

Pavement resurfacing has been shown to be a highly effective safety measure. However a comparative assessment of the NSW and Victorian research would be useful to identify the causes of the substantial difference in benefits in the two states.

(d) Shoulder and Lane Widths

Additional research is required to determine the effectiveness of sealed shoulder widths in excess of 2.0 m. Research is also required to identify the combination of traffic volumes and geometric parameters which justify increased lane and shoulder width.

(e) Overtaking Lanes and Turnouts

Overtaking lanes and turnouts are a cost-effective means of improving the capacity of two-lane roads with limited passing opportunities. However additional research is required on the less costly of the two options, turnouts, to determine their cost-effectiveness relative to more costly overtaking lanes, particularly in Australia.

(f) Geometric Parameters

Geometric parameters studied included sight distance, curvature, gradient, superelevation and crossfall. Research into sight distance improvements indicated that a BCR of 1.0 may be achievable at high flows, but research on Australian roads is required. Similarly Australian research of curvature (in conjunction with superelevation) is also lacking and is required to verify overseas results. In all future studies it is essential that controlled data sets are obtained so that the effects of individual parameters can be assessed.

(g) Roadside Hazard Management

Though extensively researched in Australia and elsewhere, additional research is required to verify rural run-off road encroachment formulae, to investigate the more widespread use of slip bases on poles, to distinguish the relative severities of hazard crashes and guard barrier crashes and identify more appropriate actions, and to examine embankment crash severities. Moreover, a coordinated national approach to utilize more actual crash data rather than theoretical formulae is recommended.

(h) Medians and Barriers

Research is required into the effectiveness of guard design barriers for Australian vehicles on Australian roads. Crash severity reductions resulting from crash attenuators currently installed in Australia should also be examined.

(i) Intersection Treatments

Research into intersection safety has concentrated on urban intersections. Corresponding research into rural intersection treatments is limited, however, and it is recommended that a comprehensive study of the full range of treatments be undertaken, particularly various intersection and junction layouts.

(j) Railway Crossing Treatments

Accident records need to be examined to relate implemented improvements or design features to crash rates.

(k) New Road Construction

Further research is required to investigate crash reductions that occur from the implementation of different classes of new roads. However, research on low volume rural roads may be difficult to justify.

3.3 CONCLUSIONS

This study has enabled comparisons to be made between a wide range of improvements on a very approximate basis. It shows that low cost improvements often offer the best BCR where they have not already been implemented. It also indicates that most safety improvements are cost-effective and it is thus a question of allocation of funds to implement them in an appropriate order or priority. Considerable further research in Australia seems appropriate, together with a standardisation in data recording and a more standard approach to recording the results of research.

PART B

DETAILED FINDINGS

4.0 ROAD DELINEATION

4.1 INTRODUCTION

Road delineation treatments are used to enhance the driver's perception of the road by marking the travelled way. Delineation treatments include:

(1) centre-lines and lane-separation lines;
(2) edge lining or pavement edge marking;
(3) raised reflective pavement markers (RRPM);
(4) guide posts with reflectors;
(5) barrier markings and chevrons;
(6) transverse road markings;
(7) illusionary edge lining;
(8) signage which warns of horizontal alignment changes (e.g. chevrons);
(9) bridge width indicators;
(10) coloured shoulders.

These treatments are used in isolation or in combination, and several are now common practice on all roads. In particular the marking of centre-lines and lane-separation lines is standard practice where road width permits, and for this reason is excluded from evaluation.

Delineation treatments are classified as long- and short-range, the latter intended to aid the driver in his immediate path control task, particularly at night or under poor visibility conditions. Long-range delineation gives drivers information on the road ahead several seconds in advance.

Delineation has been shown to be generally cost-effective at hazardous locations and on curves but not necessarily on straight stretches of road. In fact wholesale application of delineation may not be cost-effective and could detract from its effectiveness on curves where crash rates are typically higher.

The following sections report on the safety effectiveness of measures (2), (3) and (4) for which studies have been undertaken.

4.2 PAVEMENT EDGE MARKINGS

4.2.1 Description

The road safety benefits of centre-lines and lane-separation lines (on multi-lane roads) were established long before evidence began to grow supporting the effectiveness of edge lining. Edge lines are used to delineate the outer edge of the travelled way or lane for the following purposes (Smith, 1976):

- to make driving more comfortable and simplify the driving task;
- to reduce the crash rate; and
- to reduce pavement edge wear.

Edge lines can achieve these purposes by discouraging drivers from travelling on the shoulders (particularly on curves), by providing a continuous guide for the driver (whether at a hazardous location such as a curve or for long distances), and by acting as a guide past objects which are close enough to the edge of pavement to constitute a hazard.

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) found that 55% of serious casualty crashes on rural highways in Victoria for the years 1977-84 were of this type. Furthermore, Johnston (1980) showed that in rural areas 76% of night time alcohol related crashes were of the run off the road type (particularly on curves), highlighting the need to consider the effects of roadway delineation on both sober and alcohol impaired drivers.

By providing a guide for drivers to follow when passing traffic from the opposing direction, particularly under poor visibility conditions or when headlight glare impairs driver visibility, edge lines also have the potential to reduce head-on or side-swipe crashes.

4.2.2 Safety Effectiveness

Studies conducted over the last 30 years have shown that edge marking has the potential to reduce certain types of crashes, but the degree of benefit can vary widely.

Early Studies

Studies into the safety effectiveness of edge lining date back to 1958 when Thomas (1958) examined the before and after crash rates on a section of 7.3 m wide two-lane rural road in the U.S. Thomas found that in the 6 months following the marking of reflectorised 100 mm wide solid white lines about 300 mm from the edge of the pavement, crash rates increased over the previous 6 months. However, the analysis period and number of crashes was too small to permit valid conclusions, and no mention was made of weather conditions or other variables which may have influenced rates.

Musick (1960) undertook a more extensive crash study of a two-lane rural highway in Ohio, U.S.A. A total of 116 miles (187 km) was studied of which 61 miles (98 km) was edge marked and the remainder was used as a control. Pavement width varied between 6.0 and 7.3 m with shoulder widths between 1.2 and 1.8 m.

Before and after studies on both sections for 12 month periods indicated an overall 19% reduction in crashes (representing 30 crashes) when taking into account the control. Statistical analysis showed a significant level of 78% using the 2 x 2 chi-square test. Most significant reductions were achieved at intersections and other access points which decreased by 63%.

At $2,000 per km for edge lining with a 3 year lifetime, this represents a safety cost effectiveness of 0.23 crashes per $1,000 and a benefit to cost ratio of 10:1.

The reduction in fatality and injury rates was considerably higher than the overall reduction - 37% or 53 fatalities/injuries. This was significant at the 98% level employing the 2 x 2 chi-square test.

Unfortunately no mention was made of the traffic volumes on any of the roads.

Basile (1962) undertook a controlled type of before and after crash comparison study involving 384 miles (614 km) of rural highway in Kansas, U.S.A. Twenty-nine pairs of study sections were studied, half of which were edge marked, (192 miles or 307 km), the other half left untreated. All test sections were 6.0 to 7.9 m wide with shoulder widths from 0.3 to 1.8 m. AADT's ranged between 560 and 3575, with an approximate average of 1440 vehicles.

Crash data were analysed for the year prior to and the year after edge marking. Whilst the total number of crashes or injuries remained virtually unchanged, there was a significant reduction in fatalities (from an expected 18 to 4 i.e. 78%). This was found to be statistically significant at the 93% level using the chi-square test.

The reduction in fatalities was equivalent to 0.086 crashes per MVK and translates into a benefit to cost ratio of 12:1. Converting to crash number, Australian costs and the standard methodology given in Chapter 2 shows a BCR of 22:1.

As for the Ohio study, greatest reductions (46%) were experienced at access points.

However a later study in Arizona concluded that edge lining was not effective in reducing the crash rate (Arizona Highway Department, 1963).

Recent Studies

Jackson (1981) reviewed studies examining the cost-effectiveness of traffic management measures in the U.S. and Great Britain. She found that in the U.S. pavement markings and delineation ranked second only to signage, providing a benefit to cost ratio of 6.07, whilst in Great Britain a study in Nottinghamshire determined crash reductions of 64% at bends and 58% at locations other than bends for a combination of lining and signage.

Jackson notes that the U.S. Federal Highway Administration has concluded that the application of a centre line to a previously untreated road is virtually always cost effective in terms of safety benefits. She continues by saying that now there is considerable evidence to support edge lining as a safety measure and provides a summary of results of studies world wide (Table 4.1). All these studies involved unlit rural roads and in most cases a control group of roads was used. Details of the studies in Great Britain are provided below.

Table 4.1

Road Safety Benefits of Reflectorised Edge Lines on Rural Roads
Summary Results of Studies World Wide

Test Location	Total Crash Reduction (%)	Reduction at Night (%)	Safety Benefit to Cost Ratio
1. USA(1)			
Kansas	16.5		
Kansas	14.5		
Ohio	19		
Illinois	21		
Michigan	3		
Utah	38		
Arizona	60		
West Milford	44		
Idaho	15.9		
2. West Germany(2)			
Hesse	20		
Lower Saxony	25		
3. Great Britain(1)			
East Sussex	18	37	12:1
South Yorkshire	30	38	7:1
Northamptonshire	13	42	9:1
Cornwall	N/A	38	N/A
Hertfordshire	22	N/A	N/A

(1) Edge lines added to roads already centre lined.
(2) Edge lines and post delineators added to roads already centre lined.
Source: Jackson (1981).

The studies in the United Kingdom provided mixed results. In a review of nine British studies Willis et al (1984) concluded that the evidence pointed to a reduction in crash rates as a result of edge marking, and that there were indications that continuous edge lines give better results than the combination of broken lines on good alignment and solid lines in hazardous locations only. A summary of the studies is presented in Table 4.2. Only the East Sussex study has been published in the literature (Charnock and Chessell, 1978).

Fifteen miles (24 km) of rural test road and 18 miles (29 km) of control road with an average AADT of approximately 6200 vehicles were studied in a before and after study in East Sussex. Treatment consisted of continuous reflectorised 100 mm edge lines. Injury crashes for the 2 years prior to and 2 years after edge marking were compared.

A net reduction of 18% compared to the anticipated total number of injury crashes was achieved, i.e. a drop from an expected 65 to 53 crashes for a two-year period. The chi-square test indicated that the results were statistically valid (but level of confidence was not stated). The greatest reduction was in crashes occurring in the dark.

The study also revealed that the greatest benefits accrued on sections of road with good alignment (a 53% reduction) and that both "single vehicle out of control" and "opposite direction crash/conflict" crashes were reduced (by 35% and 29% respectively).

The overall annual reduction is equivalent to 6 injury crashes for 54.4 MVK of travel, or 0.11 crashes per MVK. The resulting benefit to cost ratio is 15:1.

Because the studies reviewed by Willis et al were considered to be generally deficient for results to be accepted with great confidence, Willis et al (1984) set up one extensive controlled trial designed to determine the safety effectiveness of edge lining. A total of 405 km of tested road and 203 km of control road with AADT's ranging from 4200 to 5300 vehicles were studied over a period of 5 years. The results were disappointing in that they demonstrated no evidence that edge lining reduced crashes, though it was pointed out that a larger sample size would have been desirable. However the authors concluded by noting that the East Sussex study which showed significant benefits should not be ignored.

Table 4.2

Summary of Edge Marking Studies in Great Britain

County	Control Site Selection [1]	Length [2] of Road Studied (km)	Number [2] of Crashes in Before Period	Percentage Change in Crashes: Mixed	Percentage Change in Crashes: Continuous	Percentage Change in Crashes: Control	Other Features of Interest	
East Sussex	a	24 (28.8)	68 (80)		-22	-4	Crashes in darkness:	-37% at treated sites +6% at control sites
Buckinghamshire	a	22.7 (48.1)	88 (174)		+1	-3	Crashes in darkness:	+6% at treated sites -34% at control sites
South Yorkshire	b	5 sites unknown length	90 (315)		-13	+17	Crashes in darkness:	-38% at treated sites +29% at control sites
Hertfordshire	b	35 (38)	169 (98)		-59	-22		
Northamptonshire	c	6 sections unknown length	136		-13		Crashes in darkness:	-42%
Staffordshire	b	145	948 (1003)	+26		+11	Crashes in darkness:	+16% at treated sites +12% at control sites
Hampshire	c	16	59		-28			
Hampshire	c	6	4	+75				
Cornwall	b	12 sections unknown length	43 (373)		-14	-12	"Relevant" crashes:	-38% at treated sites -12% at control sites
Lincolnshire	b	357 (310)	324 (221)		+20	-1	Relative increase of 36% on good visibility roads Relative decrease of 17% on poor visibility roads	

Notes: (1) "a" denotes control sites selected by similar criteria as treated sites.
"b" denotes control sites selected by other criteria, so not necessarily a good match for treated sites.
"c" denotes no controls.
(2) First figure relates to treated sites. Figure in parentheses relates to control sites (where known).

Source: Willis et al (1984)

The effect of 150 mm wide edge lines impregnated with glass beads on over 650 km of highway in Western Australia was studied by the Main Roads Department. Moses (1986) reports that whilst the reduction in total crashes was not that great (8%), the reduction in the more severe out-of-control single-vehicle crashes was substantial (34%). He concluded that the cost of the edge lines was recouped in crash savings within 6 months. As the lines are repainted every 2 years, the benefit to cost ratio for crashes savings alone equals 4.

Nicholas Clark and Associates (1984) also reported the results of centre and edge lane marking on 130 km of rural road in Western Australia. Whilst there was an overall decrease in the crash rate on three of the five highways treated, it was concluded that this was more likely the result of the road improvements. However, it was also concluded that centre lines did have a significant effect in reducing multi-vehicle, day-time crashes, and edge lines a significant effect in reducing night-time, single vehicle crashes.

Wider Edge Lines

Wider edge lines have been trialled in 31 states in the U.S. where over 27,000 km of 200 mm edge line have been applied (Senior, 1986; Anonymous, 1986). Whilst controlled before/after crash evaluations have not been undertaken, preliminary evidence indicates significant safety benefits. In Washington State, net reductions ranged from 19% for all crashes and 32% for injury crashes when compared to the standard 100 mm line. A larger sample size was analysed in New Jersey to reveal an 8% net reduction in dry weather crashes compared to 100 mm line marking (statistically significant at the 95% level).

Nedas et al (1982) conducted an experiment using surrogate measures of driver performance to compare the effectiveness of 100 mm and 150 mm wide edge lines. Compared to 100 mm lines, the wider lines were found to provide increased benefits for both alcohol-impaired and unimpaired drivers. Specifically the use of wider lines resulted in drivers centralising their position in the driving lane to a greater degree than the 100 mm line.

Cottrell (1987) also undertook field studies to determine the effectiveness of wide edge lines on lateral placement and speeds of vehicles on rural roads. An investigation of 12 locations on 2 sections of road indicated a significantly lower mean lateral placement with a 200 mm wide line as compared to a 100 mm width. However, the difference was not significant from a practical viewpoint.

Johnston (1983) examined the effects of roadway delineation on curve negotiation. Earlier studies by Johnston (1981) had shown that short-radius curves (less than about 600 m) and curves with a radius significantly lower than curves in the immediately preceding road section are over-represented among the sites of curve crashes. Since over 75% of single-vehicle night time crashes on rural road curves involve alcohol-affected drivers, Johnston included alcohol-impaired drivers in his study. He compared the effects of nine delineation treatments on the driver's cornering performance and speed on a test track under night time conditions. The nine treatments included:

(1) no edge line;
(2) post mounted delineators (with corner-cube delineators);
(3) chevron alignment signs;
(4) 80 mm wide edge lines;
(5) 150 mm wide edge lines;
(6) 4 combined treatments;

Delineation treatments comprising chevron signs, alone and with edge lines (particularly the 150 mm width) resulted in the best performance. However, chevron signs alone encouraged corner-cutting strategies by alcohol-impaired drivers, an effect not apparent when chevrons were combined with edge lines.

The study also found that on a section of alignment comprising several short radius corners, post mounted delineators provided no additional benefits than those available from edge lines alone.

Triggs et al (1979) found the converse to be true in laboratory tests, i.e. post-mounted delineators provided more effective information to drivers than edge lining which was found to be ineffective.

Good and Baxter (1985) also evaluated a variety of delineation treatments on a rural road and found that 150 mm edge lines were more effective than 80 mm lines in aiding driver control in the immediate task (i.e. functioning as short-range delineators). Unlike Johnston, chevrons were found to produce ambiguous results, whereas post-mounted delineators appeared to have marginal effects.

With respect to long-range delineation, however, post-mounted delineators had the greatest effect, indicating the need for a combination of wide edge lines and post-mounted delineators.

4.2.3 Cost-Effectiveness

Benefit to cost ratios of 10:1 and higher have clearly been achieved by edge lining in some circumstances (Jackson 1981 and Willis et al 1984). However the precise circumstances under which the safety effectiveness is maximised cannot be determined from the information provided in the literature as the sections of roads studied most likely featured a broad range of characteristics.

An indicative estimate of cost benefit may be made from the Musick (1960) data although the data quoted makes it difficult to assess the severity improvements achieved. In a length of 98 km, 30 crashes were estimated from a total of 158. Similarly 53 fatalities or injuries (not injury crashes) were eliminated from 143. To achieve a conservative estimate of severity, a factor of 2.5 fatalities or injuries per fatality/injury crash is taken, giving 21 such crashes eliminated from 57.

Type of Crash	Before	After	Redn	Saving ($/Crash)	Savings ($)
Fatality/injury	57	36	21	125,500	2,035,500
Other	101	92	9	2,600	23,400
Total (98 km)	158	128	30		2,058,900
Total/Km	1.61	1.31	0.31		27,100

Taking a 2 year life gives a NPB of $51,500/km.
The cost (including maintenance) is $2,380/km.
The BCR is thus 22:1.

It is also apparent that wider edge lines provide additional benefits. Whilst the safety cost-effectiveness rating may not be increased by wider lines it is of the same order and the additional cost can be justified by the corresponding reduction in the absolute number of crashes.

4.3 RAISED REFLECTIVE PAVEMENT MARKERS

4.3.1 Description

Raised reflective pavement markers (RRPM's) are used to augment or simulate painted lines on the road surface (Australian Standard AS 1742.2-1986). They provide a more effective and durable pavement marker than painted lines because:

- they are not generally obscured at night under wet conditions;
- they provide an audible and tactile signal when traversed by vehicle wheels; and
- they are conspicuous in all conditions.

They are however considerably more costly than painted lines.

4.3.2 Safety Effectiveness

Moses (1985) reports a dramatic reduction in head-on and side-swipe crashes involving vehicles travelling in opposite directions with the installation of RRPM's on undivided roads in Western Australia. Road sections totalling 28 km were treated, and the total number of crashes decreased from 1071 in the 12 months before treatment to 1003 after treatment (a 6% reduction). However, head-on crashes decreased from 33 to 10 and side-swipes with vehicles travelling in opposite directions decreased from 29 to 4 crashes. The reduction was particularly dramatic for night time crashes.

Furthermore, Moses reports the greatest decrease in crash rate for an undivided four lane highway - from 461 to 382 crashes (17%). The cost of the markers on this undivided four lane road was shown to be recouped within two months by crash savings.

A study of 550 km of rural highway in Victoria showed a similar reduction (15%) in the casualty crash rate following the installation of RRPM's (Sanderson and Fildes, 1984). A report to the Victorian Government also reported that RRPM's were found to reduce head-on and single-vehicle crashes, which accounted for 70% of casualty crashes on rural roads in Victoria in 1981, by 20% (Social Development Committee, 1984).

4.3.3 Cost-Effectiveness

From the Moses (1985) report, the yearly crash benefits may be calculated:

Type of Crash	Before	After	Redn	Saving ($/Crash)	Savings ($)
Head-on	33	10	23	65,141[1]	1,498,243
Opposite direction side-swipe	29	4	25	52,112[2]	1,302,800
Other	1009	989	20	21,714[3]	434,270
TOTAL (28 km)	1071	1003	68		3,235,313
TOTAL per km					115,547

Notes: 1 average crash cost x 1.5 severity factor
2 average crash costs x 1.2 severity factor
3 average crash cost x 0.5 severity factor

Severity factors are engineering judgement estimates.

Taking a 5 year life for RRPM's gives a NPB of $47,400/km.
The cost per km (including maintenance) is $5,800.

This gives a BCR of 8:1.

4.4 POST-MOUNTED DELINEATORS

4.4.1 Description

Post mounted delineators have a similar function to raised reflective pavement markers installed on edge lines in that they delineate the edge of the road under night time conditions. They typically consist of reflectors mounted on marker (guide) posts.

4.4.2 Safety Effectiveness

Research on post-mounted delineators has yielded conflicting results.

Vincent (1978) conducted a before/after study on the safety effectiveness of corner-cube delineators mounted on guide posts on a 16 km length of road in Victoria. Comparing the three-year periods before and after replacement of retro-reflective sheeting delineators with corner-cube delineators, revealed a 60% reduction in night time fatal/injury crashes compared to only a 20% reduction during the same period for a control site. However the results could not be considered conclusive and traffic volumes were not provided.

A study conducted in Ohio concluded that 75 mm circular reflectors mounted 1.2 m above the pavement were cost-effective in reducing crashes on all curves greater than 5 degrees (i.e. with radius less than 350 m) and more cost-effective on all curves of 10 degrees or less (radius 175 m or greater) with central angles between 20 and 40 degrees (Taylor and Foody, 1966).

The Federal Highway Administration reported two studies undertaken for post-mounted delineators in the U.S. (Bissell et al 1982). Montana Department of Highways found a 30% reduction in run-off-the-road night time crashes at delineated curve and narrow bridge locations, with larger delineators being more effective. Research also showed that although post-mounted delineators had a negligible effect on lateral placement on tangents, they did affect speeds and placement variance on curved sections.

Jorgensen (1966) reported several studies which demonstrated that post-mounted delineation on curves was very effective at reducing total crashes if there was a high proportion of night time crashes. Reductions of up to 40% of total crashes were reported. The degree of curvature and the central angle influenced the effectiveness of the delineation.

An Arizona study on the other hand found that steel post delineators placed on the outside of the curve had no effect on crash rates (Arizona Highway Department, 1963). Johnston (1983) also found that post-mounted delineators did not enhance the effectiveness of edge lining on short radius curves.

However, a previous study by Triggs et al (1979) which investigated drivers' reaction to various roadway delineation treatments by testing 30 subjects in a laboratory situation indicated that post-mounted delineation provided more effective information to a driver approaching a curve under night conditions than edge lining. In fact, no benefit was found from edge lining.

Good and Baxter (1985) found that post-mounted delineation was effective for long-range information, but did not function effectively as short-range delineators.

Crash figures for Victoria reported by Sanderson and Fildes (1984) show guide posts themselves as having a high crash involvement and severity although work by Pak-Poy and Kneebone (1986) indicates these to be over-reported (see Section 10.1.2).

4.4.3 Cost-Effectiveness

Indications are that post-mounted delineators are potentially as effective as RRPM'S, if not more so under certain conditions. Curves in particular can benefit from this measure.

Based on the percentage reductions reported, a benefit to cost ratio comparable to RRPM's (8:1) can be conservatively expected.

4.5 FURTHER RESEARCH

Jackson's (1981) contention that delineation ranks highly as a safety measure appears to be supported by research in the United States, the United Kingdom and Australia.

All three types of delineation described in this section have high benefit to cost ratios, although additional studies are required to confirm the effectiveness of RRPM's and post-mounted delineators as the number of studies is limited and the level of confidence of the reported results uncertain.

Because of their potential benefits and relatively low cost, additional studies of the measures are warranted and feasible. In particular the following questions need to be addressed:

> What type of location most benefits from delineation, as the characteristics of the road and traffic are not specified in the reports.
>
> What combination of delineation treatments is most effective for various types of road and traffic conditions. This should indicate other forms of delineation as described in Section 4.1.
>
> The actual involvement of guide posts in crashes as distinct from crashes in which the guide post was the first object hit (and thus reported) but damage/injury was caused by something else.

Because all three forms of delineation are widely used, it may be a matter of analysing before and after data (plus suitable control data) available from State authorities.

5.0 SIGNAGE

5.1 DESCRIPTION

"The traffic sign system controls, informs and guides road users so that their journeys are made in a safe and orderly manner. Consequently the elements of the traffic sign system serve, at least, the dual function of improving the efficiency of the roads and the safety of motorists.

Different traffic signs will have a different balance of these two functions, some signs being predominantly safety oriented and some predominantly efficiency oriented. For example a curve warning sign is heavily weighted towards the safety aspect, the function of a guide sign is primarily to improve road efficiency, and a stop sign may be considered to function equally in improving efficiency and safety."

This passage from Jenkins (1986) places road signage in its context in the traffic system as a whole. Both advisory and regulatory signs are used in Australia to control speeds, warn of hazards, direct and inform drivers.

5.2 SAFETY EFFECTIVENESS

Most authors view road signage as an important factor in road safety and crash rates, although Jenkins (1986) expresses doubt about the availability of evidence for this conclusion. He cites Sabey and Staughton (1975) in the UK and Treat (1977) in the USA as showing that around one third of road crashes are caused at least in part by the road environment, but offers no other evidence.

The Texas Transportation Institute refers to a study which found that relatively large decreases in speed were achieved by several alternative sign configurations (both advisory and regulatory) warning of a hazardous horizontal curve in a rural two lane situation, however, no sign configuration was found to be consistently more effective in reducing speeds than another (Bissell et al 1982).

Sanderson & Fildes (1984) reports that Kneebone (1964) has shown that advisory speed signs have been effective in reducing vehicle speeds and the severity of crashes, particularly on bends.

Jackson (1980) reports that improved signing at junctions gave a crash reduction of 34% in Nottinghamshire County. Extensive safety effectiveness estimates are given by ADI Ltd. (1981) for a range of road signs, listed in Table 5.1. Estimated crash rate reductions range from 14% to 75%, and average 37%.

5.3 COST-EFFECTIVENESS

Costs of a range of road signs have been estimated for Canada in 1981 (ADI Ltd., 1981) and are shown in Table 5.2.

The high cost range figures from this table have been multiplied by 1.5 to provide present value 1987 costs in Table 5.3.

Crash cost savings have been estimated using an average crash rate of approximately 1.0 crashes per million vehicles per 0.5 km length of road (ADI Ltd., 1981) for a rural road of 2,000 AADT resulting in approximately one crash per annum.

The average cost of rural road crashes has been taken as $43,427 and present values have been calculated for a common ten year life at a 10% discount rate.

Resultant benefit cost ratios range from two to 750 with an average of 280 and would be approximately proportional to traffic volume.

Jackson (1981) reproduces results from a study by Strate (1978) that indicate a benefit cost ratio of 14 for traffic signs, the highest of any road safety improvement studied.

Table 5.1

Crash Reductions Due to Signage

Sign Type	Source	Total Crash Rate Reduction (%)	Reductions for Specific Crash Types
Intersection Signing			
1. Install Four-Way Stops	Hunter & Council(1975)	70	
2. Change Two-way to Four-Way Stops	Automotive Safety Foundation (1968)	56	67% for head-on crashes. 20% increase for rear end crashes. 75% for right angle crashes. 38% for sideswipe crashes. 33% for left turn crashes. 50% for fixed object crashes.
3. Two-Way Stops	Jorgensen (1966)	65	89% for fatal crashes.
4. Yield Signs	Jorgensen (1966)	59	80% for fatal crashes.
5. Stop Ahead Signs	Jorgensen (1966)	47	96% for fatal crashes.
6. Overhead Lane Signs	Hunter & Council (1975)	15	
7. Regulatory Signs	Pigman (1974)	48	
8. Directional or Warning Signs	Jorgensen (1966) Pigman (1974)	37	19% for fatal crashes.
9. Side Road Signs	Pigman (1974)	19	
10. Side Road and Warning Signs	Pigman (1974)	27	
11. Signs & Markings (General)	Pigman (1974)	24	
Warning Signs			
12. Curve Warning	Jorgensen (1966) Pigman (1974) California DOT (1975)	57 30 20	71% for fatal crashes.
13. Curve Warning & Advisory Speed	California DOT (1975)	20	
14. Advisory Speed Warning	California DOT (1975)	36	

Cont'd.

Table 5.1

Cont'd.

Sign Type	Source	Total Crash Rate Reduction (%)	Reductions for Specific Crash Types
15. Special Curve Warning	California DOT (1975)	75	
16. Stop Ahead Warning	Pigman (1974)	25	
17. Warning (General)	Jorgensen (1966) Hunter & Council (1975) Pigman (1974)	36 20 35	32% for fatal crashes.
General Signing			
18. Regulatory	Pigman (1974)	22	
19. Guidance	Pigman (1974)	14	
Combination of Improvements			
20. Signs and Markings	Jorgensen (1966) Pigman (1974)	22 36	41% for fatal crashes.
21. Signs and Delineators on Curves	Pigman (1974)	28	
22. Signs and Maintenance on Curves	Pigman (1974)	47	
23. Regulatory & Warning Signs at Intersections	Pigman (1974)	16	

Source: ADI (1981)

5.4 FURTHER RESEARCH

Most roads in Australia have good signage and the above benefits are thus not available any more. However, the very high BCR's found would indicate that signage may have a good BCR even at extremely low flows. Further research is thus suggested into signage on low flow local roads.

Table 5.2
Cost-Effectiveness of Signage

ntermeasure	Service Life (Years)	Estimated Crash Reduction[1] (%)	Cost Range	Initial Cost ($)	Annual C&M Cost ($)	Salvage Value ($)	Clarification of Items Included in Countermeasure Cost Estimates
NING							
rsection Signing							
Install Four-Way Stops	10	70	High	260	0	0	4 signs
			Low	130	0	0	2 signs
Change Two-Way to Four-Way Stops	10	56	High	160	0	0	2 signs
			Low	100	0	0	
Two-Way Stops	10	56	High	160	0	0	2 signs
			Low	100	0	0	
Yield Signs	10	59	High	160	0	0	2 signs
			Low	100	0	0	
Stop Ahead Signs	10	47	High	160	0	0	2 signs
			Low	100	0	0	
Overhead Lane Signs	10	15	High	18,000	0	7,000	Signs on overhead aluminium truss
			Low	14,000	0	8,000	(roadway width = 3 lanes)
Regulatory Signs	10	48	High	260	0	0	4 signs
			Low	130	0	0	2 signs
Directional or Warning Signs	10	32	High	260	0	0	4 signs
			Low	130	0	0	2 signs
Side Road Signs	10	19	High	130	0	0	2 signs
			Low	65	0	0	1 sign
Side Road Signs & Warning Signs	10	27	High	260	0	0	4 signs
			Low	130	0	0	2 signs
Signs and Markings (General)	*2	24	High	1,260	0	0	Apply paint and install 4 signs and remove old pavement markings.
			Low	630	0	0	Apply paint and install 2 signs.
ing Signs							
Curve Warning	10	36	High	160	0	0	2 signs
			Low	100	0	0	
Curve Warning & Advisory Speed	10	20	High	300	0	0	4 signs
			Low	200	0	0	
Advisory Speed Warning	10	36	High	160	0	0	2 signs
			Low	100	0	0	
Special Curve Warning	*2	75	High	2,800	120	350	Install 2 signs (each with a warning beacon)
			Low	800	120	350	
Stop Ahead Warning	10	25	High	160	0	0	2 signs
			Low	100	0	0	
Warning (General)	10	30	High	160	0	0	2 signs
			Low	100	0	0	
ral Signing							
Regulatory	10	22	High	160	0	0	2 signs
			Low	100	0	0	
Guidance	10	14	High	160	0	0	2 signs
			Low	100	0	0	
ination of Improvements							
Signs and Markings	*2	29	High	1,500	0	0	Install paint and 8 signs and remove old pavement markings.
			Low	750	0	0	Install paint and 2 signs
Signs and Delineators on Curves	10	29	High	420	45	0	Install 2 signs and delineators
			Low	280	45	0	
Signs and Maintenance on Curves	*2	47	High	3,300	135	0	Grader spread pavement patching & 2 signs
			Low	375	135	0	Manual pavement patching and 2 signs.
Regulatory & Warning Signs at Intersections	10	16	High	500	0	0	8 signs
			Low	250	0	0	4 signs

Estimates of accident reduction levels were obtained from Table 5.1
This countermeasure involves a combination of countermeasures with different service lines. The initial cost is actually the sum of the costs of the various component countermeasures.

e: ADI (1981)

Table 5.3
Benefit Cost Ratios of Signage

		Estimated Crash Reduction (%)	Crash Cost Savings ($)	Road Sign Cost ($)	Benefit Cost Ratio	Ranking
SIGNING						
Intersection Signing						
21.	Install Four-Way Signs	70	201,000	400	500	5
22.	Change Two-Way to Four-Way Stops	56	161,000	250	650	3
23.	Two-Way Stops	65	186,000	250	750	1
24.	Yield Signs	59	169,000	250	700	2
25.	Stop Ahead Signs	47	135,000	250	550	4
26.	Overhead Lane Signs	15	43,000	23,000	2	23
27.	Regulatory Signs	48	138,000	400	350	8
28.	Directional or Warning Signs	32	92,000	400	250	13
29.	Side Road Signs	19	55,000	200	250	11
30.	Side Road Signs and Warning Signs	27	77,000	400	200	14
31.	Signs and Markings (General)	24	59,000	1,900	40	20
Warning Signs						
32.	Curve Warning	36	103,000	250	400	6
33.	Curve Warning & Advisory Speed	20	57,000	450	125	16
34.	Advisory Speed Warning	36	103,000	250	400	7
35.	Special Curve Warning	75	215,000	5,200	40	19
36.	Stop Ahead Warning	25	72,000	250	300	10
37.	Warning (General)	30	86,000	250	390	9
General Signing						
38.	Regulatory	22	63,000	250	250	12
39.	Guidance	14	40,000	250	150	15
Combination of Improvements						
40.	Signs and Markings	29	83,000	2,300	40	21
41.	Signs and Delineators on Curves	29	83,000	1,100	80	17
42.	Signs and Maintenance on Curves	47	135,000	6,300	20	22
43.	Regulatory and Warning Signs at Intersections	16	46,000	750	60	18

Source: ADI (1981)

6.0 PAVEMENT RESURFACING

6.1 DESCRIPTION

Low frictional characteristics of worn or poorly constructed road surfaces have been identified by many studies (Galloway et al 1982, Road Traffic Authority, 1986, McCullough & Hankins 1966, Roy Jorgensen & Associates 1978, Lamm (1984)) as being a significant contributor to road crashes. In these crashes, the frictional grip of the tyres on the road is not sufficient to prevent skidding, and consequently control of vehicle direction and speed is lost to some extent. This is particularly significant on wet road surfaces and causes a further reduction in tyre grip and, in extreme cases, hydroplaning.

Remedies for these problems involve either resurfacing the road pavement (usually with a sprayed seal or open graded asphaltic concrete overlay) or modifying the existing surface (most commonly by transverse or longitudinal grooving) (Galloway et al 1982). These procedures result in a rougher road surface with improved friction characteristics particularly for wet conditions where the aggregate or groove height is sufficient to prevent a layer of water developing between road and tyre.

6.2 SAFETY EFFECTIVENESS

Research on surface properties of pavements was undertaken by the Texas Highway Department in the early 60's (McCullough & Hankins, 1966) using a random sample of 517 predominantly rural test road sections in Texas. Distributions of occurrence of friction coefficient measured at both 20 and 50 mph (32 and 80 kph) were developed as shown in Figure 6.1 and 6.2 (McCullough & Hankins, 1966).

Crash data from these 517 test sections in relation to friction coefficient are shown in Figures 6.3, 6.4, 6.5 and 6.6 for 20 and 50 mph and for both total crashes and fatal and injury crashes. The same data is presented in cumulative percentage terms in Figure 6.7 and 6.8 (McCullough & Hankins 1966).

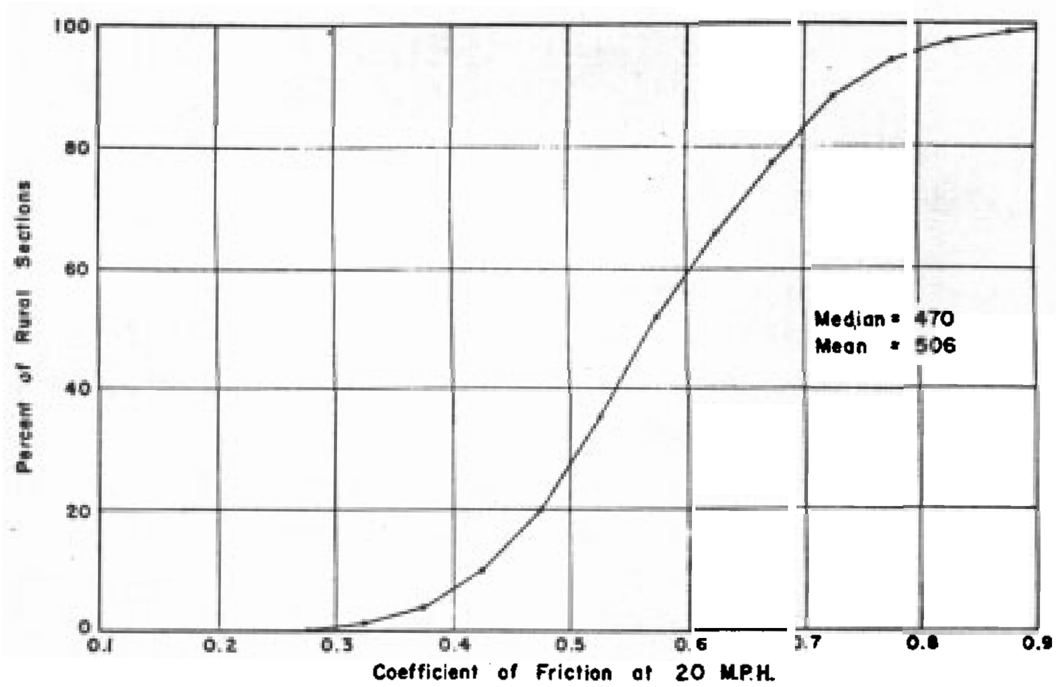


Figure 6.1:

Cumulative Percent of Rural Section Compared With Coefficient of Friction at 20 mph (32 kph)

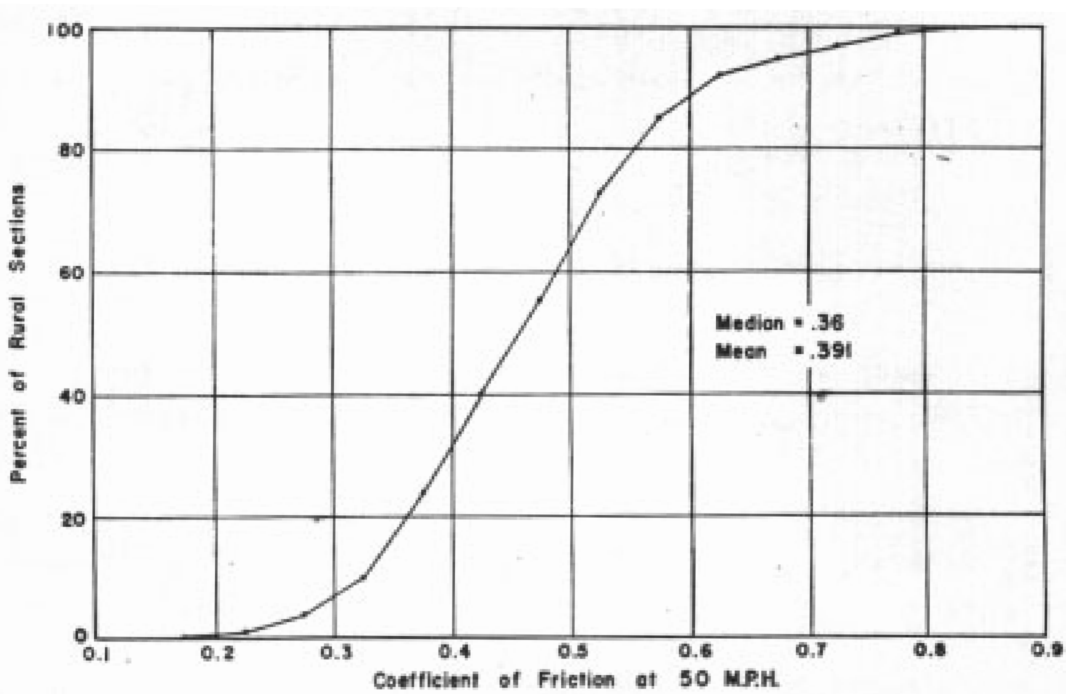


Figure 6.2

Cumulative Percent of Rural Section Compared With Coefficient of Friction at 50 mph (80 kph)

Source: McCullough & Hankins (1966).

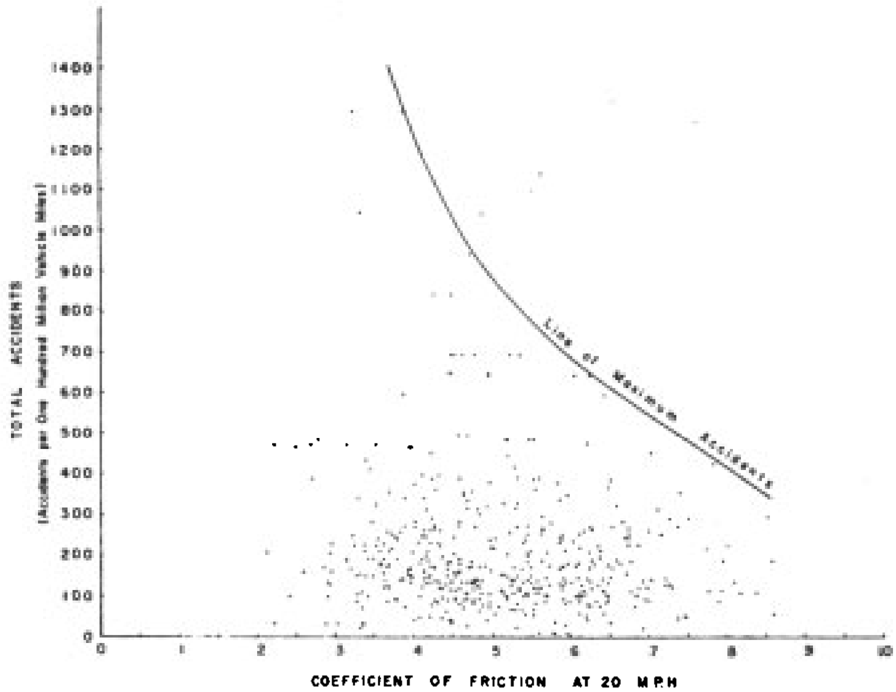


Figure 6.3

Comparison of Total Crashes and Coefficient of Friction at 20 mph (32 kph)

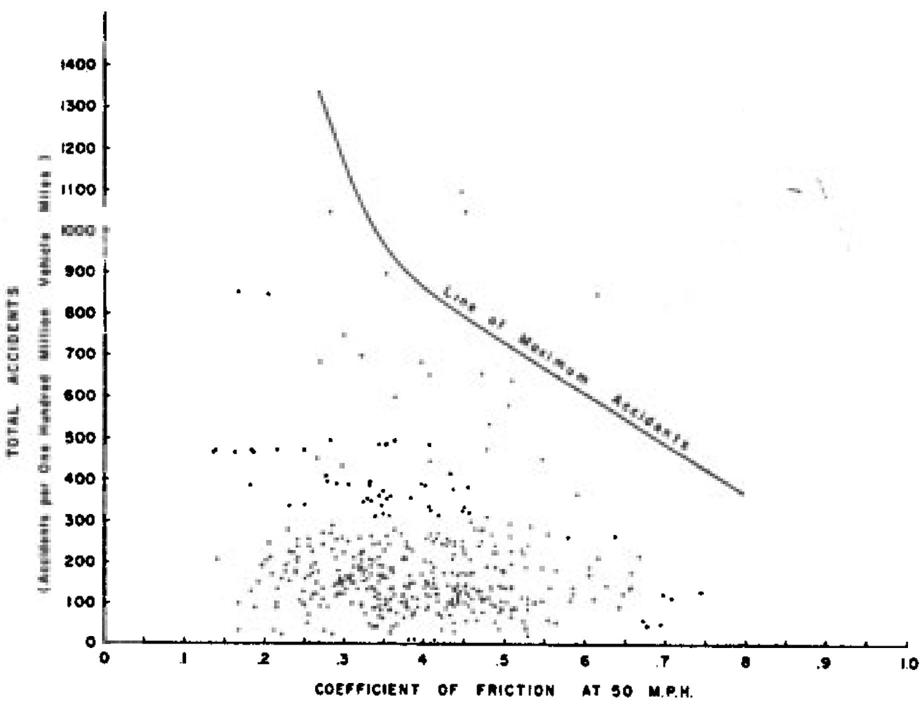


Figure 6.4

Comparison of Total Crashes and Coefficient of Friction at 50 mph (80 kph)

Source: McCullough & Hankins (1966)

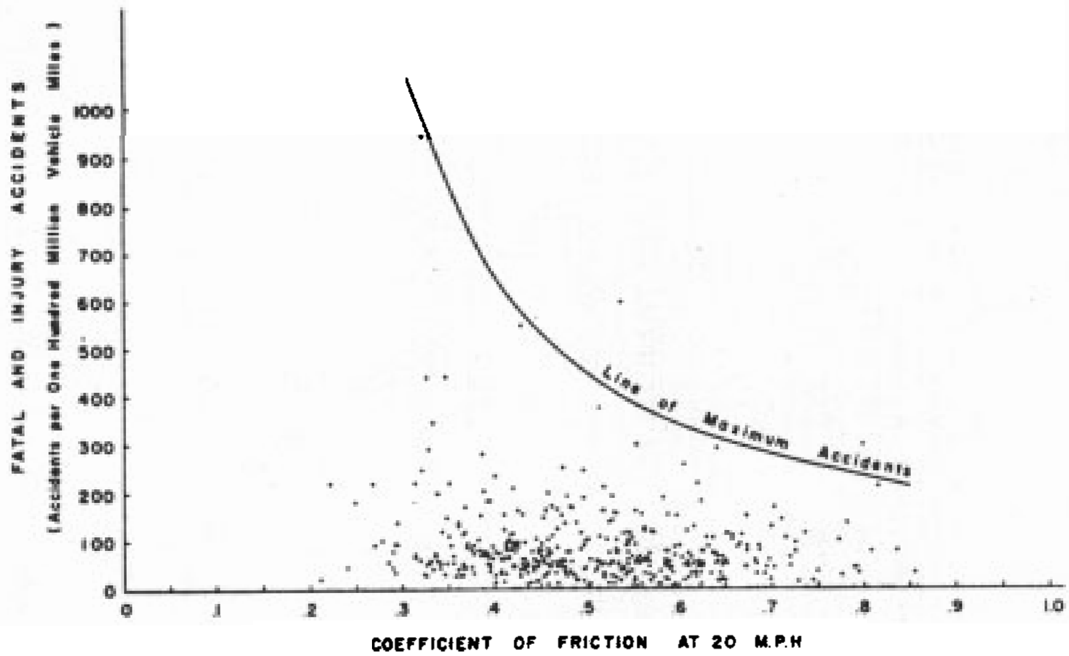


Figure 6.5

Comparison of Fatal and Injury Crashes and Coefficient of Friction at 20 mph (32 kph)

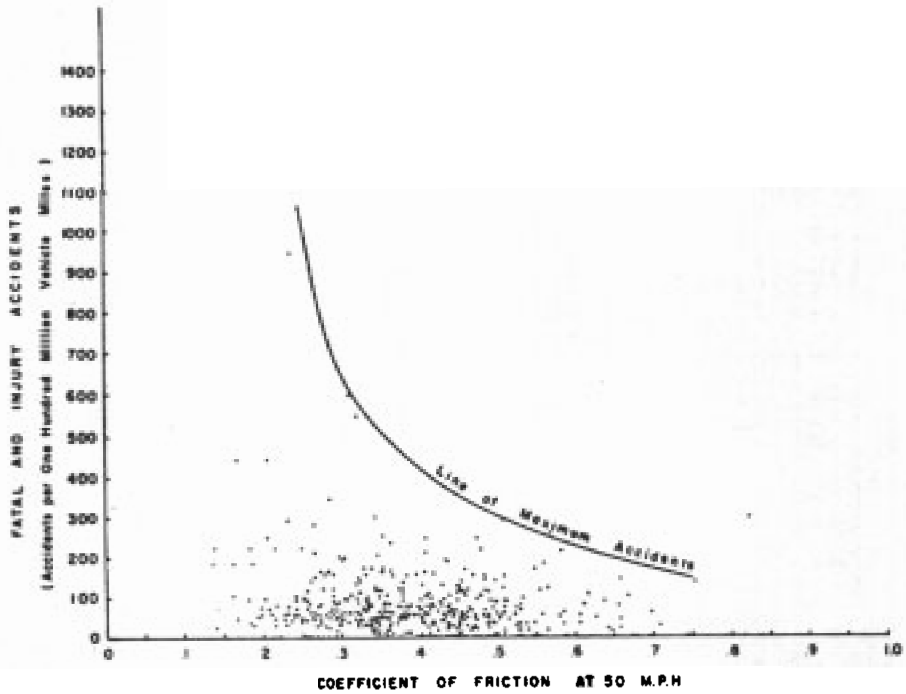


Figure 6.6

Comparison of Fatal and Injury Crashes and Coefficient of Friction at 50 mph (80 kph)

Source: McCullough & Hankins (1966)

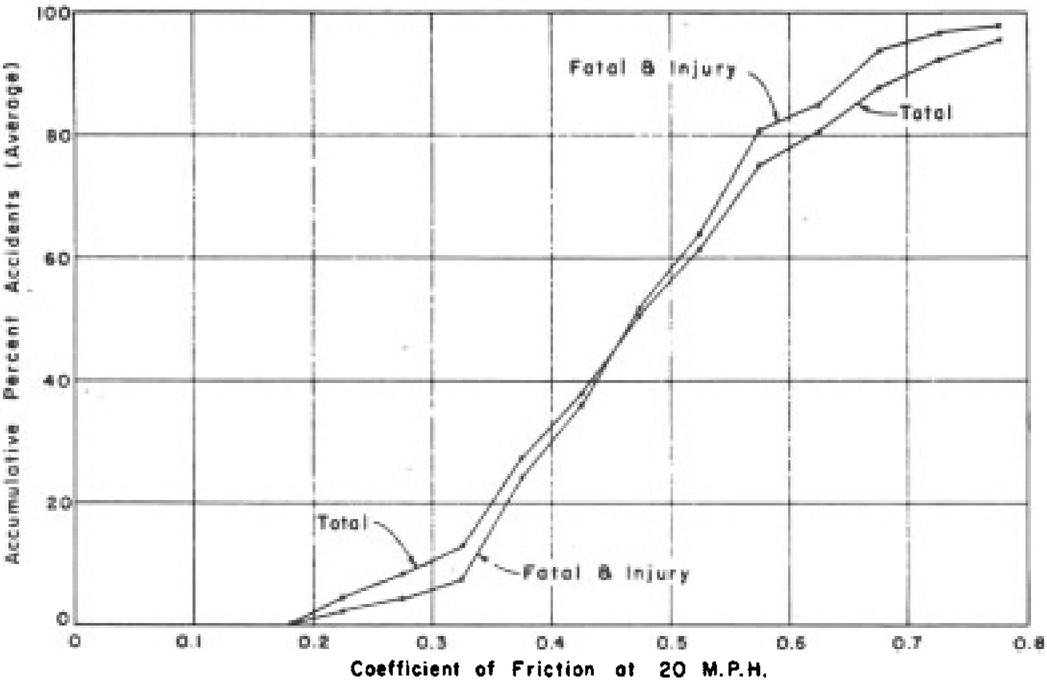


Figure 6.7

Study of Average Cumulative Percent Crashes and Coefficient of Friction at 20 mph (32 kph)

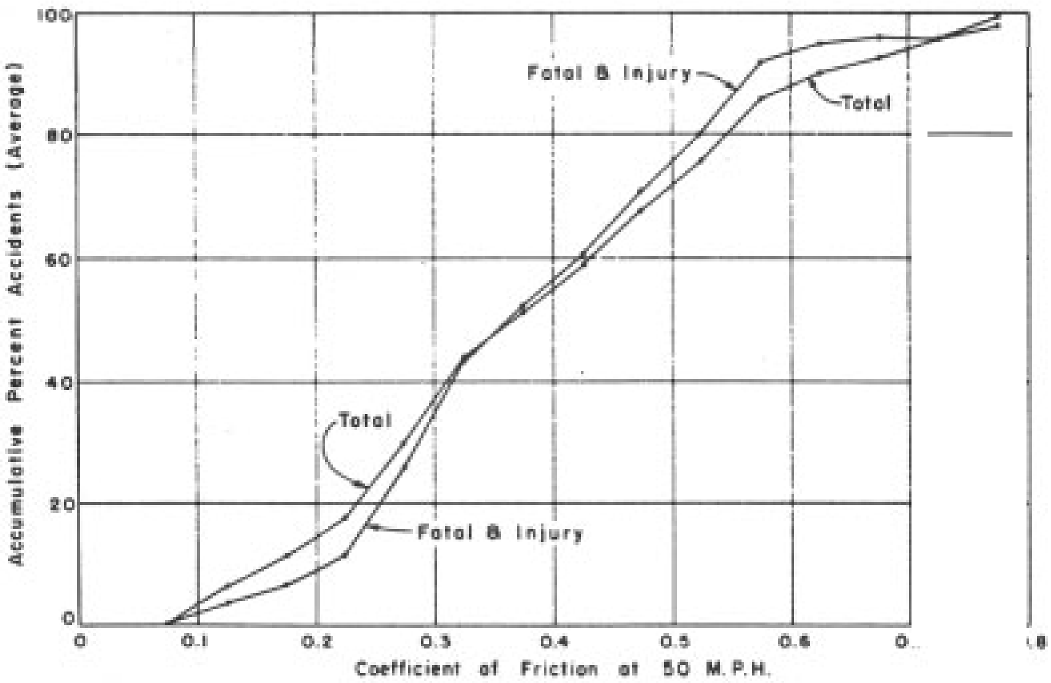


Figure 6.8

Study of Average Cumulative Percent Crashes and Coefficient of Friction at 50 mph (80 kph)

Source: McCullough & Hankins (1966)

The authors (McCullough & Hankins) conclude from these graphs of crash data that minimum desirable friction coefficients to limit crash rates are 0.4 (measured at 20 mph) and 0.3 (measured at 50 mph). Figures 6.1 and 6.2 have indicated that 27% of Texas highways do not meet this 20 mph (32 kph) friction criteria and 32% fall below the 50 mph (80 kph) criteria.

It can also be concluded from Figures 6.7 and 6.8 that crash severity would be reduced as well as crash occurrence.

McCullough & Hankins (1966) also obtained data on crash reductions due to an asphaltic concrete overlay on a previously longitudinally grooved pavement. These are shown in Table 6.1, with friction coefficients measured at 30 mph (48 kph) on wet pavements.

Table 6.1

Crash Reductions Due to Overlays

Section	Coefficient Before	Coefficient After	Crashes[a] Before (1963)	Crashes[a] After[b] (1964)	Percent Reductions in Crashes
1	.275	.462	974	560	42.5
2	.275	.359	1,272	814	36.0
3	.275	.467	931	620	33.4
Sawed Concrete	.275		960	770	19.8

a. Crashes are given per 100 million vehicle miles based on one year of observations.

b. "After" crashes have been extrapolated to a yearly basis from seven months of information.

Source: McCullough & Hankins (1966)

This data demonstrates crash reductions of between 14 and 23%, which is consistent with the survey data in Figures 6.3, 6.4, 6.5 and 6.6, and shows that resurfacing of road pavements can reap significant reductions in crash rates.

McCullough & Hankins also quote other researchers to show that skidding crashes occur chiefly in wet weather and friction coefficients are lower under wet conditions and therefore that crashes are "in some way" related to skid resistance.

In this regard Giles and Sabey (1959) of the Road Research Laboratory, United Kingdom, report that 8% of the total number of crashes in dry conditions involved skidding, whereas 27% of the total number of crashes on wet roads involved skidding. Mills (1959) of Virginia reports 0.66% of the total number of crashes in dry conditions were skidding crashes and 14.65% of the total number of crashes on wet roads were skidding crashes. Mills also reports that skidding "of some nature" occurred in 35% of 37,507 crashes during 1956 in Virginia. Werner (1959) reports that from 1953 to 1956 in open country one crash out of every four or five involved slippery road conditions as a cause in Germany. Giles and Sabey (1959) reports that urban areas, even though they have the majority of crashes, are by no means the chief areas, since over one third of all skids on wet roads occur on rural roads in the U.K.

A study by Burns and Peters (1973), quoted in the report prepared by Roy Jorgensen Associates (1978), concluded that most wet weather crashes occurred on low skid resistance road surfaces. It was discovered that 29% of wet weather crashes in Arizona occurred on the less than 3% of the highway system with (MU-meter measured) friction coefficients below 40 and 43% of wet weather crashes occurred on the 7% of roads with coefficients below 50. The distribution of skid resistance readings for Arizona is shown in Figure 6.9.

Also quoted in the Roy Jorgensen report (1978) was the study by Mahone and Runkle (1972) in which the relationship of the "predicted stopping distance number" (PSDN) with the percentage of wet weather crashes for various site categories (shown in Figure 6.10) was developed from an examination of 521 sections of interstate highway in Virginia. As expected, the percent of wet weather crashes was higher for low PSDNs.

Jorgensen (1978) reports another study of 501 wet weather crashes in Texas by Hankins et al (1971) where five factors were believed to be important to the wet weather crash rate, listed in order of importance.

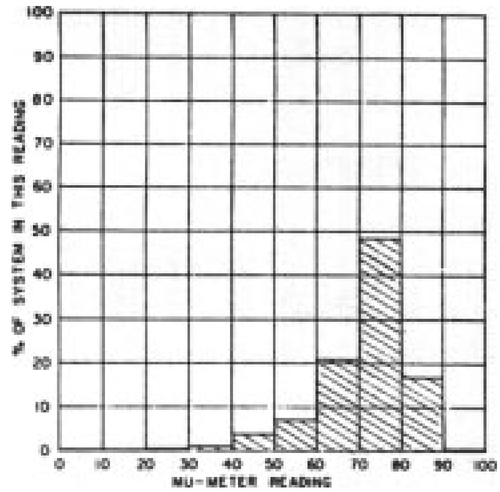


Figure 6.9

Interstate, State and U.S. Highway Friction Levels

Source: Burns & Peters (1973)

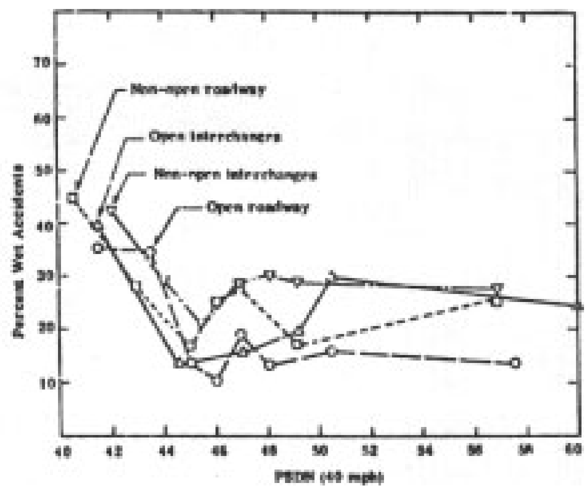


Figure 6.10

Summary of Skid Numbers Versus Percentage of Wet Crashes For all Four Site Categories

Source: Mahone & Runkel (1972)

1. The texture of the pavement at the crash site was fine macro-texture (TX).
2. The tread depths of the vehicle involved were small (TD).
3. The friction value of the pavement at the crash site was low (FR).
4. The speed of the vehicle immediately prior to the crash was high (SP).
5. The tire pressures of the crash vehicle were high (PR).

An important additional finding was made, namely that 40% of the wet-weather crashes involved a turning manoeuvre.

To gain better insight to the problem, crashes were classified as follows in Table 6.2 from Hankins et al (1971), and an analysis of variance was performed.

Table 6.2

Classification of Crashes

Description	Category Number	Crashes Number	Crashes Percent
Crashes occurring on a tangent or straight roadway section with no braking involved	1	57	14.4
Crashes occurring on curves	2	125	31.5
Crashes occurring on a tangent with braking involved	3	42	10.6
Crashes involving multiple vehicles	4	56	14.2
Crashes occurring while passing	5	28	7.1
Miscellaneous crashes	6	88	22.2
Crashes in categories 1, 2, 3 and 5	7	252	63.6
Crashes in all categories	8	396	100.0

Source: Hankins et al (1971)

The results of the analysis showed the variables in order of importance for each crash category, as well as the direction of influence of each variable on the crash rate, as shown below.

(i.e. "-TX" indicates that an increase in pavement texture produced a decrease in crash rate for that category).

Category	Variable Order				
1	-TX	+SP	-TD	-FR	+PR
2	-TD	-FR	+PR	+SP	-TX
3	-FR	+PR	-TX	+SP	-TD
4	-SP	+TD	-FR	+PR	-TX
5	-TX	+SP	-PR	-TD	-FR
6	+PR	-TD	-TX	-SP	-FR
8	-TX	-FR	+PR	-TD	+SP

Adam and Shah (1974), as reported in Jorgensen (1978), support McCullough and Hankins' (1966) conclusions that significant crash rate declines can be produced by resurfacing. Adam and Shah found that wet weather crashes in particular were reduced, as shown in Table 6.3.

Table 6.3

Crash Reduction Before and After Resurfacing

Period	Crashes Total	Crashes Wet	Crashes Percent Wet	Rain Factor*	Crash Rate Total (mvm)	Crash Rate Wet	Crash Rate Reduction Total (%)	Crash Rate Reduction Wet
Before								
January 1970 to May 1970	37	21	56.7	70	3.78	114.1		
After								
June 1970 to December 1970	38	9	21.0	84	2.80	41.1	25.9	64.0
December 1970 to June 1971	17	2	11.8	29	1.72	28.6	54.5	74.9
June 1971 to December 1971	38	5	31.2	96	2.78	19.2	26.5	83.2

* Number of one hour periods during which 0.1 in (2.5 mm) or more rain was recorded.

Source: Adam and Shah (1974)

Numerous studies of the relationship of wet weather crash rate to skid resistance were reported in Galloway et al (1982) as shown in the following graphs Figures 6.11 to 6.18.

Holbrook (1976) reports a wet pavement crash rate decline of approximately 25% due to pavement resurfacing at intersections as shown in Table 6.4.

Kummer & Meyer (1967) provide recommendations for minimum skid resistance requirements as presented in Table 6.5.

Table 6.4

Wet Surface Crash Prevention Benefits with Intersection Resurfacing

Basis of Computations	Number Wet Pavement Crashes		Location Months		Wet Pavements Crashes Per Location Per Month		Wet Pavement Crash Rate Decline	Estimated Number of Wet Pavement Crashes Prevented During the First Year After Resurfacing
	Before	After	Before	After	Before	After		
Police Files	556	590	384	526	1.45	1.12	-23%	120
Model Predictions	618	635	384	526	1.61	1.21	-25%	144

Source: Holbrook (1976)

Table 6.5

Tentative Interim Skid Resistance Requirements For Main Rural Highways(a)

Traffic Speed (mph/kph)	Recommended Minimum SN(b) Measured At Traffic Speed	Recommended Minimum SN(b) Measured At 40 mph (64 kph)
30/48	36	31
40/64	33	33
50/80	32	37
60/97	31	41
70/113	31	46

(a) From Table 18, NCHRP Report 37. These values are recommended for main rural two-lane highways. For limited access highways lower values may be sufficient, whereas certain sites may require higher values.
(b) SN - skid number, measured according to ASTM Method E274.
Source: Kummer & Meyer (1967).

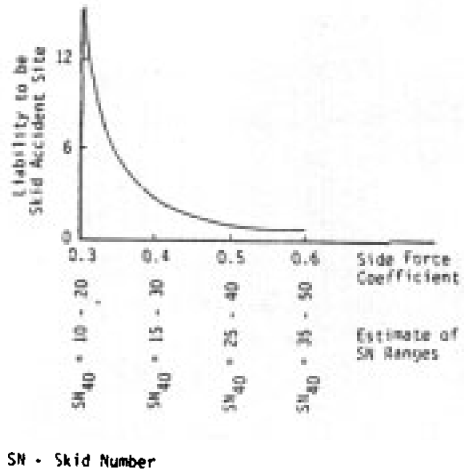


Figure 6.11

Estimate of the Liability to be a Skid Crash Site

Source: Ivey & Griffin (1977); Giles (1957)

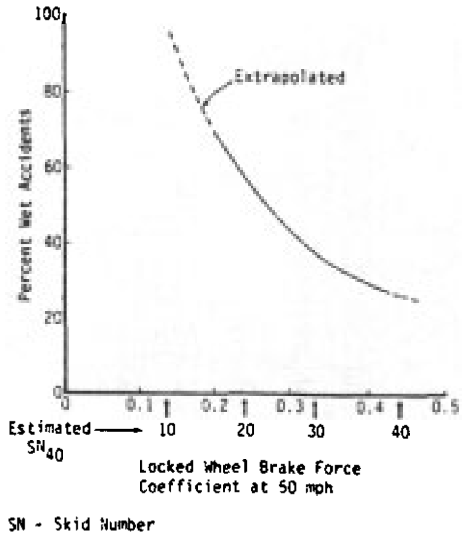


Figure 6.12

Wet Pavement Crash Sensitivity to Pavement Friction

Source: Schulze (1975)

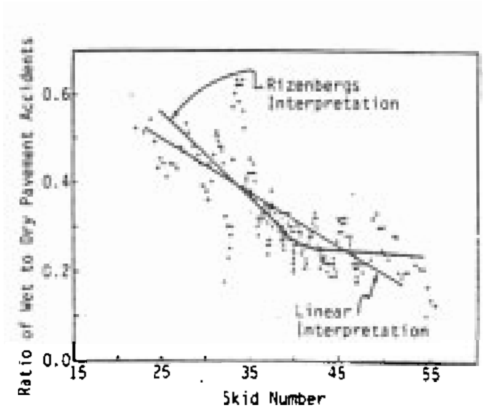


Figure 6.13

Ratio of Wet to Dry Pavement Crashes Versus Skid Number

Source: Rizenbergs et al (1976)

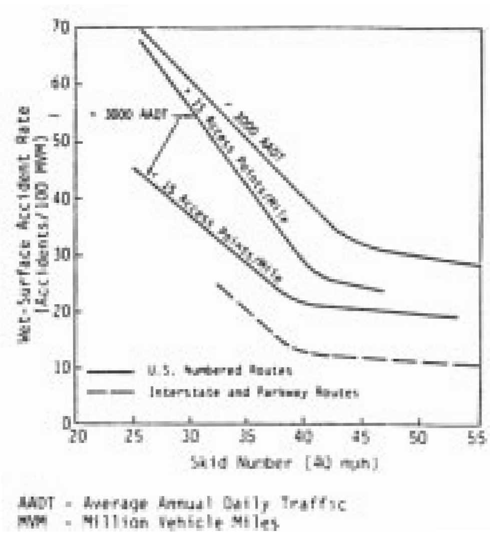
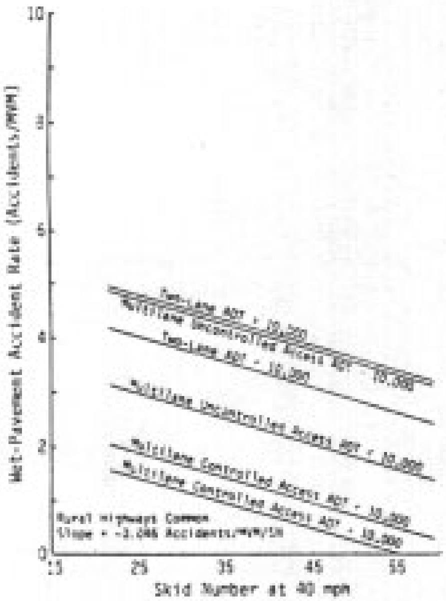


Figure 6.14

Relationship Between Wet-Surface Crash Rate and Skid Number

Source: Havens et al (1974)

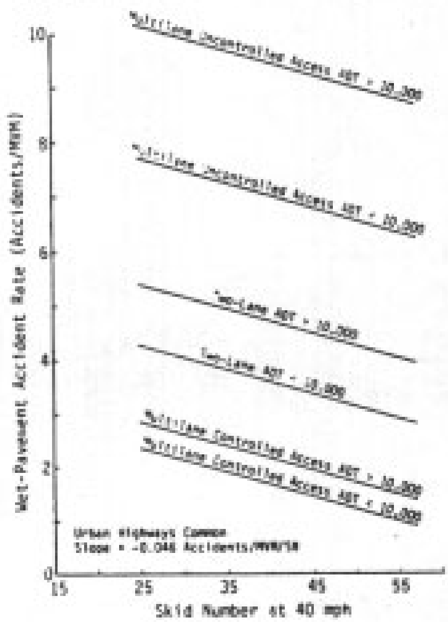


ADT - Average Daily Traffic
MVM - Million Vehicle Miles
SN - Skid Number

Figure 6.15

Relationship Between Wet-Pavement Crash Rate and Skid Number at 40 mph (64 kph) for Rural Highways

Source: Blackburn et al (1978)



ADT - Average Daily Traffic
MVM - Million Vehicle Miles
SN - Skid Number

Figure 6.16

Relationship Between Wet-Pavement Crash Rate and Skid Number at 40 mph (64 kph) for Urban Highways

Source: Blackburn et al (1978)

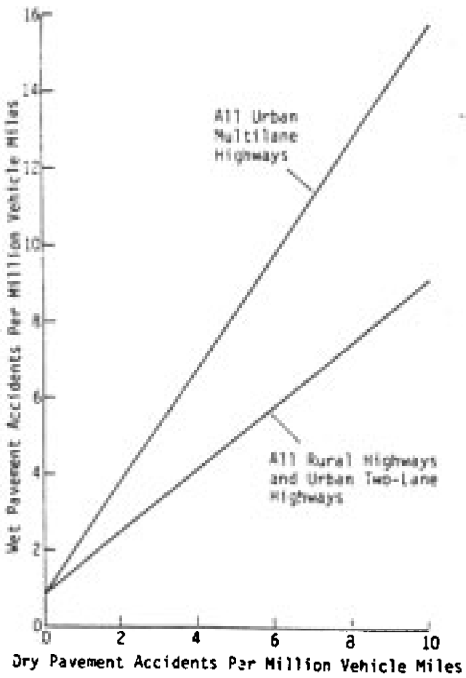


Figure 6.17

Relation Between Dry-Pavement and Wet-Pavement Crash Rates

Source: Blackburn et al (1978)

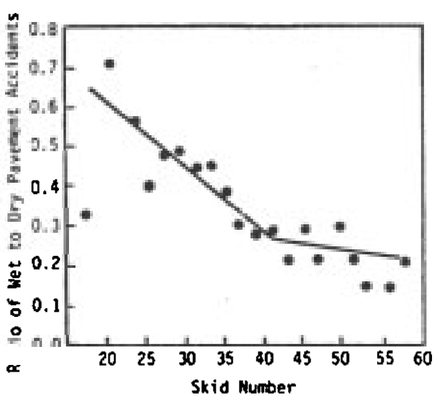


Figure 6.18

Ratio of Wet to Dry Pavement Crashes to 230 Test Sections in Kentucky - Grouped by Skid Number - versus Skid Number

Source: Rizenbergs et al (1976); Holbrook (1976).

Galloway et al (1982) also reports reductions in crash rates due to grooving of pavement surface. Table 6.6 shows results from 14 locations in the Los Angeles area from Farnsworth (1969).

Table 6.6

Summary of Crashes at Pavement Grooving Locations in Los Angeles

Pavement Location and Type Route	Milepost From	Milepost To	Pavement Type	Grooving Pattern (Inches) Depth	Width	Pitch	Before Crashes Years	Dry	Wet	After Crashes Years	Dry	Wet
LA-5	78.6	78.9	PCC	1/8	1/8	1/2	2	2	7	7	32	0
Ora-5	23.3	23.6	PCC	1/8	1/8	1/2	3	17	55	4	22	6
LA-405	2.1	2.6	PCC	1/8	1/8	1	1	10	20	4	34	1
LA-405	4.9	6.1	PCC	1/8	1/8	3/4	1	41	61	3	123	8
LA-101	0.5	0.8	PCC	1/8	1/8	3/4	1	28	23	2	42	3
LA-5	29.5	30.5	PCC	1/8	1/8	3/4	1	10	12	3	20	5
LA-102	8.9	9.3	AC	1/4	1/4	1	1	55	139	3	116	26
LA-101*	7.7	8.9	AC	1/8	1/8	3/4	2	110	89	1	47	14
LA-10	22.6	22.8	PCC	1/8	1/8	3/4	1	17	26	4	23	5
LA-10	44.9	45.6	PCC	0.095	1/8	3/4	2	79	35	1.5	62	3
Ven-101	27.0	27.6	PCC	1/8	1/8	3/4	3	16	8	2	10	1
Ven-191	29.0	29.7	PCC	1/8	1/8	3/4	3	20	16	2	9	1
LA-5	75.0	75.5	AC	1/8	1/8	3/4	3	12	14	1	3	0
Ven-101	10.9	11.2	PCC	1/8	1/8	3/4	1	3	10	2	8	3
TOTALS							25	420	515	39.5	551	76

* Southbound only
PCC Portland Cement Concrete
AC Asphaltic Concrete
Source: Farnsworth (1969)

In this study, dry weather crashes were reduced by 17% and wet weather crashes by 90%, giving an overall reduction of 48%. A similar study by Beck (1974) showed reductions in crash rates of around 75% due to grooving on an expressway with traffic levels of around 50,000 vpd, as shown in Table 6.7.

In this study, although it was found that skid resistance had reverted to pre-grooving levels by 1974 due to wear, crash rates remained low.

Table 6.7

Wet Surface Crashes on the Jones Falls Expressway

	Before Grooving 1968	1969	After Grooving 1971	1972	1973	1974	1975
Grooved Sections (G)	54	57	20	31	14	25	22
Non Grooved Sections (NG)	86	62	82	118	105	55	63
Ratio G/NG	0.63	0.91	0.24	0.26	0.13	0.45	0.36

The actual groove depths wore down over the years.
Source: Beck (1974)

Other studies reported by Galloway et al (1982) showed a 69% reduction in wet pavement crash rates in California (Smith and Elliott, 1975), a 136% increase in dry pavement crashes with a 50% decrease in wet pavement crashes in Ohio (Long, 1971), and a 27% reduction in wet weather crashes in Louisiana (Walters & Ashby, 1974) due to grooving of the pavement surface.

Galloway et al (1982) have less information on the effectiveness of resurfacing pavements. Kamel and Gartshore (1980) are reported as identifying 461 highway locations in Ontario, Canada (46.1 km of pavement) with an excessive rate of wet pavement collisions, i.e. - three or more wet pavement crashes and a ratio of wet to total crashes greater than 30%. Crash rate reductions resulting from laying an "open graded friction course" at these locations are shown in Table 6.8.

In Australia, studies by the Department of Main Roads (DMR), NSW (1986) on the Pacific Highway indicate that resealing of selected sections with high wet weather crash rates could reduce the wet to total crash ratio to 30% or less, and therefore reduce total crash rates by 11.7%. The Road Traffic Authority (RTA) in Victoria (1986) estimates potential crash rate reductions of at least 6% due to resealing.

This data gives some indication of the range of distribution of frictional characteristics of Australian roads.

Table 6.8

Ontario's Wet Crash Reduction Program Results

Type Roadway	Number Sites	Years	Wet Crashes Before	Wet Crashes After	Wet Crashes Change	Total Crashes Before	Total Crashes After	Total Crashes Change
Freeways	8	1976-78	257	118	-54%	742	524	-29%
Intersections	5	1977-78	35	10	-71%	71	38	-46%

Source: Kamel & Gartshore (1980)

It is reasonable that crash rate reductions available from skid resistance improvements in Australia should be lower than in the USA, Britain or Germany, due to two factors:

1. generally lower traffic levels; and
2. less frequent incidence of wet weather.

The overseas data seems to indicate available crash rate reductions of from 25% to 75% with the higher figures coming from heavier trafficked conditions. Thus adopting a base figure of 25% from overseas rural experience, and introducing the two factors above for conversion to Australian conditions, reductions of around 5-10%, depending on traffic volume and weather patterns, would be a reasonable estimate for Australian conditions, consistent with DMR-NSW and RTA-Victoria estimates.

6.3 COST-EFFECTIVENESS

6.3.1 Treatment Costs

The DMR-NSW (1986) report estimates resealing costs at around $20,000 per kilometre for the Pacific Highway, based on $2.00/m^2. Information from recent work in Australia indicates that grooving would be a similar cost, while open graded asphaltic concrete would be of the order of $4 to $5/m^2 for a 25 mm overlay, i.e. 2 to 2.5 times the cost of a sprayed reseal or grooving treatment. Asphaltic concrete would in general be used only on heavy trafficked, high speed roads such as urban or major inter-urban freeways.

The RTA in Victoria (1986) estimates treatment costs variously as $18,000 or $30,000 per site.

6.3.2 Crash Occurrence

The actual number of crashes is a parameter that must be ascertained for the site(s) under consideration for treatment, and this will determine the cost-effectiveness of treatment adopted for that site. The Federal Office of Road Safety (1984) data indicates the total number of road crashes in 1983 to be 580,000.

The proportions of occurrence of various categories of crashes are shown in Table 6.9, derived from three sources:

1. Federal Office of Road Safety (1984) for Australia;
2. DMR-NSW (1986) for Pacific Highway;
3. SA (1986) for S.A. Rural Roads.

Table 6.9

Relationship of Crashes to Traffic Volumes

Crash	% Occurrence Australia	 Pacific Highway	 S.A. Rural Roads(1)
Fatal	0.6	1.9	3.7
Injury	11.4	21.2	32.8
Property	88.0	76.9	63.5
Severity Index	4.8	9.3	15.0

(1) Refer Section 2.0.

It is evident from these figures that fatal and injury crashes increase as a proportion of total crashes as traffic volumes decrease, i.e. from the predominantly urban data for Australia as a whole, to the major inter-urban Pacific Highway, to the very low trafficked S.A. rural roads.

6.3.3 Benefit Cost Ratio

DMR-NSW (1986) cost figures for rural crashes are $474,000 for a fatality crash, $16,300 for an injury crash and $2,700 for a property damage only crash.

The DMR-NSW (1986) evaluation gave an additional expenditure on reseal work of $4m over ten years, resulting in crash savings as indicated in Table 6.10.

Amortisation of the costs and savings gave a benefit cost ratio of 8.8.

Table 6.10

Crash Savings

	Total Crashes Per Year	Number Reduced Per Year (*)	$ Saved (*)
Fatal	56	6.5	3,080,000
Injury	630	73	1,190,000
Property	2,280	266	720,000
			4,990,000

* This is the number reduced after the three year resealing increase and maintained thereafter.

The crash savings are:

Year 1:	1,660,000
Year 2:	3,320,000
Year 3:	4,990,000
Years 4-10:	34,930,000
TOTAL	45,000,000

The RTA, Victoria (1986) has estimated benefits of skid resistance surface treatments as $30,000-$40,000 and costs as $30,000 p.a. per site giving a benefit cost ratio of 1.2. Elsewhere, the Authority (1986) has given crash reductions of at least 6% in Victoria and costs as $18,000 per site, giving a benefit cost ratio of between 1 and 2. These ratios are much lower for this general Victorian work than for the specific Pacific Highway Study undertaken by the DMR-NSW.

Using the preceding conclusions, it is possible to make some independent estimate of the likely benefit cost ratio for skid resistance treatments given the assumptions detailed in Table 6.11. From this type of analysis, it is possible to estimate the benefit cost ratio of skid resistance treatment for a site with a particular crash frequency.

Table 6.11

Skid Resistance Treatments

	Major Rural Highway	Minor Rural Road
Crash rate reduction	10%	5%
% of Total		
Fatal	2%	4%
Injury	21%	33%
Property	77%	63%
Cost of Crashes		
. Fatal	$474,000	$474,000
. Injury	$16,300	$16,300
. Property	$2,700	$2,700
Annual Number of Crashes at Site	X	Y
Annual Cost of Crashes at Site	$15,000 X	$26,000 Y
Annual Cost Saving due Crash Reduction	$1,500 X	$1,300 Y
Area of Reseal	9 m x 1,000 m	7 m x 500 m

(Cont'd)

Table 6.11

(Cont'd)

	Major Rural Highway	Minor Rural Road
Cost of Reseal (every 10 years)	$18,000	$7,000
Discount Rate	8%	8%
Present Value of Cost Savings	$11,000 X	$9,500 Y
Annual no. of Crashes at Site for:		
B/C = 1	X = 1.6	Y = 0.7
2	3.2	1.5
3	4.9	2.2
5	8.2	3.7
10	16.3	7.4
B/C Ratio for Annual No. of crashes		
X = Y = 1	B/C = 0.6	B/C = 1.4
2	1.4	2.7
3	1.8	4.1
5	3.0	6.8
10	6.1	13.6
"Worst Case" Annual Crash Rate	12	3
Benefit Cost Ratio	7.3	4.1

It can be seen from this exercise that treatment for a major rural road would be cost-effective at locations with an annual crash rate greater than 1.6, and for a minor rural road at a rate greater than 0.7. Anticipated benefit cost ratios for "worst case" annual crash rates of 12 for major and three for minor rural roads are 7.3 and 4.1 respectively. These annual crash rates are most likely to be experienced at rural intersections and on isolated curves.

6.4 FURTHER RESEARCH

Further research to investigate the substantial difference in benefits found in NSW and in Victoria would be useful.