OFFICE OF ROAD SAFETY

DOCUMENT RETRIEVAL INFORMATION

Report No.	Date	ISBN	Pages
Cr 22	February 1984	0 642 509883	97

Title and Subtitle

EVALUATION OF THE EFFECTIVENESS
OF MITERS TYPE PROJECTS

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Keywords

Site Improvements/Academic Locations/Traffic Engineering/
Site Treatments/Evaluation/MITERS.

Abstract

This report describes the results of an evaluation of minor traffic engineering projects carried out in South Australia and Western Australia during the period 1974 to 1980. The report finds that these minor traffic engineering improvements were highly cost effective in reducing accident numbers.

It however, recommends that more attention in the choice of sites to the potential for accident reduction could increase further the cost effectiveness of these traffic engineering expenditure.

The methodology used was described in an earlier Office of Road Safety Report No. Cr 8, ISBN 0 642 51082 2.

Note:

This study was commissioned by the Office of Road Safety and the Report is disseminated in the interest of information exchange.

The views expressed in this Report are those of the author and do not necessarily represent those of the Commonwealth Government.

EVALUATION

OF THE EFFECTIVENESS

OF MITERS TYPE PROJECTS

FEBRUARY 1984

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CHAPTER 1

INTRODUCTION

1.1 The MITERS program

From 1974-75 to 1979-1980 the Commonwealth Government provided grants to the States to enable them to undertake minor improvements in traffic engineering for road safety. The program became known by its acronym MITERS.

While it was in operation, States submitted details of minor traffic engineering projects for approval for funding in the MITERS program. Initially the maximum cost of projects eligible for funding was $50,000 (though this was later raised to $100,000), a relatively low value for road and traffic engineering projects. This limit was selected to increase the number of projects which could be funded with the budget of the program which, for example, was $13.7 m in 1975-76, the first full year of operation. It was assumed that a large number of projects would result in the greatest benefit and ensure maximum overall impact on the road safety problem.

Traffic engineering projects which were eligible for funding in the program included:

(a) traffic signals;

(b) road signs and pavement marking;

(c) speed control systems;

(d) elimination of intersections on arterial roads, modification of multi-street intersections, provision of median strips or new or modified traffic islands and roundabouts;

(e) pedestrian crossings (including flood lighting) and the provision of pedestrian safety zones;

(f) localised improvements to street lighting, or new lighting at isolated locations;

(g) bus stopping bays;

(h) turning lanes, channelisation and lane marking;

(i) use of slip-base and frangible street lighting poles and sign supports at locations with high accident records;

(j) relocation or protection of roadside objects at hazardous locations;

(k) protection devices at railway crossings;

(l) the adjustment to super-elevation on curves and improvement of visibility on crests or curves;

(m) provision of guardrails on embankments, curves and bridge approaches.

(n) other low cost safety treatments.

Projects were approved for inclusion in the program if they were likely to reduce accidents in a cost effective manner. Over the years of the program a substantial body of information on traffic engineering projects was developed. Prior to the current project, there has been no review of the overall effectiveness of these projects in reducing road accidents.

This is the report of the evaluation of the safety effectiveness and the cost effectiveness of the minor traffic engineering projects carried out in South Australia between 1974 and 1978, and Western Australia between 1977 and 1979. In the case of South Australia, all projects in the evaluation were MITERS projects, but in Western Australia, MITERS type projects funded from State financial sources were also included.

All minor traffic engineering projects for which suitable data could be found were included in the analysis irrespective of their original source of funding. However some low cost safety measures, such as skid treatments, were <u>not</u> included either because data was not available on these measures, or these measures were not applied during the period studied in the states surveyed in this project.

This report therefore does not purport to cover all low cost traffic engineering measures.

The study, commissioned in 1978 by the Office of Road Safety of the Federal Department of Transport, proceeded in two stages. Firstly, there was an examination of the statistical methods available to measure satisfactorily the safety effectiveness of these minor traffic engineering projects.

The feasibility study (Clark, Gipps, MacLean & Teale, 1979), demonstrated that satisfactory statistical tests could be developed to measure the actual effect of these projects on accident numbers and accident severities.

The second stage, the main study which is covered by this report, was carried out with the cooperation and assistance of the Highways Department of South Australia and the Department of Main Roads of Western Australia.

1.2 Statistical techniques

This report presents the results of the evaluation, and in its statistical and data annexes, deals with mathematical and theoretical concepts involved in the evaluation.

Measurement of the effectiveness of all accident countermeasures is affected greatly by uncertainty about the significance of what has actually been observed. For example, an observed reduction in accident numbers from one year to another could have occurred in any case, without the accident countermeasure.

The statistical techniques used in the study to adjust for this problem, and many others, are reported (Clark, Gipps, MacLean & Teale, 1979). Their application to this evaluation is described in Appendix C of this report. Other problems caused by uncertainty about the reliability of data which were available for this study, particularly records of accidents and traffic flows at sites of improvements, are described in Appendix D.

The basic methodology used was the before and after technique. In this technique the accident rates at a site before treatment are compared with accident rates at a site after treatment.

Use of one site first without, and then with the treatment, matches all site characteristics except for those relating to the treatment and traffic volumes. Unfortunately measurements of traffic volumes are rarely sufficiently frequent or accurate to allow reasonable estimates of changes in traffic volumes at a site. One of the main reasons for this is the lack of data on local seasonal traffic patterns to allow realistic comparison with other traffic counts that may be taken at a different time of year. Hence, in general, traffic counts could only be used to detect sites where traffic volumes changed substantially from normal growth patterns. Such sites had to be excluded.

However, there are many other factors that vary over time which may affect accident rates. To control the effects of these factors, a separate control group was used. The control groups that were chosen were made as large as possible to minimise the effects of statistical variation within the control groups. The way that this was done is explained in more detail in the appendices, and briefly described below.

1.3 Use of control groups and factors

For selection of control groups the State was divided into four zones as follows:

1. City
2. Urban
3. Country towns
4. Rural areas.

The control group was selected from the zone where the site itself was located.

Both States have a classification hierarchy for roads. A non-intersection site was deemed to have this classification while an intersection site was deemed to have the highest classification of any of the roads meeting at the intersection.

Sites were only included in the control group if they had the same classification as the site being examined. However, if the resultant control group would have less than 200 accidents per year, this condition was relaxed. This minimised random fluctuations introduced by the control group at the expense of some slight possible bias in the control group.

TABLE 1.1

Control Groups

Project	Description	Control Group
106	Convert cross intersection to T junction	All non-signalised four way intersections
110	Median closure	All non-signalised intersections
131,133, 261,262	Street lighting	New and upgraded street lighting
172	Safety bars	All intersections
200	Modify signals	All signalised intersections
201	New signals	All non-signalised intersections
202	New channels at signalised intersection (including signal modification)	All signalised intersections
204	Modify channelisation	All signalised intersections
205	Roundabout	All non-signalised intersections with four or more legs
214	Additional lanes at non-signalised intersection	All non-signalised intersections with four or more legs

215	New channelisation	All non-signalised intersections with four or more legs
241	New pedestrian signals	All non-intersection sites (note most accidents did not involve pedestrians)
243	Pedestrian refuge islands	All intersections and non-intersection sites
251	Realign short section	All non-intersection sites
256	Median installation	All non-intersection sites on same classification road
352	Signal coordination	All signalised intersections
400	New signals & channelisation	All non-signalised intersections
401	Modify signals & channelisation	All signalised intersections
402	New signals and channel modifications	All non-signalised intersections
403	Street closures	All intersections on same classification road
404	Roundabout (part of area traffic management)	All non-signalised intersections with four or more legs
410	Street lighting (general)	All non-intersection sites
411	Parking control	All sites (in zone)
413	Rail crossing	All rail crossings (in zone)
440	Zebra crossing	All non-signalised sites
441	Zebra crossing with channelisation	All non-signalised sites
450	Pedestrian protection	All sites (in zone)
999	Cycle way	All sites (in zone)

1.4 Summary of results

The following general conclusions may be drawn from this study.

- The projects funded by the MITERS program (and similar State programs) were effective in reducing the number of accidents of all types.
- The projects did not reduce the ratio of severe accidents (those involving injury to persons) to all accidents, although they did reduce the number of persons injured through the overall reduction in the number of accidents.
- The projects were highly cost effective when their cost is compared with the saving in injury and accident costs.
- The data suggests that projects were not necessarily implemented at locations where there was a history of a large number of accidents. There appeared to be some selection of projects on the basis of perceived hazard, that is the likelihood of causing accidents, rather than on the basis of numbers of accidents recorded.
- Almost all types of projects were effective in reducing accidents and were also cost effective. There was far greater variation in both safety and cost effectiveness between projects of the same type than there was between the average effectiveness of different project types.
- No evidence could be found to demonstrate a reduction in effectiveness in later years compared to earlier years of the program. This suggests that continuation of the program, in one form or another, is justified.
- The average reduction in accident numbers brought about by each type of project is shown in Table 1.2

The MITERS program was highly cost effective in reducing accidents, and it appears that such a program could continue to be effective in accident reduction. Concentration on sites with high accident numbers, however, could further increase the number of accidents avoided for the same budgetary outlays.

TABLE 1.2

Average effectiveness of project types

Classification number	Description	% Reduction in accidents SA Point est-imate	SA 90% confid-ence inter-val	WA Point est-imate	WA 90% confid-ence inter-val
106	Convert cross intersection to T junction	47%	28%,66%	84%	69%,99%
110	Median closure	59%	43%,75%	5%	-39%,49%
131	New street lighting	45%	16%,74%		
133	Upgrade street lighting	- 7%	-39%,25%		
172	Safety bars	14%	4%,24%		
200	Modify signals	14%	10%,18%	36%	20%,52%
201	New signals	19%	12%,26%	20%	14%,26%
202	New channels at signalised intersection (including signal modifications)			41%	35%,47%
203	Modify channels at signal-ised intersection			-69%	-137%,-1%
204	Modify channelisation			6%	-21%,33%
205	Roundabout	57%	52%,62%		
214	Additional lanes at non-signalised intersection	22%	8%,36%		
215	New channelisation	17%	10%,24%	22%	12%,32%
216	Modify channelisation	-117%	-164%,-70%	28%	9%,47%
241	New Pedestrian signals	39%	32%,46%		
243	Pedestrian refuge islands			38%	28%,48%
251	Realign short section	26%	3%,49%	42%	-62%,100%

256	Median installation			77%	37%,100%
352	Signal coordination	-29%	-74%,16%		
400	New signals & channelisation	40%	35%,45%	46%	32%,60%
401	Modify signals & channel-isation	-20%	-30%,-10%	-6%	-66%,54%
402	New signals and channel modifications			24%	10%,38%
403	Street closures	77%	73%,81%		
404	Roundabout (part of area traffic management)	65%	35%,95%		
407	School pedestrian crossing	21%	-8%,50%		
410	Street lighting (general)	58%	35%,81%		
411	Parking control	26%	-18%,70%		
413	Rail crossing	-10%	-145%,100%		
440	Zebra crossing			-66%	-175%,43%
441	Zebra crossing with channelisation			10%	-97%,100%
450	Pedestrian protection			23%	-27%,73%
999	Cycle way			82%	-5%,100%

NOTE 1 Negative numbers indicate an **INCREASE** in accident rates

2 This table covers projects studiedµ i.e. projects in S.A. and/or W.A. where suitable data was available. It does **NOT** cover all minor traffic engineering projects

CHAPTER 2

EFFECTIVENESS IN ACCIDENT REDUCTION

2.1 Introduction

In this chapter the effectiveness of broad classes of projects is discussed. Detailed results for specific project types are presented in Appendices A and B giving project descriptions and the results of the study. More detailed listings of accident data, rates etc. for individual sites are contained in a series of working papers prepared during the evaluation. These are held by the Office of Road Safety.

The projects studied were predominantly in urban areas. Nevertheless all MITERS type projects in rural areas were included in the analysis.

While there were no major differences in the cost effectiveness of different project types, there were major differences in the cost effectiveness of specific treatments. This arose, not because of variations in the effectiveness of treatments in reducing hazard, but in the scope for accident reduction. That is, the same treatment was applied in different locations where the accident rates in the before periods were vastly different. In general there was no evidence of concentration on specific project types.

The low rural traffic volumes in the States examined mean that few rural projects could be justified on a cost effective basis.

Rural traffic flows are much lower in these two States than in the Eastern States. Hence there could be considerably more scope for minor traffic engineering in rural areas of the Eastern States.

While the treatments even at the sites with lower accident rates in the before period were effective in reducing accidents, and indeed cost effective, they were not as cost effective as similar type treatments at sites with higher accident rates in the before period as projects had similar percentage reductions in accident rates.

To ensure that the greatest number of accidents are prevented with the funds spent on minor traffic engineering improvement, there is a case for the review of existing warrants for installation to, require either higher accident rates or higher traffic volumes to justify specific treatments. The purpose of this move would be to rearrange priorities for treatments.

However, it would certainly be necessary to review warrants regularly, relaxing requirements as soon as it became clear that most of the sites meeting the current warrants had been treated. It would also be necessary to ensure that this stiffening of warrants was not interpreted as a signal that less funding was required for minor traffic engineering. In addition, it is also necessary to consider the place of minor traffic improvements in comprehensive area traffic management procedures where the desired effect on traffic flows and the numbers and types of accidents is achieved by an integrated program of traffic management works which may include street closures, street narrowing as well as more conventional traffic engineering works.

It must be stressed that this study has concluded that treatments that meet current traffic engineering warrants are cost effective in reducing accidents. However, there are still many minor engineering improvements awaiting implementation which have a cost benefit ratio much greater than unity. The above suggestions are purely designed to ensure that projects with the highest cost benefit ratios receive priority.

2.2 Urban non-intersection projects.

While the great majority of urban projects were intersection treatments, some mid-block projects were carried out. These included:

Lighting
Median closures

Pedestrian crossings refuges and/or signals.

Lighting

Accident numbers were not sufficient to allow detailed analysis of street lighting projects. However, the main benefits of lighting installations appear to have been in reducing right angle accidents at intersections and not in avoiding mid-block rear end or sideswipe accidents or pedestrian accidents.

Median closures

Whether median closures should be classified as mid-block or intersection treatments is a moot point. However they cause substantial rerouting of traffic and this creates problems in analysing their overall safety impact. Available data is not usually sufficient to determine the rerouting that has occurred, and so detailed examination of these project types would require the setting up of an evaluation program along with the commissioning of such projects.

The system effects of these treatments must be determined to evaluate fully the safety impact of these treatments. From this study there is limited statistical evidence that accident rates at the treated sites dropped more than the corresponding exposure indices, or the likely increases in accident rates at nearby sites. If this is so, then more closures and the introduction of further limited access arrangements on roads with medium traffic flows would be justified on safety grounds. However, in-depth studies of such projects need to be carried out first before this conclusion is accepted.

Pedestrian crossing treatments

Very few accidents at pedestrian crossing sites actually directly involve pedestrians. Indeed, even though accidents where pedestrians are involved are serious, as they nearly always involve injury, few pedestrian crossing treatments of any type could be justified purely on the reduction in pedestrian accidents.

However all types of pedestrian crossing treatments had major effects on vehicle-vehicle accidents, which make up the great majority of accidents at these sites. All types of treatments (including signals) reduced the number of rear end collisions at these sites. Rear end collisions in all instances were the chief type of accident occurring at these sites. Thus it is quite clear that the main problem is the sudden manoeuvre or stop to avoid pedestrians. Motorists clearly make every attempt to avoid pedestrians, and this often leads them into an accident with other vehicles. A major aim of pedestrian crossing treatments then is to stop unexpected interruption of the traffic stream by pedestrians. The reduction in vehicle-vehicle accidents is an important part of the justification of pedestrian crossing treatments.

2.3 Intersection treatments

There are a range of intersection treatments which differ substantially in cost. These are discussed in order of increasing cost. The cheaper treatments, while often effective from a safety angle, are not operationally suitable for higher traffic volume sites.

Low cost treatments

For low to medium traffic flows, there are several inexpensive but operationally acceptable treatments. The first is partial closure of intersections resulting in major rerouting of traffic. This procedure, however, reduces the number of possible turning options at each specific site, and hence the variety of conflict situations. The systems effects of such projects may be considerable, but could not always be calculated due to lack of suitable data. However, from analysis of accident types at specific intersections, these schemes do seem to have reduced the total number of accidents.

Partial closures may also be used to control entry onto major arterials; again there is some evidence that this technique could be used more widely with safety benefits, though operational inconvenience to users of the system would have to be considered.

Other low cost intersection control options that are available are small roundabouts and stop or giveway signs. Small roundabouts (created by raising the centre of an existing intersection, and possibly rounding off the existing kerbs) are usually only operationally acceptable at the intersection of local roads, while signs can be used on local road intersections as well as on entries to major arterials. Both approaches are highly effective, reducing the accident rate by at least half.

Roundabouts appeared to be slightly more effective on local road intersections than signs though, of course, they are more expensive. **Sign installations controlling entry to** major arterials appeared slightly more effective than installations on local road intersections. No significant difference could be detected between initial installations of giveway and stop signs. **However different warrants apply** and so they are installed in different situations. Where conditions changed and giveway signs were replaced by stop signs, there was a further improvement in safety, indicating some benefit from the enforced stop in addition to the giveway requirement. There were, however, major differences in effect from site to site that call for careful individual site examination before any sign is installed.

When the costs of sign installations are considered, they are the most cost effective measure that was examined.

Medium cost treatments

For intersections carrying larger traffic volumes, the only treatments that are operationally acceptable are large roundabouts or some combination of channelisation and/or signalisation. These treatments are of course considerably more expensive. Options for installation of channels or large roundabouts may be highly restricted, particularly in inner urban areas, by space availability.

The safety impact of signal and channel installations varies very markedly with the precise details of the installation. For example the order of phases in a signal installation may affect their safety.

In many cases there are opportunities to improve the safety of installations with detailed upgrading. For example, old electro-mechanical traffic signal controllers have frequently been replaced with modern microprocessor controllers to reduce maintenance costs. These upgradings have increased the flexibility of signal phasing at the site. They have also had safety benefits due to the improved phasing arrangements and a reduction in the time that the installation is out of action.

The old adage that signals reduce right angle collisions and increase rear end collisions is only partly true. Where signals were installed with appropriate phasing patterns and with channels to separate turning vehicles, rear end collisions actually decreased. However where signals were installed with no changes in road layout, there was an increase in rear end collisions.

Fortunately the design features which are introduced to improve operation or capacity of a site also usually improve the safety of the site. The initial upgrading of the phasing pattern from a two-phase layout to a multi-phase layout with specific turning phases (as a result of replacing an old controller) is certainly the most cost effective of all signal treatments from a safety point of view. It may however increase average delays for traffic. Amongst the other options - new signal installations, further modification of phasing patterns, channel installations or combinations of these - there appears to be little difference in cost effectiveness.

At signal installations, several types of accidents may occur, including:-

a) Rear end collisions between through vehicles
b) Rear end or sideswipe collisions between a vehicle turning and a following through vehicle, or between a through vehicle swerving round a turning vehicle and a following vehicle
c) Head on or indirect right angle collisions between a turning vehicle and oncoming vehicles travelling in the opposite direction

d) Right angle collisions between vehicles approaching on two legs which are approximately at right angles.

A simple installation of signals with two phases will reduce type (d) accidents but actually increase the numbers of type (a) accidents. The effects on (b) and (c) may be quite variable. This will often lead to a decrease in the average severity of accidents.

Many of the rear end collisions are of type (a), and the number of these can be further exacerbated by some co-ordination plans. A coordination plan cannot let platoons on all legs stay intact, but usually has to favour one direction. The statistical evidence of this study suggests that the drivers in the rear of platoons may anticipate clearing signals but end up running into the rear of earlier members of the platoon.

The primary safety effect of the introduction of additional turning phases, which are often necessary for operational reasons, is the reduction of accidents of type (c). However, a reduction of type (b) accidents may also occur. The installation of channels is complementary to the introduction of turning phases. Their primary safety effect appears to be a reduction of type (b) accidents though they also do reduce type (c) accidents. Statistical fluctuations are too large to ascertain whether the combined effect of these two measures are greater than the sum of the individual effects, but the contribution to safety of the two components is certainly of the same order.

While in general these installations are beneficial, no general rules can be given for their optimal design. The effects of alterations were found to be very variable indeed. In some cases substantial increases in accident rates occurred.

2.4 Rural projects

There were only a few rural projects that could be studied in either State. The accident rates at the few sites available for study were in most cases too low to allow any reasonable analysis. This is due both to the very low traffic flows in the rural areas of these States, and the relatively few low cost treatments that are appropriate in rural areas. Projects in rural areas fell into the following categories:

- Traffic signals or channelisation of intersections in country towns
- Flashing lights or boom gates at rail crossings
- Realignment of small sections or adjustment of super-elevations
- Line marking on rural highways.

Except for line marking, there were insufficient numbers of accidents to evaluate these rural projects effectively. However the following comments may be made:

The treatments examined were:

i) Intersection treatments in country towns.
While the effects of these treatments seem to have been similar to those observed in the metropolitan areas, accident rates were not sufficiently high for any statistically valid conclusions to be drawn. Though they appear to have been as effective as urban projects in reducing hazard and accident rates, they were not as cost effective as many urban projects. Even if they had eliminated all accidents at the sites treated, the number of accidents avoided would be lower than the number of accidents avoided by a similar urban treatment due to the much lower traffic volumes in the country centres.

ii) Rail crossing treatments.
Both boom gates and flashing lights were examined. Both treatments were effective in reducing the accident rate. However, the accident rates were too low to permit comparison of the treatments. The accidents at these sites in the before period had been very severe.

The large number of rail crossing treatments, and the cost of these treatments, deserve special mention. Ten flashing light installations whose average cost was \$25,100 and five boom gates whose average cost was \$37,100 were examined. The average number of accidents per year (averaged over all sites) in the before period was less than 0.5, although these were severe.

However, even allowing for the high severity of these accidents, rail crossing treatments were not as cost effective as many projects on urban arterials. Most of the sites treated had accident rates in the before period of less than one accident per year. This suggests a preoccupation with the safety of rail crossings.

iii) Realignment and/or super-elevation adjustment of short sections.
Accident rates at such sites were far too low to allow any realistic analysis.

iv) Line marking on rural highways.
Centre line marking has long been considered a safety measure. The results confirm this for the roads examined in Western Australia. The effect is seen through a reduction in daytime head on and sideswipe accidents relative to other accident types. However other changes both to the roads themselves and regulation and policing of rural roads preclude an estimate of the effect of centrelining as an individual factor.

Some edgelining was also carried out in Western Australia under the maintenance program. The Department of Main Roads has found that edgelining decreases the amount of shoulder maintenance required. This study, however, was concerned with the safety aspects of edgelining. It has caused a significant decrease in single vehicle night time accidents. Again it was not possible to estimate the size of the effect due to other complicating factors.

CHAPTER 3

COST EFFECTIVENESS IN ACCIDENT COUNTERMEASURES

All the projects types examined were cost effective. Indeed, the costs of these projects were so low compared to the real costs of accidents that any project that could be shown to have reduced the accident rate was cost effective.

In discussing cost effectiveness great care must be taken to distinguish the value of dollars quoted. In this section, unless specifically stated to the contrary, dollars are taken to be June 1982 dollars.

At a practical level, the costs of some projects could not be determined and so the sample used to estimate the cost effectiveness of a project type was a subset of the sample used to estimate the safety effectiveness. Hence there may appear to be some slight changes in order between the safety effectiveness and cost effectiveness results. However there are no substantial differences, and these differences are, in any case smaller than uncertainties in costing accidents.

In estimating the cost effectiveness of these projects there were two major factors which did not arise in the estimation of the safety effectiveness of projects.

Briefly these were:

1. Assignment of a cost to a road accident
2. Non-reporting of accidents.

When calculating the cost effectiveness of the measure it is clearly essential to estimate the number of accidents that have been avoided rather than the drop in the reported number of accidents. Hence it was necessary to estimate the number of accidents which were not reported. The methodology used is described in Appendix C but a summary of conclusions is given below.

Conveniently the reporting rates for accidents in S.A. and

W.A. were similar in the base years used for the adjustment of accident statistics. These base years were 1975 for S.A. and 1978 for W.A. For these years, for each report of an accident an average of

- 0.005 fatal accidents (all reported)
- 0.19 injury accidents (good estimate)
- 1.64 property damage only (PDO) accidents (estimated - many unreported)

occurred.

No apparent change in accident severity (i.e percentage of injury vs PDO) was detected as a result of most of the treatments. Hence the above breakdown of a reported accident can be used for both the before and after period.

The analysis then can be conducted in terms of the cost of a "reported" accident, where each "reported" accident is a composite of the above accident types in the above proportions.

On the above reporting rates, it is thus estimated that each accident reported (of any type) represented (on average) a cost to the community for fatalities, injuries and property damage of approximately $7,000 in June 1982 dollars.

Estimates of the costs of each type of crash vary greatly depending on the costs considered attributable to a motor accident. There are many grey areas such as lost productivity of workers involved in accidents.

However, to obtain the above figure, the following commonly accepted costs were used and converted to 1982 dollars.

	Original cost	1982 cost
Fatality cost (Sims & Dobinson, 1979)	$130,000	173,000
Personal injury costs (Troy & Butlin, revised by UNSW, 1976)	$ 3,185	5,560
Repair costs (Searles, 1975)	$ 1,340	2,700

Weighting the costs by the proportions above to make up the average composite accident gives a cost for a "reported" accident of $7,000 in June, 1982 dollars.

The major cost of most minor traffic engineering improvement projects is the initial installation cost. However, the installation will have a useful life of many years, and so benefits will accrue into the future. Accruing benefits for ten years and discounting future benefits by 10% (a very high rate for use in social benefit analyses) a project that reduced the accident rate by one reported accident per year would, on a conservative estimate, have a current benefit value in 1982 dollars of $48,000. If the project also decreased the severity of accidents, then this figure would be higher. Turned round the other way, minor traffic engineering projects are cost effective if they reduce the reported accident rate by as little as 0.02 accidents per year for each thousand dollars capital cost.

It is not hard to see that minor traffic engineering projects may be highly cost effective. In fact any project types that were shown to be effective in reducing the accident rate were also cost effective. The statistical error in estimating the number of accidents avoided per thousand dollars spent was often greater than the number required for cost effectiveness.

Table 3.1 shows that the capital costs of traffic engineering projects, that were actually effective in reducing accidents, were recouped in under three years. Some site treatments had very high benefit/cost ratios, while very few individual site treatments were not justified on a benefit/cost basis.

In the projects examined in this study, there were huge differences in cost effectiveness of specific treatments within the one project type. This was far more marked than differences in the average cost effectiveness of different project types.

In terms of safety improvements for dollars spent, there is no evidence that there has been over-concentration either on specific project types or specific classes of roads. However, there would appear to be a need to review selection procedures for sites to be treated.

The huge variation in cost effectiveness of projects of one type arose not from variations in cost or safety effectiveness in reducing hazard, but in the initial number of accidents occurring before treatment; that is, the product of hazard and traffic volumes (or exposure). Thus this major variation in cost effectiveness could have been expected before projects were initiated.

The following tables show the number of reported accidents avoided per year per thousand dollars spent on counter-measures. The large variability of these estimates as quoted by their standard deviation preclude all but a few comparisons of cost effectiveness.

There are other theoretical reasons as well for avoiding many of these comparisons, as discussed in Appendix D.

TABLE 3.1

South Australian Projects

Project Type	No	Total cost $ •	Reported accidents avoided per year	std dev.	Reported accidents avoided per year/ $ '000 cap. cost	std dev
Convert cross intn to T junction	17	135850	15.498	5.314	0.114	0.039
Median closures	3	30900	7.175	3.922	(0.232)	0.127
New street lighting (isolated intn)	4	29800	18.513	7.179	0.621	0.241
Upgrade St lighting (isolated intn)	1	8010	-1.800	4.099	-0.225	0.512
Safety bars	46	42180	17.092	9.784	0.405	0.232
Modify signals	44	480800	79.728	29.236	0.166	0.061
New signals	19	354000	176.087	14.441	0.497	0.041
Roundabout	53	422560	88.013	10.367	0.208	0.024
Additional lanes at intersection (not signalised)	4	68640	-16.758	9.859	-0.244	0.144
New channelisation	19	340545	29.345	9.886	0.086	0.029
Modify channelisation	2	11440	-45.880	9.616	-4.010	0.840
New signals (pedestrian)	16	151150	51.500	9.255	0.341	0.061
Realign short section	1	12000	5.500	3.564	0.458	0.297
Traffic signal coordination	2	30890	-12.335	6.593	-0.399	0.213
New signals and channelisation	16	643380	130.697	15.772	0.203	0.024
Modify signals and channelisation	12	134200	-45.720	20.604	-0.341	0.153
Street closures (part of 317)	62	167130	107.647	7.990	0.644	0.048
Roundabout (part of 317)	3	18300	2.460	1.301	0.134	0.071
School pedestrian crossing	11	27930	5.150	3.262	0.184	0.117
Additional lane	1	50000	-0.250	5.022	-0.005	0.100
Street lighting (general)	3	50500	5.875	5.518	0.116	0.109
Parking control	2	350	1.425	2.237	4.071	6.393
Rail crossing	1	36428	0.975	1.104	0.027	0.030

• Dollars used are 1976 dollars

Note: Negative values indicate increased number of accidents

: Brackets indicate values not significantly different from zero

TABLE 3.2

Cost effectiveness
average over all treatments in W.A.

Project Type	No	Total cost $ •	Reported accidents avoided per year	std dev.	Reported accidents avoided per year/ $ '000 cap. cost	std dev
Convert cross intn to T junction	3	5370	16.667	3.155	3.104	0.588
Modify signals	5	46624	21.317	7.131	0.457	0.153
New signals	38	841110	126.150	24.791	0.150	0.029
New channelisation at signalised intersection	30	605256	67.183	15.260	0.111	0.025
Modify signals	2	31100	-11.016	4.438	-0.354	0.143
Additional lanes at intersection (not signalised)	1	7200	(2.333)	7.658	(0.324)	1.064
New channelisation	25	530430	(25.400)	13.738	(0.048)	0.026
Modify channelisation	6	77900	24.133	7.671	0.310	0.098
Pedestrian refuge islands	20	216601	41.650	10.517	0.192	0.049
Realign short section	2	26350	(7.367)	4.122	(0.280)	0.156
Median installation	2	16510	3.333	1.605	0.202	0.097
New signals and channelisation	4	120422	12.433	5.921	0.103	0.049
Modify signals and channelisation	3	89500	(-9.033)	11.247	(-0.101)	0.126
New signals and channel modifcns	8	223530	(15.167)	11.633	(0.068)	0.052
Improve visibility	1	24000	(0.400)	0.365	(0.017)	0.015
Zebra crossing	1	5000	(-4.600)	3.587	(-0.920)	0.717
Zebra crossing plus channels	1	9850	(-0.033)	2.095	(-0.003)	0.213
Pedestrian protection	3	37000	(2.267)	3.515	(0.061)	0.095
Pavement marking	1	3500	(7.917)	7.735	(2.262)	2.210

• Dollars used are 1978 dollars

Note: Negative values indicate increased number of accidents

: Brackets indicate not significantly different from zero

As already indicated analysis of the data, however, showed that some projects were carried out at sites with fairly low accident rates in the before period. In some instances these rates were so low that even if the treatment prevented any further accidents, that specific treatment would not be cost effective. Hence from the data it was clear that cost effectiveness, at least as an accident reduction measure, was not a prime consideration in the choice of some projects.

This was particularly true in Western Australia, so revised estimates were also made for the six most common project types using for each project type thosesites where cost data was available and the accident rates in the **before** period were above the median rate for these types of sites. Note that the accident rate in the after period did **not** affect selection of these sites.

These revised figures give a better estimate of the cost effectiveness of these projects if they are chosen primarily on benefit/cost grounds.

TABLE 3.3

Cost effectiveness
Selected Sites in W.A.

averaged over sites where accident rates in the before period were above the median rate for sites receiving this type of treatment

Project Type	No	Total cost $ *	Reported accidents avoided per year	std dev.	Reported accidents avoided per year/ $ '000 cap. cost	std dev
New signals	20	405760	159.8330	21.0990	0.3939	0.052
New channelisation at signal. intern (incl signal modn)	16	306381	84.7000	13.3876	0.2765	0.044
New channels at non-signal. intern	13	345610	40.9667	11.2156	0.1185	0.032
Modification of channels at non-signalised intn	3	51180	23.0667	7.2541	0.4507	0.142
Pedestrian refuge islands	10	113110	28.5167	9.1453	0.2521	0.081
New signals and channelisation	3	131380	9.7500	9.7635	0.0742	0.074

* Dollars used are 1978 dollars

Cost Effectiveness in Site Selection Procedures

This study has found that in the selection of sites for treatment, hazard reduction has taken priority over the overall reduction in accident numbers or cost effectiveness. Hazard reduction and cost effectiveness in avoiding accidents are different.

In this report hazard is a relative concept. Hazard has been defined as a measure of the number of accidents likely to occur per vehicle passing the site. Hence, there may be more accidents at a busy site that is not regarded as hazardous than at a hazardous site where traffic volumes are low.

Certainly pressures for site improvements are centred on users' identification of hazard at a site rather than the total number of accidents occurring at a site, and so the choice of site improvements could not be completely divorced from hazard. However, the overall benefit of traffic engineering projects would be greater if more emphasis were placed on the total reduction in accident numbers at the expense of hazard reduction per se. Such a change of emphasis may attract further criticism from localised pressure groups, along the lines that until there have been several casualties at a site, nothing is done.

Unfortunately, with current levels of road facilities, treatment of sites where few accidents have occurred must be at the expense of other sites where there is more potential for accident reduction.

It is impossible to ignore the link between "safety" projects and other road projects. Many site improvements which affect safety are of course not only carried out to improve safety, but also to increase operational efficiency. In many cases operational efficiency and safety are quite closely linked. For example, the provision of a turning pocket at an intersection not only increases the intersection capacity and reduces delays, but also improves the safety of the intersection by separating traffic streams.

The separation of traffic streams at the intersection increases the intersection capacity substantially. This also leads to a marked reduction in rear end collisions. In fact most projects on urban arterials have a combination of safety and operational effects.

This interrelation is generally recognised within Road Authorities, and operational and safety aspects of projects frequently are not identified separately in planning and design stages.

For administrative purposes, some project types are assigned to the safety improvement program and others to operational improvement or maintenance programs, but this assignment is often arbitrary. Often the balance between expected safety and operational improvements is not even considered in detail.

Similarly, some measures may for administrative purposes be assigned to the maintenance program. For example, in Western Australia road edge marking of rural highways has been assigned to the maintenance program, and indeed internal studies have shown that reduced road shoulder damage is sustained after edge marking. However, these markings are shown in this study to improve night time safety.

Hence there are substantial benefits that have not been considered in this study. If the operational benefits of some of these projects are also considered, then their cost effectiveness may be greater than indicated in this study.

Fortunately from a safety point of view, improvements that lead to substantial capacity increases, such as channelisation, are as effective in terms of safety as many other projects that do not have major operational benefits. Hence there is, in practice, little conflict between requirements for treatments to improve operational conditions and requirements for safety. In short the current situation, where little distinction is made between the two in budgetary allocations, may continue without any real disbenefits for road safety.

On less trafficked roads, projects are carried out mainly for safety benefits. Road capacity in these situations substantially exceeds demand as the road has been built to a level of service, and this effectively provides more capacity than is required.

CONCLUSION

Minor traffic engineering improvements are extremely cost effective measures in a wide variety of circumstances. As the effectiveness of projects in later years was as high as in the earlier years, there still appear to be many sites where such work could be carried out to great benefit.

At lightly trafficked locations, there is still considerable scope for site improvements. However, some of the more complex improvements at these sites are being carried out at the expense of improvements at busier sites, more emphasis could be placed on the potential for reduction in accident numbers rather than reduction of hazard.

APPENDIX A

SOUTH AUSTRALIAN RESULTS

In the following discussions of the performance of specific projects, frequent reference is made to accident numbers. These are not true accident counts as recorded in official Highway Department records. The counts referred to in this text (unless specifically mentioned to the contrary) have been adjusted by control factors to represent estimated counts if 1975 conditions had applied. That is, accident numbers quoted for years other than 1975, have been adjusted to allow for changes in reporting rates, changes in overall system performance (such as law enforcement, seat belt wearing etc.) and exposure changes away from the level applying in 1975. The methodology is explained in Appendix C, Section 3.

Individual totals have been separately adjusted by the most appropriate control total to give the maximum likelihood estimate of the number of such accidents at the site. Thus when the proportions of particular types of accidents, or the severity of accidents at a particular site, are different from the system average, then the adjusted individual totals will not sum exactly to the adjusted overall total. (The sum of two maximum likelihood estimates is not necessarily the maximum likelihood estimate of the sum of the underlying variables.)

All analysis then is based on adjusted accident numbers. While nearly all injury accidents and all fatal accidents are reported, some (particularly minor) Property Damage Only accidents are not. Actual reporting levels are discussed in detail in Appendix C. They do not affect the analysis of the effectiveness of projects, except that due to the reduction of the numbers of accidents included in the calculation, the statistical fluctuation in the results is increased.

Non-reporting of accidents however does affect estimates of the cost effectiveness of projects. Theoretical discussion of this problem is contained in Appendix C, and practical results are contained in the last section of this appendix.

The project types examined in detail are listed in the following table by project type number.

TABLE A.1

PROJECT TYPES

106	Convert cross intersection to T junction
110	Median closures
131	New street lighting (isolated intersection)
133	Upgrade St lighting (isolated intersection)
172	Safety bars
200	Modify signals
201	New signals
204	Additional lanes at signalised intersection
205	Roundabout
214	Additional lanes at intersection (not signalised)
215	New channelisation (non-signalised intersection)
216	Modify channelisation (non-signalised intersection)
241	New signals (pedestrian)
251	Realign short section
261	Upgrade street lighting (isolated treatment)
262	Upgrade street lighting (linear treatment)
352	Traffic signal coordination
400	New signals and channelisation
401	Modify signals and channelisation
403	Street closures (part of area traffic management)
404	Roundabout (part of area traffic management)
407	School pedestrian crossing
410	Street lighting (general)
411	Parking control
413	Rail crossing

The accident numbers are summarised in the following table. Following the table there is further discussion of individual project types.

TABLE A.2

SUMMARY OF ACCIDENT RATES

South Australian Projects

Project	No of Installations in stats	Ratio accident rates: rate after/rate before, Projects undertaken in period 74-5	75-6	76-7	77-8	Ratio overall	Variance of ratio	Severity change *	X^2	Number of accidents BEFORE: PDO	BEFORE: Inj+F	BEFORE: Total	AFTER: PDO	AFTER: Inj+F	AFTER: Total
106	15	None	None	(1.10)	.49	.53	.014	D	4.47	142.5	49.1	193.9	26.9	2.3	29.4
110	3	None	(.82)	.11	None	.41	.009	NS	0.75	75.1	10.1	84.9	53.6	4.3	59.1
131,261	3	None	.24	None	1.21	.55	.032	NS	.85	79.4	14.6	93.3	22.4	2.1	23.2
133,262	1	None	None	(1.07)	None	(1.07)	.039	D	3.88	63.9	20.3	84.8	41.2	4.4	46.4
172	57	(1.04)	.70	(.97)	(.79)	.86	.004	NS	0.01	359.6	114.9	474.9	326.8	105.9	427.9
200	49	(1.00)	.74	.82	(1.09)	.86	.0005	D	6.52	3433.6	669.9	4090.0	2659.6	437.7	3115.8
201	24	None	(.81)	.86	.26**	.81	.002	NS	0.27	1153.1	222.8	1369.3	767.2	127.4	890.7
205	59	.56	.30	.58	.48	.43	.001	D	11.98	487.8	208.6	705.3	202.5	46.3	248.5
204,214	4	None	.51	(1.35)	(1.18)	.78	.007	NS	2.06	343.5	83.8	427.8	132.9	22.4	156.6
215	21	.75	.70	.76	(1.05)	.83	.002	NS	0.08	412.3	91.6	502.1	310.3	66.1	373.2
216	1	None	None	None	2.17	2.17	.081	NS	0.72	178.5	15.5	194.1	79.4	4.3	84.7
241	17	.56	.55	(1.08)	None	.61	.002	NS	0.67	360.2	71.7	429.6	226.0	53.0	277.3
251	1	None	.74	None	None	.74	.020	NS	0.04	55.8	9.7	65.4	40.8	7.9	48.9
352	2	None	None	1.51	(1.03)	1.29	.075	NS	0.57	139.2	35.8	173.2	70.8	14.0	85.1
400	16	None	.81	.47	.81	.60	.001	NS	0.12	1238.7	223.1	1477.9	305.6	61.2	368.0
401	14	None	None	None	1.20	1.20	.004	NS	0.00	1708.3	314.7	2021.4	407.7	75.5	484.4
403	71	.24	.24	None	.08	.23	.0006	NS	0.20	304.0	131.6	444.1	87.4	34.2	119.2
404	4	None	.40	None	.27	.35	.034	NS	-	26.6	1.5	28.5	4.7	1.1	5.8
407	14	.77	.81	None	None	.79	.031	NS	0.28	33.0	9.9	43.4	39.4	9.0	48.3
410	2	.42	None	None	None	.42	.020	NS	1.19	12.6	5.2	18.4	14.3	2.2	16.4
411	2	.74	None	None	None	.74	.072	NS	0.27	9.4	4.2	14.3	17.7	5.3	22.8
413	4	(1.10)	None	None	None	1.10	.674	NS	-	1.4	1.5	3.9	7.5	3.3	10.7

* D Significant decrease at 5% level
NS no significant change
** one site only

All accident numbers adjusted to base year 1975 by control factors

Note that the sum of PDO and Injury plus Fatal columns does not equal the Total column exactly. Each column has been adjusted by a control factor for this class of accident. The total column is the adjusted value of the total number of accidents, and not the sum of the preceding two columns

For all city and urban intersections 18% of reported accidents involved injury in 1975

( ) indicates not significantly different from 1.0

Project type 106 - Convert Cross Intersection to T-Junction

Sixteen projects were examined. Data from one site was unusable due to changes in location coding leading to doubt on the completeness of the records for the site. Of the remaining fifteen sites, twelve were treated in the 1977-78 period and three in the 1976-77 period.

All fifteen sites treated were urban and had relatively low traffic volumes and accident numbers (on average 3.6 accidents per site per year.) However, these accidents were quite severe - 26% of reported accidents involved injury as against 18% for the control group. That is, accidents at these sites were more severe than average.

The treatment significantly reduced the accident rates at these sites. The best estimate that can be made is that the accident rate dropped to 53% of the earlier rate. This estimate is subject to considerable error (s.e. 12%).

Not surprisingly, the reduction in accident numbers resulted from a decrease in right angle collisions. This was the only type of accident for which there was a significant change in numbers. The severity of accidents also decreased significantly. The relatively short after period, however, does not allow any realistic estimate to be made of the change in the severity index.

The closure of one entry into an intersection, however, would cause substantial rerouting with traffic entering the major road from a different entry point. Most of the sites only had a one year after period, and it is not possible from traffic count data to determine what rerouting occurred.

The improvement in safety at the sites examined resulted from a combination of reduction of hazard and also of exposure. It is not possible to estimate these two effects accurately but both were apparently important.

While no statistical significance could be attached to the increase, there were some increases in accident rates at adjacent intersections. The reduction in accident numbers at the actual sites should be discounted by this increases at adjacent sites when evaluating the effectiveness of these measures.

However, the reduction in severity is a real benefit. The sites treated apparently had a variety of visibility problems which presumably led to the higher than usual rate of severe right angle collisions. The diversion to other better visibility intersections would presumably only lead to a small increase in accident numbers and these accidents would not differ in type or severity from the usual urban intersection accidents.

Project Type 110 - Median Closures

Only three projects of this type were available for study. One was on a busy urban main road, the other two were on much lower volume unclassified roads.

The performance at the two types of location was substantially different but the type of flows at the two categories of site was also different.

The arterial road site was the intersection of Nelson and Nile Streets in an industrial area (Port Adelaide) and was the first cross intersection along from a major T-intersection controlled by traffic lights. Average daily traffic volumes on the two opposing arms of the T in 1976 were 9,700 and 10,500. The volume on the tail of the T (Nelson Street) was 18,500. Nelson Street leads over Birkenhead Bridge, one of the three crossings of Gawler Reach.

There are two intersections on Nelson Street between the bridge and St Vincent Street. The intersection closer to St Vincent Street (the T-intersection) was the one treated.

Many of the turning movements at this intersection would have been made by traffic attempting to avoid the traffic lights. Closure of the median was designed to prevent these manoeuvres.

There was a non-significant decrease in accident numbers with the rate dropping to 82% of its earlier level (s.d. 15%). There was no significant change in severity level or accident type.

The other two sites are really part of the one extended intersection formed by several adjacent T-junctions on an unclassified suburban road. Here the median closures redefined feasible movements and reduced the number of potential conflicts at each critical point along the major route.

At this site accident reduction was dramatic. The accident rate after treatment was only 11% (s.e. 13%) of the rate before treatment. This resulted from a reduction in right angle collisions. The accidents in the before period were far more severe than average; there were not sufficient accidents in the after period to comment on their severity.

Project type 131 - New Street Lighting (isolated intn)
261 - New Street Lighting (linear treatment)
133 - Upgrade Street (isolated intersection)
262 - Upgrade Street (linear treatment)
410 - Street Lighting (general)
(combination of above)

These were 13 projects involving new street lighting. Of these several were carried out in the same period as other major projects, such as traffic lights, which were likely to affect accident rates. Other sites were not identifiable in the accident coding system. Eventually it was decided that only three sites provided reliable data for evaluation of new lighting projects.

Of these three sites, one site was on a much busier road than the other two. The site, an acute angled intersection on the edge of the central city area, was controlled by traffic signals. At this site there is no apparent change in overall accident rate, severity or accident type, whether overall statistics are used; or night and day rates are compared for the before and after periods. A total of ninety accidents were recorded over the six years.

The other two sites are very substantially different from the first. One is in a semi-rural area and is a T-junction on a 80 kph limit road where there is a kink in the tail of the T. The other is a spread out T-intersection on a secondary road in Elizabeth where relatively high speeds are likely, especially at night. At these sites there are only 28 accidents recorded and so conclusions can only be tentative. There was, however, a reduction in the number and severity of night time accidents. here was a drop in right angle collisions though this was not statistically significant.

Of the three sites where street lighting was upgraded only one site yielded data that could be used to evaluate upgrades. This was a major five-way intersection controlled by signals. Two major roads intersected at an oblique angle with the fifth leg being the start of a minor road. At this site there were a total of 131 accidents. In the period after installation of upgraded street lighting (treatments) there were several significant changes in accident statistics. The number of rear end accidents increased significantly. The number and severity of right angle accidents decreased. However there was no significant change in the ratio of night time accidents to daytime accidents at these sites from the before to the after periods. While no evidence of other changes was found, these figures suggest other nearby site changes may in fact have been made.

The other projects, street lighting (general) are thought to be new lighting at intersections, but could not be identified accurately. All but two sites received other treatments as well during the study period (in many cases traffic light installation or improvement). This made isolation of the lighting effect impossible as the possibility of a second order interaction between traffic signal controls and lighting could not be ignored. At the two remaining sites, there were only a total of 35 accidents over the total before and after period. Nevertheless a significant drop of 58% in the accident rate was recorded (68% for night-time accidents). The major drop was in night-time rear end accidents. There was no shange in day-time rear end collisions, so the cause was lighting, and not some other site change.

Project Type 172 - Safety Bars

Safety bars are a common feature in South Australia, though they have not been installed in any number in other States. They are designed to separate vehicles and pedestrians, and could be described as pedestrian fencing preventing access to the roadway by pedestrians except at designated crossing points.

There was a total of 57 safety bar projects spread over the four years as follows:

Year	No Projects	No Accidents Before	No Accidents After	Ratio rates After/Before **	Var
74-5	20	126.5	265.2	1.04	.013
75-6	14	130.0	91.2	* .70	.009
76-7	14	110.7	54.4	.97	.026
77-8	9	107.6	17.2	.79	.043
				* .86	

* Significantly different from unity.
** Note this is the ratio of rates, not of numbers. i.e. the ratio is not affected by the length of the before and after periods.

Overall there was a slight decrease in accident rates of 14% which was significant. There was no significant change in severity but a significant increase in rear end and decrease in right angle collisions.

The year-to-year changes, however, should be noted. There is no secular trend evident when a test is made of the null hypothesis of decreasing effectiveness of the later projects. (The alternate hypothesis was chosen on the argument that the worst sites were treated first.) Indeed the figures are consistent with the null hypothesis that the ratios for each year come from the same distribution. (The test statistic $X_3^2 = 5.92$).

Examination of sites did not produce any clear change in site characteristics from year to year either.

Project 200 Modify Signals

This project type includes updates to signal sites not involving changes to road layout. The updates to the signal sets involve the replacement of an old electro-mechanical controller with a new microprocessor controller. This replacement has allowed the implementation of more complex signal plans with special turn phases etc. In many cases extra lanterns have also been installed to allow the extra phases in the new plan to be displayed.

The upgrades were installed for three reasons:

a) to improve reliability by removal of old electro-mechanical controllers;

b) to increase signal plan flexibility;

c) to allow integration of signals into area control.

It is not now clear which was the most important factor in specific upgrades. Even where reliability of the old controller was a major factor, the signal plan for the site was upgraded as a matter of course.

Overall there was a significant drop of 14% in the accident rate. The variation from year to year was also highly significant at .1% ($X_3^2 = 27.5$), though no secular trend was evident. There was also a significant reduction in accident severity.

The proportion of casualty accidents as a fraction of total accidents dropped from 16.4% to 14.1%; i.e. the ratio dropped by 15%. Numerically, casualty accidents (after correction for reporting changes, exposure changes etc) dropped 28%.

The more complex plans led to major changes in accident types. The following changes were significant.

Head on	Decrease
Rear end	Increase
Sideswipe opp. direc.	Decrease
Right angle	Decrease
Hit pedestrian	Decrease

401 - Modify Signals and Channelisation

The sites covered by these projects involve alteration of intersection geometry with the inclusion of a turning pocket. In many cases the signal plans were changed to take account of the turning pockets. Some cases also involved installation of additional lanterns.

The fourteen sites studied were busy sites being the intersection of two major roads. Typically, the major legs experienced volumes of 30,000 vehicles per day and the minor legs volumes of 15,000 vehicles per day in urban areas well out from the CBD.

All projects were carried out in 1977-1978 leaving only one year after data. This poses some problems of adjustment of figures for exposure etc, as traffic count data is only collected every two years. This is particularly important, as these changes may well have system effects, with a change of route being made with the increased ease of turning movements at the treated sites.

The results of statistical analysis appear analogous when compared with new signal installations. It might be expected that behaviour would be quite similar.

The accident rate increased 20% (a significant increase) while the severity index did not change. The incidence by accident type was also different from type 200 projects.

This was largely caused by an increase in accident rates at two specific sites. Traffic flow figures at these two sites in the expanding South Western urban area were not increasing rapidly. Unfortunately, turn counts could not be found. However, the possibility of major rerouting cannot be discarded in view of the project type. Significant increases in turning movements would not necessarily show up in the available traffic counts. The number of right angle accidents at these sites however suggests that there was an increase in turning movements.

If these two sites are excluded then the accident rate still increased by 11% which is a significant increase. Accident rates increased at eight of the remaining twelve sites.

The following changes were significant:

Rear end	Increase
Right angle	Decrease

The decrease in right angle accidents, however, was not nearly as great as for new signal installations and is only significant relative to total numbers of accidents. There is no significant difference in the number of right angle accidents after adjustment for exposure and reporting trends.

This is to be expected. The original installations at these sites already had turning phases. Consequently most changes did not significantly alter the level of conflict for turning movements, but did increase the capacity of the intersections.

Project Type 201 - New Signals

Twenty-four signal installations were examined, eighteen from years 75-6, five from 76-7 and one from 77-8. One site was deleted from consideration (as the opening of a new stretch of road had increased traffic volumes five fold on one leg).

The sites were well scattered over the metropolitan area. Thirteen were in the city, six on the urban arterials, and the remainder on unclassified urban roads. The installations were all microprocessor controlled signal sets with a variety of signal plans. No geometric changes were carried out as part of these installations, although some of the intersections already had turning pockets in place.

In the period following signal installations, a significant 19% drop in accident rate was recorded. No change was recorded for accident severity.

The pattern of accident type showed major changes. The right angle accident rate decreased by 64%. The proportion of right angle accidents fell from 62% to 27% of all accidents at these sites.

Whereas rear end accidents accounted for 27% of all accidents in the before period, they accounted for 55% of all accidents in the after period. The actual number of rear end accidents increased by 55%.

Project Type 205 - Roundabout
Project Type 404 - Roundabout (Part of Area Traffic Management)

Fifty-nine isolated roundabouts and four roundabouts which formed part of an area traffic management scheme were studied. These latter may involve traffic rerouting. However, the traffic counts are not sufficiently detailed to allow accurate assessment of these system effects.

Statistically, in terms of changes of accident rates, accident types and severity, these two classes cannot be distinguished. However, the total number of accidents at the sites which were part of area management schemes was only 34 and thus the comparison test is not very powerful.

For the isolated sites, there were a total of 954 accidents which allows detailed examination of accident types etc.

The sites covered 48 intersections of non-classified roads, two country town sites and one city site. The remainder covered low traffic volume classified urban roads.

The results for the four years are not homogeneous (test statistic $X_3^2 = 31.86$), but do not show any specific trends. The non-homogeneity is due to the apparent higher effectiveness of 1975/76 projects.

Some significant site differences must be assumed to be responsible for these variations, but the nature of these could not be determined.

The site treatments achieved a significant reduction in accident severity. However, it should be noted that accident severity at the treatment sites was higher than average in the before period and comparable to the overall system in the after period. The average over all city and urban intersections was for 18% of accidents to involve injury. For the treated sites, however, in the before period 30% of accidents involved injury while in the after period 18% involved injury, a significant drop in severity.

The roundabouts eliminated 80% of right angle accidents but increased other accident type rates significantly. Numerically, the most significant increases were in rear end and sideswipe accidents.

Project Types 204,214 - Provision of Additional Lane at Intersection

There were only four separate sites of this type as two of the sites listed on jobsheets were effectively part of the one system.

These sites were all significantly different, and are discussed separately.

1. The first site was an intersection at the corner of the South Australian Institute of Technology campus - the

total of 20 accidents occurred over the combined before and after period. Treatment consisted of an additional lane to allow separation of the left and right turners from the College onto Main North Road. The site is open and controlled by a stop sign. No change in accident rates or types was apparent.

2. The next site was another T-junction in a shopping centre just along from pedestrian signals. Here the tail of the T, the entry onto the main road, was widened, again separating the left and right turners. Here the accident rate dropped over 50% in the tail approach to the intersection with a large drop in rear end and sideswipe (same direction) accidents.

3. The third site was a major intersection on the corner of the central square mile - North Terrace and Dequetteville Terrace. First, the northern approach was widened and then the intersection itself was widened. There was no change in accident rates in the system (the approach and intersection itself).

4. The last site was an outer urban T-intersection of Springbank Road and Goodwood Road just along from another T. Together the two Ts form an extended dog-leg intersection on a major eastbound commuter route. No change in accident rates could be detected at this site either.

In general there appeared to be no evidence that the provision of an extra lane affected the accident rate. However, in a specific case where the existing single lane had been stretched by users to include a second by default, a noticeable effect was detected. This would seem to indicate that the improved operational layout did not improve safety except where the improvements rectified an improvised lane arrangement.

Project Type 215 - New Channelisation (non-signalised intersection)

Twenty-one projects involving installation of channels were carried out during the four year period. Over the period a total of 875 accidents occurred in the before and after periods.

All sites were on urban arterial roads. There were no discernible site to site differences in the behaviour of the treatments. Overall, the treatments reduced accident rates by 17% with no discernible effect on the severity of accidents.

Rates of all types of accidents except hitting of fixed objects appear to have dropped, with the biggest drop being in sideswipe accidents. The only statistically significant change in the proportion of each accident type was a drop in sideswipe accidents (from 12.5% to 9.4%).

Unfortunately accident data for some rural sites which were channelised was not available for the before period. These sites still exhibited extremely high severity rates during the after period. Lack of before data, however, precludes real comparison with the urban sites.

Project Type 216 Modify Channels

Only two sites were included and the results were dominated by one site where 99% of the recorded accidents occurred. This intersection only is considered.

The intersection is a T-junction where the 1976 volumes were:

W leg 24,500
E leg 18,800
S leg 13,000.

There are major turning movements from the W to S leg and from the S to W leg. The western approach to the intersection is open with only two intersections (both T-junctions entering from the north) in the preceding kilometre.

The channel modification involved lengthening the channels on the eastern and western approaches to the intersection.

The accident rate at the intersection, however, more than doubled after treatment, due solely to an increase in rear end collisions.

Project Type 241 - New Pedestrian Signals

Seventeen sets of pedestrian signals were examined. With one exception, these were all installed at end block locations on major urban arterial roads. The exception was a set of pedestrian signals in King William Street near the Festival Theatre. These are very close to an access road to parking areas for the railway and the theatre.

Accident effects at this one site were substantially different from the other sites and seem to be associated with the access road to railway and theatre facilities.

Ignoring this site there was a major decrease of 45% in accident numbers due to the installation of the pedestrian signals. The changes in type, however, were minor and severity did not change significantly.

Accident types in the before and after period were:

	Before	After
	% of total	
Rear end	71.2	66.7
Side swipe	16.0	21.2
Right angle	4.2	5.6
Hit pedestrian	5.4	4.1
Other	3.2	2.4
	100.0	100.0

There is no significant change in accident type following installation of the signals. However, the reduction in numbers of each type of accident is significant.

First it should be noted that very few accident reports imply that a pedestrian was involved in the sense that the pedestrian became recorded in accident statistics.

However, many accidents at these sites clearly involve pedestrians, where several vehicles may be involved in an accident when one vehicle tried successfully to avoid a pedestrian. The very high rate of rear end collisions illustrates this with 70% of accidents being rear end collisions compared with 27% for non signalised intersections and 55% for signalised intersections.

After the installation of the pedestrian signals, the proportion of rear end collisions dropped slightly (but not significantly), whereas at a normal vehicle intersection the proportion rose from 27% to 55%.

Clearly then the pedestrian signals have greatly reduced the number of unexpected vehicle movements where drivers attempt to avoid pedestrians. Most of these movements are apparently successful in avoiding the pedestrian, but often lead to a collision with another vehicle.

The numbers of fatalities (all pedestrians) are too small for any change to be significant. The fact that the number of accidents where pedestrians were hit decreased significantly would suggest that the reduction in the fatality rate (from 1.1 per year to 0.4 per year) was real and not a random change.

Project Type 251 - Realign Short Section

The one realignment listed involved closing off the fifth leg of an intersection, and is treated under project type 106.

Project Type 352 - Traffic Signal Co-ordination

In most cases the systems were too complex to allow the area affected to be defined accurately. However, two small systems were isolated, in each case comprising two signal sets.

At one site there was no discernible effect on accident rates. At the other site, (two signal sets 400m apart) however, the accident rate increased significantly, due solely to a doubling in the number of rear end collisions. It appears that this was due to the tail of the platoon formed at the first set of signals not reaching the second set before the green phase was ending.

Project Type 400 - New Signals and Channelisation

Four sites, all in the South West corridor on Main South Road where traffic volumes had increased fourfold, were deleted from consideration. Of the remaining sixteen sites, thirteen were on urban arterials, one was a city site, and two were rural sites.

Overall there was a 40% drop in accident rates after installation of the signals and channelisation, significantly greater than with the signal only installations where the drop was only 19%.

In comparing these projects with new signal installations where channels are not installed, some site differences are noticeable. In most cases these projects are at sites where higher average speeds would be expected, and indeed this is reflected in accident statistics. The proportion of rear end collisions at these intersections in the before period was 37%, compared with an average of 27% for those sites where signals only were installed. However, after treatment the proportion of rear end collisions was similar at 55%.

Substantial pedestrian movement at the city site made it significantly different from the other sites in the project group. Here there was actually a reduction in the proportion of rear end collisions. The channelisation appears to have been an important factor in reducing rear end collisions where the movement away from the signals is often restricted either by pedestrian movement or other vehicular congestion.

Project Type 403 - Street closures (part of area traffic management)

These projects are usually carried out for a combination of environmental and safety considerations. From a safety viewpoint the aim of the projects is to redirect traffic away from hazards onto a more suitable route. It is hardly surprising that accidents on the sections of road affected decreased dramatically.

However these projects clearly have a system effect; any analysis of them must consider the effects on adjacent sites. Insufficient traffic flow data was available to determine traffic rerouting caused by the street closures. Thus an examination was made of all nearby sites. No statistically significant change could be detected in this overall system, but this is not surprising as the changes would be small incomparison to the total number accidents in the area. A definitive answer to the effectiveness of these projects then could only be given were traffic flow data more comprehensive.

Project type 407 - School pedestrian crossing

As with other projects carried out to improve pedestrian safety, the effect was largely a reduction in vehicle collisions. Overall accident rates decreased by 21%. Only two reported accidents - one in the before period and one in the after period - involved pedestrians.

The predominant accident types at these sites were rear end collisions, followed by sideswipes. The improvement in safety at these sites then would appear to result from a reduction in sudden movements by vehicles to avoid pedestrians.

Project type 411 - Parking control

Accident numbers at the sites treated were insufficient to allow detailed analysis.

Project type 413 - Rail crossing treatments

Accident numbers at the sites treated were insufficient to allow detailed analysis. These types of sites receive considerable publicity due to the severity of accidents associated with them. However the number of serious accidents is still low, and the potential for reduction of serious accidents is considerably less than at many other types of sites amenableto similar cost treatments.

APPENDIX B

WESTERN AUSTRALIAN RESULTS

In the following discussions of the performance of specific projects, frequent reference is made to accident numbers. These are not true accident counts as recorded in official Main Roads Department records. The counts referred to in this text (unless specifically mentioned to the contrary) have been adjusted by control factors to represent estimated counts if 1978 conditions had applied. That is, accident numbers quoted for years other than 1978, have been adjusted to allow for changes in reporting rates, changes in overall system performance (such as law enforcement, seat belt wearing etc.) and exposure changes away from the level applying in 1978. The methodology is explained in Appendix C, Section 4.

Individual totals have been separately adjusted by the most appropriate control total to give the maximum likelihood estimate of the number of such accidents at the site. Thus when the proportions of particular types of accidents, or the severity of accidents at a particular site, are different from the system average, then the adjusted individual totals will not sum exactly to the adjusted overall total. (The sum of two maximum likelihood estimates is not necessarily the maximum likelihood estimate of the sum of the underlying variables.)

All analysis then is based on adjusted accident numbers. While nearly all injury accidents (including fatal accidents) are reported, some (particularly minor) Property Damage Only accidents are not. This phenomena is discussed in detail in Appendix C. It does not affect the analysis of the effectiveness of projects, except that by reducing the numbers of accidents, it increases the statistical fluctuations in the results.

It does, however, affect estimates of the cost effectiveness of projects. Theoretical discussion of this problem is contained in Appendix C, and practical results are contained in the last section of this appendix.

Unlike the situation in South Australia, no change in accident severity was observed for any project type. While for the projects where the total number of accidents was small, the test for severity change is not powerful, the test when applied to projects with several hundred accidents in toto has a reasonable power. For example, for traffic light installations there was a probability of 50% that a change in the underlying proportion of injury accidents from say 17.9% to 20.5% would be detected. These proportions are marginally below the estimate for the before period, and marginally above the estimate for the after period respectively.

For the sake of brevity, as no severity changes were detected, severity is not mentioned in the following discussions.

The project types examined are listed below:

TABLE B.1

PROJECT TYPES

106	Conversion of cross intersection to T-junction
110	Median closure
200	Modify signals
201	New signals
202	New channelisation at signalised intersection (including signal modification)
203	Modify channels at signalised intersection
204	Modify channelisation (include additional lane)
215	New channels at non-signalised intersection
216	Modification of channels at non-signalised intersection
243	Pedestrian refuge islands
251	Realign short section
256	Median installation
400	New signals and channelisation
401	Modify signals and channelisation
402	New signals and channel modifications
414	Improve visibility
440	Zebra crossing
441	Zebra crossing plus channels
450	Pedestrian protection
997	Pavement marking
998	Bus lane
999	Cycle way

Giveway signs
Stop signs

Centre line marking
Edge line marking

TABLE B.2

SUMMARY OF ACCIDENT RATES

W.A. Projects

Proj. Type	No	Ratio of accident rates: rate after/rate before, Date completed 1977	1978	1979	Overall	Variance of ratio	Severity Change •	χ^2	Number of accidents: BEFORE Inj+F	PDO	Total	AFTER Inj+F	PDO	Total
106	2	-	-	0.16	0.16	0.008	NS	0.99	14.1	46.1	59.9	0.0	3.3	3.3
110	1	-	0.95	-	0.95	0.070	NS	0.09	2.4	25.1	28.1	3.1	24.6	27.6
200	5	-	0.66	0.57	0.64	0.01	NS	0.00	20.9	114.5	137.1	10.3	55.1	65.1
201	44	0.90	1.02	0.47	0.80	0.0015	NS	3.39	184.8	860.8	1049.1	290.3	1115.9	1407.7
202	39	0.79	0.52	0.76	0.59	0.0015	NS	0.20	140.6	542.6	681.6	103.5	426.0	529.4
203	2	-	1.69	-	1.69	0.169	NS	0.37	4.0	24.1	28.5	4.9	45.7	50.9
204	1	-	-	0.94	0.94	0.027	NS	2.68	30.9	106.2	137.2	4.9	38.8	43.4
215	38	-	0.78	0.78	0.78	0.004	NS	1.14	163.0	661.1	824.7	48.1	236.5	284.6
216	7	-	-	0.72	0.72	0.013	NS	2.83	29.0	175.2	206.5	11.9	37.7	49.9
243	26	0.89	0.53	0.79	0.62	0.0041	NS	0.16	72.6	293.2	364.9	34.3	126.2	161.0
251	1	-	-	0.58	0.58	0.400	---		8.6	45.9	50.8	1.0	10.0	10.8
256	2	-	-	0.23	0.23	0.060	---		3.6	9.8	13.3	1.0	3.2	4.3
400	7	0.57	-	0.49	0.54	0.007	NS	1.32	20.8	124.3	146.7	19.2	81.2	100.5
401	3	-	1.31	0.95	1.06	0.13	NS	1.58	53.8	213.0	268.5	24.6	136.1	160.1
402	8	1.61	0.66	0.77	0.76	0.007	NS	0.69	41.1	262.2	306.4	19.9	161.5	180.5
414	1						---		1.6	0.0	1.2	0.0	0.0	0.0
440	1	-	-	1.66	1.66	0.44	---		2.6	16.0	18.6	1.0	10.0	10.8
441	1	-	-	0.90	0.90	0.42	---		0.0	9.6	9.8	2.0	1.1	3.3
450	4	-	0.0	0.77	0.77	0.091	---		4.6	27.9	33.0	1.0	7.8	8.7
500	6	0.55	2.08	-	0.59	0.006	NS	0.31	19.5	97.6	117.9	40.7	171.9	211.9
997	6	-	0.47	1.15	0.59	0.003	NS	1.01	66.9	343.3	413.4	34.3	138.2	172.7
998	1	-	-	2.07	2.07	2.54	---		0.0	5.2	5.3	1.0	3.3	4.3
999	1	-	-	0.28	0.28	0.28	---		7.0	26.8	34.0	1.0	2.2	3.3
SIGNS														
GIVEWAY	27	0.42	1.33	0.82	0.53	0.004	NS	0.36	35.6	162.4	198.8	44.0	172.9	216.8
GIVEWAY (repl STOP)	2	-	1.53	0.31	0.41	0.029	NS	0.57	9.3	36.0	45.6	7.2	18.1	25.4
STOP	67	0.74	0.30	1.01	0.48	0.003	NS	0.17	59.8	215.9	274.0	39.4	156.5	196.1
STOP (repl GIVEWAY)	45	1.75	1.00	0.68	0.78	0.005	NS	0.55	85.9	407.8	495.8	47.5	194.4	242.0

Overall for Perth 19% of reported accidents involve casualties.

- • D Significant decrease at 5% level
  NS no significant change at 5% level

Project Type 106 - Conversion of Cross Intersection to T-junction

There were two of these project types where data could be collected. These projects and others in the vicinity have caused major rerouting of traffic in the area but traffic counts are not sufficiently detailed to determine the degree of rerouting.

However, it does appear that turning movements have only been reduced by the order of 50% while accidents were reduced by 84%. This reduction was achieved by complete elimination of right angle accidents and an 80% reduction in rear end collisions. The reduction in the number of conflict situations would appear to have led to an even greater reduction in the number of sudden changes which resulted in rear end collisions.

Project type 110 - Median Closure

After eliminating a project where there had been a major change in traffic volumes, there was only one site where this project type was carried out. This project is associated with another project approximately one kilometre away which closed off the other end of a kilometre bypass around a major T-junction with traffic light control. There was no significant change in accident numbers, severity or type at this site. Most turning movements at this intersection before closure of the median were left turns into the major highway and these were not affected by the closure. Elimination of the few cross movements and right turns at this site do not appear to have changed the accident rate.

Project Type 200 - Modify Signals

There were five of these projects carried out in 1978 and 1979, where signals were upgraded with new controllers with additional phases and in most cases additional lanterns. The effects at all sites were particularly uniform.

Overall there was a drop of 36% in the accident rate with no change in accident severity. There were, however, substantial changes in accident types. There was a slight increase in the numbers of rear end collisions and a very substantial increase in the proportion of these types of accidents.

Head on collisions were eliminated and right angle accidents reduced significantly in number. Sideswipes in the same direction also decreased. The increase in actual numbers of rear end collisions, however, suggests that the phasing changes could have created some problems for following vehicles incorrectly anticipating the sequence of changes.

Project Type 201 - New Signals

Overall the installation of new signals reduced accidents by 20%. However results were very different from site to site. Installations in 1977 were homogeneous in their effect, resulting in a 10% drop in accident rates. However, a major increase in the accident rate of 1978 installations was caused by one major T-intersection. If this site is not included, then the remaining sites show results similar to the preceding year. However, this one site, where 20% of all accidents for the group were recorded, did not suffer any substantial changes in reported traffic volumes, and there is no evidence to suggest miscoding of accident data could have occurred.

The recorded increase in the accident rate at this particular site of 380% then appears to reflect an actual increase in hazard. The signals installed replaced stop signs on the tail of the T. The major increase in accident numbers occurred as indirect right angle accidents between vehicles turning into the tail of the T. It would appear that the phasing pattern was either not clearly displayed or was inappropriate for the intersection. This illustrates the importance of the phasing pattern from a safety point of view.

Project Type 202 - New Channelisation at Signalised Intersection (including signal modification)

These projects involved the provision of turning pockets at intersections, and in some cases signal phasings were changed. The effects of the projects were quite varied, and proved to be non-homogeneous statistically. A significant proportion of sites showed no improvement in the overall accident rate though over the 39 sites there was an average reduction of41% in the accident rate.

Virtually all sites showed a decrease in rear end collisions illustrating the value of separating the turning vehicles out of the straight through stream of vehicles. At some sites the numbers of right angle or indirect right angle accidents did not decrease but actually increased. (These sites showed no overall change in accident rates.)

Changes in phasing arrangements during the channelisation changes could not be determined, but it is clear that phasing is critical to the accident rates of these intersections and require more attention in redesign of intersections.

Project Type 203 - Modify channels at signalised Intersection

Two projects were classified in this group. However, the results were dominated by one site, where nearly all the accidents occurred. The project at this site involved the conversion of a T-intersection where the major traffic flows involved a turning movement. In fact, the main route turned through ninety degrees, with a minor entry along the straight continuation of the main route. After conversion, one arm was blocked off so that there was a sharp turn in the major route with no entry to the third leg of the original intersection. There was no apparent change in traffic volumes on the major legs.

There was a significant decrease in rear end collisions, presumably due to removal of unexpected turns out of the major traffic flows. However, there was a major increase in the sideswipe accidents between vehicles travelling in the same direction, with the overall accident rate increasing 70%.

One explanation could be increased average speed of vehicles as they turned the corner with subsequent decrease in accuracy in lane discipline.

Project Type 204 - Modify Channelisation

Only one project of this type was found. The site was a T-intersection on a major highway where a left turn lane was added to the tail of the T which was a local urban road in the outer urban area. There was no significant change in the accident statistics at this site.

Project Type 215 - New Channels at Non-Signalised Intersection

Thirty-eight projects of this type were available for study. Results were fairly similar from site to site with an overall reduction of 22% in the accident rate. There was also a reduction in accident severity and some changes in accident types, namely a particularly large reduction in sideswipe and head on collisions. Rates of all types of accidents, however, did decrease. The largest reduction in accident numbers occurred in right angle accidents.

Project Type 216 - Modification of Channels at Non-Signalised Intersection

Seven channel modification projects examined at major sites where a total of 256 accidents occurred in the before and after periods allowing accurate analysis.

Overall, there was a statistically insignificant increase in the number of right angle accidents. However, there was a dramatic decrease in rear end and sideswipe accidents, pointing to an improvement in separation of traffic streams making different types of movements. The near elimination of these predominantly minor collisions led to an increase in severity of the remaining accidents. It should be noted that before treatment average severity of accidents at these sites was lower than average, while the number of rear end accidents was higher than average.

Project Type 400 - New Signals and Channelisation

There were seven of these projects and a total of 246 accidents in the combined before and after periods. On average these projects reduced the accident rate by 46%, which was greater, though not significantly so, than the reduction achieved at sites where signals were installed without channelisation.

There were, however, differences in accident patterns between the two classes of sites. At the sites where both signals and channels were installed, there was a reduction in both right angle **and** rear end collisions. The rate of rear end collisions actually increased at sites where signals only were installed. This points to the benefit of separating the traffic stream as it approaches the intersection more effectively with the channelisations, and suggests that while the accident numbers are not great enough to show that the different rate of accident reductions was significant, the difference may, nevertheless, be real.

Project Type 401 - Modify Signals and Channelisation

There were three such projects carried out in the study period. The treatment consisted of adding turn pockets and changing the signals. Additional phases for turning were added, though the exact changes could not be determined. Where necessary, additional lanterns were installed to display the additional phases. There was no significant effect on the accident rates at these sites. However, there was a decrease in rear end and an increase in right angle collisions. Again, there appears to be better separation of traffic streams approaching the intersections, according to their intended movement. This explains the reduction in rear end collisions. The increase in right angle collisions points to either lack of clarity in definition of the phases as seen by the approaching motorists: - a false sense of security engendered an apparent provision of a turning only phase either as a result of layout of the channels or display of signals - when in fact conflicts were possible in the phase.

Project Type 402 - New Signals & Channel Modifications

Eight of these projects were undertaken during the study period. Overall these projects resulted in a significant 24% reduction in accident rates. This was effected by a 61% reduction in right angle collisions with no change in rear end collisions. There were reductions also in sideswipe and head on collisions but the total numbers of each of these was small.

Again, these results illustrate the value of signals in reducing right angle collisions and that, if the intersections are channelised properly, increases in rear end collisions can be avoided.

Summary of Projects Involving Signals and/or Channelisation

There were several different project types involving either installation of new, or modification of existing, signals and road channels. These were:

200 Modify signals

201 New signals
202 New channels at signalised intersection (including signal modifications)
203 Modify channels at signalised intersection
215 New channels
400 New signals and channelisation
401 Modify signals and channelisation
402 New signals and modify channels

Although different project types had significantly different effects, some underlying trends may be isolated. The installation of signals, whether at a site without channels or along with the installation of channels, always resulted in a large drop in direct right angle collisions, often of the order of 50%. In some cases there may be a slight increase in indirect right angle collisions predominantly from vehicles turning through a stream of traffic approaching in the opposite direction.

An increase in rear end collisions occurred where the signals were installed without any road channelisation. However, where the road was also appropriately channelled, particularly to include turn pockets, there was no increase in rear end collisions. In fact, on their own, such channels reduced rear end collisions. Channels also had some other benefits in reducing all types of accidents.

Project Type 243 - Pedestrian Refuge Islands

Twenty-six of these projects were undertaken. Even in the before period only a small number of accidents involved pedestrians directly (i.e. pedestrians were actually hit in the accident). There were fifteen such accidents in the combined before and after periods: ten in the before and five in the after periods. Given the lengths of these periods there was no apparent change in the rate of accidents directly involving pedestrians.

There was, however, a decrease of 38% in the overall accident rate at these sites. This resulted from a reduction in rear end collisions, elimination of head on collisions and a substantial reduction in sideswipes.

Clearly, some of these benefits have arisen from the separation of the traffic streams caused by the median effect of the islands. However, the effects of the refuge islands were different from those of medians installed at non-signalised intersections. The accident reduction was more marked and the changes in specific types of accidents were significantly different. In particular the reduction in rear end collisions was far greater with the refuge islands. This may have been due to the reduction in sudden stops by motorists trying to avoid pedestrians.

Project Type 251 - Realign Short Section

Only three sites received this treatment. The results were completely dominated by one urban site where 61 of the 66 accidents occurred. The treatment consisted of realignment of a short section on the approach to a major intersection to improve visibility. The reduction in the accident rate was achieved purely through a reduction in the numbers of right angle collisions.

Project Type 256 - Median

Accident numbers were too low to allow analysis.

Project Type 414 - Improve visibility

Insufficient data was available to allow analysis.

Project Type 440 - Zebra Crossing
441 - Zebra Crossing with channelisation
450 - Pedestrian Protection

There is insufficient data for any of these project types to draw any conclusions.

Project Type 997 - Pavement Marking

These projects covered a range of projects where road markings were printed to lay out an intersection more clearly. The projects covered a variety of signs including centre lines, edge lines and turn arrows. Overall these projects reduced the accident rate by 40%.

This was achieved by substantial reductions in

head on
sideswipe
right angle

accidents with no change in rates of rear end collisions.

These projects have apparently not altered the extent to which motorists can predict the actions or movements of preceding vehicles. However, lane discipline improved substantially. Accidents resulting from bad vehicle positioning decreased.

Project Type 998 - Bus Lane

Insufficient data was available.

Project Type 999 - Cycle Way

Only one of these projects was available for study. Provision of a cycle way resulted in a significant 72% reduction in the accident rate. This has been achieved by a large drop in the two common types of accidents at the site - rear end and right angle.

Most of the accidents in the before period did not involve cycles directly, in the sense that a cycle was mentioned in the accident record. However, many may have been caused by vehicles avoiding cycles which did not comfortably fit into the traffic stream.

Project type - SIGNS

Giveway Signs

A sample of twenty-nine giveway sign installations was selected randomly. Twenty seven of the installations were new, two were replacements of stop signs. There was a wide variation in the effectiveness of the signs. The 1978 installations actually resulted in a significant increase in accident rates, while the 1977 and 1979 installations showed a significant drop in accident rates.

Over twenty seven sites, there was a significant drop of 47% in accident rates. This resulted from a large drop in right angle accidents and a small increase in rear end accidents. Other types of accidents did not occur in sufficient numbers to allow investigation.

Stop Signs

A sample of 112 installations was selected randomly. Of these, 67 were new installations. Forty five were replacements of giveway signs. New installations are discussed first.

There were major variations in effectiveness between the signs installed in different years. The 1979 installations apparently had no effect on either the overall accident rate or types of accidents while the 1977 and 1978 installations reduced accident rates by 26% and 70% respectively. Note that with these signs, Main Road Department records of installation dates are quite clear and so this cannot be explained by errors in choice of the rather short after period.

The installations where stop signs replaced giveway signs were again quite variable in their effects. These sites had approximately double the accident rates of the sites where new installations were made. Overall, the accident rate decreased by 22%, but there was no apparent change in accident rates resulting from the 1978 installations. At these sites, the overall rate did not change while there was a non-significant increase in rear end and non-significant decrease in right angle accidents. The 1979 installations, however, showed the same decrease in rear end and right angle accidents.

Comparison of Sign Types

There was only a small non-significant difference between the measured accident rate reduction at sites where there were new installations of STOP or GIVEWAY signs. However, with stop signs, rear end accidents did not increase while there was a slight increase with giveway signs. Where STOP signs replaced GIVEWAY signs, there was a reduction in accidents, suggesting that these signs are indeed more effective. The comparison of new installations of each type is not a statistically valid comparison as the sites are in no way paired. Indeed, the choice of sign type installed reflected the perceived severity of the problem at the site.

Project Type - Rural Road Marking

Substantial painting of new lines or repainting of existing centre and edge lines was carried out on rural roads, particularly in 1978/79. Observation showed that, judging on current practice, lines that were repainted would have worn to the point where they would have been very hard to see or indeed impossible to see under adverse conditions. Hence, there seems little justification for treating new marking and repainting separately. In any case, this proved to be impossible from a practical viewpoint.

The treatments covered a wide range of road conditions with a variety of terrain, design standards, and traffic volumes. The treatments examined were:

Road	Treatment	Length of treatment
H1	Separation lines	314 km
H2	Edge lines	130 km
H4	Separation lines	247 km
H5	Separation lines	420 km

H1Ø Separation lines 147 km

The road sections treated covered substantial lengths of road and again it was not practically possible to determine all other changes to these sections of road over the study periods. Analysis concentrates on examination of changes in accident types and under specific lighting conditions. Certainly, it would be rash to attribute reductions in overall accident rates solely to the line painting.

Further, it should be noted that during the study period, there were substantial changes in the proportions of specific accident types in the reported accident rates. These changes were much greater than for metropolitan accidents.

The overall reported accident rate for non-intersection rural accidents did not change much. (In fact, it increased 3.7% from the before to the after period - though small, a significant change.) The rate of casualty accidents, however, increased 7.3% in the same period, and so it seems that the reporting rate of minor PDO accidents dropped over the period. The changes in the rates of specific accident types, however, was very much greater, as shown in the following table.

There are several technical statistical factors at play here as well as a change in the underlying accident rates.

These technical factors are:

- a decrease in the proportion of minor accidents reported will lead to an apparent reduction in the rate of accident types which tend to be less severe, (such as sideswipes, rear end) and conversely;
- the large number of accidents in the before period whose type is unknown. The statistical test of change in accident type assumes that these accidents are in fact distributed amongst accident types in the same proportion as those accidents whose type is known;
- changes in the classification system.

The first two factors, however, could not explain the large change in the recorded accident type; no substantial changes in the classification system have been discovered. **Hence,** there appear to be other secular influences altering the accident rates for specific accident types.

Hence, in examining the treated road sections, allowance must be made for accident types to vary over time due to factors other than those being examined.

Further, the types of accidents should be expected to vary from road to road, reflecting different conditions.

On three of the five highways, there was no change in overall accident rates, while on the other two there was a decrease in the overall rate. This, however, more likely represents the effects of other road works on the two highways where the overall accident rate dropped. **Overall** accident rates are shown in the following table.

Overall Accident Rates on Treated Sections

Highway	Accident numbers: Highway Section Before	Highway Section After	Control group Before	Control group After	Change in accident rate X^2	
1	504	165	15638	6490	6.83	Reduction
2	417	177	14182	6490	0.68	No change
4	303	77	14667	5155	9.40	Reduction
5	759	290	14667	5155	0.05	No change
10	134	66	14667	8419	1.03	No change

Accident Types For All Rural Roads

Type		Actual Before	Actual After	Expected * Before	Expected * After
1	Rear end	1505.3	568.0	1440.8	632.5
2	Head on	934.3	240.7	816.6	358.4
3	Side swipe- opp. dirn	381.3	155.7	373.2	163.8
4	Side swipe- same dirn	806.7	476.0	891.4	391.3
5	Right angle	1302.7	857.3	1501.1	658.9
6	Ind. - right angle	168.7	113.7	196.2	86.1
7	Hit - pedestrian	218.7	124.0	238.1	104.5
8	Hit - animal	1390.0	495.0	1310.0	575.0
9	Hit - object	3730.3	1869.3	3891.4	1708.2
10	Non-collision	4215.3	1532.7	3994.5	1753.5
	Months	35	14		
	Total	14,653	6,432		
11	Type unknown	985	57		
	Grand Total	15,638	6,489		

* Assuming type is independent of period.

Accident Numbers Treated Section

Accident Type *

		1	2	3	4	5	6	7	8	9	10	11	Total	Control
Highway 1														
Before	Day	32	11	2	25	7	4	2	8	48	67	12	218	7137
	Night	8	12	2	6	3	0	0	17	44	39	5	136	3983
After	Day	16	1	0	10	2	3	0	3	22	23	1	81	3570
	Night	3	1	2	2	1	0	0	14	26	29	0	78	2800
Highway 2														
Before	Day	74	5	5	22	5	1	2	6	18	41	13	192	6335
	Night	17	4	3	4	2	0	3	17	23	23	8	104	3380
After	Day	46	3	3	14	4	2	3	2	11	24	0	112	3570
	Night	8	2	1	5	2	1	1	18	17	7	1	63	2800
Highway 4														
Before	Day	16	6	4	16	4	0	1	4	13	65	4	133	6586
	Night	9	3	4	2	0	1	0	11	14	31	5	80	3597
After	Day	0	0	1	4	0	0	0	0	10	21	1	37	2997
	Night	0	2	2	1	0	0	0	2	6	27	0	40	2416
Highway 5														
Before	Day	53	28	7	42	26	6	5	15	62	78	32	354	6586
	Night	12	9	8	12	2	0	3	23	60	51	7	187	3597
After	Day	22	5	7	21	11	4	3	0	34	40	3	150	2997
	Night	14	5	4	9	6	1	3	8	50	29	1	130	2416
Highway 10														
Before	Day	3	2	2	2	0	1	0	1	9	23	2	45	6586
	Night	0	1	0	0	0	0	2	9	7	13	0	32	3597
After	Day	2	1	0	4	1	1	0	0	5	14	1	29	5055
	Night	1	0	3	2	1	0	0	8	7	13	0	35	4154

* Types listed in previous table

Accident Numbers by Type
(Type 11 {unknown} excluded)

Accident Type	Numbers (actual) Before	After	Numbers scaled by control factor for each accident type *	expected scaled to total also **
Highway 1				
1	59.0	19.0	22.3	17.8
2	26.0	2.0	6.7	5.4
3	5.0	2.0	2.0	1.6
4	40.0	12.0	23.6	18.9
5	13.0	3.0	8.6	6.8
6	4.0	3.0	2.7	2.2
7	5.0	1.0	2.8	2.3
8	39.0	17.0	13.9	11.1
9	140.0	51.0	70.2	56.1
10	144.0	54.0	52.4	41.9
Total	475.0	164.0	205.1	164.0
Highway 2				
1	120.0	54.0	49.8	49.5
2	14.0	6.0	3.8	3.8
3	8.0	4.0	3.7	3.6
4	38.0	19.0	25.1	24.9
5	14.0	6.0	10.6	10.6
6	1.0	3.0	0.8	0.8
7	5.0	4.0	3.1	3.1
8	36.0	21.0	13.9	13.8
9	54.0	28.0	30.2	30.0
10	90.0	31.0	36.1	35.9
Total	380.0	176.0	177.1	176.0

* Expected number is $n_{ib} . N_{ia} / N_{ib}$

** Expected number is $n_{ib} . N_{ia} / N_{ib} \cdot \dfrac{\Sigma n_{ia}}{\Sigma n_{ib} . N_{ia} / N_{ib}}$

where n_{ia} is number of accidents in after period of type i on treated highway section

N_{ia} is number of accidents in after period of type i in control group

n_{ib} is number of accidents in before period of type i on treated highway section

N_{ib} is number of accidents in before period of type i in control group

Highway 4

1	32.0	0.0	11.1	8.0
2	12.0	2.0	2.7	2.0
3	13.0	3.0	4.7	3.4
4	20.0	5.0	10.8	7.8
5	4.0	0.0	2.4	1.8
6	1.0	0.0	0.7	0.5
7	1.0	0.0	0.5	0.4
8	24.0	2.0	7.8	5.7
9	43.0	16.0	19.6	14.2
10	134.0	48.0	44.2	32.2
Total	284.0	76.0	104.5	76.0

Highway 5

1	87.0	38.0	30.1	30.7
2	44.0	11.0	10.0	10.2
3	20.0	11.0	7.2	7.3
4	68.0	31.0	36.6	37.4
5	32.0	18.0	19.5	19.8
6	7.0	5.0	4.7	4.7
7	17.0	6.0	9.1	9.3
8	51.0	8.0	16.5	16.8
9	182.0	88.0	82.8	84.5
10	191.0	69.0	63.1	64.3
Total	699.0	285.0	279.6	285.0

Highway 10

1	5.0	3.0	2.6	2.4
2	5.0	1.0	1.7	1.6
3	2.0	3.0	1.1	1.0
4	2.0	6.0	1.6	1.5
5	1.0	2.0	0.9	0.9
6	1.0	1.0	0.9	0.9
7	2.0	1.0	1.4	1.3
8	20.0	8.0	9.9	9.1
9	28.0	12.0	19.8	18.2
10	61.0	28.0	30.7	28.2
Total	127.0	65.0	70.6	65.0

Analysis of accident type showed that there was a significant change for highways 1, 4 and 10. Similarly, analysis of the ratio of day to night accidents on these five highways showed a significant increase in the proportion of night accidents on highways 1, 4, 5 and 10, and a significant decrease on highway 2. Further checks reveal that for highways 1, 4, 5 and 10 there was a significant decrease in daytime accidents on these four highways, and no significant change in nighttime rates. However, on highway 2 there was a decrease in nighttime accidents, but no change in daytime accidents. The decrease on highway 2 in night-time accidents was attributable to a decrease in single vehicle accidents.

The decrease in the daytime accident rates on highways 1, 4, 5 and 10 occurred in multi-vehicle accidents.

In summary, while the changes in overall accident rates were small, centre lines did have a significant effect in reducing multi-vehicle daytime accidents. Edge lines had a significant effect in reducing nighttime single vehicle accidents.

APPENDIX C

STATISTICAL TECHNIQUES

C.1 Introduction

This appendix contains a brief description of the statistical methodology employed in this study. However, for a detailed explanation of much of the standard statistical theory employed, a good statistics reference text should be consulted.

The earlier feasibility study (Clark, Gipps, MacLean & Teale, 1979) and other studies (Clark, Odgen, 1973) contain a detailed critique of the range of methodologies available for such evaluations. This is not repeated in this current report. The feasibility study, however, clearly indicated that a before and after approach was the most appropriate methodology.

In effect, the accident situation at selected sites is observed **before** implementation of each project, and compared with the accident situation at these sites **after** implementation.

For such an analysis to be effective, it is necessary to develop suitable statistical techniques to determine whether the observed change in the accident situation represents a change that is due to implementation of the project rather than a result of random fluctuations in the numbers of traffic accidents, and thus not related to the improvement.

C.2 Before and after experiments

The before and after approach, as used in this study, is the only design that can be applied, due to lack of power of the researcher to control key inputs to the experimental situation.

At any site it is quite clear that there are many factors that contribute to the hazard of that site. These factors range from geometric design details affecting site characteristics, to traffic volumes and weather conditions. It may not be possible to change any of these factors. Further it is often difficult or even impossible to define many factors in an objective manner.

To evaluate the effect of a factor, it is necessary to observe situations with this factor at different levels. For road safety projects there are usually only two levels - either the treatment has or has not been applied. Both the practical problem of determining the levels of other factors, and of setting up experimental situations, make it impossible to set up an experiment with two sites differing only in the treatment under study.

In a before and after experiment, no attempt is made to duplicate the site or traffic conditions. The same site and traffic conditions are used for the complete experiment with the factor under investigation being changed during the experiment. In most cases this factor has only two levels - either a specific feature is included or excluded.

Duplication of the experimental factors is obtained by spreading the experiment through time. In a later section on control the question of assuring that other factors do not change over time is discussed. The first consideration, however, is the timing of the change in the factor under investigation. When before and after experiments are discussed, many assumptions are invariably made, often implicitly, about the timing of the change.

These assumptions almost invariably imply that under the null hypothesis (- that the change in the factor being investigated had no effect -) the test statistic, be it accident numbers or whatever, will behave similarly in the before and after period. This usually requires the assumption that the change of the factor under investigation occurs either at a random time, or else at a time predetermined by the experimenter. Neither of these conditions prevailed in this study. However, it is shown in the next appendix that due to the mechanism for the choice of projects undertaken, it may safely be assumed that the time of implementation is a pseudo-random event.

C.3 Non-reporting of accidents

All accident analyses must be based on official accident records. However, not all accidents are reported, and thus are not recorded in official statistics.

It may be assumed that accident reporting is a stochastic process where the probability of reporting is a function of severity and to other driver-related factors, but not related to site characteristics.

It can be shown that both the actual number of accidents and the number of reported accidents follow a Poisson distribution (MacLean & Teale, 1982). Thus non-reporting only increases the uncertainty of analyses of safety effectiveness through a reduction in the number of accidents included in the sample.

However, in estimating the cost effectiveness of projects, adjustments must be made for non-reporting of accidents. Accident numbers were adjusted by the control factors (explained in Section C.4), so that the numbers of accidents used in analysis all reflected the same reporting rate as in the base year (for S.A. this was 1975 and for W.A. it was 1978).

No suitable South Australian or Western Australian data could be obtained to estimate the level of reporting of accidents in those States. The use of A.C.T. accident statistics was considered as all accidents should be reported in the A.C.T., but other conditions in the A.C.T. were considered atypical of the States (S.A. and W.A.) which were the subject of this study. Rather the estimate of reporting rates was based on a survey of NRMA insurance data and offical N.S.W. accident data (Searles, 1980). This survey found that 11.6% of all accidents involved injury. Further, 95% of accidents involving injury were reported. The conditions under which accidents had to be reported were similar in all three States (N.S.W., S.A. and W.A.) for the period of the NRMA study (1975) and this study (based on

1972-1980 data).

Estimates of reporting rates were based on the percentage of reported accidents that involved injury. It is known that nearly all injury accidents are reported.

The proportion of reported accidents involving injuries or fatalities varied by less than one per cent between S.A. and W.A. in the base years used for adjustment of accident statistics. These base years were 1975 for S.A. and 1978 for W.A. As it is known that nearly all injury accidents are reported, it has been assumed that reporting rates for accidents in the two States were similar in the base years.

For these years, for each report of an accident it was estimated that an average of

0.005 fatal accidents (all reported)
0.19 injury accidents (nearly all reported)
1.64 property damage only (PDO) accidents (many unreported)

occurred.

As few of the projects affected the severity of accidents that did occur, it is possible to conduct analyses of cost effectiveness on the basis of reduction of reported accidents, where the probability that a reported accident involved casualties or fatalities did not change from the before to the after period.

C.4 Control of extraneous factors

The success of any statistical experiment depends heavily on the control of extraneous factors. The control of these other factors is particularly difficult in this study as it is not even easy to identify them all. In many statistical experiments it is common to use matched pairs or matching groups. The purpose of the matching procedures is twofold:

- to remove the other factors not under study and thus also

- to reduce the variability of the test results.

Where pairing is used, the intention is to match the factors not being examined. **This often removes much of the** variability which arises from the effects of these extraneous factors.

However, when matching accident sites, variability is not reduced. To appreciate the reason for this, it is important to understand the basic statistical process behind accident occurrences.

For the purpose of discussion, consider the occurrence of accidents at a specific location. It is generally agreed that this location will have a certain degree of hazard associated with it. While there are differences of opinion on specific values, there is also considerable agreement on the geometric and other factors that determine the hazard of the site. All these factors contribute to the "hazard index" - that is, a number that specifies the probability of an accident occurring in a very short interval of time.

The actual occurrence of accidents, however, follows a stochastic process; the probability of a single accident in a very short interval is proportional to the length of the interval and the hazard index, while occurrences in different intervals are independent. From these assumptions one may derive the standard result that the number of accidents follows a Poisson distribution where the mean rate of occurrence is the "hazard index". These assumptions also lead to the conclusion that some other statistics - such as the number of injuries sustained at the site - do **NOT** follow a Poisson distribution. (Maclean & Teale, 1982).

The distribution is sometimes referred to as a "stuttering Poisson". It is similar to a Poisson distribution but its variance is always greater than its mean (unlike a Poisson where they are equal).

Any pairing or matching of sites can only match site characteristics that determine the "hazard index". **The stochastic process, however, cannot be paired or matched.**

Thus while pairing or matching of sites may correct results for unknown biases etc, **it will not reduce the variability of the results, but indeed increase them.** This is the opposite of many of the situations described in statistics tests where the pairing process decreases the variability of the key statistic being measured.

In the classic description of the pairing process, it is assumed that the process being examined is highly deterministic. The statistical fluctuation largely arises from the action of factors not measured or explicitly controlled. The pairing process should match these factors, and thus cancel their effects, which would otherwise have been measured in the random error term. In the situation here, however, the fluctuations arise from the intrinsic stochastic nature of the accident process. These stochastic processes cannot be paired or matched.

Matching of sites is really an attempt to match the factors that determine this hazard index. However, the innate variability of the accident processes at two different sites **cannot** be matched. They are by nature independent.

The variability of the difference of accident numbers at two sites is, therefore, the sum of the variability of the individual sites. Hence pairing, while it may remove biases if the two sites are correctly matched, will not help eliminate random fluctuations, but will increase the fluctuations, further obscuring underlying trends.

In view of other reports that have attempted to assign a hazard index to specific sites and the large variation between different experts' attempts, there are even grave doubts that sites can be properly paired (Taylor, 1976).

Thus, rather than matching sites, the appropiate method for control is to identify separately non-site and site factors that may vary with time and then find methods to measure these changes with maximum possible accuracy.

This requires that the largest possible number of sites, where these changes can be reasonably assumed to be homogeneous, should be used as the control group for a specific site or group of sites at which accident countermeasures have been applied.

Fortunately, the factors that should be eliminated by the use of control groups were fairly widespread in their action. Thus it was possible to specify a large control group, and thus minimise the variability introduced by the control group.

In selecting a control group, non-reporting of accidents need not be considered as it is not specifically site related. However, as the level of reporting of accidents changes with severity, the control group should at least reflect the level of severity of accidents in the experimental group. Hence the control group should reflect the type of road, such as urban arterial, and if a specific accident type is being studied in the experimental group, then only that type of accident in the control group should be examined, so that severity and hence reporting levels will match.

For the two States that were examined, it was appropriate to divide them into three zones for consideration of changes in hazard indices. These areas are defined as:

1) Major metropolitan area, including the Central Business District - respectively Adelaide for South Australia and Perth for Western Australia.

2) Rural towns.

3) Rural hinterland.

Accidents within each zone were further divided into intersection and non-intersection accidents. Some of these widespread factors, such as seat belt wearing, might have different effects on these two classes of accidents.

It is not the role of this study to establish either the overall or differential effects of non-site changes such as seat belt wearing rates or vehicle design standards. However, it is important that their effects be discounted when examining the effect of site changes. Therefore, these other changes are examined briefly only. **The purpose of** this examination is solely to establish control groups.

Changes to traffic laws and regulations occur regularly. The vehicle fleet, fuel costs, driver population, community attitudes and vehicle use patterns all have some effect on the hazard index at individual sites. All these factors are continually changing. However, in most cases the effects would be fairly homogeneous over large areas.

Many of the changes are of course interrelated, but prima facie may affect accident statistics. For example, there is some evidence from N.S.W. traffic counts that trends in vehicle use in rural and metropolitan areas are diverging. The rise in fuel price has helped induce a shift towards smaller vehicles but perhaps has also had some effect on vehicle speeds, and mode choice for long trips. This clearly will affect the severity of accidents, more so in rural areas.

Similarly, legislation that affects the whole State may have differential effects. The introduction of compulsory seat belt wearing is a case in point. This resulted in a reduction in the level of severity of accidents. In both States the drop in the proportion of casualty accidents amongst reported accidents was higher for rural accidents than for urban accidents.

Some legislative or regulative changes, of course, clearly affect a more limited range of sites. Changes such as allowing left turns on red, or changing the meaning of a STOP sign, are only going to affect intersections with these types of control. Indeed, they will only affect certain types of accidents at these sites.

The control group for a site has normally been chosen as the area where the site is located (urban, rural town or rural hinterland) including either all intersections or non-intersection sites in this area depending on whether the site under examination is an intersection or not. In some cases accidents of a specific type only are considered for control purposes.

It can be argued that this approach does not give a perfect control group in some circumstances such as the two examples already listed - turn left on red or change in the meaning of a STOP sign. Selection of a specific control group, however, proved very difficult and unreliable. The increased statistical variation in this smaller control group in any case negated any improvement from potentially better matching.

Some site specific changes are, of course, not matched by this procedure. These include

(a) Physical site changes;

(b) Site control changes;

(c) Traffic volume and speed changes.

This investigation is about the effects of changes at specific sites of (a) and (b) above. However, in many instances, it was desirable to discount the effects of changes in traffic volumes and speed which in turn are correlated. This posed a major statistical problem, due to the quality and availability of data. These problems are discussed in some detail in Appendix D.

Whether adjusting accident data for large changes in exposure is in fact meaningful is open to debate. It is reasonable to assume that at a specific site traffic speed is very closely correlated with volume, and that the two may effectively be treated as the one variable. However, where there is a major change in volume, the type of control required may well change as an increase in the capacity of the intersection is required. For example, as the volume on a crossing of a main road increases first a stop or give way sign might be erected and as volumes increase further, a set of signals may be installed.

In studying the effect of the stop sign, is it appropriate to use data up to the date of signal installation? By this time the stop sign is inappropriate and is probably limiting the volume of the intersection to the point where drivers are prepared to take unusual risks to cross. Is it appropriate to include data from this period either in an evaluation of the stop sign or the signals, as the sign is operating under inappropriate conditions? It is operating in quite different conditions to those prevailing when it was installed.

A certain amount of judgement must, therefore, be employed in selection of before and after periods so that the change in traffic volumes is not too high.

Some allowance for changes in traffic volumes is made by the control groups selected. This allowance is for the average increase in vehicle use (as might be measured from fuel sales). However, the control group does not adjust for larger than average changes in traffic volumes occasioned by area development or by local rerouting of traffic.

The paucity of traffic flow data makes these effects difficult to detect. The time lag between successive counts is so large that in many cases where there is a major increase in traffic volumes, the site must be excluded as there is not sufficient data to allow a reasonable adjustment to be made.

The issue of local rerouting of traffic poses a more severe conceptual problem. In practice, data limitations preclude detection of this except in exceptional circumstances. In theory it may be argued that if intersection changes attract traffic away from other nearby sites, this increase in volume should not be discounted in examining the safety effect of the change. In any case, in practice it was not possible to allow for rerouting as it could not be measured accurately, but where it occurred it has been noted in the comments.

There are a variety of seasonal factors which may affect road hazards. These include:-

- traffic volumes
- lighting (glare)
- rain
- road surface condition
- day/night.

Some of these changes may be fairly site specific, and change radically between nearby sites. Hence, these would not be properly controlled by the control groups selected. However, they have been eliminated by choosing before and after periods to be multiples of one year. This was necessary in any case for several practical reasons, and so has not resulted in any loss of data for evaluation.

Control Factors

The actual control factors used are computationally very simple, once the control group and accident type have been chosen.

Let $N_{i,j}$ = number of accidents at control group sites in year i of type j

$n_{i,j}$ = number of accidents at site being examined in year i of type j

$f_{i,j}$ = control factor for accidents in year i of type j

$a_{i,j}$ = be the adjusted number of accidents in year i of type j

Then $f_{ij} = N_{bj} / N_{ij}$

and $a_{ij} = n_{ij}.f_{ij}$

where b is the base year.

NOTE 1. j may indeed represent a single accident type or severity level or some combination of these factors.

NOTE 2. a_{iS} may not be exactly equal to $\sum_{s \in S} a_{is}$ where a_{iS} is the adjusted number of accidents of some composite class S of accident types and/or severity.

NOTE 3. a_{ij} is approximately a Poisson variable for the range of N_{ij} used in this study.

C.5 Statistical tests used

Following is a brief outline of the statistical tests used by the study. Of course, in specific cases some minor changes had to be made. The theory is applicable either to unadjusted or adjusted accident numbers, but in all the applications of the tests, adjusted numbers have been used.

Test to assess accident reduction

The test described in this section was developed for use in a before and after study evaluation. The purpose of the statistical test is to provide a basis for determining whether any change in accident behaviour observed after the introduction of a particular project can confidently be attributed to that project's implementation.

As in most cases the incidence of accidents at a particular site is not high, any procedure designed to test for a change in the accident experience of a single site is not very powerful. In other words there is a low probability that the test will indicate a change in the underlying accident rate when one indeed does occur. For this reason it is necessary to combine results from several sites where the same type of minor traffic engineering project has been carried out.

The test therefore compares the number of accidents which fall into the before-and-after periods at a group of sites where a particular type of minor traffic engineering project improvement has been carried out. In this description of the test no explicit mention is made of control for:

- changes in site exposure
- changes in the secular trend of accidents
- seasonal factors.

A test for accident reduction

Suppose we have a group of sites numbered 1 to n, and at each of the sites a particular type of minor traffic engineering project has been implemented. For site i, let

p_i	be the ratio of accidents in the after period to the total number of accidents observed in the before and after period if no improvement in accident incidence occurs
N_i	be the total number of accidents observed in the before and after periods
$N_i p_i$	be the expected number of accidents in the after period if no improvement occurred
n_i	be the observed number of accidents in the after period.

The test is designed to answer the following question :

> Does the number of accidents observed in the after period, when compared with the number in the before period, indicate that the project has improved the safety of the group of sites?

Using the notation given above, we want to know if

$\sum_{i=1}^{m} n_i$ is significantly smaller[1] than $\sum_{i=1}^{m} N_i P_i$

where m is the number of sites.

Thus we wish to determine a critical value $\delta(a)$, such that if

$$\sum_{i=1}^{m} n_i \text{ is smaller than } \sum_{i=1}^{m} N_i P_i - \delta(a)$$

we can conclude that the project has improved the safety of the group of sites. This is if the total number of accidents observed in the after period at sites 1 to m must

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[1]Strictly speaking the first quantity may be larger than the second and still indicate improvement in safety. We assume, however, for the purposes of exposition, that the before and after periods are of equal length and that changes in exposure and in secular trends are negligible. These assumptions are not necessary, as will become apparent.

fall short of the expected number by at least $\delta(a)$ to indicate that the project has improved safety.

The quantity [a] represents the probability that the conclusion drawn is wrong.[1] That is, if we conclude that the project **has** improved safety, there is a 100a per cent probability that the indicated improvement was due to chance alone and that the project has **not**, in fact, led to any improvement in safety.
The value of δ depends on the value chosen for a. Typically this is 0.05 or 0.10 indicating respectively a 5% and 10% probability that an indicated improvement could be explained by chance.

The quantity $\delta(a)$ may be calculated using a Normal approximation as long as N is over say 50.

$$\delta(a) = N_i p_i (1 - p_i)\ q(a)$$

where q(a) is the a percentile point of the Standard Normal Distribution.

Power of test

In the above, a test was described for which the conclusion that safety has been improved by the project is subject to a small 100a% chance of being wrong. Conversely, we should determine the probability of detecting an improvement if safety **has** been improved. In statistical terms, we denote $1-\beta$ as the probability of the test indicating an improvement in safety, given that one has, in fact, occurred[2]. The quantity $1-\beta$ is known as the power of the test.

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[1] This is known as the probability of a type I error.

[2] The quantity β is known as the probability of a type II error.

If, for likely test situations,[1] the power is reasonably high, then the test procedure should be regarded as satisfactory. Alternatively, it is necessary to determine those situations which yield a test of unacceptably low power.

The power of the test is dependent on the actual improvement in safety resulting from the implementation of the project under test. It may be quantified as follows. Let

r_b be the true mean number of accidents per year over all sites in the before period, and

r_a be the true mean number of accidents per year over all sites in the after period

k be the ratio r_a/r_b.

It is necessary to define $1-\beta$ as a function of k when k is actually less than unity. (That is, when the accident frequency in the after period is lower.)

Some simplifying assumptions are useful. Suppose:

t is the sum of the durations of all after periods (in years)
T is the sum of the durations of all periods (in years)

Suppose further that sites are homogeneous with respect to time within each period. That is, the expected number of accidents for a given time period is directly proportional to the length of that time period. Then values of $1-\beta$ can be derived as a function of a,k,N and t/T and are shown in Table C.1. Normally, if the total number of accidents observed is sufficiently large, then the power of the test will exceed 0.90, particularly if a is set to equal 0.10 rather than 0.05.

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[1] By situation, we mean the state of affairs described by such things as : the total number of accidents observed, the relative lengths of before and after periods, the actual effect of the project on safety and the value chosen for a.

That is, provided the number of accidents observed is sufficiently large:

- there is low probability a (say 5% or 10%) of concluding that an increase in safety has occurred when an increase has not, in fact, occurred;
- there is high probability $1-\beta$ (in most cases 90% or better) that an increase in safety is detected when it has actually occurred.

The sample size is absolutely critical to the power of the test. In the evaluation study the cost of sampling was not significant as much of the data was selected by computer. Hence all projects that could be identified were included in the evaluation.

Nevertheless, for many project types, only a relatively small number of sites could be identified. The power of the test is determined not by the number of sites, but mainly by the total number of accidents at all sites. The power is tabulated on the following page.

Measure of size of reduction in accident rate

The test just described is the most powerful test that can be used to determine whether there has been a change in accident rates. If a change is detected, however, it is desirable to calculate some statistical measure of the size of that change. Clearly this should be a measure of the ratio of accident rates in the after period to accident rates in the before period.

TABLE C.1

POWER OF TEST OF EFFECTIVENESS

Total no. of accidents observed	Ratio of accident frequency after to before	Power of 1-'					
		Ratio of after periods duration to total periods duration t/T					
		0.75		0.50		0.25	
		a=0.05	a=0.10	a=0.05	a=0.10	a=0.05	a=0.10
N	k						
50	.9	.100	.177	.101	.181	.086	.160
	.8	.190	.297	.194	.309	.144	.249
	.7	.335	.464	.342	.486	.236	.375
	.6	.538	.664	.550	.692	.371	.536
	.5	.762	.849	.775	.873	.552	.719
100	.9	.125	.214	.131	.225	.109	.195
	.8	.276	.401	.296	.432	.218	.347
	.7	.511	.642	.548	.638	.395	.554
	.6	.773	.859	.811	.896	.627	.773
	.5	.946	.973	.963	.985	.848	.930
200	.9	.169	.273	.184	.295	.148	.251
	.8	.423	.560	.431	.614	.353	.503
	.7	.749	.843	.806	.891	.647	.780
	.6	.953	.977	.975	.990	.895	.953
	.5	.998	.999	1.000	1.000	.989	.997
500	.9	.280	.409	.320	.453	.251	.383
	.8	.726	.828	.801	.887	.662	.789
	.7	.974	.989	.990	.996	.951	.980
	.6	1.000	1.000	1.000	1.000	.999	1.000
	.5	1.000	1.000	1.000	1.000	1.000	1.000
1000	.9	.436	.576	.508	.649	.402	.550
	.8	.933	.967	.970	.988	.906	.956
	.7	1.000	1.000	1.000	1.000	.999	1.000
	.6	1.000	1.000	1.000	1.000	1.000	1.000
	.5	1.000	1.000	1.000	1.000	1.000	1.000

NOTES

(a) For a general description of power of a test see any statistics test.

(b) $$\beta = 1 - \Phi\left\{ \frac{\frac{tN}{T} - \delta\sqrt{\frac{t}{T}\left(1 - \frac{t}{T}\right)N} - \frac{kt/T}{kt/T + 1 - t/T}}{\sqrt{\frac{kt/T(1-t/T)N}{(kt/T+1-t/T)^2}}} \right\}$$

where $\Phi(a)$ = probability that standard normal variate is less than a.

and $\Phi(\delta) = 1 - a$

For a specific site the quantity to be estimated is

$$k_i = r_a/r_b$$

If T_i is total length of before and after periods
t_i is length of after period

N_i the number of accidents in the before and after period
n_i the number of accidents in the after period.

Then dropping the subscript and referring to (Tin, 1965)

The maximum likelihood (M.L.) estimate
$$\hat{k} = (n/(N-n)).((T-t)/t)$$

The unbiased estimate is:

$$k' = (n/(N-n)).((T-t)/(1+1/(N-n))$$

with variance
$$\text{var }(k') = (n/(N-n))^2.(1/n+1/(N-n)).((T-t/t)^2$$

This estimate however is not robust when r_a or r_b is small.

When several sites are available for analysis, methods to combine these estimates are required. The simple method would be to use the standard method for stratified samples - namely combine the estimates using weights inversely proportional to the variance of individual estimates. This, however, still gives an estimate that is not particularly robust.

Where there are a set of sites which have the same before and after periods, a more robust measure is obtained by summing the accident numbers directly.

i.e. $N = \Sigma N_i$ where the summation is over a set of sites with the same before and after periods

$n = \Sigma n_i$

and the same formula may be used as an estimate of the reduction factor. To combine estimates for groups of sites (or individual sites) a weighted average of these must be taken.

$$K^* = \Sigma\, k_i{}'\, W_i \text{ where}$$

$$W_i = \{1/\hat{var}\,(k_i)\}/\{\Sigma\, 1/\hat{var}\,(k'_i)\}$$

and $\text{var}\,(k'_i) = (n/(N-n))^2 . (1/n + 1/(N-n)) . ((T-t)/t)^2$

and i may refer to a single site or a group of sites with the same before and after periods.

Of course to test for effectiveness of the projects, one could test whether K^* was significantly different from unity. However, this test would not be as powerful as the test described earlier.

Comparison of different types of projects or different versions of projects may also be attempted.

Where the before and after periods are different, it is necessary to estimate this ratio of accident rates for each group and compare these. However, if the before and after periods are the same, then a two way contingency table test may be used.

To examine the effects on severity and/or accident types, contingency tables may be used, even when it is assumed that the overall accident rate has changed, and the before and after periods differ from site to site. In these examinations the null hypothesis is of the form - "the proportion of casualty or the proportion of rear end collisions, for example, is unchanged from the before to the after period." Aggregation of sites with different before and after periods is permissible.

APPENDIX D

RELIABILITY OF DATA

D.1 Accident Data

This study relies heavily on traffic accident data collected by the State Road Authorities, who, in turn, rely on reports from police or traffic patrolmen, and reports from persons involved. This leaves considerable scope for inaccuracies, and non-recording of accidents. In addition, very minor accidents may not need to be reported under the laws applying at the time of the accident.

In the two States where the study was conducted, all accidents that are reported to police are recorded. In both States all casualty accidents must be reported. However, where property damage only (PDO) is involved, accidents must only be reported where damages exceed a prescribed amount. In practice many accidents where damage exceeds the prescribed amount are not reported, as shown from insurance claims. There are a variety of reasons for this: e.g. drivers underestimate damage caused or drivers do not wish police to be called (e.g. they may fear prosecution or otherwise may agree that it is not necessary to call police).

Research work in N.S.W. (Searles, 1980) has shown many minor accidents are not reported, but nearly all accidents involving injury and most serious PDO accidents are reported. Further, as the cost of accidents decreased, so did the proportion that were reported. There is every reason to believe that this general pattern would be repeated in the States where this study was carried out, as regulations regarding reporting of accidents are similar.

It is quite reasonable to assume that the reporting of an accident that has occurred is a stochastic process where the probability of reporting is a function of the accident severity. Certainly treatment of a site will not affect the reporting process.

On this assumption it can be shown (see MacLean & Teale,

1982) that the distribution of reported accidents and actual accidents are similar, though of course the parameters of these distributions are different. This random non-reporting of accidents does not affect the analysis except in so far as it reduces the total number of accidents included in the analysis. The statistical power and accuracy of the tests are the same as if the actual number of accidents were to be equal to the number reported and all accidents were reported.

The accuracy of reports is a separate issue. There are several types of errors that may be made which prima facie could affect the analysis in this project. These include incorrect reporting of:

- location
- type
- severity.

Analysis of the effects of these errors is similar to the analysis of non-reporting. Again it is reasonable to assume that errors in accident reports are random. Given that an accident of a specific type occurs, then there will be a high probability that it is reported as one of the recognised types. Detailed analysis again shows that the distribution of reported accidents of a specific type will be similar to that of the distribution of actual accidents of that type. However, the proportion of a specific accident type in reported and actual numbers of accidents may be different, depending on the probabilities of the different errors in reports.

Similar effects occur for accident severity. The analysis in this study, however, is concerned with changes from the before to the after period. These analyses are concerned not only with numbers but also with proportions. Where the effect of a treatment affects the severity in reported proportions and actual proportions, some error will be generated. These effects, however, are second order effects, and are insignificant compared to random fluctuations.

Given the system of site identification for accidents used in the States where this study was conducted, errors in the location information on the original report form would normally either be corrected in the coding of the site of the accident or result in non-recording of the accident where the site cannot be positively identified from the report form. Thus the effect of errors in location data will be similar to non-reporting of accidents. However, there will be some instances where errors in location information lead to intersection locations being coded as non-intersection accidents and vice versa. This will in effect result in incorrect classification of accident type.

In summary, for the purposes of this study, errors in accident reports did not have a significant effect on the analysis. Non-reporting of accidents simply reduced the power of tests and increased the error in estimates of the safety improvements achieved. However, it did not bias results in any significant way.

D.2 Site Data

Establishing details on site work carried out and exact times and costs of that work proved to be difficult in some instances. Some sites had to be excluded where it proved impossible to establish what was done or when it was done.

Overall control of projects was exercised by the head office of the State Road Authority. However, work was carried out either by a division of the Authority or a local authority. In many instances project details had to be approved by the Road Authority and various local authorities. This often entailed changes in the plans and considerable delays in implementation.

Once there was agreement on project design the only concern of the central office was control of expenditure. Design and implementation information was not recorded in the main accounting system. Once approval was given, the only central records kept were the accounting records and so some implementation data could not be determined accurately.

There were good statistical reasons to allow a gap of a whole year between the end of the before period and the beginning of the after period. This allows the before and after periods to be exact multiples of a year. This eliminates seasonal effects from both the before and after periods. As seasonal factors may vary markedly between two nearby sites, this is the only reliable method to remove seasonal effects. This means that the inaccuracies in site data for time of implementation are not critical.

D.3 Exposure Data

Data on traffic flows is the most unrealiable of all the data used in this review. There were several problems with the traffic flow data.

First, counts at specific sites are only taken infrequently. On main urban roads in Adelaide, counts were normally available every two years, but data for country areas of South Australia and all of Western Australia were far more patchy. Even if there were no statistical problems in interpretation of these counts, their spread, in most cases, prevented detection of changes in traffic volumes as a result of site improvements. For example, while a change in signal phasing at a site on a main arterial could well affect turning movements, either increasing or decreasing them, in most cases it was not possible to get this data from the counts available.

There are also major statistical problems in interpreting actual traffic count data. In most cases the data available is an estimate of average annual daily traffic (AADT) taken from a twenty-four hour count. Enquiries revealed that seasonal adjustments were not attempted in the estimation procedures. Successive counts at a given site were not always taken at the same time of the year, and hence in comparing counts for different years there could be systematic differences of seasonal effects which could be as high as 8% judging by seasonal effects measured in Sydney (Teale, 1980). This is higher than the average increase in road traffic over the system as a whole for two years. In addition, the random error in estimates based on a 24 hour count would be of the order of 4% for a major arterial and higher for less trafficked roads (Teale, 1980).

Daily patterns (essentially the size of the peak relative to off-peak) at specific sites do not change rapidly and thus do not have much effect on exposure comparison of the before and after periods at a specific site. However, these patterns may differ substantially from site to site and have a major effect on inter-site comparisons.

It is generally accepted that exposure at an intersection is measured as:

$E = k(V_1 . V_2)^{1/2}$ where k is a constant and V_1, V_2 are traffic volumes on the two intersecting roads.

However, the exact measurements of V_1 and V_2 are often not specified.

In fact the measurements should be instantaneous measures of volumes giving an instantaneous measure of exposure.

Thus to obtain an overall measure of exposure this formula should be integrated over time.

$$E = k \int V_1^{1/2}(t)\ V_2^{1/2}(t)\ dt \ldots (1)$$

This may be rewritten as

$$E = k\ \bar{V}_1 \bar{V}_2 I \quad \text{where}$$

$$I = \int r_1^{1/2}(t)\ r_2^{1/2}(t)\ dt \ \ldots (2)$$

where $\bar{V}_1$ and $\bar{V}_2$ are average volumes over the period of integration and $r_1(t)$ and $r_2(t)$ are volumes over a short period.

$$\text{i.e.} \quad V_i(t) = \bar{V}_i\ r_i(t)$$

$$\text{and} \quad \int r_i(t)\ dt = 1$$

This r_i is the daily profile. Using actual profiles measured in Sydney, this integral I may vary by a factor of two from heavy commercial/industrial areas to pure commuter routes. Comparison of exposure between sites, then, should not depend only on measures of AADT.

With the large control group selected, there was a general adjustment for average traffic changes in the control group which should not be duplicated by explicit adjustment.

In practice, explicit adjustment was only attempted where it was quite clear that traffic flow changes were much greater than system wide changes.

One last point, of course, is that traffic facilities may cease to be appropriate where there are very large changes in traffic flows. Such sites were excluded from analysis.

D.4 Bias

The before and after experiment analysis assumes (though it is often not explicitly stated) that the treatments are applied at times under the analyst's control. This certainly was not the case in this study, unlike the situation in many other statistical analyses. In fact the installations studied were those commissioned by the roads authorities, usually on the basis that they were justified on one of the recognised warrants.

Certainly the projects installed and the time of installation were not under experimental control and were not randomly chosen. Potentially, this could create a serious bias problem, as the sites may have been selected not due to their underlying accident rates, but due to an higher than normal rate of accidents in the immediate past. Such a run will from time to time occur for all sites. This is a version of the reversion to the mean phenomenon.

If the before period is chosen to exclude all periods from which data was used in the selection of sites for treatment, then for the purposes of analysis, the timing of treatment can be assumed to be random, and so there would be no chance of the above kind of bias. In this study, the before periods largely covered periods after those used in collecting accident statistics for choice of treatments. This occurred both because of the age of statistics used in selecting sites for treatment, and the delay between the decision to proceed with a treatment and its implementation. Further, there seemed to be little correlation between some of the accident rates quoted on the documents detailing choice of sites for treatment, and the accident numbers subsequently extracted from the official accident statistics.

It was also clear that in many cases accident rates were only a minor consideration in the commissioning of minor traffic facilities. Certainly projects were not commissioned in the order of greatest potential for accident reduction.

Bias from the method of selection of sites for treatment then did not prove to be a serious problem.

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