

**TRAFFIC ENGINEERING ROAD SAFETY:
A PRACTITIONER'S GUIDE**

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**DEPARTMENT OF CIVIL ENGINEERING
MONASH UNIVERSITY**

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Abstract

This report is intended to assist those with the responsibility for traffic engineering and road safety by providing a ready source of information, with guidelines for action and information. It is aimed especially at engineers and others with responsibility for traffic engineering and management, especially in local government or regional offices of State road and transport agencies.

Keywords Road safety, traffic engineering, accident data, black spots, safety audit, road design, traffic management, speed, roadside, evaluation

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TRAFFIC ENGINEERING ROAD SAFETY: A PRACTITIONER'S GUIDE

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EXECUTIVE SUMMARY

It is widely recognised that road and traffic engineering measures have an important role to play in contributing to safer roads. In recent years there has been considerable emphasis on the treatment of accident black spots and significant funding of remedial programs targeted at improving the safety of sites which have a demonstrated accident record. More pro-actively, good road design and well-developed traffic management measures produce roads which are safer and which are less likely to develop as black spots, while road safety audit procedures can be used to attempt to ensure that both new and existing roads have potential safety problems removed before they lead to crashes.

However, all of these outcomes are dependent upon the skill of the engineer responsible for the design or management of the road segment concerned. Notwithstanding the value of publications such as Austroads' *Guide to Traffic Engineering Practice* or manuals and guides produced by the various State and Territory road and transport agencies, there appears to be a need for a ready source of detailed information on the identification of problem areas, the selection of cost-effective countermeasures, and the evaluation of traffic engineering road safety programs.

This report aims to contribute to that need. Its intent is to assist those with responsibility for traffic engineering road safety by providing a ready source of information, with guidelines for action and information on where to go for more or detailed information. It is aimed specifically at engineers and others with responsibility for traffic engineering and management, especially those in (or engaged by) local government or regional offices of State road and transport agencies.

Specifically, the objectives of the report are to document existing research material to support the adoption of best practice by providing practical guidelines on:

- . identification of accident black spots through the use of mass accident data,
- . selection of cost-effective countermeasures appropriate to the nature and scale of the problem (including the adoption of pro-active measures), and
- . evaluation of treatments to determine their effect and cost-effectiveness.

This is achieved through:

- . presentation of an overview of processes and information sources in use in each State and Territory in the area of traffic engineering road safety,
- . an overview of road safety strategies, showing how and where traffic engineering approaches to road safety fit into a broader road safety framework,
- . a discussion of data and its use, emphasising the need for a reliable statistical data base and rigorous analysis as a prerequisite for the development of road safety programs,
- . a review of the requirements for the identification of hazardous sites, routes, areas or opportunities for mass action programs,
- . an outline of methods for diagnosing crash problems on existing roads (black spots),

- . a detailed discussion of the development of traffic engineering road safety countermeasures, including:
 - road design features,
 - traffic management and design,
 - traffic engineering,
 - road construction and maintenance,
 - speeds and speed limits, and
 - the roadside
- . a review of the implementation and evaluation of road safety programs, including cost-effectiveness and benefit-cost evaluation,
- . an overview of road safety audits.

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1. INTRODUCTION

1.1 CONTEXT OF THE STUDY

It is widely recognised that road and traffic engineering measures have an important role to play in contributing to safer roads. In recent years there has been considerable emphasis on the treatment of accident black spots and significant funding of remedial programs targeted at improving the safety of sites which have a demonstrated accident record. More pro-actively, good road design and well-developed traffic management measures produce roads which are safer and which are less likely to develop as black spots, while road safety audit procedures can be used to attempt to ensure that both new and existing roads have potential safety problems removed before they lead to crashes.

However, all of these outcomes are dependent upon the skill of the engineer responsible for the design or management of the road segment concerned. There is anecdotal evidence, supported by the author's personal experience (and reinforced in the course of interviews conducted for this study) that there is a need for better guidance on what constitutes "good practice" in relation to traffic engineering and road safety. Notwithstanding the value of publications such as Austroads' *Guide to Traffic Engineering Practice* or manuals and guides produced by the various State and Territory road and transport agencies, there appears to be a need for a ready source of detailed information on the identification of problem areas, the selection of cost-effective countermeasures, and the evaluation of traffic engineering road safety programs.

This need has become more cogent in recent years with the down-sizing of specialist areas within road and transport agencies (including in several cases the reduction of staff numbers and skill levels in the areas of road safety and traffic engineering) and the associated trend towards outsourcing of technical capability. Traffic engineering road safety contains a lot of art as well as science, and it is clear that these management practices have led to a situation where the skills capability and pool of resources in this area has almost certainly diminished in recent years.

This report aims to assist those with responsibility for traffic engineering road safety by providing a ready source of information, with guidelines for action and information on where to go for more or detailed information. It is aimed especially at engineers and others with responsibility for traffic engineering and management, especially those in (or engaged by) local government or regional offices of State road and transport agencies.

1.2 OBJECTIVES

Specifically, the objectives of the report are to document existing research material to support the adoption of best practice by providing practical guidelines on:

- (1) identification of accident black spots through the use of mass accident data.
- (2) selection of cost-effective countermeasures appropriate to the nature and scale of the problem (including the adoption of pro-active measures), and
- (3) evaluation of treatments to determine their effect and cost-effectiveness.

1.3 METHOD

The project essentially comprised two stages. In the first, contact was made with each State and Territory road or transport agency, and discussions were held with those responsible for traffic engineering and/or road safety programs in that jurisdiction. This involved in every case a personal contact either by personal visit, or telephone. Information was obtained about:

- . State/Territory programs and processes in relation to traffic engineering and road safety;
- . the use of guides or other information for use by engineers and others within the State/Territory on this topic; and
- . the mass accident data base in that State/Territory and its use.

In addition, input was sought on the content and direction of the current study, with a view to determining what information and outcomes would be of most value to practitioners in the field of traffic engineering road safety.

The second stage involved a comprehensive review of the literature to determine and document best practice in traffic engineering approaches to road safety. This stage included the identification and diagnosis of road safety problems, road safety audit, statistical techniques for analysis of road accident data, selection of road and traffic engineering accident countermeasures, and evaluation of road safety treatments.

1.4 FORMAT OF THE REPORT

Chapter 2 presents an overview of the processes and information sources used in each State and Territory. This type of information will normally be the starting point for any practitioner seeking to implement a traffic engineering road safety program. While inevitably this information is transient (due to changes in organisations and institutions), a documentation of what information is available, from whom, and what procedures are currently adopted is a useful and necessary foundation.

Chapter 3 overviews road safety strategies and shows how and where traffic engineering approaches to road safety fit into a broader approach to road safety. This grounding is important to place traffic engineering road safety in a broader context.

Chapter 4 discusses data and its use, and emphasises the need for a reliable statistical data base and rigorous analysis as a prerequisite for the development of road safety programs. Brief mention is made of techniques and tests used in the analysis of crash statistics.

Chapter 5 discusses the identification of hazardous sites, routes, areas or opportunities for mass action programs.

Chapter 6 outlines methods for diagnosing crash problems on existing roads (black spots).

These then lead into Chapter 7, which discusses the development of countermeasures. Specific countermeasures are discussed, and their role and reported effects are outlined. Measures include road design features, traffic management and design, traffic engineering, road construction and maintenance, speeds and speed limits, and the roadside.

Chapter 8 then examines the implementation and evaluation of road safety programs, including cost-effectiveness and benefit-cost evaluation.

Chapter 9 presents an overview of road safety audits.

2. CURRENT AUSTRALIAN PROCESSES AND SOURCES

2.1 INTRODUCTION

In this chapter, we briefly overview the current situation in each State and Territory concerning the procedures used for traffic engineering approaches to road safety, and the principal sources used to assist in that task.

The information is necessarily brief, since it would not be possible to do justice to each situation and every source document. The important point in the context of this report is that the reader is made aware of what steps can be taken and what assistance is available in the form of either written reports, guides etc, or in terms of expertise or data available in the State and Territory road and transport agencies.

The chapter also includes reference to sources outside the respective States and Territories, especially the Federal Office of Road Safety, Austroads, the Australian Road Research Board, and Standards Australia.

2.2 NEW SOUTH WALES

In this State, the Road Safety Bureau (RSB) of the Roads and Traffic Authority (RTA) has the responsibility for establishing and maintaining the State's accident data base. Information in this data base is accessible by the RTA's regional offices. RTA regions run stand alone crash database management systems ("PC Crash").

Local government Councils get crash data on microfiche every three months, and can request paper or disk data. Some Councils up-load data into analysis packages such as "PC Star" produced by Mosman Council, or run GIS-based systems.

Prime responsibility for the delivery of traffic engineering road safety programs on State Highways rests with the RTA regional offices. Road safety "black spot" projects may be generated within each region, or use can be made of a listing generated periodically by the RSB which shows the worst 1000 sites (approx) in the State. Priorities are set within the regions, not by the RSB.

However, the RSB is currently developing a formal accident investigation and prevention (AIP) program which aims to formalise procedures for the implementation of safety programs. This envisages a role for the RSB in terms of strategic direction and technical support, and regional responsibilities in terms of program development, implementation and monitoring.

To facilitate this, the regions have officers who have received training in the use of the data base, and will be trained in the collection of supplementary data and development of priorities using this data source.

For roads which are not the RTA's responsibility, decisions about black spot programs are made by the respective local Council. The RTA often proposes and funds such works, and permission to implement all works (including State roads) must be obtained by Councils from the RTA. As mentioned, Councils receives RSB accident data on microfiche, and local government officers will be welcome to attend AIP and other RTA training programs as they are developed, at either central or regional locations.

In matters of a technical traffic engineering nature, the resources of the RTA's Traffic Technology Branch are used. This branch has acted as an internal consultant to the RSB in the development of (for example) safety audit procedures, road environment safety guidelines (see below) and aspects of the AIP program. The Branch is also a centre of technical expertise in matters related to traffic engineering, and assists the regions and local government on request in this area. This includes aspects related to traffic engineering road safety.

The RTA has developed guidelines for road safety audit (Roads and Traffic Authority, 1991a), including procedures to check new work at various stages of planning and design, and to auditing of the existing road network. This is implemented to a varying degree by the regions, according to resource and skill constraints.

The RTA has in place an explicit cost-benefit analysis procedure, documented in its publication *Economic Analysis Manual* (Roads and Traffic Authority, 1994). This outlines the principles used by the Authority and specifies the values of costs and benefits to be used in evaluations. However, there is no requirement to use this for traffic engineering projects, because the procedures outlined are oriented towards major construction projects and the Government does not mandate that an economic analysis be undertaken if the project costs less than \$100,000.

The future of road safety evaluation is considered to lie more with use of the procedures recently developed by Andreassen (1992 a,b,c) at the Australian Road Research Board. The RTA Economic Analysis Manual does not detail these procedures, but does list individual accident costs for the various accident types which were categorised by Andreassen. The RTA Sydney region has prepared a computer package *Road Proposals Program* (O'Donnell and Hunt Pty Ltd, 1993) that performs benefit:cost analysis using the Andreassen approach. This is used by all 42 Councils in Sydney to evaluate proposals submitted to the region for State funding as part of a blackspot program. The program uses up to 5 accident types which are likely to be reduced by the proposed treatment, and calculates first year rate of return and benefit cost ratios.

The RTA also has formal technology transfer procedures in place aimed at keeping its professional and technical staff up to date on developments. Road safety and traffic engineering are both involved in this process. As mentioned, the Authority is developing an accident investigation and prevention training program which its officers may attend. Many of these technology transfer mechanisms are available to local government, at both a central and a regional level, although the participation of local government engineers in road safety and traffic engineering programs has not been high.

At a broader policy level, NSW (like other States) has produced a strategic plan for road safety in the State (Roads and Traffic Authority, 1992), *Strategic Plan for Road Safety in NSW*. Its strategies related to "safer roads" include (op cit, p 17):

- . improved speed zoning, to achieve traffic speeds more appropriate to conditions
- . further developing and applying traffic control systems, such as signals, signs and line markings, to help road users drive safely,
- . reviewing proposed and existing road works and road developments to ensure that their safety is acceptable,

- continuing to treat the roadside by sealing edges and moving power poles and other roadside features that are hazardous, so that crashes are prevented and the severity of those that do occur is lessened, and
- improving the way that road and traffic systems accommodate pedestrians and bicyclists.

These principles are further expanded in a RTA report entitled *Road Environment Safety Guidelines* (Roads and Traffic Authority, 1991b). This aims to link the broader RTA Road Safety Strategy (Roads and Traffic Authority, 1992) to particular standards, guidelines and practices in use in the Authority and elsewhere in the State. *Road Environment Safety Guidelines* is a particularly comprehensive and valuable document, the use of which deserves to be encouraged in order that road environment safety is fully considered in the development, operation and maintenance of the road network.

There is also an earlier publication *Handbook of Highway Safety Practice* (Department of Main Roads, 1986). Although a little dated in places and largely superseded by the *Road Environment Safety Guidelines*, it is nevertheless a useful document.

2.3 VICTORIA

In Victoria, responsibility for delivery of traffic engineering road safety programs lies with VicRoads' regions and with local government.

Road safety strategy in Victoria is the responsibility of the Road Safety Coordinating Council, a joint body with representation from VicRoads, the Transport Accident Commission, and Victoria Police. The Victorian Strategy (Road Safety Coordinating Council, 1993) has a number of elements, one of which is "safer roads". In respect of this, the strategy aims at:

- continuation of the on-going program of targeted road engineering improvements at hazardous locations (this is in addition to general programs for maintenance and improvement of the road system),
- accident blackspot treatments, such as traffic signals, intersection improvements, overtaking lanes, pavement widening, skid resistance, hazard removal, signing and lighting, shoulder sealing, pedestrian facilities, guardrail installation.

The Road Safety Department of VicRoads has prepared a publication entitled *Guidelines for Road Condition Sub-program: Project Selection*, which is updated periodically (VicRoads, 1992). The road conditions sub-program is one of four VicRoads road safety programs (the others being concerned with road safety strategy and coordination, road users, and vehicles).

These guidelines provide directions for the generation of candidate projects in relation to accident black spots, mass action projects and railway level crossing projects. Candidate sites are identified on the basis of the number of crashes exceeding a particular threshold level (e.g. for intersections, 6 casualty crashes in the previous 5 years). The publication contains guidelines on the likely accident reduction which is to be expected for a wide range of treatments.

An economic evaluation must be performed (using procedures outlined in the Guidelines) for each candidate site, and those which have a favourable economic worth are considered for inclusion in VicRoads' Road Conditions Sub-program. Evaluations using these guidelines are performed within VicRoads' regions or in local authorities, and the selection of projects is undertaken by the VicRoads Road Safety Division.

Some funding for this program has been provided by the Transport Accident Commission (\$75 million over the two years to June 1994). VicRoads' calculations of safety benefits differ from TACs; VicRoads consider safety benefits and capital costs only, whereas the TAC calculations are based on benefit to TAC (i.e. the estimated crash cost savings related to the lower payouts made by TAC for various accident types). This results in a lower estimate of benefit than those calculated by VicRoads using the average casualty crash costs of \$60,000 for urban crashes and \$94,000 for rural crashes.

Safety is also taken into account in the evaluation of major rural and urban projects, but safety benefits in these instances tend to be small compared with other user benefits.

Data bases on road crashes in Victoria are maintained by the Victoria Police, VicRoads and TAC. All have a common input (the police report form), but the police keep the data for their own purposes, TAC maintains a data base for insurance purposes, and VicRoads maintains a data base for the development of road safety programs. The VicRoads data base is routinely used by VicRoads regions and is available to local government for the identification of hazardous locations and the development of road safety programs. It is available in either paper form or on disk. Computer software (*V/Crash*) has been developed to aid users in the use of the data on the disk (Turnbull Fenner Pty Ltd, 1994).

The primary source of advice to VicRoads' regions and municipalities to assist in the design and implementation of traffic engineering road safety projects is the Austroads *Guide to Traffic Engineering Practice* series, although VicRoads' Design and Traffic Management Services Section produce supplemental design guides periodically. Training programs are also presented on these matters.

The Road Safety Division produces a newsletter *Safe Roads*, which has short articles on topical issues related to road safety. It is distributed within VicRoads, and to municipalities and consultants. Included in this from time to time are articles related to traffic engineering road safety, such as standards and practices, research results, etc.

The concept of road safety audit has been adopted by VicRoads as part of the quality assurance approach to achieve desired outcomes. While the frequency of safety audits of works carried out by regions is not yet in accord with VicRoads' requirements, all major projects carried out by the Design Department are submitted for audit at the functional and detailed design stages. Guidelines for the implementation of safety audits have been developed and training sessions conducted.

2.4 QUEENSLAND

The Queensland Road Safety Strategy (Queensland Government, 1993) contains a number of detailed strategies and actions aimed at improving the safety of roads, the road environment, and the management of traffic. These are focussed on five broad strategies:

- . ensure that safety factors are given a high priority in the planning, design, construction and maintenance of roads.
- . improve the management of safety in neighbourhoods and residential areas, including safety in the vicinity of community facilities such as schools.

- . ensure that safety factors are given a high priority in the development and management of traffic management systems including signals, signs, and road markings.
- . utilise "best practice" road and traffic engineering solutions to deal with accident blackspots and high risk road user behaviour such as fatigue, speed and drink driving.
- . ensure that vulnerable road users such as children, older people, pedestrians, bicycle riders and people with disabilities are safely accounted for in the development and management of roads and traffic systems.

Responsibility for the implementation of traffic engineering road safety work on declared roads in Queensland predominantly lies with the Districts of Queensland Transport. (There are 15 Districts in five regions.) Local government has responsibility on local roads, aided where appropriate by Queensland Transport regions.

The Road Transport and Safety Division of Queensland Transport, based in Brisbane, is responsible for the preparation of Statewide guidelines and standards. Of particular interest here is its *Traffic Accident Remedial Program (TARP)* (Queensland Transport, 1993a; Walsh and Dileo, 1992). This sets out procedures for identifying, diagnosing and prioritising hazardous road locations, and for evaluating the effectiveness of remedial treatments. An accompanying spreadsheet has been developed to assist in carrying out TARP procedures. This program was developed initially for use by the Districts, but is now available in a local government format (Queensland Transport, 1994a).

Within TARP, priority determination is carried out on a benefit:cost basis, with the benefits being expected accident rate reductions valued according to accident type using the costings developed by Andreassen (1992 b,c).

Maintenance of Queensland's road accident data base is the responsibility of the Road Transport and Safety Division. A program called "Roadcrash" enables a download of the police accident data base. This is further enhanced (especially with respect to location data) by another package called "Phylak", which can be used to produce various reports which assist in the identification and diagnosis phases of TARP. Output from this program, together with local knowledge, is used by the Districts or local government to develop safety-related works programs and remedial treatments.

The Brisbane City Council further enhances the contents of the Roadcrash data base to identify hazardous road locations within its area of responsibility.

The development of policy and practices with respect to road safety audit is also the responsibility of the Road Transport and Safety Division. Interim guides have been prepared covering both the design of new roads and the safety audit of existing roads (Queensland Transport, 1993b, 1993c respectively). A number of audits have been conducted.

The Division has also developed draft guidelines for mass action programs, directed at such features as narrow bridges, merges, pedestrian facilities, overtaking lanes, and roadside clear zones (Queensland Transport, 1994b).

The Road Transport and Safety Division is also responsible for the development of a speed management strategy with a view to bringing about consistency and credibility to speed zoning. A "Schoolsafe" program operates in Queensland, managed by the Division with local government responsible for implementation.

The Transport Technology Division (a commercial arm of Queensland Transport), in its Traffic Engineering and Operations Team, provides technical support to the Road Transport and Safety Division and the Regions/Districts in matters related to traffic engineering and management. It maintains the Department's *Traffic Engineering Manual* (Queensland Transport, 1993d), which is intended to be a "best practice" guide. The Team also supports local government in technical matters related to traffic engineering and management.

The Department runs regular training programs in such aspects as the use of the TARP procedures, accident investigation and prevention, road safety audit, traffic engineering practice, and on other relevant issues. These programs are available to Districts, local government, consultants, etc, and the Department is moving towards a cost recovery policy for these activities.

2.5 SOUTH AUSTRALIA

Road safety policy in South Australia is the responsibility of the Road Safety Management and Coordination Group, comprising representatives of a number of State agencies. The State's draft strategic plan for road safety (ROSMAG, 1993) included eight strategies aimed at providing "safer roads and roadsides":

- . to promote best practice in the planning, design, construction and maintenance of roads and associated facilities and the management of traffic.
- . to facilitate effective hazardous road location identification and treatment programs.
- . to promote a safer and more forgiving roadside environment.
- . to promote adherence to recognised road safety principles in land use zoning, planning and development.
- . to promote effective local area traffic management schemes
- . to promote improvement in the safety of the road environment for unprotected road users: pedestrians, bicyclists and motor cyclists.
- . to promote an acceptable system of speed management, including speed limits, which takes account of road and traffic conditions.
- . to increase awareness of the hazardous effects of adverse atmospheric and lighting conditions on safe road use.

The Office of Road Safety within the Road Transport Agency (RTA) of the Department of Transport is responsible for coding and maintaining the State's accident data base. Access to this data base is freely available to RTA regional offices, the RTA Traffic Management Services Section, and local government, on paper or on disk. Its use by local government to date has been limited.

The aforementioned Traffic Management Services Section is responsible for the planning, programming and much of the design of the traffic engineering road safety program Statewide. In the past, when the Federal blackspot program was in place, it had developed a prioritisation policy based upon crash frequencies at sites or lengths of road, and this approach is still in use. The program is developed using the accident data base, together with suggestions put forward by the regions which are evaluated on the same basis. There is an intention to move towards the Andreassen (1992 a,b,c) approach developed at the Australian Road Research Board.

Similar approaches are used for mass action programs, such as shoulder sealing, guard fencing, street lighting and some intersection remodelling.

Implementation of these programs is the responsibility of the RTA regions, or with local government in the case of local roads. Use is made of a publication entitled *Code of Practice for the Installation of Traffic Control Devices in South Australia*, prepared by the former Department of Road Transport (1991).

Technology transfer occurs at a modest level, and there is concern that local government participation in training programs is infrequent. Current training needs in accident analysis and prevention and in road safety audit have been identified.

In relation to road safety audit, a pilot study has been undertaken involving safety audit at the road design stage. Since all major road design in South Australia is undertaken at the RTA Head Office, implementation of safety audit procedures should be relatively straightforward once procedures and policies are adopted.

2.6 WESTERN AUSTRALIA

The Road User Services Directorate of the Main Roads Department is responsible for maintaining the mass accident data base in Western Australia. Summary data in standard format is made available in hard copy form to MRD regional offices, local government, and other interested parties. Processed information in non-standard format is available upon request.

Blackspots are ranked for consideration by accident frequency, taking into account accident type, type of control (intersection, mid block, etc), and rural/urban locations. Data on traffic volumes are generally sparse, so exposure measures are used only where traffic volume data are available.

The Technical Services Directorate is responsible for traffic engineering matters within the Department, and it acts as a technical resource on traffic engineering for MRD and local government. It periodically arranges training programs which are attended by both MRD and local government personnel in various areas including traffic engineering and road safety. The prime written source of technical information in this area is the Austroads *Guide to Traffic Engineering Practice* series, but the Department has also assembled a set of notes and papers for use in its training activities (Main Roads Department, 1993).

A State road safety strategy is under preparation, and the Western Australia Municipal Association (1993) has produced a *Road Safety Strategy for Local Government in Western Australia*. Among its contents are strategies aimed at road and transport planning, speed and traffic management, pedestrians and cyclists, delineation and signing, work zone safety, and road safety audit.

2.7 TASMANIA

The Policy and Coordination Division of the Department of Transport and Works (DTW) is responsible for coding and maintaining the State's accident data base, using police forms as the primary input. This data is available to DTW Head Office and regions, and to local government, for the purposes of identification of hazardous road locations, and the analysis of road safety problems. In practice, most use is by the DTW Traffic Management Branch.

This Branch has as one of its responsibilities the identification of hazardous road locations, but implementation is the responsibility of the DTW regions or local government. Periodically, the Department uses this information to prepare a listing of sites with a poor accident record. This provides one of the inputs to the work program of the Department's Transport Infrastructure Division (which has responsibility for road works) and local government. Whether that site is treated, and the design of the treatment, is then the responsibility of the Transport Infrastructure Division or local government as the case may be.

The Traffic Management Branch presently has authority to approve all traffic control devices on Tasmania's roads. Some of this approval authority has been devolved to the Transport Infrastructure Division. However, Councils have no authority to install any such devices without DTW approval.

The Branch has produced a number of guidelines or information bulletins for use by the Department or local government in relation to traffic engineering or management. Examples include resident permit parking schemes, drive-in bottle shop provisions, and road humps.

2.8 AUSTRALIAN CAPITAL TERRITORY

The Roads and Transport Branch of ACT City Services is responsible for both the road accident data base and the programming and design of remedial treatments in the ACT.

Because of the ACT's small size, accident frequencies are low, and therefore to get a statistically significant sample it has been found necessary to code and analyse all reported crashes, including non-injury crashes. These data are used to identify sites with a poor safety record.

Canberra's rapid growth means that ideally the Branch would like to be pro-active in identifying deficient sites and treat those in growth areas before they develop a poor safety record. Procedures for doing this are in their infancy, but essentially will involve a form of road safety audit of the existing road network.

Priorities for works are developed on a cost:benefit basis, using standard accident costs (based upon Andreassen, 1992 a,b,c). Procedures for prioritisation are outlined in the guide, *Transport Capital Works Programming* (ACT City Services, 1993). Likely accident reductions being assessed on the basis of professional judgement for the accident patterns and road environment modifications which are proposed.

2.9 NORTHERN TERRITORY

While the Northern Territory does not have a specific identified program for traffic engineering road safety projects, road safety nevertheless forms an integral part of the Territory's assessment process for prioritisation of road projects.

The Northern Territory Road Safety Strategy (Department of Transport and Works, 1993) includes a number of specific strategies aimed at the road environment. Included in these is a strategy aimed specifically at giving "special consideration to the problems of the remote area road environment (e.g. as it affects single vehicle rollovers)".

A Road Environment Working Group has been established to address specific traffic engineering road safety issues. It comprises representatives of the Department of Transport and Works, local government, consultants, contractors, and the NT Road Safety Council. Road safety audit, based on the forthcoming Austroads guidelines, is being considered by this Working Group.

The Department of Transport and Works has recently taken over management of the Police Vehicle Accident Data base, and is currently in the process of addressing aspects of uniformity of data input, and simplified reporting processes to make the whole system more user friendly and accessible. It is planned to link the accident data base to the Department's road information management system to facilitate more accurate locational data for assessment purposes. This is partly in recognition of the fact that in remote areas of Australia, traffic volumes are low and accidents are generally isolated. Therefore "black spots" are not easy to identify. Fatal accidents are individually assessed, and sites visited by DTW staff to establish any road environment contributory factors

2.10 SOURCES OF FURTHER INFORMATION

In addition to the guides, manuals, policies etc developed within each State or Territory, there are a number of useful and relevant publications from Austroads, ARRB, BTCE and Standards Australia. These are listed and briefly described below:

2.10.1 Federal Office of Road Safety

Sanderson JT, Cameron MH and Fildes BN (1985) Identification of hazardous road locations: Final report. *FORS Report CR 37*.

Sanderson JT, Cameron MH and Fildes BN (1985) Identification of hazardous road locations: Procedural guidelines. *FORS Report CR 38*.

This pair of reports detail a practical and effective procedure for identifying and ranking hazardous road locations. The procedures have since been widely adopted in Australia, for example in the Austroads publication *Guide to Traffic Engineering Practice, Part 4, Road Crashes*. The identification procedure for intersections is based upon the casualty accident rate being significantly greater than the system average, while that for road sections is based upon the casualty accident number related to road distance being significantly greater than the system average.

Pak Poy and Kneebone Pty Ltd (1988) Road safety benefits from rural road improvements. *FORS Report CR 71*.

This report describes the results of a literature review undertaken to determine the cost-effectiveness of a range of safety improvements for rural roads. Treatments discussed include delineation, signage, pavement resurfacing, shoulder and lane widening, overtaking lanes, geometric improvements, roadside hazard management, medians, intersection treatments, railway level crossings, and new road construction

Nelson English, Loxton and Andrews (1988) An analysis of the relationship between road improvements and road safety. *FORS Report CR 75*.

This report sought to investigate the relationship between crashes by location and road parameters such as alignment, roughness, etc. Data deficiencies, especially the difficulty of establishing precisely where the crash occurred, precluded robust conclusions, although some correlation was found between road alignment (curves and grades) and crash frequency. Lane width and road roughness did not appear to have any affect on crash frequency.

Sweatman PF, Ogden KW, Haworth N, Vulcan AP and Pearson RA (1990) NSW heavy vehicle crash study: Final technical report. *FORS Report CR 92*.

This report examines the causes of crashes involving heavy vehicles in NSW in 1988 and 1989. It included a retrospective examination of the sites of fatal truck crashes on the Hume and Pacific Highways, and, inter alia, led to conclusions about road and traffic factors associated with rural truck crashes. Safety benefits were expected to flow from the provision of divided roads, treatment of accident blackspots, sealing of shoulders, improved delineation, treatment of roadside hazards (especially culvert protection) and enforcement of speed limits.

Western Sydney Regional Organisation of Councils and Geoplan Town Planning (1990) Neighbourhood safety and amenity. *FORS Report CR 98*.

This report reviewed local area traffic management (LATM) practices and the effectiveness of LATM in promoting residential amenity and reducing vehicle speeds, with particular reference to Western Sydney. It reached a number of conclusions about the effectiveness of LATM schemes, and the steps necessary to promote its wider and better use. It led directly to the preparation of *CR 126* (see below).

Armstrong HB, Black JA, Lukovich T, Sheffield D and Westerman HL (1992) Environmental adaptation of the main street in rural towns: Towards guidelines. *FORS Report CR 110*.

This report examines ways in which the "main street" of rural towns can be better managed in the interests of safety and environmental amenity, without compromising the integrity of through traffic movements. Although it focuses particularly on pedestrian safety, other safety aspects are reviewed also.

Western Sydney Regional Organisation of Councils (1993) Towards traffic calming: A practitioners manual of implemented local area traffic management and blackspot devices. *FORS Report CR 126*.

The report gives practitioners a guide in devising appropriate treatment for specific traffic problems in the context of local area traffic management. Examples are given.

Fildes BN and Lee SJ (1993) The speed review: Road environment, behaviour, speed limits, enforcement and crashes. *FORS Report CR 127*.

Fildes BN and Lee SJ (1993) The speed review: Appendix of speed workshop papers. *FORS Report CR 127A*.

This report reviews the results of a study of the role of vehicle speed in road crashes, including consideration of speed limits, enforcement and behaviour, and the environment. 22 items requiring further research were identified, as well as 12 items for which immediate action was recommended. Included in the latter were low cost perceptual road treatments, an Australia-wide expert system for determining speed limits, speed zone policy, more repeater signing in speed zones, and widespread use of effective speed reduction technologies.

Westerman HL, Black JA, Brindle RE, Lukovich T, and Sheffield D (1993) Sharing the main street. *FORS Report CR 132*.

This report outlines practical guidelines for the adaptation of sub-arterial roads with the aim of cost-effectively enhancing safety, traffic operations and amenity. These roads, where there is a need to satisfy both traffic movement needs and amenity (or servicing road frontage activities) have significant safety and amenity problems, and the guidelines are intended to assist in managing these streets.

2.10.2 Australian Road Research Board

The Australian Road Research Board has produced a number of reports dealing with aspects of traffic engineering road safety. These include:

Charlesworth KD (1987) Creating a safer roadside environment. *ARRB Internal Report AIR 404.5*. 11 p. (Australian Road Research Board, Melbourne).

Cairney PT (1988) Safety at traffic signals. *ARRB Internal Report AIR 394-10*. 21 p. (Australian Road Research Board, Melbourne).

Andreassen DC (1989) Strategies for safety problems. *ARRB Research Report ARR 163*. 101 p. (Australian Road Research Board, Melbourne).

Catchpole JE (1989) The role of road and environment factors in fatal accidents: Data source and data summaries. *ARRB Research Report ARR 172*. 82 p. (Australian Road Research Board, Melbourne).

Wigan MR (1989) What is it worth? Safety valuation applications and research requirements. *ARRB Internal Report AIR 1159-1*. 14 p. (Australian Road Research Board, Melbourne).

Andreassen DC (1991) Model guidelines for road accident data and accident types. *ARRB Technical Manual ATM 29*. 38 p. (Australian Road Research Board, Melbourne).

Cairney PT and Catchpole JE (1991) Road user behaviours which contribute to accidents at urban arterial/local intersections. *ARRB Research Report ARR 197*. 69 p. (Australian Road Research Board, Melbourne).

Ogden KW and Pearson RA (1991) A review of road and traffic factors in truck accidents: Australian truck safety study task 1. *ARRB Research Report ARR 201*. 68 p. (Australian Road Research Board, Melbourne).

Andreassen DC (1992a) A guide to the use of road accident cost data in project evaluation and planning. *ARRB Research Report ARR 226*. 16 p. (Australian Road Research Board, Melbourne).

Andreassen DC (1992b) Costs for accident types and casualty classes. *ARRB Research Report ARR 227*. 36 p. (Australian Road Research Board, Melbourne).

Andreassen DC (1992c) Trucks, semi-trailers and motor cycles: Accident costs for project planning and evaluation. *ARRB Research Report ARR 232*. 23 p. (Australian Road Research Board, Melbourne).

Cairney PT (ed) (1992) *Improving Safety at Railway level Crossings: Conference Proceedings*. 137 p. (Australian Road Research Board, Melbourne).

Cairney PT (1992) On-road tests of bicycle night conspicuity aids. *ARRB Research Report ARR 237*. 35 p. (Australian Road Research Board, Melbourne).

Jarvis JR (1992) An investigation of road humps for use on bus routes: Final report. *ARRB Research Report ARR 222*. (Australian Road Research Board, Melbourne).

2.10.3 Bureau of Transport and Communication Economics

Recent reports related to traffic engineering road safety conducted by the Bureau of Transport and Communication Economics include:

Bureau of Transport and Communication Economics (1992) Social cost of transport accidents in Australia. *BTCE Report 79*. 119 p. (AGPS, Canberra).

Bureau of Transport and Communication Economics (1993) Cost effectiveness of black spot treatments: A pilot study. *BTCE Working Paper 9*. 37 p. (Department of Transport and Communications, Canberra).

2.10.4 Austroads

Recent Austroads (or NAASRA, as Austroads was formerly known) publications relevant to this report include:

National Association of Australian State Road Authorities (1984) *Road Medians*. 28 p. (NAASRA, Sydney).

National Association of Australian State Road Authorities (1988a) *Guide to Traffic Engineering Practice. Part 4. Road Crashes*. 74 p. (NAASRA, Sydney).

National Association of Australian State Road Authorities (1987) *Safety Barriers*. 29 p. (NAASRA, Sydney).

Austroads (in press) *Road Safety Audits*. (Austroads, Sydney).

2.10.5 Standards Australia

The Standards Australia publications most relevant to traffic engineering road safety are:

Standards Australia (various) *AS 1158 Public Lighting Code*. (Standards Australia, Sydney):

- AS 1158.1: Performance and Installation Design Requirements*
- AS 1158.2: Computer Procedures for the Calculation of Light Technical Standards for Category A Lighting*
- AS 1158.3: Guide to Design, Installation and Maintenance*
- AS 1158.4: Supplementary Lighting of Pedestrian Crossings*

Standards Australia (various) *AS 1742 Manual of Uniform Traffic Control Devices*. (Standards Australia, Sydney):

- AS 1742.1: General Introduction and Index of Signs*
- AS 1742.2: Traffic Control Devices for General Use*
- AS 1742.3: Traffic Control Devices for Work on Roads*
- AS 1742.4: Speed Controls*
- AS 1742.5: Street Name and Community Facility Name Signs*
- AS 1742.6: Service and Tourist Signs for Motorists*
- AS 1742.7: Railway Crossings*

AS 1742.8: Freeways
AS 1742.9: Bicycle Facilities
AS 1742.10: Pedestrian Control and Protection
AS 1742.11: Parking Controls
AS 1742.12: Bus, Transit and Truck lanes
AS 1742.13: Local Area Traffic Management

Standards Australia (1989) *AS 1743 Road Signs*. (Standards Australia, Sydney).

2.10.6 Books

In addition to the above, books related to traffic engineering road safety recently published in Australia include:

Ogden KW and Bennett DW (1989) *Traffic Engineering Practice (4th edition)*. 479 p. (Monash University, Melbourne).

Underwood RT (1990) *Traffic Management: An Introduction*. 222 p. (Hargreen, Melbourne).

3. ROAD SAFETY STRATEGIES

Traffic engineering approaches to road safety, or road environment safety as it is sometimes known, is of course but one of a number of strategies aimed at reducing the costs of road trauma. In this chapter, we briefly place traffic engineering road safety in a broader context, and introduce the concept of hazardous road location (HRL) programs.

3.1 THE ROAD TRAFFIC SYSTEM

The road traffic system can be said to comprise three components, the human, the vehicle and the road (Ogden and Bennett, 1989, chapter 1). Crashes, which may be thought of as breakdowns in the system, likewise have three components - pre-crash, in-crash and post-crash.

Putting these two concepts together, we get a matrix, known as the Haddon matrix, after William Haddon, one of the pioneers of the scientific approach to trauma analysis (Figure 3.1)

	Before Crash	In Crash	After Crash
Human	Training Education behaviour (e.g. avoidance of drink driving), Attitudes Conspicuous clothing on pedestrians and cyclists, etc.	In-vehicle restraints fitted and worn	Emergency medical services
Vehicle	Primary safety (e.g. braking, roadworthiness, visibility) Speed Exposure	Secondary safety (e.g. impact protection)	Salvage
Road	Delineation Road Geometry Surface Condition Visibility	Roadside Safety (e.g. no hazardous poles)	Restoration of Road and Traffic Devices

Source: Lay, 1986, p 552

Figure 3.1 Haddon Matrix

These nine boxes each give a possible focus of attack on elements of the road trauma problem.

It is useful to look at the factors contributing to crashes in the road traffic system. Two studies of this issue were conducted in the early 1980s, one in US and one in UK (Sabey, 1980). They both involved in-depth analysis of a large number of crashes. Contributing factors were identified as being road, road user or vehicle, or interactions between them. Results (in percentage terms) were as follows:

	UK	US
Road environment alone	2	3
Road user alone	65	57
Vehicle alone	2	2
Road and road user	24	27
Road user and vehicle	4	6
Road and vehicle	1	1
All three factors	1	3

In total, the road contributed to 28-34 per cent of crashes, the human to 95-94 per cent and the vehicle to 8-12 percent.

These results are valuable, because they highlight the key role of the road user. The high involvement of the user is not surprising - ultimately, perhaps we would expect that the user is involved in 100 per cent of crashes, because in almost every case, some alternative action is possible.

However, such analyses are of limited value in developing *countermeasures*, for two reasons. First, these analyses are based on the premise that the outcome would have been different if a particular feature had not been present. This gives rise to some problems of interpretation (e.g. a head on crash on a dry well-lit roadway would likely be entirely road user. But that crash would not have occurred if the road had been divided highway. Similarly, outcomes are not directly related to factors - the same crash, with identical factors, could have different outcomes depending on such things as vehicle size, seat belt use, emergency services, etc.)

Second, factors which contribute to a crash do not necessarily point in the direction of cost-effective countermeasures. It is not valid, for example, to say that because only 8 or 12 per cent of crashes involve a vehicle-related factor, that such things as braking, crash worthiness, etc are not cost-effective.

From a traffic engineering viewpoint, the important point to note from the above is that since the driver is the key, the traffic engineer must be aware of human factors and realise that traffic engineering applications and countermeasures work through their influence on human behaviour (Ogden, 1990).

Conversely, it needs to be emphasised that although road-related factors may contribute to only 25 per cent or so of crashes, road and traffic engineering countermeasures have a much greater contribution to play that just affecting that 25 per cent, since these measures act, in many cases, by assisting or influencing the behaviour of the dominant factor, namely the driver. This was well-expressed in the NSW road safety strategy (Roads and Traffic Authority, 1992), where it referred to "developing and applying traffic control systems, such as signals, signs and line marking *to help road users drive safely*" (author's emphasis). Almost all traffic engineering and management measures work through their influence on human behaviour, and thus these are an important component of an overall road safety strategy.

3.2 ROAD SAFETY STRATEGIES

Trinca et al (1988) have usefully reviewed crash trauma reduction strategies in five categories, as follows:

- exposure control
- crash prevention
- behaviour modification
- injury control
- post-injury management

Traffic engineering road safety falls mainly within the second of these categories, and partly within the third.

Road engineering can have a dramatic effect on road safety - a modern freeway can be 10 times safer per vehicle kilometre than an undivided 2-lane road. Road design, construction, maintenance and management all contribute to safety. However, the costs of this are high, and interestingly, road construction can rarely be justified on safety grounds alone. Safety benefits are typically 15 per cent of the total benefits of an urban road project and 5 per cent of the benefits of a rural road project - although since benefits usually outweigh costs by 4 or 5 to one, safety benefits are considerable (Lay, 1986, p 52). Moreover, road infrastructure is long-lasting, and cannot be modified quickly in response to an emerging safety problem. Hence this strategy as a safety measure is a long term one.

Nevertheless, safety should be an important input to road decisions - whether they are built, their design, their construction standard, and their operation. The new field of road safety auditing (to be discussed in Chapter 9) attempts to focus on this potential.

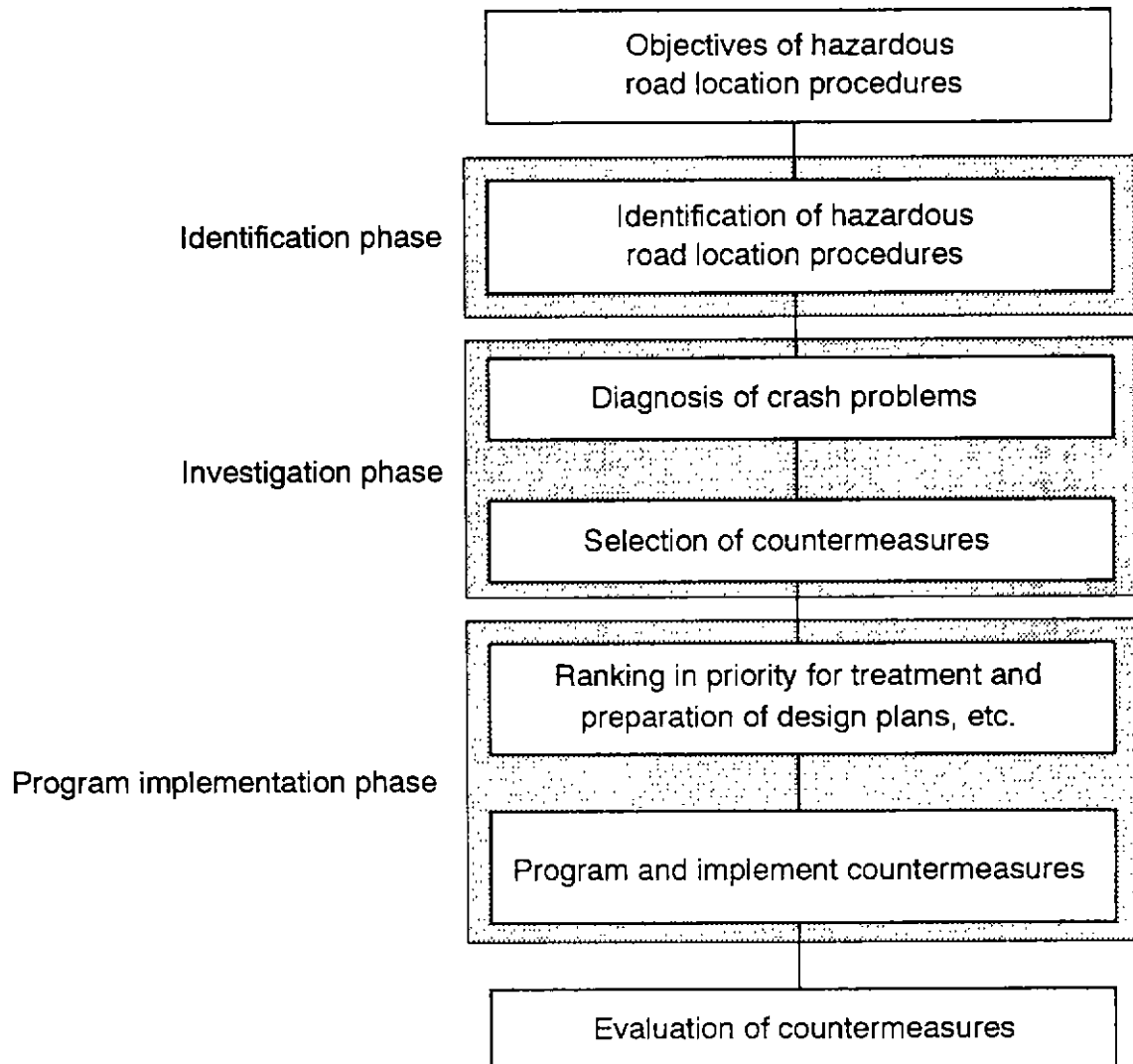
Of more relevance to this report is treatment and improvement of the existing road network through traffic engineering approaches to road safety (sometimes known as road environment safety). This can involve two main aspects:

- the development and implementation of a hazardous road location (HRL) program which aims to identify locations within the road system which have a higher than expected incidence of road crashes, and develop appropriate treatments to reduce the incidence of crashes, and
- road safety audit, which aims to build safety into the road network pro-actively, rather than wait until unsafe road locations are revealed through accidents.

The latter will be considered in Chapter 9. We will first consider HRL programs.

3.3 HAZARDOUS ROAD LOCATION PROGRAMS

The HRL program is summarised in Figure 3.2 (National Association of Australian State Road Authorities, 1988a, p 18; Sanderson, Cameron and Fildes, 1985). We will consider *objectives* and the *identification* phase in this chapter and the remaining phases in following chapters.



Source: National Association of Australian State Road Authorities, 1988a

Figure 3.2 Hazardous Road Location Program Elements

The general objectives of HRL programs include (Sanderson, Cameron and Fildes, 1985; Cameron, 1987; Smith, 1990):

- . the identification of locations at which:
 - there is an inherently high risk of accident losses, and
 - there is an economically justifiable opportunity for reducing this risk, and
- . the identification of countermeasure options and priorities which maximise the economic benefits from the HRL program.

In general, HRL programs are in four categories (Institution of Highways and Transportation, 1990a, p 10; National Association of Australian State Road Authorities, 1988a, p 17; Organisation for Economic Cooperation and Development, 1976):

Single sites (or blackspots): treatment of specific sites or short lengths of road at which crashes cluster (e.g. traffic signals).

Route action: application of remedies to a road having above-average crashes for that type of road (e.g. delineation, pavement resurfacing).

Area action: aggregation of remedial measures over an area with a high crash rate, particularly aimed at dealing with scattered crashes (e.g. local area traffic management).

Mass action: application of a known remedy to locations having common crash factors (e.g. guard fencing, bridge treatments).

4. DATA NEEDS AND LIMITATIONS

Central to any systematic scientifically-based analysis of the road crash situation and the development of rational countermeasures is the availability of reliable data on road crashes. In this Chapter, we review what data is needed, and briefly overview how it may be analysed. This material is necessary at this point, as subsequent chapters concerned with details of a hazardous road location (HRL) program implicitly or explicitly assume the availability of information.

4.1 INFORMATION REQUIREMENTS

For the purpose of research and analysis of safety problems, information is needed about crashes or accidents - the terms are essentially interchangeable, and, if it is desired to relate crashes to exposure, some measure of traffic volumes is also necessary.

4.1.1 Crash Data

To enable systematic analysis of the road crash problem at any location, the following information about each crash is required (Howie, 1989):

where crashes occur: location by map co-ordinates, road name, road classification, road layout and type of traffic control,

when crashes occur: by year, month, day of month, day of week and time of day,

who was involved: people, vehicles, animals and roadside objects,

what was the result of the crash: fatal, personal injury, or property damage,

what were the environmental conditions: light condition, weather and pavement surface condition, and

how (or why) did the crash occur.

4.1.2 Traffic Volume Data

To enable the estimation of exposure, information on traffic flow is required. Two way annual average daily traffic (AADT) is normally the best that can be obtained (Sanderson, Cameron and Fildes, 1985b, p 11), unless hourly flows are available from either special collections or can be extracted from traffic signal detector inputs.

Sanderson, Cameron and Fildes (op cit) note that if AADT volumes are unavailable, estimates will often suffice, since the calculation of exposure is not sensitive to minor estimation errors. Similarly, if count data are not available for every year, interpolation between years is acceptable.

4.2 POLICE REPORTS OF CRASHES

The source of most crash data is a Police report form. Every State and Territory has its own report form, and in most cases, every accident attended by a police officer results in a report form being generated. (However, it will only be entered into the mass accident data base if it satisfies that State or Territory criterion for entry.)

Data extracted from Police accident reports generally answer the where, when, who and what questions but not the how. There is also information in report form narratives which can give a lead to an understanding of the causes of crashes, but this information is not generally included in the crash data bases maintained by traffic authorities.

Police reports of the circumstances associated with crashes and the persons involved are a primary source of data about the road crash problem. The original purpose of reports to Police was to help assess responsibility and determine liability. Even though settlement of legal issues may still be an important purpose, the data derived from these reports has become more essential for crash research and development of countermeasures.

There are two major limitations with data collected from Police reports which need to be recognised (Howie, 1989). These are:

Reporting bias (systematic and random).

Systematic bias arises from the regulations covering crash reporting. In some jurisdictions (e.g. the Australian Capital Territory) reporting criteria require that all but minor damage crashes be reported. In most other jurisdictions only injury crashes and property damage crashes involving third party damage are required to be reported. Random bias occurs where the likelihood of a crash being reported is dependent on the presence of Police or the determination of the persons involved.

Coding errors.

These can occur throughout the process from the filling out of the report form to the data entry at the computer terminal. These types of error are difficult to estimate and are generally not identified until the data are used for detailed investigation of crashes at individual sites.

4.3 SUPPLEMENTARY DATA SOURCES

While the Police report is the basic source of crash data, there are some other sources which may be useful and applicable in certain circumstances. These include the following:

Local knowledge is an important source of information about safety problems in the road network. Obviously, opinions and anecdotal information about crash problems must be regarded as subjective, but this information can be used as a pointer to problems. People who can be tapped for this information are local government staff, local safety groups, residents, and local businesses (Howie, 1989).

Interviews of road users in a structured format have been a source of useful information for traffic authorities in the development of crash countermeasures (e.g. Struick, 1988).

Special surveys such as in-depth studies of particular groups of crashes (e.g. single vehicle fatalities) have been used to gain a better understanding of the causes of crashes. These types of studies can be very costly but have the potential to obtain more useful data than is available from Police accident report forms.

Traffic conflict surveys may be used where the collection of crash data is not practical or the period of evaluation too short to collect sufficient samples. These involve field observations or video recording of conflicts (near misses) (Organisation for Economic Cooperation and Development, 1976; National Association of Australian State Road Authorities, 1988a, p 26) The type of information gained is valuable in getting a sound understanding of the dynamic traffic operation and the inter-actions which occur between traffic streams at the site. As a proxy measure of safety, assumptions must be made about the relationship between the proxy measure (conflict) and crash rates.

Coroner's reports can be a useful source of additional information concerning specific fatal crashes. For example, use was made of this source in the NSW truck crash study, which involved, inter alia, a detailed examination of a sample of fatal truck crashes on NSW rural highways (Sweatman, et al, 1990).

4.4 CODING OF CRASH DATA

Crash data obtained from Police accident report forms is coded for purposes of efficient computer storage and retrieval. Microfiche copies of the original forms, without confidential information such as names of drivers and passengers, are also held for later reference. Narratives from witnesses and those directly involved in the crash are held in Police files. Access to these can usually be arranged for research purposes.

The alpha-numerical coding of crash data can sometimes give the impression of accuracy which the data may not deserve. An understanding of the methods by which the data files are prepared is therefore necessary if it is to be used for research and investigation (Howie, 1989).

Data are coded at two stages of the reporting process. At the crash site and later at the Police station, the reporting officer fills out a codified form. For many of the data fields, the officer can select from a list of responses on the form. For most crashes, the selection of an appropriate response will be straightforward. However, there will be a proportion of crashes where the answer is unclear or ambiguous.

The next stage of coding occurs at the point of data entry. From the information provided by the Police officer, the data coder has to decide a response to two very important pieces of information for the traffic engineer who will be using the data for site analysis. These are first, whether the crash occurred at an intersection or a section of road between intersections (mid-block), and second, the road user movements involved in the crash.

Each jurisdiction has a legal definition of an intersection. In Victoria, for example, a crash is regarded as occurring at an intersection if it is within a legally defined intersection area (the area bounded by the extension of the building lines of the intersecting roads), plus the portion of the approaches to the intersection within 10 m of the legally defined intersection zone. Analysis problems can arise from this definition, particularly where the influence of the traffic control at the intersections can extend some distance from the intersection zone. Rear end crashes at signalised intersections are an example (Howie and Oulton, 1989)

Coding of road user movements requires skilful interpretation of sketches and written descriptions provide by the Police officer. Practice varies between jurisdictions, although there is a general tendency toward the matrix type of code which presents diagrammatic representations of various vehicle-to-vehicle and vehicle-to-other-road-users movements (Figure 4.1 shows the DCA (Definitions for Coding Accidents) diagrams recommended in the Australian model guidelines (Andreassen, 1991).

	0	1	2	3	4	5	6	7	8	9
	PEDESTRIAN on foot, in toy/pram	INTERSECTION vehicles from adjacent approaches	VEHICLES FROM OPPOSING DIRECTIONS	VEHICLES FROM ONE DIRECTION	MANOEUVRING	OVERTAKING	ON PATH	OFF PATH, ON STRAIGHT	OFF PATH, ON CURVE	PASSENGERS AND MISCELLANEOUS
1	NEAR SIDE 01	THRU - THRU 11	HEAD ON 21	REAR END 31	U TURN 41	HEAD ON 51	PARKED 61	OFF CARRIAGEWAY TO LEFT 71	OFF CARRIAGEWAY RIGHT BEND 81	FELL IN/FROM VEHICLE 91
2	EMERGING 02	RIGHT - THRU 12	THRU RIGHT 22	LEFT REAR 32	LEAVING PARKING 42	OUT OF CONTROL 52	DOUBLE PARKED 62	LEFT OFF CARRIAGEWAY INTO OBJECT 72	OFF RIGHT BEND INTO OBJECT 82	LOAD OR MISSILE STRUCK VEHICLE 92
3	FAR SIDE 03	LEFT - THRU 13	RIGHT LEFT 23	RIGHT REAR 33	PARKING 43	PULLING OUT 53	ACCIDENT OR BROKEN DOWN 63	OFF CARRIAGEWAY TO RIGHT 73	OFF CARRIAGEWAY LEFT BEND 83	STRUCK TRAIN 93
4	PLAYING, WORKING, LYING, STANDING ON CARRIAGEWAY 04	THRU - RIGHT 14	RIGHT RIGHT 24	Vehicles in parallel lanes 34	PARKING VEHICLES ONLY 44	CUTTING IN 54	CAR DOOR 64	RIGHT OFF CARRIAGEWAY INTO OBJECT 74	OFF LEFT BEND INTO OBJECT 84	STRUCK RAILWAY XING FURNITURE 94
5	WALKING WITH TRAFFIC 05	RIGHT - RIGHT 15	THRU LEFT 25	LANE SIDE SWIPE 35	REVERSING 45	PULLING OUT REAR END 55	PERMANENT OBSTRUCTION 65	OUT OF CONTROL ON CARRIAGEWAY 75	OUT OF CONTROL ON CARRIAGEWAY 85	ANIMAL 95
6	FACING TRAFFIC 06	LEFT - RIGHT 16	LEFT LEFT 26	LANE CHANGE RIGHT 36	REVERSING INTO FIXED OBJECT 46	TEMPORARY ROADWORKS 66	TEMPORARY ROADWORKS 66			PARKED CAR RAN AWAY 96
7	DRIVEWAY 07	THRU - LEFT 17		LANE CHANGE LEFT 37	LEAVING DRIVEWAY 47	TEMPORARY OBJECT ON CARRIAGEWAY 67	TEMPORARY OBJECT ON CARRIAGEWAY 67			VEHICLE MOVEMENTS NOT KNOWN 97
8	ON FOOTWAY 08	RIGHT - LEFT 18		RIGHT TURN B/S 38	LOADING BAY 48					
9	STRUCK WHILE BOARDING OR ALIGHTING 09	LEFT - LEFT 19		LEFT TURN B/S 39	FROM FOOTWAY 49					
	OTHER 00	OTHER 10	OTHER 20	OTHER 30	OTHER 40	OTHER 50	OTHER 60	OTHER 70	OTHER 80	OTHER 90

Source: Andreassen, 1991

Figure 4.1 Definitions for Coding Accidents

4.5 DATA LIMITATIONS

Although data on accidents is an essential input to a systematic HRL program, there are some limitations and problems with such data. These include (National Association of Australian State Road Authorities, 1988a, p 20; Hoque and Sanderson, 1988, p 28):

- . under-reporting of crashes (especially property damage only crashes)
- . there may be inconsistencies in the crash history of a specific location,
- . historic crash data may not be applicable to those locations where traffic conditions have changed,
- . exact locations (especially in rural mid-blocks) can be inaccurate or imprecise as discussed above,
- . different identification ranking procedures or referencing methods can sometimes lead to incorrect locations being identified (e.g. all mid block crashes in a road segment are coded as occurring at the same point on rural roads in Vic),
- . road feature records may not be available,
- . definitions or interpretations of field data may be changed over time by those responsible for coding and recording.

4.6 ANALYSIS OF CRASH STATISTICS

The previous discussion in this chapter has emphasised the importance of a sound and rigorous analysis of a statistical data base in the development of HRL programs. It is helpful to provide here a brief introduction to the techniques which are available, and the pitfalls to be aware of in performing such analyses.

Some familiarity with statistical concepts is assumed in the following discussion. It is important to stress however that what follows is a limited exposition of the use of statistical techniques in crash investigation; for further information, an appropriate text should be consulted, (e.g. Taylor and Young, 1988). There is also a brief overview of statistical tests for use in this particular field presented in National Association of Australian State Road Authorities, 1988a, Appendix C, and Howie, 1989).

Essentially, there are two statistical applications in HRL analysis:

- . given a set of crash data for a site (or route or area) before and after a remedial treatment, is the difference in the crash experience statistically significant?
- . given crash data for a test site and a control site (which is as near as possible similar to the test site in all of its characteristics), is there any difference between the before-and-after crash experience at the test site compared with the control site?

For both of these situations, the chi-squared test is appropriate and has been widely used (Taylor and Young, 1988, p 112). (For examples of its application to various road safety applications see for example Jordan and Young, 1982; Andreassend, Hoque and Young, 1984; Fairlie and Taylor, 1990). The chi-squared test is based upon a **contingency table** - a table showing both the observed values of a set of data (O), and their corresponding expected values (E). The chi-squared statistic is then given by:

$$c^2 = \sum_{i=1}^n \sum_{j=1}^m \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where O_{ij} is the observed value in column j and row i of the contingency table
 E_{ij} is the expected value in column j and row i of the contingency table
m is the number of columns
n is the number of rows

Clearly, the smaller the value of chi-squared as calculated from the above formula, the closer the "observed" and the "expected" values, until of course we get to the point where the observed and the expected values are identical, in which case, chi-squared is zero. Hence, we can use tables which show the probability that the "expected" values and the "observed" values are drawn from the same sample, with a small value indicating that there is a high probability that there is no difference between the "observed" and the "expected", and a high value indicating a low probability that there is no such difference. These tables also require us to know the number of degrees of freedom in the contingency table, and this is given by:

$$\text{degrees of freedom} = (n-1)(m-1)$$

These tables may be found in any good statistics text book or published tables of statistics (e.g Taylor and Young, 1988, p 342).

Worked examples of the application of these procedures are given in National Association of Australian State Road Authorities (1988a, page 61), and Andreassen (1992a).

4.7 DESIGN ISSUES

While there are suitable methods of testing for statistically significant differences (such as those briefly described in Section 4.6), there are other problems of an experimental design nature which need to be recognised. These include (Howie, 1989):

Regression to the mean.

Over a period of years, crashes at a site per unit of time will fluctuate about a mean value due to the random nature of crashes. Because sites are selected for treatment on the basis of their ranking in numbers of crashes compared to all other sites, there is a high possibility that sites will be chosen when they are higher than their long term mean. Even without treatment, the crash rate at these selected sites is likely to experience a lower rate (i.e. regress to the mean) in the year following selection.

This aspect of crash experience is likely to be a problem in the post-implementation evaluation of safety measures at sites. The problem is to separate the real gains from the particular treatment from the changes due to regression to the mean. The problem can be substantially minimised by increasing the number of years of data used in the site selection process.

Crash migration.

The hypothesis here is that crashes may increase at sites surrounding the improved site due to changes in trip pattern or drivers' assessment of risk. For example, increased use of right-turn phases at signalised intersections may result in a declining ability of drivers to deal with sites with no right-turn phase. The extent of this problem is difficult to determine.

Confounding factors.

Safety improvements often take several years for implementation after a site has been included on an improvement program. During this time, traffic and physical conditions can change, thus increasing the difficulty of separating out safety benefits which are due to the safety improvements.

Controlling other variables.

Application of statistical tests generally assume an ability to control (or hold stable) variables which are not related to the variable being tested. For example, crash rates may be the dependent variable being tested in relation to the independent variable which may be cost of treatment. However, there will be many other independent variables which the analyst is unable to control or model, such as changes in the composition of driver and vehicle populations, weather conditions, road network changes, urban structure, other safety programs, enforcement levels, level of economic activity, etc.

Decisions are needed at the outset of the analysis on how to estimate general population statistics against which to judge the before and after performance of the subject sites. Even where matching pairs comparisons are used (i.e. one control site for each treated site), there is the possibility of differential system-wide changes which raise questions about the validity of the analysis of changes.

5. IDENTIFICATION OF HAZARDOUS ROAD LOCATIONS

As discussed in Chapter 3, hazardous road location (HRL) programs may be directed at single sites, routes, areas, or mass application programs. In this chapter, we examine the criteria for identification of hazardous locations in each of these categories, together with a discussion of the related issues of exposure, severity, site specification, and time period for the analysis.

5.1 IDENTIFICATION OF HAZARDOUS SITES

Sites are specific locations, concentrated in space, such as an intersection, a short length of road (e.g. a bend) or a specific road feature (e.g. a bridge).

5.1.1 Criteria

A number of criteria have been used to identify hazardous sites, the most common being (Sanderson, Cameron and Fildes, 1985a, chapter 4; Nicholson, 1990, p 2; National Association of Australian State Road Authorities, 1988a, p 18; Hoque and Sanderson, 1988, p 27; Zegeer, 1982, 1986; Walsh and Dileo, 1992):

- . the number of crashes (or crashes per km) in a given period exceeding some set level (e.g. 3 per year); note that this takes no account of exposure,
- . the rate of crashes (per veh km or per vehicle) for a given period exceeding some arbitrary value; this does take account of exposure,
- . the number and rate of crashes both exceeding some arbitrary threshold value,
- . the rate of crashes exceeding a critical value derived from statistical analysis of rates at all sites (the so-called "rate quality control method"),
- . the potential crash reduction method, based on the system average crash rate,
- . the number of crashes of specific type and/or combination of types in a given period.

There is little agreement on which criteria are most appropriate (Sanderson, Cameron and Fildes, 1985b, p 9; National Association of Australian State Road Authorities, 1988a, p 18; Nicholson, 1990, p 2). Proponents of the crash frequency approach argue that it focuses attention upon the locations where most crashes occur, and hence such a program has the most potential to reduce the number of crashes. Also, this approach will tend to focus upon sites on high volume roads which have a large number of crashes. Proponents of the rate approach argue that it identifies sites where there is something truly unusual, not just a high level of traffic. This approach will lead to site selection on lower volume roads having fewer crashes and therefore less potential for improvement.

Hence, the third criterion has some attraction, in that it leads to selection of sites that have a high risk (in terms of crashes per unit of exposure) and where there are relatively large numbers of crashes.

5.1.2 Exposure Measures

The problem of accounting for exposure to risk of a road traffic crash is one of the major theoretical and practical problems facing safety analysts (Organisation for Economic Cooperation and Development, 1984, p 6 ff).

In principle, the concept of "exposure" is relatively simple: the more a person is involved in road traffic (e.g. amount of travel), the more likely it is that the person will be involved in a crash.

Furthermore, the differential involvement of participants in the road traffic system points to the need for a meaningful basis for assessing the relative safety of the system. This is most evident when comparisons are made, for example, between different groups of drivers, or across time periods, etc.

For HRL sites, a measure of exposure may be used directly, or a proxy measure in terms of an index (which may or may not reflect exposure) might be used. Typical measures include (National Association of Australian State Road Authorities, 1988a, p 19; Sanderson, Cameron and Fildes, 1985):

- . for road sections:
 - crashes per kilometre
 - crashes per vehicle kilometre (AADT x length of section, usually expressed as crashes per 10⁸ vehicle km of travel (VKT))
- . for intersections:
 - sum of entering vehicles

- $2\sqrt{\frac{V1+V3}{2} \cdot \frac{V2+V4}{2}}$

where V1 ... V4 are the entering flows (four way intersection - variations for 3 way and other intersections)

5.1.3 Severity

Crashes can be stratified by severity, where the severity of a crash is based upon the most severe injury sustained by any person involved in the crash. Classifications vary, but the one recommended in the Australian model guidelines (Andreassen, 1991) is:

- . killed, or died within 30 days
- . injured, admitted to hospital
- . other injured, requiring medical treatment (e.g. by a medical practitioner)
- . injured, not requiring medical treatment
- . not injured.

These codes are not universally applied. For example, Victoria has a 3-level code:

- fatal crash (at least one person killed)
- casualty crash (at least one person killed or injured in the crash; an injury is defined to include any level of injury, including minor injuries not requiring treatment by a medical practitioner)
- non-injury crash (no person requiring any medical treatment)

Severity classifications may be used in an attempt to identify those sites having a high number and/or high rate of serious crashes. This can be done in three ways:

- Crashes of different severity can be weighted by the average cost in each severity category (National Association of Australian State Road Authorities, 1988a, p 19).
- A variation on this is to give each crash a weight representing the average cost of crash in the severity category in which it falls. This leads to fatal crashes having more than 10 times the weight attached to injury crashes.
- Either of the above approaches will lead to fatal crashes dominating the identification procedure. The problem here is that the circumstances which lead to fatal crash sites may be very similar to those which produce injury crashes, the outcome being somewhat random. Concentration on fatal crashes alone (which are also a statistically rare event) may lead to spurious conclusions, i.e. the selection of sites which do not in fact have a high crash risk. Hence, a compromise approach is to weight the more severe crashes, but not with the extreme weights calculated in direct proportion to the average cost. Table 5.1 shows weights used by various Australian authorities in the mid-1980s (National Association of Australian State Road Authorities, 1988a, p 19). While this is pragmatic, it is essentially arbitrary, and there is no theoretical basis for the weights.

These approaches are likely to find lesser use in the future, since recent research on the average costs by accident type means that it is now possible to estimate costs (and hence benefits) directly, thus avoiding the need to use the proxy measures described above. This work is reported in Andreassen (1992a,b,c), and its use will be described in Chapter 8.

	ACT	NSW ¹	QLD	SA ²	TAS ³	VIC	WA ⁴
Fatal crash	16	3.0	4	20	3	N/A	12
Injury crash where casualty is admitted to hospital	4	1.8	3	20	3		3
Injury crash where casualty is not admitted to hospital	4	1.3	1	20	1		3
Property damage crash only	1	1.0	1	1	1		1
1. In NSW this basic factor is tow-away crashes							
2. In SA the various weightings are approximately based upon the crash rates included							
3. In Tasmania the various weightings are used for different purposes							
4. In WA weights are generally not used							

Source: National Association of Australian State Road Authorities, 1988a, p 19

Table 5.1 Australian Road Crash Severity Weightings, early 1980s

5.1.4 Site Specification

With hazardous sites, it is necessary to define the road length, or in the case of intersections, to be specific about the definition. With the subdivision of roads into sections, the various factors which need to be considered include (Nicholson, 1990, p 3):

- . roadway and traffic factors should be fairly uniform within the section,
- . the section length should be in keeping with the level of precision and degree of error in reporting crash location, and
- . statistical reliability.

With respect reliability, as the section length gets very small the probability of either zero or one crash in the period tends towards unity. Conversely, as the section length gets very large, the effects of isolated hazardous features will be submerged and lost. Zegeer (1982) suggests that data for road segments of less than approx 0.5 km or carrying less than 500 veh/d are unreliable.

Intersections are defined in the model guidelines (Andreassen, 1991) as the area bounded by the projections of the property boundaries, plus 10 m of the approach roads; crashes occurring within this area are classified as intersection crashes, and all others as "mid-block" crashes.

5.1.5 Time Period

The factors affecting the before-and-after time period include (Nicholson, 1990, p 4):

- . attempt to avoid having environmental (e.g. traffic growth) and other trends affecting results,
- . use annual crash count data to avoid the effects of cyclic variation in crash occurrence,
- . computer storage and processing costs,
- . changes in data base definitions introducing discontinuity in the data.

A shorter period will perhaps lead to the early detection of any sudden changes in the crash rate, but a longer period will improve statistical reliability, giving both a larger sample size and a smoothing of short term fluctuations. Common before and after periods range from one to five years (Nicholson, 1987), with three years being common.

5.2 IDENTIFICATION OF HAZARDOUS ROUTES

The identification of hazardous routes is different in some respects to the identification of hazardous sites; routes are defined as specific sections of road, having reasonably homogeneous conditions. The following discussion highlights these differences; unless mentioned here, the same factors apply for routes as discussed in Section 5.1 above for sites.

5.2.1 Criteria and Exposure

The most commonly used criteria for the identification of hazardous routes are (Nicholson, 1990, p 4)

- . the crash frequency exceeding some threshold value (this ignores variations in route length and traffic flow),

- the crash frequency per kilometre of road exceeding some threshold value (this ignores variations in traffic flow), or
- the crash rate (per vehicle km) exceeding some threshold value.

Either of the last two is acceptable. As before, a frequency-based measure focuses on routes with high flows and crashes, whereas a rate-based approach focuses on routes which have low flows. A combination of the two may be appropriate.

5.2.2 Road Length

With hazardous route identification, the focus is upon an extended length of road. Route segments may vary from around 1 km to several km (say 10 km).

5.2.3 Time Period

The comments in Section 5.1 in relation to hazardous sites apply equally to routes. However, the statistical reliability factor is not as critical, because although the crash frequency for any specific site may be very variable, the frequency for an aggregation of sites (i.e. the route) will be much less variable. Hence a shorter time period is required for equivalent precision (Nicholson, 1990, p 5).

5.3 IDENTIFICATION OF HAZARDOUS AREAS

An area-based analysis incorporates a relatively homogeneous precinct, with roads of similar function. It should not therefore combine both arterial roads and local streets. A typical analysis would involve a discrete residential area, as used for example is a local area traffic management (LATM) scheme. Once again, we discuss here only those factors unique to the identification of hazardous areas; other factors are as discussed in Section 5.1 above for hazardous sites.

5.3.1 Criteria

This is a relatively new area of analysis, and there is some doubt about the criteria which ought to be used for identifying hazardous areas. Possible criteria include (Nicholson, 1990, p 5):

- the number of crashes per square kilometre (this does not take account of variations in the length of road and traffic flows),
- the number of crashes per head of population (ditto),
- the number of crashes per kilometre of road (this takes no account of traffic flow), or
- the number of crashes per vehicle owned or available to the population (this attempts to take account of traffic flows in a crude manner).

5.3.2 Road Length/Area, and Time Period

Typical areas are of the order of 5 km², but the size is more dictated by the purpose of the analysis. Because reported crashes may be quite few in number, a reasonable time period may be required to ensure a statistically significant sample size. If there have been LATM works in the area over the time period concerned, allowance must be made for this.

5.4 IDENTIFICATION OF SITES FOR MASS ACTION

Here the goal is to find sites where there are substantial numbers of crashes (and crashes per unit of exposure) where the crashes (Nicholson, 1990, p 5):

- are of a particular type (e.g. skidding)
- involve a particular movement (e.g. overtaking)
- occur at a particular time of day
- involve a particular category of road user (e.g. motor cyclist) and/or
- are associated with a particular road feature (e.g. bridges)

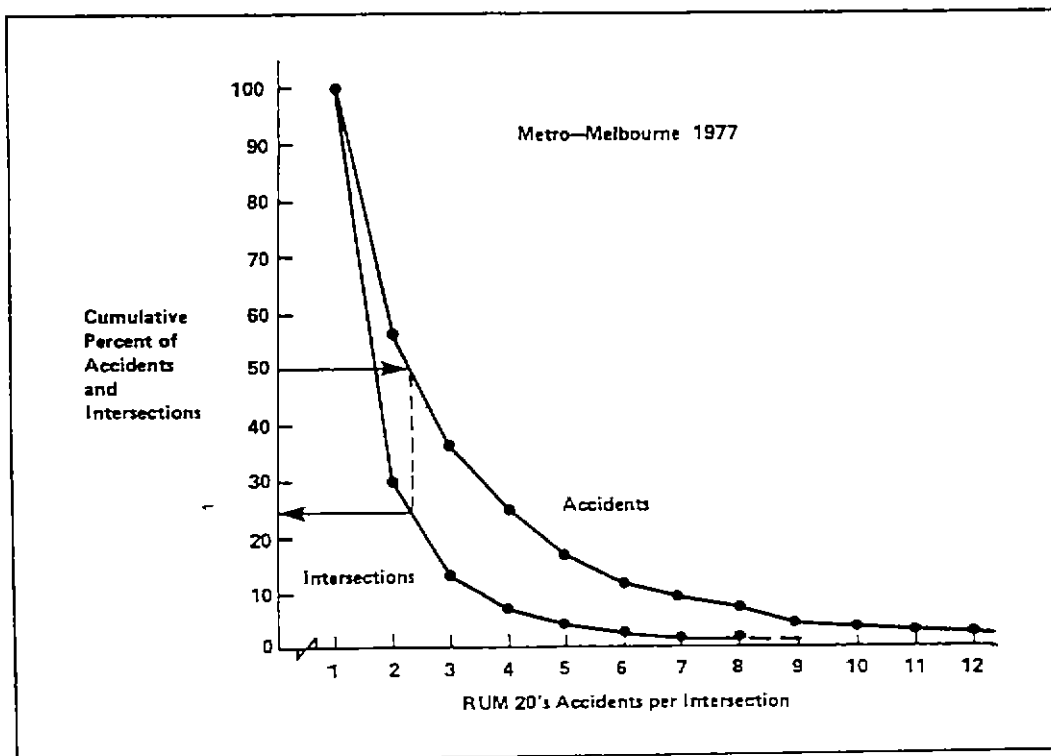
Since we are dealing with sites, rather than routes or areas, the comments in Section 5.1 relating to identification of sites (exposure, severity, length of road segment, and time period) also apply here.

5.5 CLUSTERING OF CRASHES

Central to the concept of HRL is that certain types of crashes are over-represented at specific sites. In order to identify this clustering, and thus develop a program to treat high crash frequency sites, a cluster analysis needs to be performed.

This takes the form illustrated in Figure 5.1 (Andreassen, 1989, p 6). The cumulative percentage of crashes and the cumulative percentage of sites (e.g. intersections) are plotted. (The former is produced by the product of the number of crashes per site and the number of such sites). The example in Figure 5.1 shows that 50 per cent of these particular crashes (crashes at intersections) occurred at about 23 per cent of the sites, and these sites averaged about 2.4 crashes per site.

It is important to identify this sort of clustering, because when a relatively few sites account for a large proportion of the crashes, improvements at these sites can give a big overall reduction in crashes.



Source: Andreassen, 1989, p 6

Figure 5.1 Clustering of Accidents

5.6 USE OF HRL IDENTIFICATION CRITERIA

Table 5.2 summarises specific HRL criteria currently in use in Australia.

State/Territory	Intersections	Sections
ACT	combination of number of crashes, severity index and severity rate.	as for intersections
NSW	crash numbers over two years and severity index in most recent year	crashes per km, crashes per veh km
QLD	cost, in \$/veh km (estimated from Andreassen, 1992b). If no volume data, use \$ or number of crashes.	cost, in \$/10 million entering vehicles (estimated from Andreassen, 1992 b) If no volume data, use \$ or number of crashes.
VIC	number of crashes	crashes per km
WA	number of crashes	crash rate per km significantly greater than system or road type average
SA	crash rate cost, number of crashes	crash severity index and crash rate compared to an upper control limit
TAS	severity index	severity index
NT	based on FORS	based on FORS
FORS	urban: casualty crash rate significantly greater than the system average or casualty crash rate significantly greater than system average after casualty crash number significantly greater than system average rural: no recommendation	urban: casualty crash per km significantly greater than system average or casualty crashes per veh km significantly greater than system average rural: casualty crash number per km significantly greater than system average

Table 5.2 Hazardous Road Location Criteria

6. DIAGNOSIS OF ROAD CRASH PROBLEMS

Having identified those sites, routes, areas, or mass action programs which are to be the subject of the Hazardous Road Location (HRL) program, the next step, as outlined in Chapter 3, is to diagnose the accident problem at the identified locations.

6.1 DATA BASE

The basis of any systematic, scientific HRL program is detailed analysis of the data base, as outlined in Chapter 4.

This will involve:

- . crash data
- . road characteristics
- . traffic data
- . driver behaviour

The aim here is to ascertain an appropriate level of familiarity with the site(s) concerned, such that countermeasures can be developed in a systematic way, without jumping to premature conclusions. Having said that, it will nevertheless be the case that countermeasure selection will always involve a balance of formalised procedures and engineering judgement. That is, improvements are site-dependent and will rely upon experience gained from previous applications of countermeasures.

The IHT Guidelines (Institution of Highways and Transportation, 1990a, p 25) suggest that there are six steps in the diagnosis phase:

- . study detailed crash reports
- . data sorting to determine groups of accident types and the locations at which they occur
- . data amplification by detailed on-site investigation (perhaps including conflict studies)
- . detailed analysis of all data
- . identification of dominant factors and/or road features
- . determine nature of the crash problem.

Therefore, most crash investigations involve (National Association of Australian State Road Authorities, 1988a, p 23):

- . an in-office analysis, identifying predominant vehicle manoeuvres, and summarising the accident types which are occurring; this aims to reveal the type of countermeasure needed (e.g. a disproportionate incidence of night time crashes implies a need for delineation, lighting, etc).
- . an on-site analysis involving observation of road and driver characteristics; this may be supplemented by extra studies, such as speed studies, traffic counts, turning manoeuvres, conflict analysis, etc.

6.2 CRASH DATA

The data source is the mass accident data base for the State or Territory, as outlined in Chapter 4.

In analysing site-specific crash data, the aim is not so much to consider every single crash which has occurred at the site, but rather to search for patterns in crash occurrence which will lead to identification of underlying problems (Corben and Cunningham, 1989).

6.2.1 Crash History

The first step in site investigation is to examine the patterns of so-called *accident types*. This is coded according to standard classifications. As noted previously, the classification towards which all States and Territories are moving is that included in the model guidelines developed by the Australian Road Research Board (Andreassen, 1991); see Figure 4.1.

To represent the crash history at a site, it is helpful to prepare a frequency histogram is a useful way of representing this - i.e. a bar chart showing the dominant DCA (or similar) codes.

Supplementary analyses at this stage include investigation of the frequency with which crashes occur according to (Corben and Cunningham, 1989):

- . light condition (day, dusk, dawn, dark): to see if there are particular visibility situations which are causing problems.
- . road condition (wet, dry): to see if there is evidence of a skidding problem - may be indicative of a low skid resistance pavement, drainage problems, etc)
- . time of day: to see if the problem is associated with am peak, pm peak, or off-peak traffic and manoeuvres (e.g. if the crash problem is predominantly off-peak, partly controlled right turn phases are not likely to be of much use, since these usually require a queue to form in the right turn lane before they are activated, and this is less likely to occur in off peak hours)
- . day of week: to see if there are problems associated with particular user groups, e.g. party-goers on Saturday night, tourists on Sunday afternoon, etc.

6.2.2 Collision Diagram

The fundamental tool used in site-specific crash investigation is the collision diagram (National Association of Australian State Road Authorities, 1988a, p 23-25). This is prepared by investigating the Police accident report forms for individual crashes which have occurred at that site.

The collision diagram summarises all the movements of the road users involved in all the crashes, and highlights the predominant accident types.

Data for each crash which may be shown on the collision diagram may include:

- . accident type (DCA code or equivalent)
- . severity of crashes
- . data and time of crashes
- . condition of road
- . light condition
- . geometry of the site
- . locational information
- . summary of crashes (table)

The collision diagram is the fundamental tool used by the traffic engineer in diagnosing road safety problems, and hence in developing countermeasures. It indicates which *accident types* predominate; this information is critical, because different countermeasures influence different accident types. These types might include (Andreassen, 1989, p 3):

- . collisions between vehicles entering from adjacent streets,
- . right turn collisions involving vehicles from opposite directions
- . rear end collisions
- . collisions between vehicles and pedestrians
- . collisions between vehicles travelling in the same direction (e.g. sideswiping)
- . vehicles running off the carriageway
- . collisions with fixed objects off the carriageway
- . collisions with parked vehicles.

6.2.3 Crash Summary Report

Based upon the analyses of crash histories and the collision diagrams, a crash summary report would be prepared (see National Association of Australian State Road Authorities, 1988a, Appendix B). This would summarise the information available about the site, including, for example:

- . location (e.g. street name, municipality, highway km distance, map reference)
- . site description, e.g. road geometry
- . roadworks (if any)
- . crash listing (showing details of each crash)
- . crash summary by:
 - severity
 - accident type (DCA code or equivalent)
 - road condition
 - light condition
 - time of day
 - month
 - year
 - day of week
 - factors identified (shoulder, fatigue, etc)
 - objects hit
 - types of vehicle
 - age of drivers
 - traffic volumes
 - turning volumes

6.3 ROAD AND TRAFFIC DATA

While the original road crash reports may contain some road and site data, it will inevitably be necessary to carry out a site inspection to accurately assess the road conditions and other site factors which may be relevant.

The on-site observations should attempt to identify any adverse features of road design and contributing environmental features (Corben and Cunningham, 1989). This should include night time investigation, and perhaps investigation under adverse weather conditions. The investigator should walk around the site, and drive through the site executing the specific manoeuvres which have been shown to be problematical. This can offer valuable insights into identifying and understanding factors which are contributing to crash occurrence.

Data on traffic volumes and turning volumes may be helpful. In some cases this will be available, but in other cases it may need to be collected as a special case (See Section 4.1.).

6.4 PROBLEM ANALYSIS

On the basis of the information contained in the crash summary report, perhaps supplemented by a traffic conflict study (see Section 4.3), the nature of the crash situation at the site can be investigated. The following questions are relevant (Andreassend, 1983):

- . are crashes associated with a physical condition of the road, and can this situation be eliminated or corrected?
- . is visibility adequate, and can this be corrected, or if not is there adequate warning?
- . are the existing signs, signals, and pavement markings doing the job for which they were intended? Are replacements needed?
- . Is traffic properly channelled to minimise the occurrence of conflicts?
- . would crashes be prevented by prohibition of a specific movement (e.g. a right turn), or by giving it priority (e.g. exclusive phase)?
- . can some of the traffic be diverted to other streets where the crash potential is not as great?
- . are night time crashes out of proportion to daytime crashes - indicating the need for special night time protection (lighting, delineation, etc)?
- . do conditions show the need for additional traffic law enforcement?

7. DEVELOPMENT OF COUNTERMEASURES

Having systematically analysed mass accident data to identify hazardous road locations, and analysed site-specific accident data at identified sites, the next major step is to develop countermeasure options.

7.1 PRINCIPLES OF COUNTERMEASURE DEVELOPMENT

There are a number of principles which should be considered in the development of countermeasures for specific locations (Corben and Cunningham, 1989).

In general, the traffic engineer should attempt to satisfy these principles to an extent determined by the individual needs of significant road user groups and the pattern of accidents at the site (or the potential sources of serious conflict).

7.1.1 Intersections

The main design principles for intersections are:

- . minimise the number of conflict points and hence the opportunities for crashes,
- . separate conflicts in space or time,
- . minimise the angle of conflict,
- . define and minimise conflict areas,
- . define vehicle paths,
- . ensure adequate sight distances,
- . provide clear indications of right-of-way requirements,
- . minimise roadside hazards,
- . simplify the driving task, and
- . minimise road user delay.

Many of the more commonly used intersection traffic control devices combine several of these principles, although additional refinements to the standard treatment are often needed.

Roundabouts, for example, include to some degree all of the above principles (except for separating vehicle movements in time), with the final balance being dependent upon site-specific conditions and traffic management objectives.

Traffic signals also incorporate many of these principles but some, such as ensuring adequate sight distance, minimising conflict angles and minimising the number of conflict points, are of less importance because of the ability for time-separation of conflicting movements.

Perhaps the most challenging aspect in designing solutions at hazardous road locations is to achieve the safety objective(s) for significant user groups, while at the same time striking an appropriate balance between other competing traffic and environmental objectives.

7.1.2 Mid Block Locations

For non-intersection locations (mid-blocks), the principles for safe design and operation include:

- . ensure appropriate standards of horizontal and vertical alignment,
- . develop roadway cross sections to suit road function and traffic volumes,
- . delineate roadway and vehicle paths,
- . ensure appropriate standards of access control from abutting land use, and
- . ensure the roadside environment is clear or forgiving.

Overlaying all of these principles is a vital need to consider the particular needs of all road user groups. Proper consideration of these needs is a major determinant in the quality of the final treatment.

For example, pedestrians are perhaps the most vulnerable of all road user groups, especially the young, the elderly and the alcohol-affected. They have special needs that should be separately considered when investigating safety problems and developing countermeasures (Jordan and Veith, 1989, Austroads, 1994a).

Other examples can be found in the special requirements that heavy vehicles may have in negotiating low-radius turns, curves with adverse super-elevation affecting high loads, etc. Other user groups, such as general vehicular traffic, cyclists, motorcyclists and public transport vehicles, all justify explicit attention (Ogden, 1989b; Taylor, 1989).

7.2 COUNTERMEASURE SELECTION

As mentioned previously, it is seldom possible to establish a single cause for road crashes at a site. There will often be a number of remedial measures which could be applied individually or in combination. The final choice will generally be based upon judgement and experience, utilising countermeasures which have been successful in similar circumstances.

Importantly, the countermeasure must relate to the type of crash found from analysis of the data base to be prevalent at the site (or route, area or in relation to the mass action program - see Chapter 3).

National Association of Australian State Road Authorities (1988a, pp 26-28) has provided broad guidelines on potential countermeasures applicable to specific road crash types. These are shown in Tables 7.1 to 7.4 for four categories of accident, namely:

- . intersections and major driveways
- . pedestrian-vehicle collisions
- . non-intersection collisions
- . railway level crossings

Right Angle Collisions

- Check sight distance available and where practical, clear obstructions to provide the appropriate standard of sight distance. Where standards can not be achieved, consider installation of traffic controls such as stop signs or speed controls.
- Check day and night visibility of traffic control devices.
- Consider the installation of appropriate warning signs and devices.
- Where a high frequency of night crashes are involved, consider street lighting.
- Consider installation of channelisation such as median islands in side road approaches, wide median treatments (where appropriate) and staggered intersections treatments in rural areas.
- Consider installation of a roundabout where the location is suitable and the cost is acceptable.
- Consider installation of traffic signals where warrants are met.

Right Turn Collisions with Opposing Traffic

- If the intersection is signalised, consider provision of fully controlled right turn phases.
- Check and improve if necessary sight distance from centre of road or median opening to opposing flow.

- If on a divided road with a wide median, consider alignment/shape of right turn lanes to avoid sight line obstruction by opposing right turn vehicles.
- If at a cross road intersection on an undivided road, consider centre turn lane with painted island protection.
- If a right turn phase exists, consider provision of right turn red arrow 'hold' to prohibit the filter movement.

Straight Ahead/Rear End Collisions

- Check if these collisions are due to queuing by uninvolved right turn vehicles. If this is the case, consider provision of protected auxiliary turn lane. Where a high frequency of night time crashes are involved, consider street lighting.
- If there is a high involvement of wet weather crashes, check skid resistance and pavement drainage.
- At signalised intersections, check stopping sight distance to "tail of queue", adequacy of yellow phase or all-red clearance time, visibility to signal aspects - consider provision of overhead mast arm signal.
- Where close spaced linked signals occur, check offset timing.

Right/Left Turn/Rear End Collision

- Provide protected right/left turn auxiliary lanes.
- Consider prohibition of right turn if this can be adequately catered for at other locations without adverse safety or environmental effects.

Source: National Association of Australian State Road Authorities, 1988a, p 26

Table 7.1 Countermeasures: Intersections and Major Driveways

- Install pedestrian crossing where warrants are met
- Consider barriers to inhibit "J" walking
- Consider parking prohibition and/or provide footpath extensions (into parking lane) to improve pedestrian sight lines and reduce pedestrian crossing distance.
- Consider the installation of pedestrian refuge islands where very wide two-way carriageway is to be crossed.
- Local street traffic management measures such as road humps, slow points, etc to reduce vehicle speeds.
- Consider provision of pedestrian operated signals (including pelican type) where warrants are met
- If at a signalised intersection consider adequacy of existing "walk" and "don't walk" intervals or consider provision of exclusive pedestrian phase.

Source: National Association of Australian State Road Authorities, 1988a, p 27

Table 7.2 Countermeasures for Pedestrians or Vehicular Collisions

<p>Side-swipe Collisions</p> <ul style="list-style-type: none"> • In a rural area provide or check adequacy of centre & edge lines. Where relevant, lane line delineation and supplement with retro-reflective pavement markers (RRPMs) if warranted. • Consider provision of wider lanes. • On the approach to an intersection, consider improving direction signing including overhead lane use signs where relevant. Also consider adequacy or provision of auxiliary lanes for turning traffic. <p>Head-on Collision</p> <ul style="list-style-type: none"> • In a rural area check adequacy of centre line marking and consider supplementing this with RRPMs. • If at locations where visibility is restricted, consider barrier lining. • Where justified, consider separation of opposing flows by means of a painted median with or without rumble strips or by means of a raised median where economically justifiable. • If occurring on a divided roadway, consider improving delineation, widening of the median or provision of a median barrier. <p>Run-off Road Type Crashes</p> <ul style="list-style-type: none"> • Consider improved delineation including post mounted delineators, RRPMs, edge lines and alignment markers, etc. 	<ul style="list-style-type: none"> • If at an isolated curve, consider adequacy of alignment design and superelevation. • If at critical curves, consider warning signs and advisory curve speed signing. • If in urban areas with a high night time crash involvement, consider street lighting. • If there is a high incidence of wet weather crashes, check surface texture, skid resistance and pavement drainage. <p>Hit Fixed Object Crashes</p> <ul style="list-style-type: none"> • Remove or relocate objects to less vulnerable positions. • If lighting pole or sign post, consider relocation or use of frangible poles. • If object can not be relocated or made frangible, consider provision of guard rail or crash cushion. <p>Crashes Involving a Parked Car</p> <ul style="list-style-type: none"> • Consider prohibition of parking. • If angle parking involved consider conversion to parallel parking. • Consider increasing the clearance between the parking and through traffic lanes. • If there is high night time crash involvement, consider adequacy of or the provision of street lighting.
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Source: National Association of Australian State Road Authorities, 1988a, p 28

Table 7.3 Countermeasures for Non-intersection Crashes

<ul style="list-style-type: none"> • Check adequacy of advance warning signs and markings. • Check sight distance available and improve if practicable - consider road realignment where economically justified. • If there is a high night time crash involvement, consider provision of street lighting. 	<ul style="list-style-type: none"> • Where no warning bells & lights exist, consider their provision where economically justified. • If the railway crossing is protected with bells and lights, consider adequacy of their visibility/audibility. • Where justified, consider the provision of boom barriers.
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Source: National Association of Australian State Road Authorities, 1988a, p 28

Table 7.4 Countermeasures for Railway Level Crossing Crashes

In the remainder of this chapter, we review a wide range of road and traffic factors and discuss their effects on road safety. The material in this chapter is largely drawn from an extensive review of the literature. Of particular value in the literature review were previous reviews of aspects of road and traffic safety, both for what they concluded and also for their links to the literature.

These included Roy Jorgensen and Associates (1978), Federal Highway Administration (1982), Lay (1986), Nairn and Partners (1987), Teale (1984), Carney (1986), Smith and Mason (1988), Transportation Research Board (1987a,b), Hoque and Sanderson (1988), National Association of Australian State Road Authorities (1988a), Pak-Poy & Kneebone (1988), Institute of Transportation Engineers (1993); Travers Morgan (1991); and Travers Morgan (1992).

The road design and traffic management features which are assessed for their contributions to safety are as follows:

road design

- divided and undivided roads; road medians
- lane and shoulder width
- sight distance
- horizontal and vertical alignment
- safety barriers
- bridge, structure and culvert design
- overtaking

traffic management and design

- intersections
- truck routes
- local area traffic management
- pedestrian and cycle facilities

traffic engineering

- delineation
- street lighting
- warning and direction signing
- rumble strips

road construction and maintenance

- pavement surface condition
- work zones

speeds

- speed and speed limits

the roadside

- roadside hazard treatments
- shoulder treatments

7.3 ROAD DESIGN

7.3.1 Divided and Undivided Roads; Road Medians

Road Standard.

Road standard is applicable to traffic engineering mainly in the context of the design of new networks. It is therefore relevant to note only that road standards clearly has a major effect on crash rates. In particular, freeways, with full access control, grade-separated interchanges, high design speeds, and safe roadsides are very much safer than other forms of road. Access control has been quoted as "the most important single design factor ever developed for accident reduction." (Federal Highway Administration, 1982, p 4-2).

A recent Australian Road Research Board (1988) leaflet has summarised the casualty accident rate (crashes per 10⁸ vehicle kilometres) as follows:

one-lane road	800-1200
narrow two lane road	100-200
wide two lane road	20-100
undivided arterial road	20-100
divided arterial road	10-100
all freeways	10
new freeways	5
average for all roads	200-800

In summary, freeways are much safer per kilometre of travel than other roads; the precise safety advantage cannot be explicitly given because there is wide variation within road types, but freeways are at least 4 times as safe as other roads, and maybe as much as 20 times as safe as other arterial roads. New freeways, built to contemporary standards, are the safest form of road, and may be twice as safe as older freeways built to lower standards.

Access Control.

Part of the safety advantage of freeways clearly stems from the control of access from abutting property through the elimination of unexpected events and the separation of decision points (Cirillo, 1992). However, a measure of access control can be achieved without the other design features of freeways (e.g. grade-separated interchanges).

Therefore, controlling access on existing roads through the use of service roads can be an effective safety device. Federal Highway Administration (1982, p 4-1 ff) quotes several American studies which show that the crash rate increases rapidly with the density of access driveways. For example, in one study, the difference between a low level of development (fewer than 20 driveways per km) and a high level of development (more than 20) was to more than double the number of driveway crashes per km. Similar results for Australia have been reported by McLean (1993, p C3). Interestingly, several studies were quoted which indicated that this is a rural problem as well as an urban problem in the US.

Control of access, i.e. preventing direct access from abutting property onto a through carriageway, has safety benefits, and the use of devices such as service roads has safety advantages.

Medians.

Similarly, the provision of medians has a marked effect upon crash rates, because opposing streams of vehicles are separated; this is of course another characteristic of the freeway.

National Association of Australian State Road Authorities (1988a, p 29) reports a Victorian study where 42 km of 2-lane highway was replaced with a 4-lane divided highway, with a 30 per cent crash reduction. It also reported an Adelaide study which compared crash rates for 4-lane roads having wide medians, narrow medians, and painted narrow medians, with 4-lane roads without medians. Compared with the undivided roads, the others reduced the crash rate by:

narrow painted median	30 per cent
narrow raised median	48 per cent
wide median	54 per cent

In urban areas, medians should, where possible, be wide enough to protect a turning or crossing vehicle. "Wide medians" in the above study were those which met this criterion.

In rural areas, wide medians should be provided to allow space for the driver of an errant vehicle to regain control. Pak-Poy and Kneebone (1988, p 129) have suggested that "with a median width of 9 m, between 70 and 90 per cent of vehicles encroaching on the median would not reach the other carriageway." This supports the conclusion reached in several empirical studies in the US (Federal Highway Administration, 1982, p 1-7 ff).

The frequency of median openings has also been found to affect accidents, with accident rates increasing as the number of median openings increases (Cirillo, 1993).

The separation of opposing streams by a median leads to significant crash reductions. In urban areas, medians should ideally be wide enough to protect turning or crossing vehicles, while a minimum width of about 9 m is appropriate for rural areas.

7.3.2 Lane and Shoulder Width

Lane Width.

In general, the wider the lane (up to about 3.7 m), the lower the accident record (Zegeer and Council, 1993, p 22). Lane widths of less than 3 m have been shown to contribute to multi-vehicle crashes (Nairn, 1987; Lay, 1986, p 563; Zegeer, Deen and Mayes, 1981, p 41).

A number of studies have shown the safety advantages of widening narrow lanes on roads. For example, National Association of Australian State Road Authorities (1988a) quotes an Australian study where the sealed width on rural highways were widened from 4.9 to 5.5 m, and from 6.7 to 7.3 m, with a casualty crash reduction of 43 per cent. Transportation Research Board (1987a) quote an American study where 2.7 m lanes on rural roads were widened to 3.3 m and 3 m lanes were widened to 3.6 m, with a serious injury crash rate reduction of 22 per cent.

Results for the effect of shoulder width on crashes are less conclusive. However, there is some evidence that crash rates reduce as shoulder width increases up to about 3 m. For example, an American study (Zegeer, Deen and Mayes, 1981, p 40) produced results which showed a 21 per cent reduction in crashes when a road with no shoulders had shoulders of 0.9-2.7 m in width provided. The study went on to suggest (op cit, p 41) that for roads currently without shoulders, the optimum shoulder width to be provided was 1.5 m.

The more important feature of shoulders appears to be whether they are sealed or unsealed (see Section 7.8 below). However, lane and shoulder width are not independent and the above results should not be regarded as conclusive. In 1982, the US Congress requested the National Research Council's Transportation Research Board (TRB) to study the safety cost-effectiveness of design standards and recommend minimum geometric standards. The results of this study were published by the Transport Research Board (1987a), and supported by critical reviews of current knowledge (Transport Research Board (1987b).

One of the key areas examined was that of lane and shoulder width. Zegeer and Deacon (1987), as part of this study, produced relationships showing the expected crash rate (for run off road and opposite direction crashes) as a function of lane and shoulder width. These showed clearly that increasing lane width (up to 3.6 m) and increasing shoulder width (up to 3.0 m) had a beneficial effect, but that the two effects were not independent.

Transportation Research Board (1987a, p 81) used these and other findings to also examine these relationships. It's conclusions were that widening lanes from 2.7 m to 3.6 m without shoulder improvement reduces crashes by 32 per cent. Widening shoulders is less effective than widening lanes; adding a 0.9 m unsealed shoulder where none existed reduces accidents by 19 per cent. If the 0.9 m shoulder addition were paved, the expected reduction would be about 22 per cent. The greatest gains come from a combination of improvements. For example, widening a highway with 2.7 m lanes and no shoulders to 3.6 m lanes and 1.8 m shoulders reduces crashes by about 60 per cent. However, the crash reduction as a result of improving a specific feature will be less if other features are also improved.

Based upon these analyses and calculations of the cost-effectiveness of various combinations, Transportation Research Board (op cit, p 144) then prepared recommendations for lane and shoulder widths. Their recommendations (in metres) were as follows:

Traffic Flow (ADT)	Speed (km/h)	> 10 percent trucks		< 10 percent trucks	
		lane	lane + shoulder	lane	lane + shoulder
1 - 750	< 36	3.0	3.6	2.7	3.3
	> 36	3.0	3.6	3.0	3.6
751 - 2000	< 36	3.3	3.9	3.0	3.6
	> 36	3.6	4.5	3.3	4.2
> 2000	all	3.6	5.4	3.3	5.1

Source: Transportaion Research Board, 1987a, p 144

Table 7.5 Recommended Lane and Shoulder Widths

Lane and shoulder widths as set out in the Table 7.5 represent the state of current knowledge. Lane widths in excess of 3.6 m are undesirable except where truck volumes are very high, while those less than 3.0 m are less safe. Shoulder width needs to be considered in the light of lane width, as in the table. The condition of the shoulder (sealed or unsealed), and if unsealed, its condition, are also important considerations; see Section 7.8 below.

7.3.3 Sight Distance

Neuman and Glennon (1983) in a study of stopping sight distance found that different geometric conditions were associated with hazards. These were divided into three groups as follows:

minor hazards: tangent horizontal alignment, mild horizontal curvature (>600 m radius), mild downgrade (< 3 per cent);

significant hazards: low-volume intersections, intermediate horizontal curvature (300-600 m radius), moderate downgrade (3-5 per cent), structures;

major hazards: high volume intersections, Y-intersections, sharp curvature (< 300 m radius), steep downgrade (> 5 per cent), narrow bridge, narrowed pavement, freeway lane drop, exit or entrance downstream along freeway.

Transportation Research Board (1987a, p 93) reported a study which found accident frequencies to be 52 per cent higher at sites with sight distance restrictions due to vertical curvature than at control sites. Glennon (1987c, p 75) however concluded that it was cost-effective to improve stopping sight distance only when very short sight distances were improved to provide very long sight distances, and even then only when traffic volumes were sufficiently high to justify the expense. Based upon this and other sources, TRB (*op cit*, p 94, 171) attempted to develop a model to assist in determining when it is cost-effective to lengthen a vertical curve to increase sight distance over a crest. They concluded that reconstructing such crests was likely to be cost effective when a major hazard (such as those listed above) existed, when the design speed is more than 33 km/h below operating speeds in the area, and traffic flows exceed 1500 veh/d.

Although not explicitly mentioned, one of the most common and serious hazards in this regard would be likely to be a sub-standard (<600 m radius) horizontal curve just beyond the limit of visibility on a crest vertical curve. This was evident in the recent New South Wales heavy vehicle crash study (Sweatman, et al, 1990), and is recognised as a particularly dangerous situation (see for example Glennon and Harwood, 1978).

Glennon (1987c, p 75) also warned against improving extremely sub-standard crest vertical curves to a standard which is still less than the minimum; this may actually lead to a deterioration in safety, as the length of road with poor sight distance will necessarily increase. However, improving sight distance on horizontal curves was found to be much more cost effective by Glennon (1987c). He suggested that "low-cost treatments such as clearing vegetation or other minor obstructions on the inside of horizontal curves may be cost-effective on almost all highways."

Sight distance is particularly important for trucks since their poorer braking performance must be in part, compensated by greater sight distance (Jarvis, 1994). Federal Highway Administration (1986, p 14-9) concluded that increased eye height compensates for inferior braking for the average of all truck sizes, but does not hold true for larger and heavier trucks having longer braking distances. The study also concluded that sight distance requirements in sag vertical curves, determined by headlight sight distance, is satisfactory for trucks. However, Fancher (1986) suggested that sight distances around horizontal curves were also a problem, as the extra driver's eye height is of no advantage.

Poor sight distance is associated with crashes. The degree of hazard varies with the road feature, but some, such as a sub-standard horizontal curve just beyond a crest vertical curve are more hazardous than others. There is some evidence that existing road design guides do not pay adequate regard to the needs of heavy vehicles in this area, particularly on crest vertical curves. Reconstruction of vertical curves to increase sight distance is likely to be cost effective in some cases.

7.3.4 Horizontal and Vertical Alignment

Horizontal Alignment.

All else being equal, crashes are more likely to occur on highway curves than on tangents (straight sections of road). Glennon (1987b, p 50) quotes results which suggest that the average crash rate for curved road segments is three times that of tangents, and the average single vehicle, run off road crash rate is four times higher. Moreover, curved road segments have higher proportions of severe, wet road, and icy road crashes.

Various studies have examined the relationship between curve radius and crashes. For example, McBean (1982) found that curve radii of less than about 450 m were more likely to be found at crash sites; an early US study by Raff (1953) suggested that about 600 m radius was the critical value; Neuman, Glennon and Saag (1983) based upon US data found that curvature was the main factor affecting crashes at curves, but that shoulder width, width of the travelled way, and length of the curve (in that order were also important); Johnston (1982) using Australian data found that curves with a radius of less than 600 m were associated with a higher crash rate, while Pak-Poy and Kneebone (1986, Table 4.1 and 4.2) adopted the value of 600 m as being "good" in the case of existing roads in both urban and rural areas; in rural areas a value of between 400 m and 600 m was described as "medium", while less than 400 m was "poor"; Organisation for Economic Cooperation and Development (1976, p 26) suggested that the critical value was about 430 m.

Transportation Research Board (1987a, p 91) suggested that most of these earlier studies were deficient in some way, and set out to perform a more definitive analysis. They suggested that the relationship between crashes and measures of road geometry was not strong, and was more related to the consistency of the road feature with the overall context of the road segment (see below).

Based upon this, they went on to develop guidelines for the cost-effectiveness of "curve-flattening" (i.e. reconstructing existing curves to have a larger radius) (op cit, p 148 ff); the results suggested that this was likely to be worthwhile if traffic flow exceeded 750 veh/d and the design speed of the existing curve was more than about 25 km/h below the 85 percentile of the speeds of vehicles approaching the curve. It also noted significant benefits to travellers in terms of travel time and vehicle operating costs, and that "taking these savings into account strengthens the case for curve flattening". However, it also concluded that broad nationwide guidelines were inappropriate because of the high degree of site to site variations in the cost effectiveness of curve upgrading.

This approach is similar to that of Hoban (1988) in an Australian study who concluded that "curves present a hazard to drivers when their design speed is more than 10-15 km/h below the 85 percentile traffic speed on the approach."

As with other aspects of alignment, of perhaps greater importance from a safety viewpoint than curve radius alone is the consideration of this factor in a consistent fashion with other design parameters along a stretch of road; this is considered below.

Vertical Alignment.

Vertical alignment includes both grades and vertical curves. The latter is principally a problem of crest sight distance Federal Highway Administration, 1982, p 1-15) and has been discussed above.

Steeper grades are generally associated with higher crash rates. For example, Roy Jorgensen Associates (1978, p 7) suggested that both crash rate and severity increases with gradient, both upgrade and downgrade. Organisation for Economic Cooperation and Development (1976, p 26) and Hillier and Wardrop (1966) reached a similar conclusion, but suggested that downgrades were a greater problem. Hoban (1988) concluded that steep grades above about 6 per cent are associated with a higher crash rate.

On the other hand, Pak Poy and Kneebone, 1988, p 101) suggested that the evidence that gradients alone are a contributing cause to increased crash rates on rural roads is weak; they suggested that grades and curves need to be considered together

Combinations of Horizontal and Vertical Alignment. As noted above, of perhaps greater significance than either horizontal or vertical alignment per se is the way in which they are provided and/or combined along a length of road. Transportation Research Board (1987a, p 104) summarised this as follows:

"unfortunately, (individual) safety relationships ... fail to capture situational influences present in the roadway environment that contribute greatly to road way hazards. Illustrative of these particular hazards are high-volume intersections in isolated rural settings, sharp horizontal curves following long segments of generally straight alignment, and compound curves - contiguous horizontal curves turning the same way - in which a flat curve precedes a sharper one. Common to such situations is the violation of driver expectancy ..."

For example, Kihlberg and Tharp (1968) in a US study found that simultaneous presence of two or more factors (gradients, curves, intersections, structures) typically produced 2 or 3 times as many crashes as highway segments free of such factors, and that "the presence of combinations of the geometric elements generated higher accident rates than the presence of the individual elements. Combinations gave accident rates as high as six times the rates on pure segments."

Transportation Research Board (1987a, p 105) suggested the following guidelines for dealing with situations of varying geometric standards or unexpected features:

- . provision of gradual geometric transitions appropriate to the anticipated vehicle operating speed,
- . improvement of sight distance for early detection of the presence of the critical feature,
- . provision of gentle side slopes with few roadside obstacles at critical locations, and
- . installation of traffic control devices appropriate for the situation.

Lay (1986, p 563) has suggested that "horizontal curves under 450 m and gradients of over 4 per cent should be avoided, particularly in combination".

On new rural roads, horizontal curves rural roads should not be less than 600 m radius; below about 450 m a significantly higher crash rate can be expected. Grades should not exceed 6 per cent, with a lower value (4 per cent) when there is a high proportion of trucks using the road.

In treating existing roads, particular attention should be paid to isolated or unexpected sub-standard features, including not only sharp curves and steep grades, but also other road features such as intersections. The worst situation occurs when two or more such features occur simultaneously or in close proximity to each other; this can produce a situation several times worse than one where there is only a straight, flat, road segment.

7.3.5 Safety Barriers

Safety barriers include guard fences (traffic barriers on the edge of a carriageway; if used in a median they may be referred to as median barriers) and impact attenuators (devices installed at fixed installations, such as bridge piers; they are also referred to as crash cushions).

The benefits of safety barriers are entirely dependent upon their ability to reduce crash *severity*, since of necessity they are closer to the road and longer than the hazard they guard, and therefore may have a higher crash rate than the hazard in question. In some cases, guard fences may help to prevent crashes since they assist in delineation of the roadway.

For this reason, road authorities have prepared warrants for the installation of safety barriers. Installations where they may be warranted include (Lay, 1986, p 567):

- . on embankments, where slope and height exceed certain values (e.g. they are rarely needed for slopes less than 1 in 5, or heights less than 1 m,
- . near roadside hazards; any hazard within about 10 m of the roadside should be checked,
- . on narrow medians, to prevent head-on crashes, where the flow exceeds about 5,000 veh/d,
- . where the road formation narrows, e.g. at some bridges and culverts,
- . on the outside of sub-standard curves, where the difference between 85 percentile speeds and advisory speed is greater than say 15 km/h,
- . to protect structures and pedestrians.

Guard Fencing.

Guard fences are of three types: flexible (e.g. cable barriers), rigid (e.g. concrete barriers), and semi-rigid (e.g. W-beam guard fences). Flexible barriers are rarely used in Australia, although it might be noted that recent experience in the UK with new designs has been favourable for light vehicles (Himus, 1990).

There has been a good deal of experimental and theoretical work on the design of guard fencing over the years (e.g. Michie and Bronstad, 1972; Troutbeck, 1983; Bronstad, Michie and Mayer, 1987; Institute for Road Safety Research, 1986; Cunningham, 1985). Much of this research is reflected in the guidelines for the installation of guard fencing (e.g. National Association of Australian State Road Authorities, 1987a). This will not be reviewed here; suffice it to say that if properly installed at appropriate locations in accordance with warrants, guard fencing can be effective in reducing the severity of crashes (Ross, Sicking, Zimmer and Michie, 1993). Conversely, if not properly installed, guard fencing can be ineffective or even counter-productive; a sound training program for those responsible for deciding about guard fence programs and those responsible for actual installation is an important element of a guard fence program (Crowley and Denman, 1992).

It should also be noted that conventional guard fencing is of little benefit to large vehicles because they are heavier and have a higher centre of gravity. Guard fencing capable of restraining such vehicles is expensive and is only justified in exceptional circumstances (Bronstad & Michie, 1981).

Impact Attenuators.

There are a variety of impact attenuator, all of which are based upon the principle of absorbing some of the kinetic energy of an errant vehicle before it impacts the object. These are described by National Association of Australian State Road Authorities (1987a), Pigman, Agent & Creasey (1985) and Institute for Road Safety Research (1986). This research indicates that such devices are efficacious at the ends of guard fences in medians and freeway gore areas, bridge piers in narrow medians, the end of concrete barrier walls, toll plazas, etc. However, impact attenuators are of little value for heavy vehicles greater than about 4.5 t (Michie, 1986; Federal Highway Administration, 1986).

Provided that they are properly installed and placed at locations which satisfy road authority warrants, safety barriers (guard fences and impact attenuators) can be effective in reducing the severity of crashes. However, existing installations are not suited to heavy vehicles.

7.3.6 Bridge, Structure and Culvert Design

Hazards associated with bridges can be significant. Narrow bridges increase the probability of a vehicle colliding with the bridge and reduce the opportunity for safe recovery. Bridge approaches are often on a downgrade, and the approaches may be curved. Bridges are over-represented in crashes relative to their length of the road system, and bridge crashes are more severe than crashes as a whole. However, the probability of a crash at any one site is quite low, so bridge programs need to be based upon the mass application of low cost countermeasures at a large number of sites. (Ogden and Howie, 1990; Transportation Research Board, 1987a, p 86, 158). For new bridges, Mak (1987) has recommended that the bridge should be 1.8 m wider than the travelled way (i.e. 0.9 m shoulders should be carried across the bridge.) On freeways and other roads with high traffic flows, full width shoulders may be carried across the bridge.

Culverts can be a problem also, since the culvert end wall or pipe end is often located quite close to the pavement; in many cases, the road pavement has been widened into the shoulder, leaving the culvert very close to the pavement, and producing a constriction in the width of the formation at the point of the culvert.

Ogden and Howie (1990) have produced guidelines for the treatment of bridge sites. Their recommended order of priority (based upon a Texas model, (Ivey, et al, 1979)) was dependent upon bridge width, length and traffic flow. Treatments included delineation and safety barriers.

Bridges and culverts are over-represented in crashes relative to their length of the road system. They are also associated with the more severe crashes. However, except in a few cases, the probability of a crash at any given site is small, so countermeasures should involve mass application of low cost countermeasures at a large number of sites, using delineation and/or guard fencing.

7.3.7 Overtaking

Armour (1984a) found that overtaking is involved in about 10 per cent of rural casualty crashes in Australia. On a two-lane road, overtaking slower vehicles involves entering the opposing lane. Therefore an overtaking opportunity requires a sufficiently large gap in the on-coming traffic for the overtaking manoeuvre, plus the distance travelled by that vehicle, plus a safety margin (Hoban, 1987). The road alignment (vertical and horizontal) must allow sight distances of this magnitude if overtaking is to occur. On high volume roads, opposing traffic will limit overtaking opportunities, while on hilly terrain, sight distance may not be sufficient to allow overtaking.

In these circumstances, overtaking lanes can be very effective in improving traffic operations by breaking up bunches and reducing delays caused by inadequate overtaking opportunities over substantial lengths of road; in moderate traffic, judiciously placed overtaking lanes comprising around 10 per cent of the length of a road can provide much of the benefit of full duplication (Hoban, 1987, 1989).

Several studies have assessed the safety effects of overtaking lanes. Hoban (1982) reported a 25 per cent reduction in crashes when overtaking lanes were provided. Harwood, St John and Warren (1985) in the US performed a matched comparison of 13 pairs of sites, and found that those with overtaking lanes had a 38 per cent better record for all crashes and 29 per cent for fatal and injury crashes. Pak-Poy and Kneebone (1988, p 73) report an earlier study in California which found that the provision of overtaking lanes reduced crashes from 25 - 27 per cent. Other studies have reported no statistically significant effect of overtaking lanes, suggesting that their effectiveness is greater in some situations than others, as would be expected (Harwood, St John and Warren, 1985).

Harwood and Hoban (1987) combined the results of several studies to demonstrate a statistically significant reduction of 25 per cent for roads in flat to rolling terrain. They also discussed the effect of short 4-lane sections of highway, which provide overtaking opportunities in both directions; such a feature may be part of a stage construction of an eventual full duplication of a substantial length of the highway. They found a 35 per cent reduction in all crashes and a 40 per cent reduction in fatal and injury crashes.

Overtaking is associated with crashes on rural roads, and overtaking lanes provide significant operational and safety benefits. Their specific effect depends upon the location, and the effectiveness of overtaking lanes is greater if they are installed as part of a strategy for the road segment as a whole, in terms of the intervals between overtaking lanes and the number provided in relation to the traffic flow and terrain.

7.4 TRAFFIC MANAGEMENT AND DESIGN

7.4.1 Intersections

A comprehensive review of factors affecting safety at intersections has been presented by Transportation Research Board (1987a, p 286 ff). This includes:

- . number of legs
- . angle of intersection
- . sight distance
- . alignment
- . auxiliary lanes
- . channelisation
- . friction
- . turning radii
- . lighting
- . lane and shoulder widths
- . driveways
- . right of way (rules, signs, signals)
- . approach speed

This is not the place to review these in detail. However, guidelines for the design of intersections generally take note of these sorts of factors (e.g. Lay, 1986, ch 20; National Association of Australian State Road Authorities, 1988b; Austroads, 1993a,b).

Traffic Signals

Traffic signals have the potential to reduce crashes, depending upon the traffic volumes and crash patterns. Roy Jorgensen Associates (1979, p 8) after reviewing research on this subject found that:

- . installation and modernisation of warranted signals, with proper channelisation, generally results in a reduction in crashes,
- . the installation of unwarranted signals can result in an increase in crashes,
- . fully controlled turns have safety advantages compared with letting turning traffic find gaps in the opposing traffic,
- . fully traffic-actuated signals have advantages over fixed time installations.

These findings are generally supported by Australian research. For example, Andreassend (1970) in a study of 41 intersections in Melbourne found a 32 per cent reduction in right angle crashes; Camkin (1984), based upon an analysis of signal installations in New South Wales reported that installing traffic signals led to a 17-100 per cent reduction in crashes. A Victorian study (Nguyen, Hodge and Hall, 1987) found an overall reduction of 58 per cent following installation of traffic signals at 82 cross intersection sites in Melbourne. A recent study by the Bureau of Transport and Communication Economics (1993) found a benefit:cost ratio of between 2.4 and 6.0 (depending upon the calculation method) for new traffic signal installations in Victoria and New South Wales.

Linked Signals.

Analyses of the effect of signal coordination have produced varying results. For example, Hodge, Daley and Nguyen (1986) in a study using Melbourne data found a non-statistically significant 6 per cent reduction, while Moore and Lowrie (1976) in Sydney found a significant 20 per cent reduction. Ogden and Newstead (1994) found that the effect of linking signals in Melbourne was beneficial for pedestrian crashes and adjacent direction crashes. Travers Morgan (1987) in Sydney found that signal coordination was cost-effective in reducing crashes.

Controlled Turns.

Lay (1988) has also commented that traffic signals do not always reduce crashes. He noted that while right angle (cross traffic) crashes are generally reduced, right turn crashes may increase (Cairney, 1988). The aforementioned study of the effects of traffic signal installation in Melbourne found that while all accidents fell by 58 per cent, pedestrian accidents increased by 39 per cent and right-against accidents by 52 per cent, by contrast cross accidents fell by 84 per cent, rear end accidents by 31 per cent, and "other" accidents by 66 per cent. This is one of the reasons for the tendency in recent years to install signals with full control of through and right turn movements (Corben and Foong, 1990). A NSW study found that providing a right turn phase led to a 20-70 per cent reduction, modernising signals led to a 11-80 per cent reduction, and modernisation in association with improved skid resistance led to a 14-72 per cent reduction (Camkin, 1984). A study of signal modification in South Australia (Teale, 1984) showed a 35 per cent reduction in casualty crashes. The Bureau of Transport and Communication Economics analysed black spot treatments in Victoria and New South Wales and calculated a benefit:cost ration of 6.2 to 12.6 for modifying the operation of existing signals, primarily through the introduction of exclusive right turn phases.

Rural Intersections.

In rural areas, Transportation Research Board (1987a, p 95) commented that on two-lane highways in the US, intersections are ranked with bridges and horizontal curves as the most likely sites for crashes. Various measures can be taken to improve safety at rural intersections, of which converting a cross intersection to a staggered-tee is often very effective; Nairn (1987, p 41) reports a South Australian study which showed a 47 per cent reduction in crashes from this type of treatment, while in Victoria a similar program showed an 80 per cent reduction (Hoque and Sanderson, 1988, p 18).

STOP and GIVE WAY Signs.

These can be effective in certain instances, particularly at low volume sites with low approach speeds (e.g. suburban intersections) (National Association of Australian State Road Authorities, 1988a, p 30; Cairney, 1986). However, at high speed rural sites, their effectiveness is limited unless the intersection can be redesigned to form a staggered tee or a roundabout (O'Brien, 1976).

Roundabouts.

These can also be effective in controlling traffic and reducing crashes under certain circumstances, especially in urban areas (Austroads, 1993). For example, a South Australian study (Teale, 1984) found a 78 per cent reduction in casualty crashes when roundabouts were installed at low volume sites. The Bureau of Transport and Communication Economics (1993) determined a benefit:cost ratio of between 3.1 and 6.0 for roundabout construction at black spots in Victoria and New South Wales. In some cases, the replacement of signal installations with roundabouts can reduce crashes (Corben, Ambrose and Foong, 1990).

Intersection Sight Distance.

Sight distance at intersections is important, and is in fact the key determinant of whether a STOP or GIVE WAY sign is erected at an uncontrolled intersection (Garrett, 1989). Several studies (Kuciemba and Cirillo, 1992) have shown that intersections with poor sight distance on one or more approaches tend to have a higher than normal accident rate, particularly with regard to angle accidents. Glennon (1993) has gone so far as to assert that "vigilance to prevent manmade (sic) objects from being placed and vegetation from growing in the necessary sight triangle will probably do more for highway safety at the lowest cost than most other measures."

Channelisation.

Channelisation (the provision of painted or raised islands at intersections to guide road users and provide protection for turning vehicles and crossing pedestrians, is an inherent component of all but the most simple intersections. One US study (quoted in Kuciemba & Cirillo, 1992) suggested that the minimum number of "passing" (presumably head-on) accidents per year necessary to justify particular treatments was 1.47 accidents per year for the provision of a separate lane for right turners, and 1.75 accidents per year for the provision of a by-pass lane at tee-intersection. A study of the addition or installation of intersection channelisation in South Australia and Western Australia (Teale, 1984) showed reductions of 26 per cent in casualty accidents for new channelisation at signalised intersections and 54 per cent at non-signalised intersections.

Intersections are important to overall road safety. A wide range of techniques, based upon intersection layout and design, traffic control, and sight distance, are available to make intersections safer. Table 7.6 (Barton, 1989) summarises the mean accident rate for different intersection configurations, based on Victorian experience.

INTERSECTION TYPE	NUMBER OF SITES	MEAN CASUALTY ACCIDENT RATE*
CROSS INTERSECTIONS		
Urban: <i>Signalised</i>	138	1.7
<i>Unsignalised</i>	31	2.4
High speed, signalised (> 75 km/h)	35	2.5
Rural: <i>Unsignalised</i>	128	5.2
T INTERSECTIONS		
Urban: <i>Signalised</i>	32	1.4
<i>Signalised (> 75 km/h)</i>	15	2.1
<i>Unsignalised</i>	58	1.5
Rural: <i>Unsignalised</i>	210	3.3
MULTI LEG INTERSECTIONS		
Urban: <i>Signalised</i>	13	3.2
5 LANE TREATMENT: Urban	27	1.6
ROUNDAABOUTS: Urban	68	0.9
STAGGERED-T: Rural	28	2.9
SPLITTER ISLAND INTERSECTIONS: Rural	25	10.2
PRIMARY ARTERIALS: DIVIDED AND UNDIVIDED		
Primary/Primary	49	2.4
Primary/Secondary	63	1.8
Primary/Collector	77	1.4
Primary/Local	586	0.8
Primary/All Classes	775	1.4
DIVIDED PRIMARY ARTERIALS/ALL CLASSES	409	1.41
UNDIVIDED PRIMARY ARTERIALS/ALL CLASSES	366	1.39

* Rate in Casualty Accidents per 10⁷ entering vehicles

Source: Various Road Construction Authority of Victoria studies (Unpublished), quoted by Barton (1989)

Table 7.6 Typical Intersection Accident Rates

7.4.2 Truck Routes

Control of trucks through some form of truck routing is sometimes suggested as a means of implementing an urban traffic management scheme (Ogden, 1989b). However, its application in this area is essentially to pursue amenity objectives, not safety objectives.

The only reference to truck routing from a safety viewpoint is in relation to hazardous materials routing. This is not a trivial problem however; a 1977 Virginia USA study quoted in Federal Highway Administration (1982, p 13-14) found that 13 per cent of trucks carried hazardous goods, and trucks carrying hazardous materials were involved in 6 per cent of truck crashes and 7.1 per cent of fatal truck crashes.

Federal Highway Administration (1982, p 14-13) reported a study which developed a risk assessment methodology for evaluating alternative routes. This comprised three levels of decision:

- determining a particular route's applicability based upon existing laws and physical limitations,
- calculating numeric risk values by determining the probability of a hazardous materials accident and estimating the potential consequences of hazardous materials release, and
- if the numeric risk differences are too small for making the route selection decision, then consider other criteria such as time and travel cost, land uses, fire and rescue response capability, number of highway structures, and special population groups.

Truck routing may be a valid measure in some cases, particularly in pursuit of amenity objectives in residential areas, and for hazardous goods transport. However, each case must be assessed on its merits, particularly bearing in mind that there must be exceptions to a general truck routing ordinance to permit access by trucks with legitimate access needs.

7.4.3 Local Area Traffic Management

Local area traffic management schemes are usually predicated on increasing the amenity of the area to residents, part of which involves a perception of safety perceived by residents in the area treated. There is evidence that LATM schemes increase this perception (what may be perhaps better termed "security" rather than "safety" (Wallwork, 1993)) since they can reduce vehicle speeds and sometimes traffic volumes (Western Sydney Regional Organisation of Councils, 1990) but whether they increase objective safety (as measured by accidents) is open to question. The main reason for this is that accidents are in fact very rare at any given site within a local area and to demonstrate statistically significant accident reductions is difficult (Fairlie and Taylor, 1990).

However, since some 25 per cent of urban casualty accidents occur on the local street network (Fairlie and Taylor, op cit), clearly attention to making local streets safer is an ongoing responsibility. But this needs to be undertaken with a clear knowledge of potential benefits. Fairlie and Taylor (op cit) undertook a major review of previous studies (e.g Andreassen and Hoque, 1986; Amamoo, 1986; Brindle, 1986; Organisation for Economic Cooperation and Development, 1979; Searles, 1985; National Association of Australian State Road Authorities, 1988c) of the safety effects of LATM in Australia and overseas, and performed an in-depth analysis of accident patterns within case study areas in Sydney. They concluded:

"Many of the traffic management devices used extensively in LATM fail to resolve the dominant types of accidents occurring on local streets... These were cross traffic, right-through, rear end and hit parked vehicle accidents... Current LATM schemes may not be as effective in reducing accidents as many practitioners believe."

A major focus of LATM, from the viewpoint of both safety and security, is vehicle speed. Lower speed limits in local streets, if enforceable, would enhance safety and security. The Dutch experience with 30 km/h zones appears to have a positive effect on road safety (Janssen, 1991; Vis, Dijkstra and Slop, 1992). However, currently in Australia, it appears that physical speed control devices (humps and slow points) are needed to achieve the required speed reductions. Importantly, Fairlie and Taylor (op cit) conclude that "these devices do not appear to offer direct accident reduction potential, rather their influence is indirect, through general speed reduction". For this reason, local areas need to be treated as a whole in an integrated manner, rather than on a set of site-specific treatments (Gunnarsson, 1993). This approach is also vital if the objective is to reduce traffic volumes as well as speeds, otherwise the effect of a treatment may be to merely relocate traffic to an adjacent local street, not onto a traffic route. This may also explain the apparently more conclusive European experience with LATM; there has been an unfortunate tendency which has developed in Australia to emphasise isolated devices rather than comprehensive changes to the street which aim to change the driving environment and thus, eventually, driver behaviour.

Ogden and Bennett (1989, p 477) have outlined the following "folk-lore", based upon expert opinion at the time, in relation to speed and traffic behaviour on local street networks:

- . wide, long distributors with house frontages have a poor safety record and should be avoided if possible;
- . use can be made of network discontinuities and circuitous travel paths to discourage the entry of non-local traffic into a local area;
- . the reduction of excessive speed in a local street does correspond with a reduction in accidents;
- . the influence of various factors on traffic speeds in local areas are as follows:
 - speeds are low in streets shorter than 200 m,
 - of secondary importance is micro-alignment,
 - the influence of streetscaping is positive but of unknown extent, and of doubtful influence are flowing alignments and subtle sight distance restrictions.
- . LATM action is usually required when 85 percentile speeds exceed 60 km/h
- . spacing of speed control devices at 200 m or less will keep traffic speeds below 60 km/h; a spacing of 90 m or less will reduce speeds to under 30 km/h
- . slow points should not be used in any street in which it is expected that traffic volumes will exceed 600 veh/h.

Devices other than the ubiquitous road hump are also effective. Roundabouts are effective for speed control, have a more direct influence on accidents, and are accepted by residents (Fairlie and Taylor, op cit). They are also effective in resolving cross traffic, right-near and right-through accidents that typically occur on local streets.

Local area traffic management can contribute to increased security amongst residents of the area, and may contribute towards enhanced safety. Safety benefits stem primarily from speed reductions, and these are achieved by development of an overall scheme rather than by specific devices at discrete locations. For this reason, it is vital that LATM schemes be developed and implemented on an integrated area-wide basis.

7.4.4 Pedestrian and Bicycle Facilities

Safety is one of the key considerations in relation to traffic design for pedestrians and cyclists (Jordan and Veith, 1989). Pedestrians most at risk in traffic accidents are children, the elderly, and alcohol-impaired.

A range of traffic management devices are available to provide for pedestrian traffic and to assist pedestrians to safely cross a road and control pedestrian-vehicle interaction (Zegeer, 1993; Austroads, 1994a, Barton p 8,9):

Footpaths

- footpaths in the road reserve
- separate footpath network
- shared footpath/cycle network

General crossing treatments:

- pedestrian refuge islands
- traffic islands
- medians
- footpath kerb extensions
- loading islands
- safety zones
- pedestrian fencing
- speed control devices

Time separated facilities

- pedestrian (Zebra) crossings
- children's crossings
- pedestrian operated signals (mid-block)
- Pelican crossings
- signalised intersections with pedestrian phases

Grade separated facilities

- subways
- bridges
- pedestrian malls

Integrated facilities

- pedestrian warning signs
- shared zones
- school zones
- lighting schemes

Specific examples of the safety effectiveness of pedestrian facilities include the following: Teale (1984) reported the results of erecting fences to prevent pedestrians crossing an arterial road except at designated crossings in South Australia; a small 8 per cent reduction in casualty accidents resulted. Teale (op cit) also reported the effect of installing pedestrian refuges in Western Australia; these showed a 53 per cent reduction in casualty crashes. Ehrlich (1986) reported the results of several projects trialed in America; one particular finding was that long traffic signal cycle times encouraged disobedience by pedestrians, and when cycle times were reduced from 100 s to 50 s, pedestrian violations of the signal dropped from over 50 per cent to near zero.

An extensive discussion of pedestrian facilities, including those aimed specifically at safety, is presented in Austroads (1994a), while Austroads (1993c) discusses similar issues in relation to cyclists.

Design for the safety of pedestrians and cyclists must consider the specific needs of these groups of users. A range of safety-related treatments are available, and if properly installed and sensibly located, can contribute to safety.

7.5 TRAFFIC ENGINEERING

7.5.1 Delineation

Delineation is of critical importance to the safe and efficient operation of the road system. Most of the information which the driver uses to control a vehicle is visual. Delineation is vital in enabling the driver to locate the vehicle on the roadway and to make navigation and control decisions. Adequate delineation (Good and Baxter, 1985) enables the driver to:

- . keep the vehicle within the traffic lane (short range delineation), and
- . plan the immediate forward route driving task (long range delineation).

Schwab and Capelle (1980) have noted that "delineation of the outside edge of the travel lane is highly desirable, especially for roads wider than 6 m.... there is substantial evidence that delineation provides important guidance information to motorists, especially when visibility decreases due to adverse weather or night time conditions".

Delineation has always been important, and is likely to become even more critical in the years ahead as the driving population ages; older drivers have a reduced visual capability and hence rely to a greater extent on correct delineation of the road ahead (Transportation Research Board, 1988).

Sanderson and Fildes (1984) and Hoque and Sanderson (1988) give a comprehensive review of a range of delineation devices. These include:

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

Guide Posts and Post Mounted Delineators.

Triggs, Harris and Fildes (1979) demonstrated that the combination of centre lines and guideposts with reflectors enhanced static direction judgements at night. Increasing the number of posts on the outside of a bend improved these judgements.

Good and Baxter (1985) found that PMD's were the best form of long range delineation, and that a combination of PMD's and wide (150 mm) edge lines best catered for drivers' needs for both long and short range delineation.

Long range delineation enables the driver to plan the forward route, and thus needs to be consistent and continuous; it is not restricted to locations where forward visibility is particularly confusing or critical (e.g horizontal curves over a crest vertical curve), but has application to a road as a whole. Lay (1986, p 386) has noted that "the curve characteristics of direction and curvature may need to be assessed up to 9 seconds ahead (and) even detailed tracking data for actual curve negotiation may be required 3 seconds ahead of the curve". Charlesworth (1987) has also stated that a driver must be supplied with visual information to enable a correct estimate of curvature some 3 seconds before entering a curve.

High intensity corner-cube delineators mounted on guide posts, which are much brighter than other forms of reflective material in common use, have been shown to reduce night-time crashes in Victoria (Vincent, 1978). This study showed a 60 per cent decrease in night-time crashes after their installation, compared with a 21 per cent decrease for those sections of the same highway where no change was made.

The installation of these devices is now widespread on rural arterial roads throughout Victoria. Significantly, as part of the program of installing these devices, deliberate attention was paid to pre-existing guidepost spacing and location to ensure that the installation conformed to contemporary standards (Cunningham, 1986).

Edge Lines and Centre Lines.

Centre lines have long been considered a standard form of road delineation and are virtually standard on all multi-lane roads; they assist the driver to locate the vehicle laterally on the roadway, and thus assist in avoiding collisions with both roadside objects and opposing vehicles.

Edge lines have been found to give marginal advantages in driving performance (Johnston, 1983). Their main advantage is in short-term lane positioning (Triggs, 1980). Schwab and Capelle (1980) have noted that edge lines are as effective, if not more so, on straight alignments as on curves.

Various studies have shown the safety benefits of edge lines. Nairn (1987, p 47) suggests that crashes may be reduced by 15 per cent (straight roads) to 45 per cent (curves). Jackson (1981) reported reductions in total crashes of between 13 and 30 per cent, and reductions in night-time crashes of between 37 and 42 per cent following the installation of edge lines at sites in Britain. Moses (1986) reported that following the installation of wide edge lines on rural highways in Western Australia, crashes fell by 8 per cent, but out of control single vehicle crashes fell by 34 per cent.

Edge lines are usually either 100 mm or 150 mm wide. Research has shown that 150 mm edge lines are more effective delineation devices, especially on curves (Nedas, Belcar and Macy, 1982). Recently, even wider edge lines (200 mm) have been used in some parts of the United States; Lum and Hughes (1990) found that these could be cost-effective where pavement width exceeds 7.3 m, shoulders are unpaved, and traffic volumes exceed 2,000 veh/d.

As noted, edge lines affect the position of vehicles in a lane, and therefore the incidence of vehicles leaving the paved surface is reduced. For this reason, road authorities have adopted edge lines to reduce shoulder and pavement maintenance costs, as well as to increase road safety (Nairn, 1987, p 47). (McLean, 1993)

Raised Reflective Pavement Markers.

RRPMs provide better night time delineation than painted centre lines and edge lines, especially under adverse weather conditions. Hoque and Sanderson (1988) quote various studies which show crash reductions of 15 - 18 per cent following their installation. An unpublished Country Roads Board (now Vicroads) study suggested that night-time crash reductions could be 25 per cent, and for winding roads the crash reduction could be 40 per cent overall, and 50 per cent at night. Moses (1985) reported a reduction from 33 to 10 head-on crashes, and 29 to 4 sideswipes following the installation of RRPMs on sections of rural road in Western Australia.

In a review of the use of RRPMs at narrow bridges in the USA, Niessner (1984) determined that such devices were effective in reducing encroachment across the centre line, and appeared to have a beneficial effect on safety.

Chevrons.

Delineation is critical on horizontal curves, especially isolated curves with a radius less than 600 m. (Johnston, 1982).

As part of a major study of safety and driver behaviour at horizontal curves, Johnston (1982, 1983) determined that the most effective form of delineation was a combination of wide (150 mm) edge lines and post-mounted chevron signs. The combination was especially effective for alcohol-affected drivers; chevron signs alone were almost as effective as the combination for sober drivers.

Variable Message Signs.

Hoque and Sanderson (1988) mention experimental variable message signs which have been successful in trials in reducing crashes. These include speed-activated "too fast" signs which have reduced crashes at sharp curves in Canada, and electronic freeway management systems in Holland. King et al (1978) describes a range of dynamic aids which were tested at bridge sites; these included flashing beacons, actuated flashing strobes, actuated "narrow bridge" and "oncoming traffic" signs, etc.

Novel Delineation Devices.

A number of illusory devices have been trialed at various places with the intention of emphasising hazardous locations. These include (Hoque and Sanderson, 1988; Fildes and Lee, 1993, p 78) innovative signs, road markings, irregular post spacing, transverse lines on the pavement, lane width restrictions, curvature enhancement treatments, etc. While these have been found to have had some immediate impact on reducing speed and the incidence of crashes, their effects have dissipated with time.

Good delineation is an essential part of a modern road system, and has demonstrated safety benefits.

7.5.2 Street Lighting

In urban areas, street lighting of appropriate standard contributes to road safety. Various studies have claimed crash rate reductions of around 30 per cent over the urban road system (Turner, 1973; Searles, 1985; Stark, 1975). Urban freeways in particular appear to be safer if well-lit (Box, 1971), although Nairn (1987, p 35) suggested that the benefits of lighting may need to be compared with other possible improvements such as better delineation (raised reflective pavement markers, edge lining, etc).

However, Vincent (1983) was critical of the analysis techniques used in some of these studies, and suggested that it is unlikely that a case can be made for justifying lighting expenditure on the basis of crash cost savings alone.

In rural areas, lighting of isolated grade intersections can be a worthwhile safety benefit (National Association of Australian State Road Authorities, 1988a, p 31; Lipinski, et al, 1970).

It should also be noted that the safety benefits of improved lighting can be diminished if the light poles are poorly located; about 20 per cent of urban single vehicle crashes involve utility poles (Mackintosh, 1989). The lighting layout should aim to minimise the number of poles, and should ensure that poles are not located in vulnerable positions (Standards Association of Australia, 1986).

Nairn (1987, p 35) summarised the position with street lighting as "there is little doubt that street lighting is an important component of urban road design. It provides an improved road safety potential and added personal security for urban dwellers. The applications and standard of design must however be carefully considered." Federal Highway Administration (1982) suggested that "the more complex the decision required of the driver at any particular location, the more likely lighting will be of benefit. The presence of raised channelisation, roadside development, and/or high degrees of curvature are good indications of the need for fixed roadway lighting."

Street lighting contributes to road safety on urban arterial roads, urban freeways, and in some circumstances at isolated intersections in rural areas. However, care needs to be taken with its design, especially with the location and type of poles, as these can be a major hazard in themselves.

7.5.3 Warning and Direction Signs

Warning and directions signs are an integral part of the highway system, and it is difficult to isolate the safety effects of them. However, Pak-Poy and Kneebone (1988, p 40) has quoted a Canadian study which in turn drew on other references which claimed a reduction of 20-57 per cent in crashes when curve warning signs were provided; in one such study, a 71 per cent reduction in fatal crashes was recorded.

Another study quoted in the same source suggested crash reductions of around 20-30 per cent for other warning signs, such as side road signs. Jackson (1981) reported that improved signing at intersections gave a crash reduction of 34 per cent in a British county.

Kneebone (1964) reported that the installation of a number of curve warning signs in association with advisory speed signs on the Hume Highway in New South Wales reduced casualty crashes by 62 per cent and all crashes by 56 per cent. This was associated with a reduction in speeds at those sites. US studies of such signs have shown a reduction in crashes following programs of this sort ranging from 20 per cent to 37 per cent (19 per cent for fatals in this last case) (Pak-Poy and Kneebone, 1988, p 40).

Direction signs contribute to road safety by minimising unnecessary travel, allowing drivers to position their vehicles prior to making turns, reassuring drivers so that they are not hesitant and thereby potentially disrupting traffic flow, and drawing attention to the presence of major intersections (Nairn, 1987, p 36).

It is important to note the importance of correct location, the need to use standard signs, and the need to maintain and replace signs. Signs are an accepted part of the traffic system, but much of the information they provide is only of transient value. If the driver is to recognise the sign, accept its message, and act upon it, it is essential that the sign satisfy requirements of legibility, conspicuity, comprehensibility and credibility (Ogden, 1990). Also, National Association of Australian State Road Authorities (1988a, p 30) has warned against the overuse of such signs, since their effectiveness will be reduced in those cases where they are not justified.

Direction and warning signs are an integral part of a modern road system. They appear to convey significant safety benefits as well as user amenity. It is essential that they be installed and maintained in accord with relevant warrants and guides.

7.5.4 Rumble Strips

Rumble strips are grooves or raised ridges placed on the roadway to provide a sudden audible and tactile warning to the driver. They may be used on the shoulder, the edge line, or the centre line of a road, primarily to counter driver fatigue or inattention. They may be placed on the pavement itself on an approach to an intersection or pedestrian crossing to alert the driver to the approaching hazard.

Raised reflective pavement markers give a tactile sensation when a wheel runs over them, and this may contribute towards their safety effectiveness.

Shoulder rumble strips have been shown to be cost effective on applications on rural highways in the US. For example, an application on a freeway crossing California's Mojave Desert had a series of parallel grooves pressed into the shoulder; this resulted in a 49 per cent reduction in run-off-the-road crashes and a reduction of 19 per cent in total crashes over a 7-year period (Anon, 1988b). An earlier application of a similar shoulder treatment in Arizona has been reported in Federal Highway Administration (1982, p 1-5) This showed a 61 per cent reduction in run-off-the-road crashes, and an estimated crash reduction over the 16 km section of 13 crashes in 3 years. A similar experiment using painted shoulders did not lower the crash rate. Both the California and Arizona installations were highly cost effective.

Emerson and West (1986) reported on the use of rumble strips on the approach to 52 narrow bridges on two highways in Oklahoma. Over a four year period, the number of run-off-the-road crashes per million crossing vehicles at the test sites fell by 35 per cent on one highway and 47 per cent on the other; fatal and injury crashes fell by 52 per cent and 56 per cent.

Haworth, Heffernan and Horne (1989) have reported the use of a so-called "hum strip", comprising a series of raised bumps on the centre line and edge lines which produce a humming sound when drivers run over it. They also report on the use of a commercial product called Longflex which involves the application of a series of thermoplastic ridges to the road by a special applicator. The markings are highly reflective and because they are 3 mm thick, the lines are easily visible above road water on wet days. It is claimed that the edge lining should last 6 to 8 times as long as painted lines.

Rumble strips on approach to intersections or pedestrian crossings have been shown in Britain to reduce vehicle speeds (Sumner and Shippey, 1977; Organisation for Economic Cooperation and Development, 1976, p 54).

Rumble strips appear to have great potential in reducing run-off-the-road crashes and perhaps head on crashes also. Their prime application is on centre lines, edge lines or shoulders of rural roads, as a means of alerting a fatigued or inattentive driver that the vehicle has strayed from the lane. They may also have some application in urban areas on the approach to intersections or pedestrian crossings.

7.6 ROAD CONSTRUCTION AND MAINTENANCE

7.6.1 Pavement Surface Condition

Skid Resistance.

Wet weather accidents represent between 20 and 30 per cent of casualty crashes, and up to 70 per cent of these could be ameliorated by improving skid resistance. Numerous studies have established a relationship between pavement friction and crashes. These have been reviewed in Pak-Poy and Kneebone (1988 p 44 ff), Cleveland (1987), and Federal Highway Administration (1982, p 2.2 ff); and Kumar and Cunningham, 1993. Crash reductions of up to 40 per cent have been recorded following the laying of a skid resistant pavement. Pak-Poy and Kneebone (op cit, p 65) found that skid resistant treatment of a major rural road would be cost-effective at locations with an annual crash frequency greater than 1.6.

Lay (1988) has suggested that a coefficient of friction of above 0.55 is usually enough to significantly reduce braking and turning crashes, although a value as high as 0.75 might be needed when risks are high, and as low as 0.30 may be tolerated when risks are low, such as long straight stretches of road with no interruptions to traffic. It is interesting to note that in the UK, a massive program of monitoring skid resistance on the country's major road network (about 10,000 km) has recently been launched (Hoque and Sanderson, 1988).

The Organisation for Economic Cooperation and Development (1976, p 53 ff) has reviewed the principles of skid resistant pavements. They should feature a macro-texture (rough texture) corresponding to easily visible surface particles, and a micro-texture which is resistant to polishing. Coefficients of friction between a locked tyre and the pavement vary from around 0.6 when both micro and macro texture is rough, to 0.05 when both are smooth. Various means of achieving the higher friction pavements are described.

Lay (1988) has also pointed out the necessity for good road surface drainage, as a 6 mm film of water can cause aquaplaning and reduce the friction coefficient to near zero thus making both braking and turning impossible. Roy Jorgensen Associates (1978) has shown that most wet weather crashes occur on low skid resistant pavements.

Resurfacing.

While improved skid resistant pavements may occasionally be provided as a specific safety measure, most such work occurs as part of a resurfacing or rehabilitation works program. Transportation Research Board (1987a, p 96) has presented a good overview of the issues and conclusions on pavement surface condition in this context, as follows:

"The potential effect of resurfacing on safety is a result of two factors working in opposite directions. First, resurfacing reduces surface roughness and improves ride quality, generally leading to increased average speeds. Second, resurfacing often increases pavement skid resistance, which reduces stopping distance and improves vehicle controllability when the pavement surface is wet.

"... a review of available research on the safety effects of resurfacing was conducted. This review supports the following tentative findings:

- . Routine resurfacing of rural roads generally increases dry weather accident rates by an initial amount of about 10 per cent, probably because of increased speeds. Dry weather skid resistance and stopping are unaffected by resurfacing unless the original pavement was extremely rough, so the tyres did not make contact with the paved surface.
- . Routine resurfacing of rural roads generally reduces wet weather accident rates by an initial amount of about 15 per cent. Apparently, this follows from improvements in wet weather stopping distances and vehicle controllability that more than compensate for any effects of somewhat higher speeds following resurfacing.
- . For most rural roads, the net effect of resurfacing on accident rates is small and gradually diminishes over time. Initially, the total accident rate typically increases following resurfacing, likely by an amount less than 5 per cent. When averaged over the project life, the effect of resurfacing is much less.
- . Resurfacing improves the safety performance of roads that experience an abnormally high frequency of accidents in wet weather.

Resurfacing projects provide the opportunity to correct deficient pavement cross slopes at little or no extra cost. Correcting cross slopes allows better drainage of the pavement surface and improves vehicle control in wet weather. On individual resurfacing projects, careful attention to the removal of surface defects and necessary improvements to skid resistance, surface drainage, and superelevation may help offset the potentially adverse effects of increased speeds."

Road-tyre friction affects road safety, and improving the friction characteristics of road pavements with poor friction will lead to safety improvements. However, reconstruction projects which lead to reduced roughness as well as better friction may not show much effect on safety (and may increase crashes) due to the higher speeds which they allow.

7.6.2 Work Zones

Data from the US suggests that work zones are hazardous from a road safety viewpoint. Federal Highway Administration (1982, p 101 ff) has reported various studies which show a markedly greater incidence of crashes on road segments where roadworks are in progress. For example, a Californian study showed a 21 per cent increase; an Ohio study showed a 7 per cent increase, resurfacing projects in Georgia showed a 61 per cent increase, and a freeway widening project in Virginia showed a 119 per cent increase

However, results were variable. A multi-state study of 79 projects showed an average increase of 7.5 per cent, but 24 sites indicated an increase of more than 50 per cent while 31 sites showed a decrease. Those showing the worst increases were the short duration, short length construction zones, perhaps reflecting either driver expectancy (or lack thereof) or poor roadworks signing, or both.

Federal Highway Administration (1982, p 10-5) also reviewed the factors found to have contributed to crashes at work zones. These included:

- . some aspect of the work zone
- . traffic congestion
- . lane changing
- . vehicles entering and leaving the work zone
- . unexpected presence of flagperson.

Road work zones can represent a particular hazard to road users. It is important that work sites have adequate advance warning, clear and unambiguous traffic control through the work zone, and that the work zone is left in a safe condition when work is not in progress.

7.7 SPEED AND SPEED LIMITS

Speeds.

There is clear evidence of the effect of speed on crash rates and crash severity. The energy to be dissipated in a crash is proportional to the square of the impact speed; for example, an impact speed of 130 km/h involves more than twice the energy of one at 90 km/h.

Moreover, in many crashes the impact speed is well below the travel speed, as drivers have managed to brake but not stop their vehicles before the collision. As travel speeds drop therefore, the impact speed drops also, and the collision may in fact be avoided.

Lay (1986, p 363) has suggested four factors which contribute to the greater hazard at higher speed:

- . the vehicle becomes less stable at higher speeds,
- . the driver has less time to react
- . other road users have less time to react, and
- . severity of crashes increases, as mentioned above.

Organisation for Economic Cooperation and Development (1981, p 2) has quantified the effect of speed on crashes and crash severity, based upon Swedish data, as follows:

the percentage drop in crash rates outside built up areas is n times the percentage drop in mean speed, where $n = 4$ for fatal crashes, 3 for personal injury crashes, and 2 for all crashes.

Speed Limits.

It follows from the above that, to the extent that speed limits affect travel speed, speed limits should affect crashes. Evidence for this was provided in the US, where the drop in the nationwide speed limit to 55 mph (88 km/h) in 1974 was associated with a fall in crashes (especially fatal crashes), and the increase in speed limit to 65 mph (104 km/h) from 1987 apparently led to an increase in crashes, especially fatal crashes (Anon, 1988a).

Speed Limits and Travel Speeds.

It is axiomatic that speed limits affect safety only if they affect actual travel speeds. The influence of speed limit on speed is somewhat tenuous, and relies firstly on the speed limit as being regarded as "reasonable" by the driver, and secondly on enforcement.

In relation to the former, Organisation for Economic Cooperation and Development (1981, p 2) concluded that "in order to bring about a reduction in mean speed and speed dispersion, a speed limit should be set at the 85 percentile of existing speeds, or at a lower level (but not too far below)" A speed limit set too high may have negative effects because road users often interpret the speed limit as the recommended speed rather than a ceiling. Road environment factors affecting speed perception include alignment, road category, whether the road is in an urban or rural environment, lane width, roadside development, traffic density, sight distance, parked vehicles, pedestrians and day and night vision (Fildes and Lee, 1993, p 78).

In relation to the latter, Organisation for Economic Cooperation and Development (op cit, p 6) noted that:

"Traditionally, the underlying assumption has been that enforcement would result in a reduction in mean speed and in the spread of speeds, and this in turn would lead to a reduction in accident numbers and severity.

This assumption can no longer be made without serious and specific limitations. In particular, enforcement at a specific site and time brings the average speed close to the posted speed; the effect on variability is less pronounced... (but) despite reservations about the effect on speeds, high levels of surveillance reduce the numbers of fatal and injury accidents". (their emphasis).

This is not the place for a detailed discussion of the effectiveness of enforcement, but it is relevant to note that these conclusions are consistent with observations in the Australian context by Leggett (1988) and Axup (1990).

Fildes and Lee (1993, p 35) concluded that currently in Australia, the method of setting speed limits is unsatisfactory, and that "there is a need for greater consistency across all Australian states to ensure credibility among motorists". The VLIMITS approach (Jarvis and Hoban, 1988) was seen as a move in the right direction.

VLIMITS takes account of the following factors (VicRoads, 1994, p 3):

- . road environment
- . extent and nature of abutting development
- . road users and their movements
- . existing speeds
- . accident history
- . adjacent speed zones
- . other environmental features, such as intersections, schools, pedestrian crossings and alignment

All else being equal, a reduction in the mean speed of traffic reduces crashes. However, the relationship between traffic speed and speed limit is uncertain, and depends upon whether drivers assess the speed limit as being reasonable, and upon enforcement.

7.8 THE ROADSIDE

7.8.1 Roadside Hazard Treatments

Clear Zones.

Collisions with fixed road side objects account for about 25 per cent of fatal crashes in Victoria (Symons and Cunningham, 1987). They are significant in both urban and rural environments (Nairn, 1987, p 33). In a recent major study of rural single vehicle crashes in Victoria, Armour and Cinquegrana (1990) found that a roadside object was considered to have increased the severity of 27 per cent of the crashes investigated.

These collisions involve roadside objects such as trees, poles, culverts, signs, bridge piers and abutments, embankments, ditches, guard fencing terminals, fence railings, etc. Under some circumstances therefore, it is cost-effective to treat these sites. The provision of an obstacle-free recovery area, or "clear zone" for out-of-control vehicles therefore has considerable potential for reducing the severity of such crashes.

The extent of the clear zone which must be free of hazards to allow a driver to recover control of an errant vehicle depends on the angle at which a vehicle leaves the roadway and the distance the vehicle travels along the roadway. The designated clear zone therefore attempts to reflect the probability of an accident occurring at a particular site. This depends upon traffic speed, roadside geometry and traffic volume. Various attempts have been made to define such a clear zone. (See Federal Highway Administration, 1982, p 3-3 ff for a review of US studies).

Basically, the conclusion from these studies is that a clear zone of 9 m width from the travelled pavement is recommended, and within this zone side slopes should be less than 6:1 and any obstacles within it are either to be removed or shielded with guard fencing (Pak-Poy and Kneebone, 1988, p 111). Variations on these general recommendations, based upon cost-effectiveness criteria, have been proposed by Graham and Harwood (1983) and Transportation Research Board (1987a, Appendix F).

Current Australian practice is based upon the work of Troutbeck (1983). His concept of minimum and desirable clear zones has been modified by Cunningham (1986) (see also Symons and Cunningham, 1987) to relate to vehicle flows. These results are presented in Figure 7.1. It will be seen that for speeds above 96 km/h and flows above 4000 veh/d, this gives the same 9 m clear zone as the US practice.

Since, as noted in Section 7.3 above, curves of less than 600 m radius are associated with a higher rate of crashes, the National Association of Australian State Road Authorities (1987a) guidelines recommend wider clear zones (in the absence of guard fencing) on curves with radius less than this amount.

Flatter roadside slopes have been found to have a significant effect on accidents, especially single-vehicle accidents (Zegeer and Council, 1992, 1993). Accident rates fall steadily as sideslopes are flattened from 3:1 to 7:1 or flatter. However, little accident reduction is expected from flattening a 2:1 slope to 3:1. The probability of vehicle rollovers is substantially reduced for sideslopes flatter than 4:1.

Roadside Safety Programs.

There is an extensive literature on the safety aspects of specific roadside features. This is not the place for a comprehensive review of such features; such reviews are included in Sanderson and Fildes (1984), Pak-Poy and Kneebone (1986, 1988), Transportation Research Board (1987a), National Association of Australian State Road Authorities, 1987a, 1988a), Symons and Cunningham (1987), Hoque and Sanderson (1988), Corben, Ambrose and Foong (1990), and Zegeer and Council, 1992)

Of more significance for the purposes of the current report is the development of a soundly based and consistent program for treating roadside hazards.

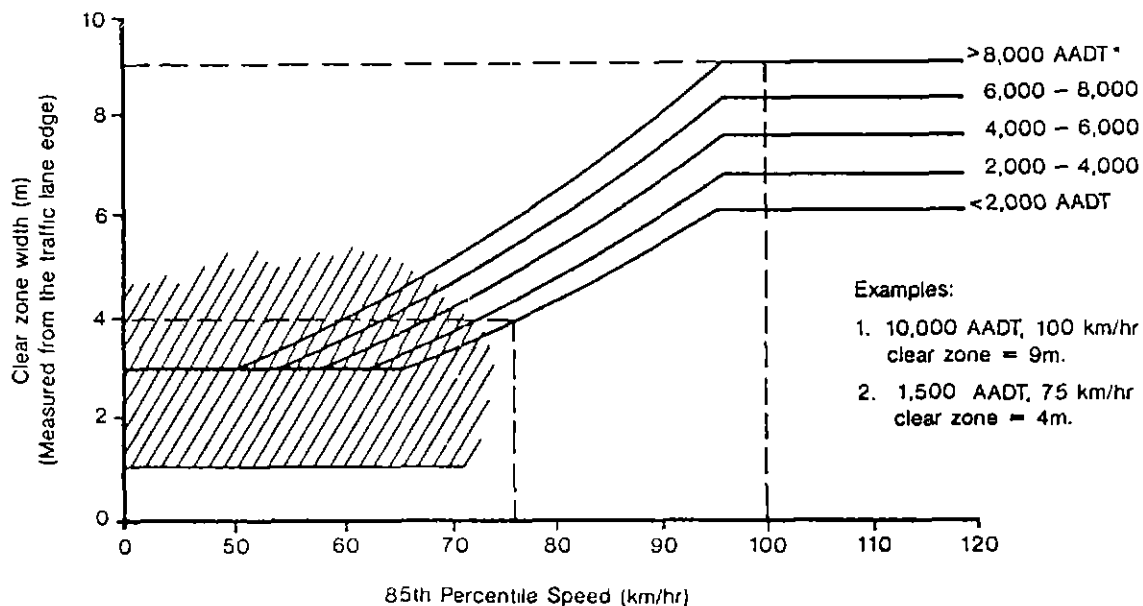
An important feature of such a program is that it needs to be based upon the crash potential for a site. Such a pro-active approach is predicated on the notion that the probability of a crash at any given site is low, and what is required is to identify the features associated with crashes of a given type, and then treat in priority order all sites which exhibit those features (Ogden and Howie, 1989).


Symons and Cunningham (1987) have outlined such a program in use in Victoria, based essentially upon selecting the worst corridors or road sections and treating all hazardous objects along it. Jarvis and Mullen (1977) have proposed a hierarchy of treatments as follows:

- (a) eliminate all obstacles from the roadside, either by good design and technology for new facilities, or the removal or resiting of all existing obstacles.
- (b) if it is not possible to eliminate all roadside objects, then either:
 - identify those most likely to be struck, establish priorities, and organise removal or resiting, or
 - make harmless those obstacles most likely to be struck, but impossible to remove.
- (c) give effective protection to and from those obstacles which cannot be removed or modified.

By its very nature, it is difficult to enumerate the effects of such programs, because of the low probability of a crash at any one site, and the difficulty in specifically relating crashes (or their absence) to the program. However, many studies have testified to the fact that such programs are a highly cost-effective form of road safety investment (e.g. Transportation Research Board, 1987a, p 165; Teale, 1984; Pak-Poy and Kneebone, 1988, p 127; Graham and Harwood, 1983; Corben, Ambrose and Foong, 1990).

Establishing and maintaining a clear zone, free of fixed obstacles, beside a road has definite safety benefits. It appears to be cost effective on rural roads even at quite low traffic volumes. For volumes in excess of 4000 veh/d and speeds of around 100 km/h, a clear zone of 9 m is indicated. Roadside hazard management programs need to be established and funded.



 In low speed environments of urban areas, a clear zone of not less than 1m wide may be accepted to achieve an appropriate balance between traffic safety and other aesthetic considerations.

* AADT - Average annual daily traffic. (Two Way)

NOTE:

- By definition the clear zone is measured from the edge of the trafficked lane and hence shoulders and verge areas will be included as part of the clear zone.
- In order to take account of increased hazard at curves and roadside embankments the desirable clear zone widths should be doubled on the outside of curves with a radii of 600 m or less, and when measuring clear zones the width of embankment slopes greater than 3:1 should not be included
- For curves with a radii larger than 600 m, whilst the desirable clear zone width is not increased, it is suggested that due account be taken of the extra risks associated with those curves.
- In urban areas where achieving the desirable clear zone width may be impractical due to restrictive right of way conditions, consideration may need to be given to the treatment of roadside hazards by other ameliorative measures.

Source: Symons and Cunningham, 1987

Figure 7.1 Desirable Clear Zone Widths

7.8.2 Shoulder Treatments

Sealed Shoulders.

There is ample evidence that sealed shoulders are much safer than unsealed shoulders on rural roads. Sealed shoulders reduce the incidence of run-off-the-road and head-on crashes by providing a greater recovery and manoeuvring space (National Association of Australian State Road Authorities, 1988a, p 28). They also (Burns, et al, 1984) reduce the potential for vehicles which stray from the sealed pavement to lose control in loose shoulder material; Armour (1984a) found this to be a contributing cause of over 50 per cent of fatal run-off-the-road crashes in New South Wales. In a recent major study of rural single vehicle crashes in Victoria, Armour and Cinquegrana (1990) found that the presence or condition of unsealed shoulders was considered to have contributed to 33 per cent of the crashes investigated.

In a comprehensive review of Australian conditions, Armour (1984a) found that roads with sealed shoulders had a fatal crash rate 60-70 per cent less than roads with unsealed shoulders. There was some evidence that the benefits were greater on road sections with curves or grades, the ratio between crash rates for roads with unsealed and sealed shoulders was about 3:1 for straight, flat road sections and 4:1 for curves or grades. More recent Australian research by Charlesworth (1987) has corroborated these results. It should also be noted that wide shoulders are usually associated with pavement edge lines, the safety benefits of which have been discussed in Section 7.5.

Pak-Poy and Kneebone (1988, p 72), using Armour's data referred to above, estimated the benefit:cost ratios for sealing shoulders under different circumstances. They assumed a 2 m shoulder width, a 5-year life, and a present value cost per kilometre for construction and maintenance of \$25,000. They showed that under all situations of road geometry (straight, grades, curves), and for traffic flows as low as 1,000 veh/d, that sealed shoulders produced benefit:cost ratios in excess of 2. That is, under all situations except for low volume roads on the straight, sealed shoulders were cost-effective.

Ogden (1993) in a study of Victorian rural roads which had been treated with sealed shoulders as part of a maintenance program (typically with a sealed shoulder of 0.6 - 1.2 m) found that such treatments had a 43 per cent lower crash rate on a vehicle km basis, and concluded that such a treatment was cost-effective (benefit:cost ratio of 1.0) at an AADT of about 350 vehicles per day.

Pavement Edge Drops.

Pavement edge drops (vertical discontinuities at the edge of the paved surface) result either from resurfacing activity unaccompanied by desirable shoulder improvements, or wear and erosion of weak shoulder materials. A particularly susceptible location of edge drops is the inside of horizontal curves, due in part to the off-tracking of the trailing wheels of vehicles, especially trucks. These have been identified as being associated with about 1-1.5 per cent of crashes in the US in various studies (Glennon, 1987a, p 39).

Recent research (Ivey and Mounce, 1984; Glennon, 1987a; Transportation Research Board, 1987a, p 98; Ivey and Sicking, 1986) has identified drop height and shape as being important, and that novice drivers are particularly at risk. Transportation Research Board (1987a, p 99) summarised by saying that "current understanding of the edge drop hazard is incomplete. In the interim, edge drops of any height or type must be considered potentially hazardous, and should not be built into the cross section as a result of either pavement surfacing or resurfacing."

Sinha and Hu (1986, p 39) have suggested that shoulder maintenance has the greatest safety impact of all routine maintenance practices.

Sealed shoulders are a cost effective means of reducing crashes on all rural roads except those with low volumes (around 500 veh/d). Ideally, the shoulder should be fully sealed (around 2 m), but if that is not possible, a narrow sealed shoulder of around 0.6 m produces worthwhile benefits.

Pavement edge drops (discontinuities between the pavement and the shoulder) have been shown to be associated with a small number of crashes, and particular attention should be paid to this in resurfacing work and maintenance activities.

7.9 OVERVIEW

Finally, a very useful and extensive overview of traffic engineering road safety is provided in the publication of the Roads and Traffic Authority of NSW entitled *Road Environment Safety Guidelines* (RTA, Sydney, 1991). A summary of the principles outlined in that publication represents a suitable overview of this topic. They may be summarised as follows, in relation to specific aspects of traffic engineering and transport planning:

- . crash investigation and prevention
 - access to timely and accurate data
 - awareness of road/vehicle/human factors
 - be aware of pre-crash, in-crash and post-crash countermeasures
 - look for preventative action as well as remedial treatments
- . remedial treatments
 - must be cost-effective
 - must target correctable crashes
 - must be long-lasting
- . evaluation
 - adequate before data is essential
 - careful selection of control sites
 - sound statistical approach
- . roadside safety
 - maintain clear recovery areas
 - shield immovable objects
 - install frangible structures
- . road design
 - develop clear objectives
 - provide consistent road geometry
 - construct safe pavements
 - create clear zones
 - reduce, separate or eliminate traffic conflicts
 - reduce glare and distraction

- . traffic management
 - establish clear objectives
 - adopt proven or well-founded methods
 - monitor effectiveness

- . traffic control devices
 - select the most appropriate device
 - consider all users
 - reduce conflicts and relative speeds

- . transport and traffic planning
 - separate pedestrians and vehicles or modify the road environment
 - encourage public transport options where appropriate
 - ensure developments are compatible with the functional hierarchy of roads and land use plans

- . sign posting
 - demonstrate a need for the sign
 - convey a clear message to all users under all circumstances
 - ensure that the sign does not create a hazard in itself

- . delineation
 - delineation must be visible under all conditions
 - special consideration is needed for sub-standard road geometry
 - a high standard of maintenance is essential

- . work zones
 - instruct and guide road users safely through, around or past the work site
 - provide advance warning of a work zone
 - *take particular care in the installation and maintenance of temporary signs and devices*

8. ROAD SAFETY EVALUATION

In this chapter, we examine the implementation and evaluation of road safety programs. National Association of Australian State Road Authorities (1988a, p 18) in its description of the phases of the development of a hazardous road location program, outlines two steps under program implementation:

- . ranking of sites in priority for treatment and preparation of design plans, etc
- . program and implement countermeasures.

8.1 RANKING AND PROJECT SELECTION

The Institution of Highways and Transportation (1990b, p 25) in its road safety guidelines outlines six steps to be followed in systematically selecting projects for inclusion in a hazardous road location program:

- . determine the range of measures likely to influence the dominant factors and road features
- . test the measures to ensure:
 - decrease in crashes are likely to occur
 - no future increase likely in other accident types
 - no unacceptable effects likely on traffic or environment
- . economic assessment of costs and benefits
- . select measures likely to give the greatest benefits
- . public consultation to ensure acceptance by the community affected
- . if necessary, amend proposals
- . select sites for priority treatment and develop action plans

Of these, the critical steps are the economic assessment of benefits and costs, and the selection (ranking) of measures which will give the greatest benefits.

8.2 ECONOMIC EVALUATION OF TRAFFIC ENGINEERING MEASURES

In recent years, it has become both possible and more common to perform a formal evaluation of traffic engineering road safety projects.

There are two reasons for this, first, governments are requiring road authorities to show that investment in roads is worthwhile, and second, the data to permit a more rigorous form of evaluation have become available, particularly in the form of the detailed costs of crashes by accident type produced by Andreassen (1992b,c).

Stages of evaluation.

Economic evaluation is essentially concerned with the economic efficiency of alternative proposals. It consists of five stages:

- . identification of relevant benefits and costs
- . valuation of benefits and costs
- . reduction of all future benefits and costs to their equivalent present day values
- . sensitivity testing where values are uncertain or risks are high
- . presentation of results.

In relation to the evaluation of traffic engineering road safety projects, the following interpretations of these general points apply. (This does not attempt to be a comprehensive overview of economic evaluation principles. For a more detailed exposition on this topic, refer to Ogden, 1989c; Wohl and Hendrickson (1984), Linard (1988) and Department of Finance (1990).

Benefits.

The benefits of a traffic engineering road safety program comprise savings in road crash costs which are estimated to result from the construction or introduction of a road safety measure. These may be due to a reduction in the **number** of crashes, or a reduction in the **severity** of crashes.

In some cases, there will be other consequences of the traffic engineering measure, such as on-going maintenance costs (e.g. maintenance of signs or roadside furniture), and ongoing operation costs (e.g. operation of traffic signals). In some cases, there will possibly be costs related to mobility which result from the measure (e.g. delays to motorists, additional fuel consumption). The **net annual benefit** (i.e. the savings in crash costs and savings in any other costs, offset by additional ongoing maintenance, operation, or road user costs) then constitute a stream of benefits which are assumed, or need to be calculated, over the evaluation period.

Costs.

The costs of a project are its initial capital cost, which usually involve only the construction costs which are incurred up-front as the project is designed and built.

Evaluation Period.

The evaluation period needs to be carefully assessed. At one extreme, a short evaluation period may be used, during which it is reasonable to assume that traffic and other conditions remain unchanged, and therefore there is some confidence in the inputs to the evaluation process. However, this may under-estimate the benefits (or perhaps costs) because benefits and costs beyond the evaluation period will not be included. On the other hand, a longer period can be used (eventually running out to the life of the project - perhaps 20 years or more). However, if this is done, it is necessary to make estimates of *future traffic flows and other conditions*, as these affect crash frequencies, operating costs, and so on.

Typically, for traffic engineering works, an evaluation period of around 5 years is used, although a longer period is appropriate if traffic is expected to be reasonably stable.

Valuation.

The valuation of costs is usually straightforward; this is the engineering estimate of the cost of the job. The valuation of benefits is more difficult. For the purposes of this report, only at the valuation of safety benefits will be considered, since the valuation of things like maintenance savings and travel time savings is a major study in itself.

Recent work at the Australian Road Research Board by Andreassen (1992b,c) has enabled a more detailed analysis of the benefits of traffic engineering road safety projects, based on a calculation of the average cost of particular "accident type groups". Knowing the accident type groups at any site, route, area or mass action program, an estimate needs to be made of the effect on these accident types of proposed countermeasures (see Chapter 7). The average standardised cost in Victoria of nineteen accident type groups, based on 1987-88 data, were estimated (Andreassen, 1992b, Table B1). These are shown in Table 8.1. (Note that these costs are State-specific, because they relate to reported crashes, and the reporting criteria differ from State to State. Average costs per crash will therefore be somewhat different in each State.)

For details of the costs of crashes involving trucks and motor cycles, refer to Andreassen (1992c).

Discounting.

Future cash flows need to be reduced to equivalent present-day values, because the value of a dollar in the future is less than the value of a dollar today. This is referred to as discounting. There are two situations relevant to the present analysis:

The present worth of a single sum of \$\$S, n years in the future, at a discount rate of $i\%$ per annum is

$$P = \frac{S}{(1+i)^n}$$

Similarly, the present worth of a stream of annual sums of \$\$R, at the end of each year for n years in the future, at a discount rate of $i\%$ per year is

$$P = R \frac{(1+i)^n - 1}{i(1+i)^n}$$

Present worth factors for single sums and uniform series are presented in any source text on economic evaluation, but they are not difficult to calculate using the relevant equation.

Discount Rate.

The discount rate appropriate to this form of economic evaluation is a matter of some controversy (Department of Finance, 1990). However, for present purposes, we may simply note that values of 4 per cent and 7 per cent are in common current use.

		Metro	Rural
One vehicle accident type			
DCA 100-102	pedestrian crossing road	79,300	148,800
DCA 164	permanent obstruction	56,000	89,800
DCA 167	animal	18,100	22,700
DCA 170,172	off carriageway, on straight	30,700	54,400
DCA 171,173	off carriageway, on straight, hit object	55,200	88,900
DCA 174	out of control on straight	31,200	53,900
DCA 180,182	off carriageway, on curve	44,400	84,100
DCA 181,183	off carriageway, on curve, hit object	69,500	107,200
DCA 184	out of control on curve	32,900	56,600
Two vehicle accident types			
DCA 110-118	intersection, adjacent approaches	38,500	90,300
DCA 120	head on	86,800	186,400
DCA 121-125	opposing vehicles turning	46,800	85,000
DCA 130-132	rear end	26,400	58,200
DCA 133-135	lane changes	22,100	81,600
DCA 136,137	parallel lanes, turning	25,300	68,400
DCA 140,141	U-turn	38,700	81,500
DCA 147	vehicle leaving driveway	31,900	69,700
DCA 152	overtaking, same direction	21,600	55,300
DCA 160	hit parked vehicle	21,700	42,200
	all others	n/a	n/a

Source: Andreassen, 1992b

Table 8.1 Costs by Accident Type, Victoria

Sensitivity Test.

An evaluation should always be subject to a sensitivity test to assess how robust the result is to changes in the assumptions used in calculating it. In particular, a range of expected crash reductions should be assessed, since one can never be certain as to what the actual outcome will be; using a low and a high estimate of possible and realistic outcomes is always good practice. If the outcome is favourable even if a pessimistic forecast is used, we can be confident that the project is worthwhile. Conversely, if the evaluation outcome is unfavourable, even with optimistic assumptions, we can be confident that the project is unlikely to be worthwhile. The middle ground - favourable under optimistic assumptions and unfavourable under pessimistic assumptions - requires us to do more work to try and get a better forecast.

Presentation of the Results.

There are four tests which may be used to indicate the worth of a candidate project - the net present value (NPV), the benefit cost ratio (BCR), the internal rate of return, and the payback period. The first two are the most common.

The superior test is the net present value. It has two advantageous features. First, since it involves subtracting costs from benefits, it does not matter if we define cost savings as benefits or include them as costs; this is a major advantage where the benefits are cost savings. This is a potential problem with the benefit cost ratio method where we can get a number of different ratios depending upon our definitions of benefits and costs. Secondly, the NPV method can be used directly to rank projects; the "best" project is the one with the highest NPV, the second best is the one with the second highest NPV and so on. Note that projects *can not* be ranked in order of their benefit cost ratio (BCR) (Linard, 1988). Examples of economic evaluation are presented in Andreassen, 1992a, p 5.

8.3 EFFECTIVENESS OF TRAFFIC ENGINEERING ROAD SAFETY MEASURES

Various studies have attempted to summarise the effects of road and traffic treatments on safety. These include Tignor (1993), Travers Morgan (1991), Travers Morgan (1992), and VicRoads (1992), Federal Highway Administration (1982), Transportation Research Board (1973). Perhaps the most interesting compilation of such factors is that assembled by Travers Morgan (1991) in a study for the Roads and Traffic Authority of New South Wales. Tables 8.2 and 8.3 show the results of their international literature review, in terms, respectively, of safety effectiveness (per cent reduction in accidents) and cost effectiveness (benefit:cost ratio).

Clearly any such estimate of per cent reduction in accidents can only be applied to another site with a great deal of caution to another site. Conditions vary from site, but also, the research which produced the sorts of results summarised in Tables 8.2 and 8.3 is almost invariably based on studies of treatments of sites which are themselves poor. Therefore, as sites are treated, it would be expected that later sites would not be as deficient and would therefore show a less spectacular reduction. Therefore, applying the results from one study to another site may possibly lead to serious mis-estimation of the effects unless attempts are made to ensure that conditions are reasonably similar.

To attempt to address this problem, Travers Morgan (1991) also undertook an international survey of experts in this field, asking them to indicate, for a range of treatments, their assessment of both the safety effectiveness and cost effectiveness of the treatment. These results are shown in Tables 8.4 and 8.5.

Feature	Treatment	% accident reduction	
		Range	Mean
Urban:			
Roadside hazard	Relocate poles	30-80	50
Intersections	Roundabouts	50-60	55
Intersections	Sheltered turn lanes	15-55	30
Roadside hazards	Frangible poles	-	30
Shoulders/lanes	Widen traffic lanes	-	20
Medians	Safety fence	-	20
Intersections	Painted channelisation	10-20	15
Lighting	Lighting	7-22	15
Rural:			
Rail level crossings	Gates/bells/lights	86-88	87
Intersections	Staggered T	-	80
Rail level crossings	Flashing lights	50-80	64
Intersections	Sheltered turn lanes	25-70	45
Shoulders/lanes	Short 4-lane sections	-	35
Geometry	Major realignment	30-35	32
Shoulders/lanes	Seal shoulders	-	30
Delineation	Reflectorised guide posts	-	30
Roadside hazards	Widen narrow squeeze points	-	30
Shoulders/lanes	Overtaking lanes	-	25
Shoulders/lanes	Widen traffic lanes	16-30	22
Roadside hazards	Guard rail	10-30	20
Signs	Warning/advisory	10-30	20
Resurfacing	At specific accident sites	-	18
Medians	Widen median	7-23	15
Medians	Safety fence	9-27	15
Geometry	Minor realignment	-	15
Delineation	Raised pavement markers	15-16	15
Shoulders/lanes	Widen shoulder	6-12	10
Delineation	Edge line marking	0-60	8

Source: Travers Morgan, 1991

Figure 8.2 Ranking of Treatments for Safety Effectiveness

Feature	Treatment	Benefit : cost ratio	
		Range	Mean
Urban:			
Intersections	Roundabouts	-	9.4
Lighting	Lighting	-	9
Intersections	Staggered T	-	1.5
Rural:			
Roadside hazards	Remove trees	3-21	10
Roadside hazards	Frangible poles	-	7
Delineation	Raised pavement markers	-	8
Delineation	Edge line marking	1-10	6
Shoulders/lanes	Widen shoulders	1-12	6
Shoulders/lanes	Overtaking lanes	-	4.5
Resurfacing	At specific accident sites	1-7	4
Intersections	Sheltered turn lanes	2-5	3.5
Signs	Warning/advisory	-	3.5
Shoulders/lanes	Short 4-lane sections	-	3
Roadside hazards	Guard rail	2-4	3
Roadside hazards	Relocate poles	1-14	3
Medians	Safety fence	0.8-4.8	3
Medians	Widen median	1.9-3.0	2.5
Rail level crossings	Flashing lights	0.6-2.2	1.7
Geometry	Major realignment	0.6-2.0	1.3
Geometry	Minor realignment	-	1
Roadside hazards	Widen narrow squeeze points	-	0.9
Shoulders/lanes	Widen traffic lanes	-	0.5
Rails level crossing	Gates/bells/lights	-	0.4

Source: Travers Morgan, 1991

Table 8.3 Ranking of Treatments for Cost Effectiveness

Cost Effectiveness (Survey Rating)	Safety Effectiveness (Survey Rating)		
	Low (1.0-2.5)	Medium (2.6-3.5)	High (3.6-5.0)
Low (1.0-2.5)	Widen Traffic Lanes Bus Transit Lanes Warning Signs Resurfacing Less Frequently	Widen Sealed Area Raised Pavt markers/Edges Widen Narrow Squeezepoints Bus Bays Lighting Widen for Parking/ Breakdown Cycle Paths Night Operations	Boom Gates/Bells/Lights New Jersey Median
Medium (2.6-3.5)	Relocate Waste Containers Reflectorised Guide Posts	Speed Zoning Electronic Guidance Flashing Lights Safety Fence Median Resurfacing More Frequently Guardrail Edge Line Marking Raised Pavt Markers/Centre Advanced Direction/ Reassurance Signs	Concrete Raised Median Roundabouts Relocate Poles
High (3.6-5.0)		Painted Median Warning/Advisory Signs Chevron Signs	Sheltered Turn Lanes Resurfacing at Specific Accident Spots Frangible Poles Painted Channelisation

Source: Travers Morgan, 1991

Table 8.4 Effectiveness and Cost Effectiveness of Urban Treatments

Cost Effectiveness (Survey Rating)	Safety Effectiveness (Survey Rating)		
	Low (1.0-2.5)	Medium (2.6-3.5)	High (3.6-5.0)
Low (1.0-2.5)	Night Operations Resurfacing Less Frequently	3 Lane Sections Short 4 Lane Sections Widen Traffic Lanes	New Jersey Median Major Realignment Boom Gates/Bells/Lights
Medium (2.6-3.5)	Warning Signs	Electronic Guidance Widen Sealed Area Resurfacing More Frequently Flatten Batters Remove Trees Widen Shoulder Passing/Overtaking Lanes Flashing Lights Raised Pavt Markers/Edges Passing Bays	Concrete Raised Median Roundabouts Relocate Poles Staggered/Replace 4 Legs Widen Narrow Squeeze- points Safety Fence Median
High (3.6-5.0)		Speed Zoning Painted Median Warning/Advisory Signs Advance Direction/ Reassurance Signs Minor Realignment	Sheltered Turn Lanes Reflectorised Guide Posts Edge Line Marking Resurfacing at Specific Accident Spots Raised Pavt Markers/ Centre Guardrail Chevron Signs Painted Channelisation Seal Shoulder

Source: Travers Morgan, 1991

Table 8.5 Effectiveness and Cost Effectiveness of Rural Treatments

9. ROAD SAFETY AUDIT

Previous chapter have reviewed various aspects of one of the two key approaches to traffic engineering road safety, namely the hazardous road location approach. As noted in Chapter 3, a second approach is based upon the concept of road safety audit. The former aims, as the previous chapters have indicated, to achieve crash reduction through the development of remedial measures at high frequency sites. The latter is aimed at crash prevention that the design of new road and traffic schemes is as safe as practicable.

However, each State and Territory has put in to place (or shortly will have in place) established policies and procedures for the conduct of road safety audits (e.g. Roads and Traffic Authority, 1991a; Queensland Transport 1993b,c VicRoads, 1992), while the release of the Austroads publication Road Safety Audits is imminent. Therefore, there is little point in going into detail here. Rather, what will be presented is an overview of the concept of road safety and what is known about its effectiveness. For details of how to conduct an audit, the checklists involved, etc, reference should be made to the local policies and guides.

9.1 DEFINITION

Road safety audit has been succinctly defined as "a systematic method of checking the safety aspects of new schemes affecting roads" (Proctor and Belcher, 1993). The Roads and Traffic Authority (1991) describe it as "a means of checking the design, implementation and operation of road projects against a set of safety principles as a means of accident prevention and treatment".

Austroads (1994b) emphasise that road safety audit is an integral, independent process:

A road safety audit is a formal examination of an existing or future road or traffic project, or any project which interacts with road users, in which an independent, qualified examiner looks at the project's accident potential and safety performance.

The essential elements of this definition are that it is:

- . a formal process and not an informal check*
- . carried out by someone with appropriate experience and training, and*
- . restricted to road safety issues.*

In one sense, highway designers and traffic engineers have always practiced a form of safety audit. However what is significant about the recent emergence of the practice is its specific incorporation as a discrete phase, independent of the designer, and the development of defined auditing procedures which are followed within a road or traffic agency. This latter aspect may be incorporated within an overall Quality Management or Quality Assurance process within that agency (e.g. VicRoads, 1993).

9.2 APPLICATION OF ROAD SAFETY AUDIT

Road safety audit may be carried out at any or all of the following five stages (Austroads, 1994b).

Stage 1, Feasibility.

As an input to the feasibility stage of a scheme, a safety audit can influence route choice, selection of design standard, impact on the existing road network, route continuity, provision of interchanges or intersections, access control, number of lanes, route terminals, stage development, etc.

Stage 2, Draft Design.

This audit stage is undertaken on completion of draft plans or a preliminary design. Typical considerations include horizontal and vertical alignment, sightlines, intersection layouts, lane and shoulder width, pavement crossfall and superelevation, overtaking lanes, provision for parked and stationary vehicles, etc. After this stage, as land acquisition becomes finalised, subsequent significant changes in road alignment become much harder to achieve.

Stage 3, Detailed Design.

This audit stage is on completion of detailed design, but normally before the preparation of contract documents. Typical considerations include line markings, signing, delineation, lighting, intersection details, clearances to roadside objects, and provision for road user groups with special requirements (pedestrians, cyclists, trucks, buses, etc).

Stage 4, Pre-opening.

Immediately prior to the opening of a scheme to traffic, the audit would involve driving, riding and walking through the project to check that the safety needs of all road users are adequate. This should involve a night-time inspection, and if possible an inspection in both wet and dry conditions.

Stage 5, In-service.

This stage involves a systematic examination of sections of the existing road network to assess the adequacy of the road, intersections, road furniture, the roadside, etc from an explicit safety viewpoint.

9.3 SAFETY AUDIT PROCESS

While each road agency undertaking a road safety audit may have its own audit processes, the four key requirements are (Jordan and Barton, 1992):

- . management commitment
- . an agreed road safety audit process
- . an independent auditor or audit team
- . a set of checklists.

Commitment.

Whether or not road safety audit lives up to its potential depends largely upon the commitment and endeavours of the organisation and staff involved. It is vital that it be seen as an integral part of an agency's overall program (which is why a relationship to a total Quality Management process can be important). Otherwise, it runs the risk of being perceived as questioning the competence and professionalism of the designer or road builder. It is important therefore that each individual and group within the agency be involved with the road safety audit process, and share a common goal of using it to promote road safety and crash prevention.

Process.

The road safety audit process must seek to take an overall view of safety. The process aims to reduce the whole life cost of a scheme. Although there will be costs of the audit process, these must be offset against the potential for savings elsewhere. The savings may be from timely alteration to plans (it is much cheaper to change a detail on a plan than to replace or remove a feature once installed), from subsequent crash prevention, and from reductions in the costs resulting from litigation. Experience in those jurisdictions where it has been introduced indicates that safety is now a more explicit factor in all levels of road decision making, rather than a minor or implicit consideration as may have been the case previously.

Organisation.

There are a number of ways in which the safety audit process may be carried out. Some possibilities are detailed in Austroads (1994b) and Institution of Highways and Transportation, 1990b, p 9). The "preferred" option in Austroads is to have a specialist audit team, either using staff employed specifically for that purpose within a road authority, or using external consultants.

There must also be a designated procedure for acting upon the audit report. If a specialist team is used, Austroads (1994b) suggests that one of three procedures can be followed:

- . prior agreement to accept the safety audit recommendations
- . assessment of the audit report by the client (or an independent third party representative), or
- . assessment of the audit report by the designer.

An agency developing a road safety audit process will need to determine which of these procedures (or an alternative) to follow, depending upon its own "culture", expertise and the role of safety auditing within a wider institutional framework, such as Quality Management. However, the key factors are the independence of the safety auditor or team, and the accountability of those making decisions in the light of the audit report's recommendations.

Checklist. The actual tasks undertaken by a safety audit team will in most cases involve the use of checklists. These typically show the sorts of issues and problems which can potentially arise at the relevant stage of the project. Checklists are included in the policies and procedures laid down by the various States and Territories, and in Austroads (1994b)

Importantly however, these checklists cannot be a substitute for expertise, and it is imperative that those responsible for undertaking safety audits have adequate training and experience in road safety engineering. It is also vital that the safety audit procedure involves a site visit, at whatever stage it is concerned with, since there will inevitably be factors present and identifiable at the site which are not evident from the plans.

Chapter 7 and 8 of this report summarise the safety effects of a wide range of road and traffic factors, and this sort of information is necessary to assist in the development of road safety audit recommendations.

9.4 EFFECTIVENESS OF ROAD SAFETY AUDIT

Because formal road safety audit work is in its infancy, it is not possible to provide authoritative information on its cost-effectiveness. In any case, such estimates would be difficult to develop in a statistical sense, because there would need to be an explicit test procedure developed, probably using control groups (i.e. comparing projects that had experienced a safety audit with those which had not). Pending such an analysis, the justification for road safety audit must rely on more subjective grounds. Those grounds are three-fold.

First, there is a priori evidence that in many cases, existing design and construction processes allow deficient or inappropriate elements of road projects to be implemented. On this argument, a formal requirement that a project be subjected to a safety audit will very likely lead to improved safety.

Second, a sensitivity test can be performed which might, for example, compare the costs of a safety audit with the benefits from eliminating even a single crash, and this would likely conclude that the audit process only has to achieve that result for it to be effective. For example, Proctor and Belcher (1993) using British data suggest that an audit may cost 6,000 - 8,000 pounds, which may be compared with the standard British crash cost of some 20,000 pounds for an urban crash or 44,000 pounds for a rural crash.

Third, the resources that need to be devoted to safety audit are in fact quite small. The Institution of Highways and Transportation (1990b), on the basis of British experience, suggests that one safety auditor is required to cover an area experiencing some 2000 casualty crashes per year. Australian and New Zealand experience suggests that safety audit adds about 4 per cent to road *design* costs. However, adopting a whole of life approach, as described above, should mean that the costs of road safety audit are more than recouped from savings elsewhere.

Austrroads (1994b) summarises the benefits of road safety audits as follows:

- . safer new highways through accident prevention and accident severity reduction
- . safer road networks
- . the enhancement of road safety engineering
- . reduced whole of life costs of road schemes
- . providing one component of local and state accident reduction targets
- . a reduced need to modify new schemes after they are built
- . a better understanding and documentation of road safety engineering
- . eventual safety improvements to standards and procedures
- . a better attitude to safety in highway authorities
- . more explicit consideration of the safety needs of vulnerable road users, and
- . the encouragement of other personnel in road safety.

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