MONASH University
Accident Research Centre

# Flexible Barrier Systems Along High-Speed Roads: *A Lifesaving Opportunity*

Prepared for
VicRoads

By

Magnus Larsson
Nimmi Candappa
Bruce Corben

December 2003

MONASH UNIVERSITY ACCIDENT RESEARCH CENTRE
REPORT DOCUMENTATION PAGE


| Report No. | Date | ISBN | Pages |
|---|---|---|---|
| 210 | 2003 | 0 7326 1720 0 | 57 |

**Title and sub-title:** Flexible Barrier Systems Along High-Speed Roads – a Lifesaving Opportunity



**Author(s):** Larsson, M., Candappa, N.L., and Corben, B.F.



**Sponsoring Organisation(s):**
This project was funded through the Centre's Baseline Research Program for which grants have been received from:

Department of Justice
Roads Corporation (VicRoads)
Transport Accident Commission



**Abstract:**
This report addresses the issue of run-off-road crashes in Victoria, through the large-scale use of flexible barriers along high-speed roads. Run-off-road crashes contribute up to four in ten fatalities in Victoria and over half of all fatalities on rural roads. Although other countermeasures such as clear zones and shoulder sealing have had some effect in addressing this major road safety issue, flexible barriers are proving to be the most effective countermeasure, eradicating, almost completely, the risk of fatal injury resulting from vehicles running off the road.

The report describes Swedish experience with flexible barriers, detailing the road safety concerns pertinent to Sweden, the different design configurations used to adapt the barriers to various road cross-sections, and its great success in reducing single-vehicle crashes as a result of large-scale use of flexible barriers.

The report then addresses how Sweden's experience can be applied on to Victorian roads to target single-vehicle crashes on high-speed roads while adapting barrier layouts to Victorian road types.

This initial assessment of flexible barrier use predicts that major savings of up to 90% in death and serious injury can be achieved, with no evidence of increased road trauma for motorcyclists. An estimate of the economic value of these savings is several times larger than the investment costs. Further study is required to define, in greater detail, the design concepts and implementation issues for providing flexible barriers along major high-speed routes in Victoria. Barrier performance in impacts with heavy vehicles and motorcyclists should also form part of any further studies.



**Key Words:**
Flexible barriers, run-off-road crashes, 2+1 barrier layout, Swedish practice, motorcyclists





Monash University Accident Research Centre,
Building 70, Clayton Campus, Victoria, 3800, Australia.
Telephone: +61 3 9905 4371, Fax: +61 3 9905 4363

# ACKNOWLEDGEMENTS

The authors wish to thank and acknowledge the very valuable contributions to this project by the following people:

- The Project Advisory Committee for its review of the study report and guidance in project direction
- Ian Johnston, Director of MUARC, for review and advice on the report
- Nisha Jacques of MUARC for assistance with the presentation of the report
- John Bryden, Sam Pirotta and Peter Newitt for their advice and review of the report
- Bruce Thompson, Nick Szwed, Peter Newitt, Sam Pirotta, and Mike Jones for attending the session provided for obtaining feedback from VicRoads staff
- Wayne Harvey and the VicRoads Road Information Services for their assistance in providing crash data
- Harry Hastas and Athula Fernando of VicRoads for provision of road cross-section data and photos
- VicRoads staff for providing feedback/information re use of flexible barriers in their regions

# TABLE OF CONTENTS

# EXECUTIVE SUMMARY

Run-off-road crashes are the largest single source of serious road trauma in Victoria - three to four of every ten fatalities and, on average, injuries of very high severity.

Conventional treatments such as shoulder sealing, delineation and clear zones have had only limited success as they make only incremental improvements in roadside safety. A more fundamental approach is needed.

Flexible barriers constitute such an approach as they gradually absorb the impact energy avoiding the severe outcomes associated with head-on collisions, crashes into rigid objects or rollovers. While not a new technology, it is only in recent times that flexible barriers have been applied over long lengths of roadway, with demonstrable success.

Sweden has used flexible barriers to reduce the incidence of fatalities on treated routes by up to 90%. This has been achieved through extensive, conventional use of flexible barriers as well as by the introduction of the innovative 2+1 road configuration. Under this layout, flexible barriers are used to separate opposing traffic by providing alternate sections of two lanes in one direction, separated from the one lane in the opposing direction.

Swedish research indicates that a large number of crashes occur on a small percentage of the road network, implying that flexible barriers need only be installed on a similarly small proportion of the road network in order to effect a large reduction in the road toll.

Although there was public opposition and wariness initially, public support for the barriers rose dramatically in Sweden within the first year of implementation.

Due to the existing road cross-sections and similarities in crash and injury occurrence in Victoria, these treatments can be applied new along Victorian roads. Indicative costs for implementing this treatment in Victoria have been established, though further work is required.

While there is concern as to the crashworthiness of flexible barriers when struck by motorcyclists (as is the case for all types of roadside barrier), the overall benefits to all road users are extraordinarily high. No evidence of increased road trauma as a result of motorcyclists crashing in to flexible barriers has been noted in Swedish monitoring and evaluations since the introduction of extensive barrier use.

This initial assessment of flexible barrier use predicts that major savings in death and serious injury can be achieved. An estimate of the economic value of these savings is several times larger than the investment costs. Further study is required to define, in greater detail, the design concepts and implementation issues for providing flexible barriers along major high-speed routes in Victoria.

# 1 INTRODUCTION

Run-off-road crashes represent, arguably, the largest single source of serious road trauma. In recent years, run-off-road crashes accounted for three to four of every ten fatalities on Victorian roads. By 2002, 43% of deaths on Victorian roads involved single-vehicle crashes. A less frequent, yet very severe crash type, especially in high-speed settings, is the head-on crash. In rural areas, head-on crashes on undivided roads are a serious concern.

A number of MUARC studies conducted in recent years have analysed these crash problems and investigated possible countermeasures. Among the most promising solutions is the use of flexible barrier systems erected over extended lengths of roadway. The main barrier implementation scenarios are:

- In medians to separate opposing directions of high-speed traffic, and to prevent vehicle rollover and crashes into rigid objects within medians;
- Along the left hand side of the carriageway, for each direction of travel, to prevent collisions with roadside trees, poles, embankments, culverts and other hazards;
- As mid-barriers along single-carriageway roads mainly to separate opposing directions of high-speed traffic, but to also prevent vehicle departures into the far roadside.

Outstanding early success has been experienced in Swedish use of flexible barriers on undivided roads.

## 1.1 PROJECT OBJECTIVES

The purpose of this project is to investigate and assess opportunities to address a major source of traffic-related fatalities and serious injuries caused by run-off-road and head-on crashes in high-speed settings, through conventional and/or innovative forms of flexible barrier use.

## 1.2 PROJECT METHOD

Given that Sweden is regarded as a world leader in terms of road safety practice, the latest experiences in Sweden as well as findings of a number of studies by MUARC in this field will be drawn upon to define possible scenarios for barrier use in Victoria. Where available, the results of actual evaluations or the findings of studies of projected effectiveness of flexible barrier systems will be documented for key implementation scenarios.

While the primary focus will be on the use of barrier systems and their effectiveness in reducing the incidence of serious road trauma, including a focus on motorcyclists, other aspects will also be considered. The implications of barrier use in high-speed settings will be examined with respect to:

- Traffic operations
- Vehicle speeds

- Road cross-sections of the future;
- Road and barrier maintenance and repairs
- Vehicle breakdowns
- Emergency services access
- Access to and from properties and intersections.
- Environmental sustainability;

## 1.3 DEFINITIONS

"Run off road" and "single-vehicle" crashes generally refer to vehicles unintentionally leaving the road pavement to the left or right, including onto the median. Other crash types may have been included in the definition of run-off-road crashes in previous studies, without affecting overall conclusions, (see Appendix A for the DCA codes included in each individual study). Although it is only one form of flexible barrier, Wire Rope Safety Barriers (WRSB) have been referred to as flexible barriers in this report.

# 2 CURRENT SITUATION

There are a number of reasons why vehicles run off the road – fatigue, lack of concentration, human error and slippery roads are only some of the reasons. In order to address some 30-40% of the road toll and create a safer road environment that will address these types of crashes, barriers are placed along medians and roadsides, particularly on highways. The aim of these barriers is not necessarily to prevent run-off-road (ROR) crashes. In some cases, the presence of barriers may actually increase the incidence of reported crashes, as some drivers who leave the roadway may be able to recover control before entering the roadside but, with a barrier installed, strike it. The aim of roadside barriers is, in fact, to dramatically limit the severe consequences of crashes that would otherwise involve vehicles striking a fixed object, driving down an embankment, or colliding with opposing traffic.

In order to better understand the nature of the problem, characteristics of ROR crashes have been summarised below, based mainly on findings from recent studies. Although the issue of vehicles that run off the road or into oncoming traffic is one that confronts both metropolitan and rural roads, there will a somewhat greater focus in this study on ROR crashes on high-speed in rural areas as the proportion of ROR to total crashes is greater in rural areas.

## 2.1 SUMMARY OF CRASH STATISTICS

As analyses of crashes and countermeasure-effectiveness have been based on previous studies by MUARC, the findings cited are often on a specific category of ROR crashes and do not necessarily address ROR crashes collectively. A general summary on ROR crashes, not distinguishing between the various types, has therefore been included below; detailed analysis can be found in Appendix B:

- ROR crashes are a significant problem in both metropolitan Melbourne and rural Victoria although in rural areas, there is a greater proportion of these crashes. Victoria-wide, between 1996 and 2000, 16 to 19% of all casualty crashes involved fixed roadside objects (Delaney, Langford, Corben, Newstead, & Jacques, 2002) and 60% of all run-off-road crashes involved a roadside hazard (Szwed, 2002). The trend of run-off-road crashes appears to be rising despite recent and current efforts to address it
- The most common types of ROR crashes involve vehicles leaving the straight section of the carriageway to the left or to the right, into objects. Head-on collisions are also quite common, as are vehicles running off curves
- ROR crashes typically result in injuries of above-average severity, with “arrive alive!” Strategy 2002 noting that 91% of fatal ROR crashes in 2000 involved fixed roadside objects
- ROR crashes generally occur on roads with speed limits of either 100+ km/h or 60 km/h. In regional Victoria, 73% of run-off-road-left crashes occurred in 100 km/h zones, while 57% of metropolitan run-off-road-left crashes occurred in 60 km/h zones. Of collisions involving fixed roadside objects in regional Victoria, 67% occurred on roads with speed limits of 100 km/h, followed by approximately 20% of collisions on roads with 60 km/h speed limits (Delaney et al., 2002)

- Cars (and car derivatives) are generally the most frequently involved vehicle type in ROR crashes, with heavy vehicles involved in up to 10% and motorcyclists representing up to 11% of reported ROR casualty crashes. In 2001, motorcyclists contributed to 14% of overall fatalities, although they represent less than 1% of travel on Victorian roads (Transport Accident Commission, TAC). The ATSB (Australian Transport Safety Bureau) found that there is an approximate 30-fold higher risk of a motorcycle rider being killed than of other vehicle operators (per 100 million kilometres travelled, 1998 - 2000)
- In regional Victoria, costs associated with collisions with fixed roadside objects account for over one-third of total average costs of all casualty crashes (Delaney et al., 2002).

# 3 CURRENT COUNTERMEASURES

There are three main forms of countermeasures in use in Victoria that aim to address the issue of ROR crashes:

## 3.1 CLEAR ZONES

The principle of clear zones is based on US research from the 1960s that indicated over 85% of vehicles that run off the road on highways can recover within nine metres of the edge of the roadway. Guidelines therefore were introduced requiring all roadside hazards to be a certain distance, ranging from three up to nine metres from the edge of the road, the required distance being a function of the daily volume of traffic in that section and the 85$^{th}$ percentile speed of vehicles on that section of road.

## 3.2 SHOULDER SEALING AND DELINEATION

Gravel shoulders have been sealed to allow errant vehicles to have a firmer surface on which to correct unintentional vehicle departures and steer back on to the roadway. Delineation such as guideposts with corner cube delineators, raised reflective pavement markings (RRPMs), audio tactile edge line marking, clear edge line marking and warning signs of changing road alignment ahead are also commonly used in combination with shoulder sealing.

## 3.3 BARRIERS

### 3.1.1 Concrete Barriers

Rigid barriers such as New Jersey barrier profiles are placed along roadsides, particularly along the centre of a highway, to prevent errant vehicles from leaving the road or colliding with opposing traffic. Due to their rigidity, concrete barriers can increase severe injury consequences to vehicle occupants and the likelihood of vehicles rebounding off the barrier.

### 3.3.1 Steel Guardrail

Semi-rigid barriers, such as W-Beam or Thriebeam guardrails, are widely used to prevent errant vehicles colliding with other traffic, or fixed roadside objects. Guardrails absorb more of the kinetic energy in a vehicle impact than do concrete barriers, thereby reducing the incidence of rebound and serious injury, and allowing vehicles to be more successfully guided back in the direction of the general flow of traffic.

## 3.4 EFFECTIVENESS OF CURRENT COUNTERMEASURES

Although in theory clear zones can be effective, it is not often affordable and/or feasible to require nine metres of roadside be cleared of all fixed objects, particularly if these objects involve endangered species or otherwise highly valued trees. Moreover, though clear zones can aid the drivers and riders of 85% of errant vehicles, 15% of vehicles that run off the road are not addressed by clear zones and, in terms of numbers of vehicles on high-volume highways, a significant number of crashes remain untreated.

In addition, increasingly, the adequacy and validity of the clear zone concept is being questioned. Corben et al. (2001), in a median encroachment study, noted that road engineering guidelines require a median barrier on high-speed roads only when the median width is less than 15 m. This guideline aims to prevent head-on collisions. Analyses of theoretical vehicle braking profiles for a range of realistic crash scenarios cast considerable doubt on the adequacy of the nine metres criterion forming a central part of the clear zone principle. So too do the crash histories of many of the roads investigated.

Shoulder sealing, with appropriate signage and line marking, can be quite effective, based on a 1988 study by the Transport and Communications Department: although considered by some to be a high-cost treatment, two metre wide paved shoulders were estimated to deliver a BCR of 12:1. Further work is required to estimate the effect of wider shoulders. Delaney et al., (October, 2002) refer to an evaluation of road safety treatments implemented in Victoria between 1989 and 1994, which found a reduction of approximately 32% in total crashes following large-scale shoulder sealing. A study of Victoria's Accident Black Spot Program found that shoulder sealing with line marking and removal of hazards was most noteworthy, resulting in reductions in both crash frequency and casualty costs of around 50%. However, as with the clear zone concept, a substantial proportion of ROR crashes are left "untreated". That is, sealed shoulders cannot protect errant vehicles from fixed roadside objects as effectively as can crashworthy barrier systems.

Current barriers, although generally effective, have a number of disadvantages: concrete barriers expose vehicle occupants to high levels of deceleration as a result of their inability to deflect during an impact, thereby causing high severity injuries to vehicle occupants and extensive damage to impacting vehicles. Tests undertaken by MUARC showed that the performance of concrete barriers was inferior in measures such as energy dissipation, deflection levels and peak forces experienced by vehicle occupants when compared with semi-rigid and flexible barriers. (Duncan, Corben, Truedsson and Fitzharris, 2001). The significant risk of vehicle roll-overs, and the inherent risk of poorly designed end-treatments for rigid barriers (Corben, Tingvall and Wilson, 1999) as well as rebounding are also problems associated with concrete barriers.

Although less severe in its means of restraining the errant vehicle, steel-beam guardrails can still cause severe injury, have the potential to spear a vehicle through poorly designed terminal treatments and are of limited effectiveness in impacts with heavy vehicles. A number of specific cases investigated by the Victoria Police have shown how a steel W-beam barrier has failed to contain a heavy vehicle in 60-100 km/h zones at approach angles of 20-45°. In some of these cases, the heavy vehicle has rolled over on excessive slopes, resulting in fatal injuries to drivers of these vehicles (Corben et al., 2003). Pak Poy and Kneebone (1988) found that, according to Australian crash data, guardrail is rarely the most effective countermeasure against crashes with fixed roadside objects, indicating that it is often more practical to remove any fixed hazards or reduce the severity index of the hazard (for example, through the use of slip bases on utility poles).

Current countermeasures to date, have also made only incremental improvements to roadside safety, Corben, Deery, Mullan, & Dyte (1997), finding that a range of engineering treatments implemented in Victoria between 1989/1990 and 1993/1994, with the aim of reducing the incidence of collisions into fixed roadside objects effectively reduced all casualty crashes by only 8.6% on average and crash costs by 15.5%.

A relatively new countermeasure, involves placing extended lengths of flexible barrier along sections of roadway in Victoria. With respect to the majority of vehicles, these barrier systems conform particularly well to the performance criteria stated by Ogden (1996), that conflicting objectives of safety barriers are that they must be capable of re-directing and/or containing an errant vehicle but must not impose excessive deceleration forces on the vehicle occupants.

Sweden, a world leader in road safety, has utilised flexible barriers to reduce dramatically fatal and serious injury crashes for the target crash types on treated routes by as much as 90% (Corben et al., 2001). This has been achieved through extensive use of flexible barriers and resulting in part, in the introduction of the innovative "2+1" road configuration. Below is a detailed account of the current crash and injury situation in Sweden, the benefits of the applied treatments and ways in which this treatment strategy can be transferred to Victoria's and indeed, Australia's roads, to address the major trauma resulting from vehicles leaving the roadway.

# 4 SWEDISH ROADS

## 4.1 SWEDISH FINDINGS

In order to establish whether the treatments applied on Swedish roads are compatible with the Australian road conditions and to provide a greater insight in to the effects of flexible barrier treatment, relevant Swedish experiences have been summarised below.

### 4.1.1 Fatality Study

The traditional crash data found in police statistics do not provide adequate detail of the crashes and sequence of events. Information on road design, presence of alcohol, seat belt usage and speed are often either missing or unreliable.

Therefore, the Swedish National Road Administration (SNRA) has been conducting in-depth studies of every traffic fatality since 1997. The material collected provides a better opportunity to find answers to questions left unanswered by traditional statistics.

The study was conducted on single-vehicle crashes that occurred on the national road network between 1997 and 2000. Two hundred and ninety single-vehicle crashes that claimed the lives of 305 people were analysed in order to obtain information such as the collision force, the road environment and driver respect for traffic rules and regulations. Some findings from this study have been summarised below (see Appendix C for detailed findings):

*Road Alignment*

- *More than half of the 290 crashes occurred on the outer curves, a little more than a third on the straight stretches and only a few crashes occurred on the inner curves. On roads with an AADT of 4,000-5,999, 65% of the crashes occurred on straight stretches.* The percentage of vehicles that ran off the road on outer curves was greater on roads with low traffic volumes, which are often narrow and winding
- When examining a crash site, the side of the road on which a vehicle ran off is also studied. *Vehicles ran off the road almost as frequently to the left as to the right*: 41% running off to the left, while 49% ran off to the right. Only 10% of the crashes involved a vehicle that exited and re-entered the road more than once before coming to a final stop

*Fixed Roadside Hazards*

- *Seventy percent of the crashes involved collisions with various kinds of fixed objects, with trees accounting for more than half. Other fixed objects included light poles, signage posts, rock faces or boulders.* These fixed objects were located an average of 4.7 m away from the road, with half of them located either in or immediately after an outer curve. *This would indicate that countermeasures should primarily be targeting crashes on outer curves and the length of road immediately after the curve.* In 25 cases, collision with a post produced the greatest force. Eight of these posts were on roads where the AADT was 2,000-3,999. The study found that rigid columns could penetrate deeply into the occupant compartment, especially those of a lattice design. The more modern, “collapsible” or frangible posts would probably have saved lives in ten of the 25 crashes

*Clear Roadsides*

- Standards for verges in Sweden specify a slope of at least 1:4, and a width of eight-ten metres with all fixed objects cleared. *The study results indicate that verges were only found in four instances of the 290 crashes included in the study.* This is probably due more to the fact that there are not many kilometres of road with flat verges rather than that few fatal crashes occur where the verges are flat
- *In 188 of the crashes, the vehicle came to a halt at the far edge of the verge or beyond. In a total of 70% of the crashes the verge was so narrow that the vehicle did not stop until it reached the far edge of it or beyond.* This clearly shows that the verges on today’s roads are altogether too narrow in relation to the speeds driven

*Speed Limits*

- *Roads with speed limits of 90 and 110 km/h constitute 29% of the total road length but account for no less than 49% of the fatal crashes.* When undertaking remedial road works, priority should thus be given to stretches where the speed limit is either 90 km/h or 110 km/h
- *It was estimated that four out of ten crash-involved drivers had kept within the posted speed limit; two out of ten had driven fast enough to be fined; and almost four out of ten had driven at a speed that would have cost them their driver’s licence*

*Seatbelt Usage*

- *Two hundred and seventy two people travelled under conditions in which a seat belt was available for use – of these only 83, or 31%, were using it. Sixty-eight of the 84 people who were killed when their vehicle rolled over in a ditch without hitting a fixed object, were not wearing their seat belt. It was estimated that a seat belt would have saved the lives of 66 of these 68 people.* This indicates that as long as the vehicle does not hit any fixed object and that a seatbelt is being used, there is a good chance of surviving a rollover crash with the ditch design in Sweden
- *The use of a seat belt would not have been able to save the lives of the vehicle occupants in 116 of the 171 crashes involving collisions with fixed objects (motorcycles excluded) as the occupant compartment had been crushed too badly by trees, columns, rock, etc.*

*Other Factors*

- The study also shows how inadequate even the best-designed cars are in relation to existing travel speeds and the physical road environments. *In 104 of the 234 crashes involving a passenger vehicle, the vehicle was so badly crushed that a seat belt would not have saved the life of the occupant.* This applied to both new and old cars. Particularly serious were roof or side impacts with a narrow object. At speeds as low as 70 km/h the collision force is enough for a column to penetrate through the side of a car and reach the gear box. Hence, it is important that there are no trees or light poles close to the edge of the carriageway even where the speed limit is as low as 50 km/h. Another alternative would be to replace traditional style posts with frangible ones

- In 145 of the 290 cases studied, it was found that the driver was under the influence of alcohol or drugs (19 were on drugs). *This means that alcohol/drugs had been detected in 50% of single-vehicle crashes on the rural road network that ended in death.* The introduction of alcohol ignition interlocks would probably have a considerable effect on reducing the number of people killed in single-vehicle crashes

*Flexible Barrier Performance*

- Flexible barriers alone would probably have saved lives in no less than 72% of the crashes. Since more than half the crashes occurred on an outer curve, priority should be given to setting up barriers on outer curves and immediately after them. In practice, this means that the barriers should be extended on either side of the road since almost as many cars run off the road to the left as to the right on outer curves

On summing up, the conclusion appears to be that a combination of 100% seatbelt usage and the presence of flexible barriers or wide, cleared, flat verges would almost completely remove the risk of people being killed in single-vehicle crashes. There are, however, cases where the speed and angle of impact are such that a barrier or a wide verge would not help, indicating that the speed of impact plays a vital role in the consequence of a collision. That is, if everyone used seat belts, flexible barriers or wide, clear, flat verges existed and if the speed limits were respected, a fatal outcome could probably be avoided in almost all single-vehicle crashes.

### 4.1.2 Crash History

ROR and head-on collisions are the main safety issues on all two-lane, undivided roads in Sweden, causing more than 66% of all fatalities, resulting in the deaths of 112 people per year through ROR crashes, and 140 people per year through head-on collisions. The sequence of events tends to be the same - the driver loses control for a particular reason and often crashes into an obstacle on the roadside or into a vehicle travelling in the opposite direction.

Single-vehicle crashes often have a serious outcome and account for more than a third of all road traffic fatalities in Sweden. Approximately 75% of all fatal single-vehicle crashes occur on the Swedish rural road network.

*Head-on collisions*

Head-on collisions are in fact often run-off-road crashes that collide with a vehicle travelling in the opposite direction instead of a fixed roadside objects. The process and the causes leading up to these crashes again are very similar.

### 4.1.3 Spatial Distribution of Crashes in Sweden

In Sweden, head-on collisions and ROR crashes are correlated with the traffic volumes on the road. That is, a high concentration of these types of crashes occurs on a small percentage of government roads. This allows large numbers of severe head-on and single-vehicle crashes to be addressed along a short length of road.

*Head on collisions in Sweden*

Head-on crashes are heavily correlated with the traffic volume of the road network. The majority of head-on crashes occur on a very small percentage of road. Figure 1 draws a relationship between the number of fatalities and the percentage of the road network where these fatalities occurred, based on the traffic volume. The x-axis in Figure 1 shows the road length by traffic volume and the y-axis shows the number of people killed.

According to Figure 1, 80% of head-on crashes can be addressed by focussing on 15% of the road network.

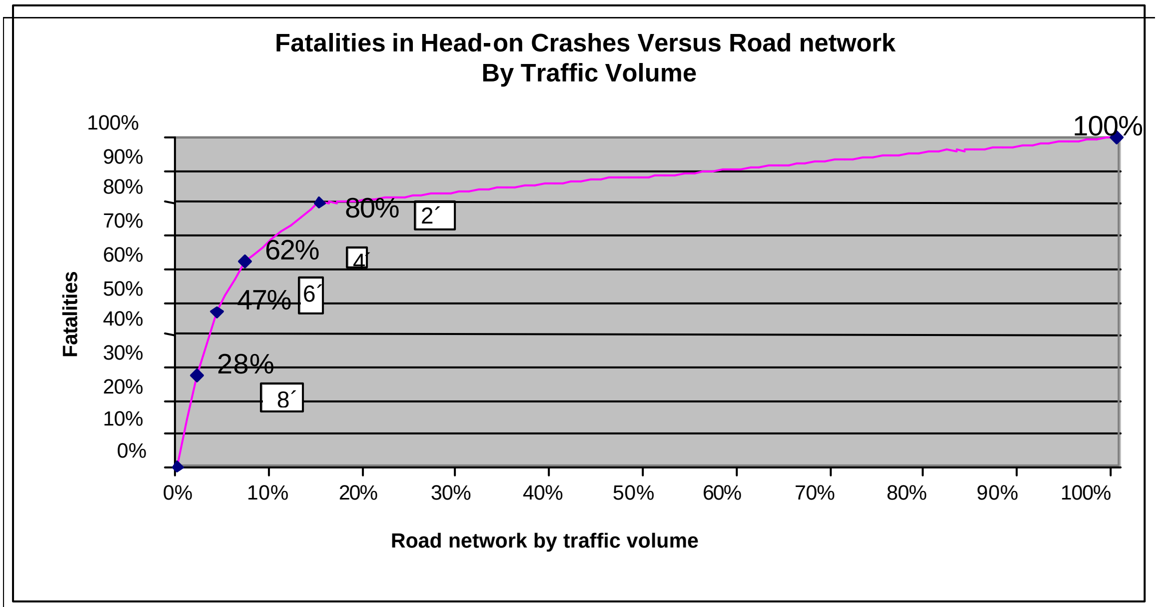



*Figure 1 - Killed in head-on collisions 1993-2000 on Swedish national roads (Motorways excluded)*

Even when the number of severely injured is added to those killed in head-on collisions (crashes on motorways excluded) and the traffic volume is taken in to account, there is still a high concentration of crashes occurring on very small percentage of the road network as seen below:

- 2% of the roads were involved in 22% of fatalities and severe injuries
- 5% of the roads were involved in 37% of fatalities and severe injuries
- 7% of the roads were involved in 53% of fatalities and severe injuries
- 15% of the roads were involved in 74% of fatalities and severe injuries

In other words, a large part of the road network (85%) accounts for only a small percentage of the fatalities and serious injuries resulting from head-on collisions (26%), suggesting that only a small portion of the road network needs to be addressed in order to have a great impact on the number of head-on collisions.

*Single-vehicle crashes in Sweden*

As with head-on collisions, a large percentage of single-vehicle crashes are concentrated on a very small percentage of the road network (Figure 2). Single-vehicle crashes are strongly correlated with the traffic volume on the road.

About 80% of the road toll due to single-vehicle crashes can be addressed by focussing on about 40% of the road length.

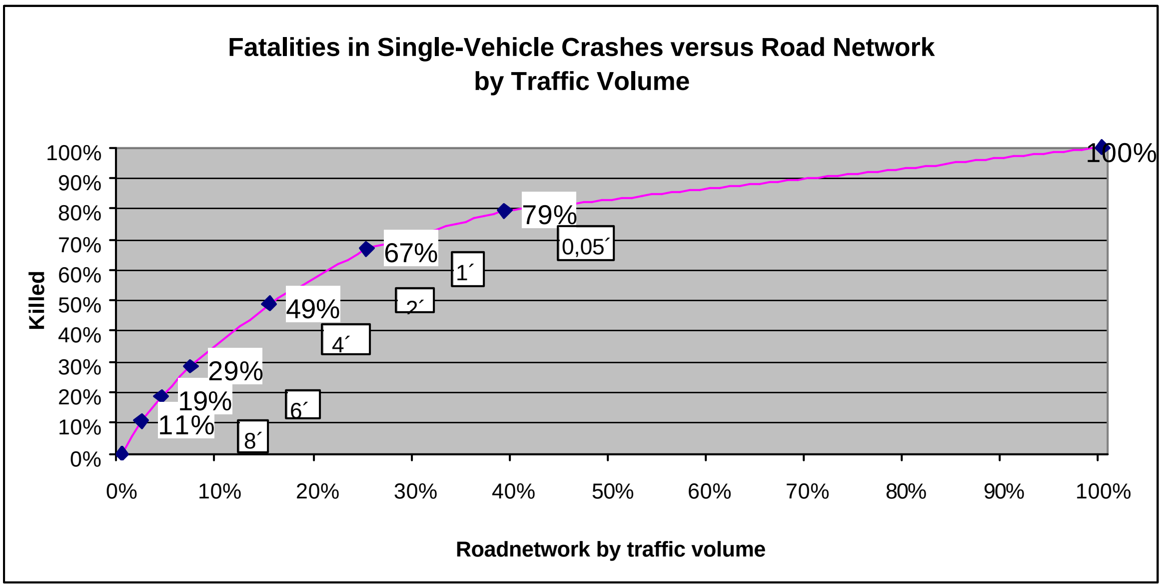



*Figure 2 - Killed in single-vehicle crashes 1993-2000 on national roads (Motorways excluded)*

In this category of crashes, when the number of severely injured is added to those killed in single-vehicle crashes (excluding motorways) and the traffic flow is considered, the concentration of crashes is even greater, as can be seen below:

- 2% of the roads were involved in 11% of fatalities and severe injuries
- 4% of the roads were involved in 20% of fatalities and severe injuries
- 7% of the roads were involved in 31% of fatalities and severe injuries
- 15% of the roads were involved in 53% of fatalities and severe injuries
- 25% of the roads were involved in 71% of fatalities and severe injuries
- 39% of the roads were involved in 84% of fatalities and severe injuries

In other words, a large part of the road network (61%) accounts for only a small percentage of the fatalities and serious injuries resulting from single-vehicle crashes (16%), suggesting that only a small portion of the road network needs to be addressed in order to have a great impact on the number of single-vehicle collisions.

Other information of interest on barrier crashes is as follows:

- Sixty-five percent of crashes occurred along one-lane segments

- Only 8% occurred in the transition zone from two lanes to one lane. This is a slightly lesser proportion than the length of road with two to one transitions (about 10%)
- About 50% of crashes have occurred in the winter period, between December-March. The proportion of the yearly distance travelled during these months is just 25%. In many cases skidding is the primary cause for a barrier crash
- Barrier crashes tend to be a winter problem

Some data have also been reported from other projects. The variation in findings tends to be significant between individual projects. Significant efforts have been made to investigate possible methods of reducing the number of crashes into barriers including analysing the effects of embedded and noise producing road markings and visual devices placed on barriers

## 4.2 IMPLEMENTED TREATMENTS IN SWEDEN

There are two alternative treatments employed in Sweden to address the problem of head-on and ROR crashes. The main possibility is using the 2+1 barrier concept and the second, more costly alternative, is to widen the road to a narrow 4lane road with dimensions of 15.75 m, with two lanes in each direction, separated by a cable barrier (denoted by 15.75:2+2cb), primarily in order to improve speed performance and decrease safety risks at vehicle breakdowns and to ease maintenance tasks.

Although some pipe fencing is used as barrier in Sweden, it is more costly and therefore not as cost efficient.

### 4.2.1 2+1 Concept

The 2+1 concept has flexible barriers (Figure 3) placed along a road layout of one continuous lane in each direction and one middle lane alternating the permitted direction of travel at intervals of 1.5-2.5 km. The layout allows central barriers to be placed while still allowing opportunities for two-lane travel for both directions. The length of the interval depends on factors such as road alignment and locations of intersections. On-coming traffic is separated by a flexible mid-barrier, preferably within the existing width of 13 m (denoted as 13: 2+1cb). The roadsides ideally would be cleared or side barriers erected.

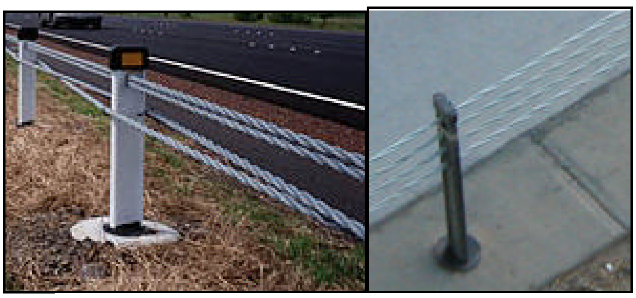


*Figure 3 - two typical designs of flexible barrier*

### 4.2.2 2+1 Cross-Section

The cross-section for the existing 13 m roads (see Figures 4 and 5), generally comprises of:

- A 1.25 m flush median with a continuous flexible barrier (based on the Committee for European Normalisation (CEN) standard, containment class N2 and working width W5, see Appendix D for details)
- 3.25 m wide traffic lanes in the two-lane direction and 3.75 m wide lane in the one-lane direction
- 0.75 m outer hard shoulders to accommodate any low volumes of pedestrians and cyclists
- A 1.0 m strip of road with full bearing capacity but without an overlay can be added on the side of the one-lane sections for emergencies if necessary.

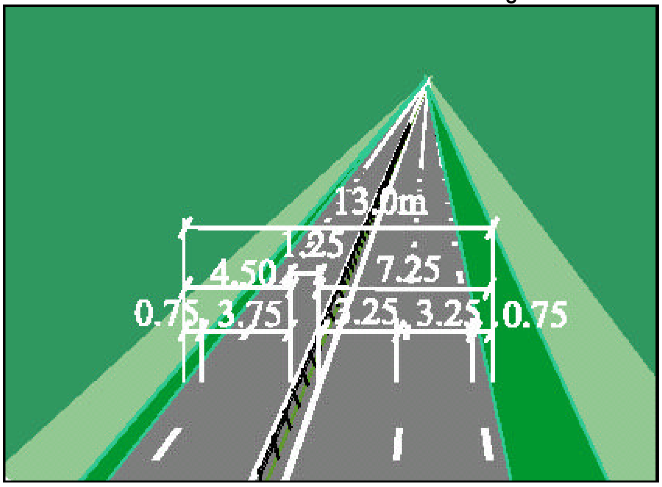



*Figure - 4 Road cross section for a 2+1 concept treatment*

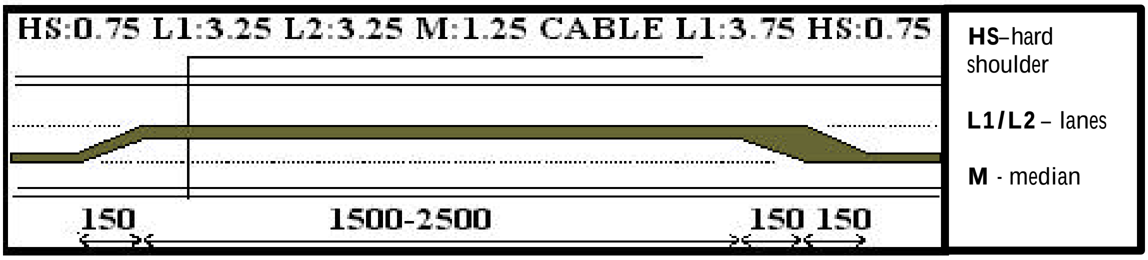



*Figure 5 - Proposed standard for 2+1 cable barrier cross-section within existing 13 m road*

"Transition zones" where the lanes merge from two lanes to one or vice versa have a length of 150 m, 300 m in total for both directions. Cable posts erected 10 m apart along the transition zone are fitted with delineators. For transitions from two lanes to one lane, double-sided signs inform the commuter of approaching lane-closure 400 m ahead of the actual merge, and at the commencement of the transition zone, see Figure 6. Transition zones from one to two lanes are 100 m long. Quick-locks create openings in the flexible barriers situated in transition zones.

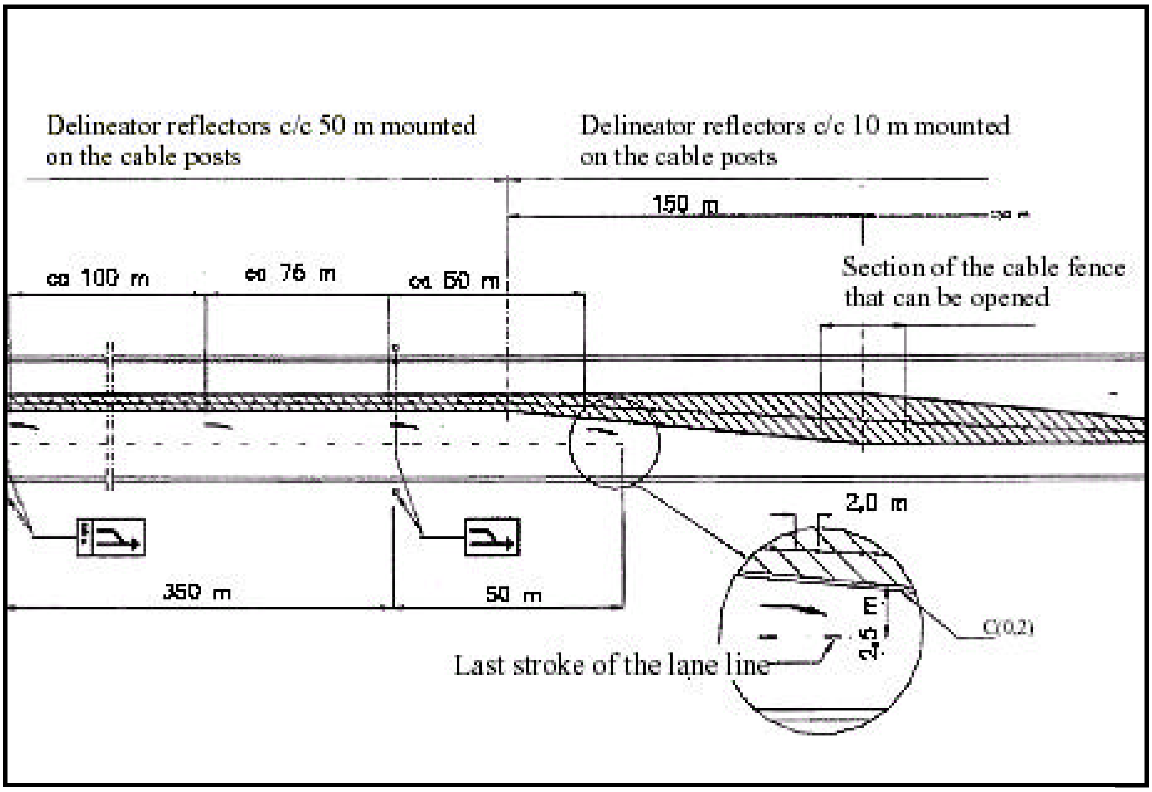



*Figure 6 - Design principles for 2+ 1 lane transition zones*

Existing roadside areas would be cleared within the right-of-way. This means that solid objects and trees should be removed and culvert ends protected. Side cable barriers should be used at dangerous locations such as right bends at rock faces and on all embankments within forest regions (see Figure 7).


*Figure 7 - Example of side and median cable barrier fence in a forest*

### 4.2.3 2+2 concept

A subset of the 2+1 concept is the 2+2 design where two or more lanes operate in each direction separated by flexible barrier placed either along the road centre or directly on the pavement. This design would be used along multi-lane divided and undivided roads as well as to avoid creating 1-lane sections on road inclines, or to improve traffic performance on sections of road where widening is feasible.

### 4.2.4 1+1 concept

Another subset is the 1+1 design where only a single lane exists in each direction separated by flexible barrier. This design could be used on long bridges that can be quite expensive to widen, and on sections of road with numerous access points. This design is also suitable for areas that have a heavy flow of pedestrians and cyclists, and where creating a separate path would be too costly or impossible – flexible barriers would separate one of the existing lanes for exclusive use by these road users.

## 4.3 RESULTS OF BARRIER USE IN SWEDEN

In total, approximately 670 km of roadway were opened for traffic in 2002 and of these, 630 km have been converted to 2+1 roads with flexible barriers along the median.

### 4.3.1 Crash Reduction

*Two-lane roads (13 m) with Restricted Access (semi-motorways) converted to a 2+1 cross section.*

The results so far correspond approximately to a reduction of 45 - 50% in the number killed and seriously injured in all crash types. Currently, the reduction in fatalities only, is up to 90%.

*13 m-roads, undivided converted to a 2+1 cross section.*

The results so far correspond approximately to a reduction of 35 - 50% in the number of killed and seriously injured in all crash types. Currently, the reduction in fatalities only, is up to 76%.

The reduction of crash energy by crashing into flexible barriers instead of into oncoming vehicles or fixed roadside object is an improvement in safety. To be able to go further though with the development of this idea of road design, the severe injuries that have occurred on 2+1 roads would need to be thoroughly examined to determine whether they really are severe. The use of biomechanical facts can be used to improve the cars and the road design. It is also important to determine the percentage of usage of personal protection systems such as seatbelts.

Details pertaining to serious injury crashes are not collected as meticulously as for fatal crashes, therefore reduction rates that include serious injuries are not as accurate.

The main conclusion however, is that a great number of crashes have been prevented as a result of median barriers although crashes against the barriers resulting in slight or no injuries have increased.

On all the lengths of semi-motorways with central barriers, a total of 121 crashes have occurred, with no one being killed or seriously injured as a direct result of impacting the barrier.

The three deaths that have occurred on the 2+1 roads were not as a result of the installation of flexible barriers: one cyclist was going the wrong way on a semi-motorway and was killed by oncoming traffic; one car driver died while pushing his car along the road - he had run out of fuel on a semi-motorway; and the third fatality was of a car driver who died in a ROR rollover on a previously undivided 13 m road. The usage of the seatbelt is unknown but the passenger survived with only minor injuries. There have been six serious injuries between 1998 and 2001 but the injuries are not directly attributed to crashing into the barriers. No motorcyclists have been involved in these crashes.

Collisions with flexible barriers along the road centre are very frequent, around 1 crash per week (National Cooperative Highway Research Program, NCHRP, 2003), but normally without injury to occupants. Factors such as skidding, flat tyres and loss of control often cause these crashes. A number of potentially severe crashes were constrained to only minor, or no-injury crashes as a result of flexible barriers along the road centre.

The flexible barrier end terminals used have been tested and approved. It has been concluded that they do not cause any “ramping” effects often associated with the terminals of guardrails.

### 4.3.2 Traffic operations

*Capacity*

The capacity in one direction is estimated to be about 1550 veh/h (on 90 km/h speed zones) and 1500 veh/h (on 110 km/h speed zones), some 400-450 veh/h less than for an ordinary 13 m road.

The transition zones have performed well in terms of traffic operations. The proportion of vehicles in the beginning of the zone, at any one time, is small. Drivers tend to handle the design of the transition zone in a cautious and responsible manner.

*Vehicle speeds and travel times*

Level-of-service for normal traffic is better than expected. Floating car studies confirm a good level of service at traffic flows up to 1,300-1,400 veh/h in one direction, (NCHRP, 2003). Speed performance on 2+1 roads with flexible barriers is the same or even better (a slight increase of 1.5 km/h on 90 km/h zones has been recorded) than on ordinary semi-motorways at one-directional flows of up to 1400 veh/h.

### 4.3.3 Road and barrier maintenance and repairs

To date, there have been 159 crashes on the E4 Gävle-Axmartave roadway, about one crash per week along this road. About 30% of the crashes were reported to the police and could be investigated. Only 30% of these reported crashes were direct collisions with the barriers, probably caused by lack of concentration. All other cases were preceded by skidding, flat tyres or uncontrolled manoeuvres.

- Work zone area safety is a major concern. Repair work (Figure 8) has so far been conducted under a Truck Mounted Attenuator (TMA) - having the overtaking lane closed and providing only one lane for each direction of traffic. One serious incident occurred where a passenger car crashed into a road lane closure device at high speed. Other concerns are emergency blockages and emergency vehicle operations


*Figure 8 - Maintenance of barriers*

The maintenance standard includes the following requirements:

1. Bridge inspections, overlay repairs, etc. should be co-ordinated to minimise the number of traffic diversions. Delineator post washing, etc. should be performed during low traffic volume conditions.
2. Snow should be removed in the first 0.4 m of the median. Edge lines should be visible.

### 4.3.4 Access Issues

*Emergency Service Access*

Permanent emergency openings are established every 3-5 km along the flexible barriers to allow emergency vehicles to U-turn.

*Access to and from properties and intersections*

Ideally, access roads should be minimised (perhaps through the use of frontage roads), and pedestrians and cyclists should be separated from other traffic where it is possible to do so at reasonable costs.

In general, major issues relating to 2+1 roads involve creating appropriate conditions for access traffic, vulnerable road users and addressing narrow one-lane sections. Narrow one-lane sections in particular, sometimes only 5m wide if the road has not been widened, can create road blockages at emergency truck stops and lower standards of emergency services and conditions for maintenance.

*Figure 9 - Flexible barriers on site*

#### 4.3.5 Public Opinion - Driver Attitudes

General survey results indicate that about 80% of those surveyed say that they want all major roads to have median barriers.

On the first length of E4 Gävle-Axmartavlan, driver attitude surveys were conducted on two occasions - autumn 1998 and autumn 1999. Some of the results have been summarised below (Carlsson et al., 2000 and 2001):

- The survey from autumn 1998 showed that most drivers preferred the 2+1 design, with only road markings, to an ordinary two-lane road. Only a marginal number, less than 1%, had the 2+1 with flexible barriers as the best alternative.
- In a new survey in autumn 1999, about 40% of the drivers considered 2+1 with flexible barriers to be the best design as opposed to 30%, who still preferred the 2+1 format with only road markings. The change in attitudes is large and significant. The changes were greatest amongst personal car drivers who were interviewed at the roadside, and included a large proportion of non-local traffic.
- It is clear that the people surveyed, both the roadside drivers and local people, have changed their attitudes toward the 2+1 road format with flexible barriers from a generally very negative attitude to a general acceptance of the design, based on their personal experiences during one year of driving.

A major public attitude survey has also been conducted on the E18 roadway with even better results.

### 4.4 COSTS OF IMPLEMENTING THE 2+1 ROAD FORMAT IN SWEDEN

The average total investment cost so far, to convert semi-motorways and 13 m roads to 2+1 roads with flexible barriers, is listed in Table 1 below:

*Table 1:Costs for the conversion of current road formats to include flexible barriers systems*

| | SEMI-MOTORWAYS | 13 m UNDIVIDED |
|---|---|---|
| **Swedish Currency (SvKr) per metre** | 1,300 | 2,000 |
| **Australian Currency ($AUD) per metre** | 250 | 380 |
| **% of total cost for FB installation ($AUD) per metre** | 21($55) | 16($60) |

As at May 2001, maintenance costs were about AUD$23,000 per km per year with around AUD$15,000 of this for cable repairs.

## 4.5 SPECIAL CASE - MOTORCYCLISTS

To address the concerns of various groups on the effect of flexible barriers on motorcyclists, motorcycle crash analysis has been presented below.

### 4.5.1 Fatal Crash Facts

In a Swedish study of all motorcyclists killed between 1997-1998 in Sweden, approximately 69 cases show the following results:

**Speed limit**:

| | |
|---|---|
| 30 km/h | 1% |
| 50 km/h | 23% |
| 70 km/h | 39% |
| 90 km/h | 26% |
| 110 km/h | 11% |

**Crash Types**:

| | |
|---|---|
| Side impact | 46% |
| Intersection | 19% |
| Head-on | 17% |
| Rear | 7% |
| Game | 6% |
| Median/guardrail etc | 4% |
| Other | 1% |

**Cause of death:**

| | |
|---|---|
| Head/brain | 39% |
| Whole body | 22% |
| Chest | 10% |
| Neck | 6% |
| Torso | 4% |
| Vein/bleeding | 9% |
| Spine | 1% |
| Emboli | 3% |
| Missing | 6% |

**Pre-crash factors:**

| | |
|---|---|
| Serious speeding | 49% |
| Alcohol/drugs | 20% |
| Own mistake | 16% |
| Mistake by other | 12% |
| Vehicle failure | 3% |

**Roadside objects:**

| | |
|---|---|
| Rock | 23% |
| Road sign pole etc | 16% |
| Lightpole | 6% |
| Tree | 13% |
| Urban fence | 13% |
| Guardrail/wirerope | 13% |
| Concrete | 3% |
| Airborne | 10% |
| Ditch | 3% |

That is, a large percentage of these motorcycle crashes occurred in 70 km/h zones; speeding contributing to about half of the crashes. Rock faces and road signs contributed to around 40% the crashes, and around 40% involved head and brain injuries. Side-impact collisions were the most common.

*Notes*

- In 14% of the cases, the motorcyclist was without a helmet
- In 9% of the cases where the motorcyclist had a helmet, the helmet dropped off, leaving him/her without protection for the head in the subsequent crash
- In 32% of the cases the motorcyclist had borrowed the motorcycle for a test ride
- In 14% of the cases the rider was without rider's licence
- 64% of the fatal crashes occurred on a motorcycle with an engine of greater than 600-cc
- 22% of the fatal crashes occurred on a motorcycle with engine greater than 1000-cc

*Additional Information*

- Motorcyclists have been involved in five fatal crashes that have lead to the deaths of three pedestrians, one cyclist and one passenger of a car
- In four cases the passenger on the motorcycle was also killed
- In one case, a mid-barrier would have saved the life of a motorcyclist by preventing oncoming traffic from entering his or her own lane

### 4.5.2 Possibilities of Improving Barriers for Motorcyclists

Some options that have been considered in order to improve the design of barriers for motorcyclists are:

1. A plastic fence (similar to the safety fences placed on downhill ski slopes) to avoid both impact and trajectory, effectively reducing impact energy to survivable levels with either no impact or before impact into roadside objects such as guardrail
2. Clearing the roadside and smoothening it with LECA marbles, (soft clay marbles), as on the tracks in the Grand Prix motor racing circuit. This solution handles trajectory quite well. The rider is decelerated gradually by a pile of clay marbles being ploughed in front of the vehicle/body. This requires a great distance to any roadside object to allow a significant decrease in speed with little or no impact
3. Adding padding to flexible barrier posts might improve the crashworthiness of the posts for motorcyclists in lower energy level crashes. There is an ongoing study for alternative guardrail for safer motorcycling through post-impact trajectory of motorcyclists in Malaysia, according to Ibitoye, A.B., Wong, S.V., Radin Umar, R.S., Hamouda, A.M.S. and Law, T.H., (2002)
4. Collaboration with the motorcycle manufacturers is crucial for achieving the best possible result in developing a more motorcyclist-friendly barrier. Already some manufacturers have created possible components that can be added on to the existing flexible barriers to address issues particular to the motorcycle rider. The interaction between the rider, the vehicle and the road has to be developed rapidly

## 4.6 SWEDEN'S STRATEGY FOR SECURING THE INFRASTRUCTURE, TRAFFIC SAFETY PLAN 2007

The Infrastructure Traffic Safety Plan 2007 strategy is making the infrastructure safe on rural roads with their current large traffic volumes and high speed limits.

On 15% of the road length, preferably called "Black types" (as opposed to Blackspots), it is cost-effective to address the safety problems using measures to separate oncoming traffic. The solution is to use mid-barriers, preferably flexible barriers, converting the road to a 2+1 or 1+1 format.

Roads with speed limits of 90 km/h or more, a width of over 7.9 m and traffic volumes greater than 2,000 AADT, as well as roads with speed limits of 70 km/h, widths between 11.5 m – 15.9 m and traffic volumes of over 8,000 AADT, should be designed and operated to prevent severe head-on and ROR collisions. This means converting the roads in to 2+1 or 1+1 roads with a separating flexible barrier through the road centre and clearing the roadside of objects or preferably installing flexible side barriers.

On 40% of the road length (again, preferably called "black types"), it is cost-effective to address single-vehicle crashes into the roadside through the modification of the infrastructure. The solution is to place side barriers, preferably flexible, along the roadways or if suitable, roadsides could be cleared of all hazardous fixed objects.

Roads narrower than 7.9 m and AADTs of over 2,000; all roads wider than 7.9 m and with AADTs of over 2,000 and a speed limit of 50 or 70 km/h; and all roads with traffic volumes of between 500 and 1,999 AADT, should be designed and operated to prevent severe ROR collisions. As noted above, this means clearing the roadside of hazardous objects or preferably installing flexible side barriers.

On 60-85% of the roads (roads with low traffic volumes), it is not presently cost-effective to address the safety problem with infrastructure measures. In these cases, it is more cost-effective to reduce travelling speed to a survivable crash speed, though this strategy will not be suitable for many of the strategically important roads.

This leads to the strategy that modifies travel speed to the current safety standard of the roads, i.e., a "safe crash" speed. On all roads that have not already been made safe in terms of severe head-on collisions, the travelling speed should be reduced by 6 km/h, using all possible measures.

## 4.7 SWEDISH FUTURE

Sweden is now investigating and planning for roads with traffic volumes of less than 4,000 AADT and road widths of less than 13 m. The solution is called 1+1 with overtaking lanes and "passing pockets", and will have flexible barriers to separate oncoming traffic.

## 4.8 FEASIBILITY OF ADOPTING SWEDEN'S TREATMENT MEASURES ONTO VICTORIAN ROADS

The feasibility evaluation will be based on how well the above issues are addressed with respect to Victorian roads as well as noting some identified advantages:

- Victoria and Sweden's similarities with respect to road standards
- Victoria and Sweden's comparable crash rates

Table 2 presents a brief comparison of conditions in Victoria and Sweden.

*Table 2: Comparison of Swedish and Victorian conditions*

| | SWEDEN | VICTORIA |
|---|---|---|
| **Car Ownership Rate (per 100 people)** | 49 | 68 |
| **Motorcyclists** | 120,000 | 30,000 |
| **Length of Road Network (km)** | 420,000 | 200,000 |
| **Speed Limits** | 90 – Highways<br>110 – Freeways | 100 – Highways<br>110 - Freeways |
| **Fatality Rate (per 100,000 population)** | 6.7 | 8.5 |
| **Motorcycle Helmet Regulation** | Compulsory | Compulsory |
| **Seat Belt Regulation** | Compulsory | Compulsory |
| **BAC** | .02 | .05 |
| **State of Headlights** | On 24 hours | On after dusk |

# 5 VICTORIAN ROADS

## 5.1 APPLICATION ON VICTORIAN ROADS

Having established the treatment applications and the effectiveness of flexible barriers in Sweden, it is imperative to determine how smoothly similar principles can be applied on to Victorian roads. The treatment is analysed below according to the three main categories of road in Victoria:

1. Four-lane, two-way, divided
2. Four-lane, two-way, undivided
3. Two-lane, two-way, undivided

Direct application of Sweden's 2+1 barrier system along Victorian roads is not necessary to change fundamentally injury risk for the occupants of vehicles that leave the roadway. The system in Sweden was created to combat both its single-vehicle crashes as well as its high number of head-on collisions along its undivided, rural roads – hence, the introduction of a central barrier specifically to separate on-coming vehicles. The 2+1 configuration was a necessary adaptation in Sweden to accommodate the concept of central barriers within restricted road reservations, while improving traffic operations.

It should be noted however, that the high level of success attained through the use of this barrier system (whose principal components are the flexible barriers and the 2+1 road layout) is mainly attributable to the effectiveness of flexible barriers rather than the 2+1 road layout per se. This suggests that the use of flexible barriers with or without the 2+1 lane configuration should still produce the predicted major reductions in road trauma.

This section therefore focuses on how to realise the benefits of flexible barriers in Victoria, while adapting its use to Victorian road safety needs. For example, a large proportion of single-vehicle crashes occur on Victoria's high-speed, "high-class" roads that have superior road standards in terms of driveability and traffic operations but can be often dangerous in terms of their standard of roadside environment. These roads have multi-lane, divided formats and therefore do not require the introduction of the 2+1 road layout for success, similar to multi-lane, undivided roads. Application of the barrier system along these roads is therefore relatively easy, as extensive road format modification is not required to accommodate barrier systems.

Incorporating the 2+1 format on to Victorian two-lane, undivided roads however, will be somewhat more challenging as the majority of these roads in Victoria are approximately ten metres in width, compared with 13 m widths in Sweden. Creating or using existing overtaking lanes (similar to the "passing pockets" being investigated in Sweden), is considered a more practical and cost-efficient alternative to widening Victorian roads to include continuous overtaking lanes as in the 2+1 format.

As the application of the barrier system along multi-lane, divided roads is generally considered the most straightforward however, and as studies tend to indicate that a major proportion of the run-off-road crashes occur along these roads, it is suggested that initial focus be given to the application of barriers along these sections of the road network in Victoria, followed by multi-lane, undivided roads and then two-lane, undivided roads. This will allow a more gradual transition in the extensive use of flexible barriers in Victoria.

The section below presents treatment options for single-vehicle and head-on crashes that occur on Victoria's typical road formats, adopting and modifying Sweden's innovative treatments such that the concept of flexible barriers can be used as successfully on Victorian roads, while still accommodating the differences in Victorian road networks.

### 5.1.1 2+2 divided roads in Victoria

*Typical Cross-sections and Examples of Roads*

M-standard roads

- Two or more lanes in each direction
- Generally 3.5 m wide lanes
- 3.0 m outer shoulders sealed
- Central median
- Clear, ample delineation

*Typical Examples of Roads: Hume Highway and Monash Freeway*

*Suggested Treatment*

Placing barriers continuously along either side of the median and on both sides of the road will provide the highest level of road performance in terms of crashworthiness.

With this solution, trees and other hard objects can remain in the median and along the roadside, as long as they are not within the working width of the flexible barrier. This is a very positive aspect for the environment and landscape.

*Expected Effect*

It is predicted that the road toll (for all single-vehicle crashes) would decrease by up to 90% once the road includes flexible barriers.

As a result, potentially severe head-on collisions and ROR crashes would be transformed into crashes against the barrier with, in many cases, slight or no injuries.

Flexible barriers will not address rear-end collisions; these will remain a significant problem. Treatment solutions for this crash type specifically are most likely to come from the car industry with developments such as the "Safe Car" project, rather than through modification of infrastructure. The vehicle manufacturing industry is developing greater crashworthiness and anti-collision warning systems to address the issue of rear-end collisions.

*Public Opinion - Drivers Attitudes*

As the 2+2 cross-section maintains the existing road design, barriers being placed on the median and along the roadside, this treatment option is unlikely to generate concern among car drivers. Motorcyclists, on the other hand, are likely to be concerned with the use of flexible barriers and therefore they should be invited to take part in the discussion and development of barrier-use on high-speed roads in Victoria.

*Traffic Operations*

It is anticipated that there will be no change in capacity of the road, as the road cross-section will remain the same. Road closure due to severe traffic crashes will decrease. An increase in minor disturbances due to crashes into barriers will occur, which will be similar to the current situation of incidents and crashes.

*Vehicle Speeds and Travel Times*

No significant change in travel speeds is expected.

*Emergency Service Access*

Permanent emergency openings are to be established every 3-5 km in the flexible barrier to allow emergency vehicles to U-turn. Part of the barrier can be dismantled quickly should the need arise to get across to the other side of the road.

*Road and Barrier Maintenance and Repairs*

Work zone area safety is a major concern. Repair work is to be conducted with a TMA, a closed lane and full traffic along other lanes.

*Access to and from Properties and Intersections*

Number of access roads should be minimised where it is possible to do so at reasonable costs.

### 5.1.2 2+2 undivided roads in Victoria

*Typical Cross-sections and Examples of Roads*


M Standard without duplication

- Two in each direction
- Generally 3-3.5 m in width
- May have sealed shoulders
- Clear, ample delineation
- No median

*Typical Examples of Roads: South Gippsland Hwy, Koo Wee Rup*

*Treatment*

Placing continuous barriers along the centre and sides of the road will provide the highest level of road performance in terms of crashworthiness.

As with the two-lane, two-way, divided road this solution allows trees and other rigid objects to be left on the roadside, as long as they are not within the working width of the flexible barrier, making it more environmentally friendly.

*Effect*

It is anticipated that there will be up to a 90% reduction in the number of single-vehicle crashes when the road is converted into a "divided" 2+2 road format. Again it will turn potential head-on collisions and ROR crashes into crashes against the barrier with, in many cases, slight or no injuries.

Rear-end collisions will not addressed by flexible barriers and will need to be addressed through other measures including car manufacturer initiatives.

*Public Opinion - Drivers Attitudes*

Confirming the existing road design with barriers is unlikely to generate concern among the car drivers, although there might be some initial worry regarding the restricted opportunities to cross the centre of the road as a result of the treatment. With this format as well, motorcyclists are likely to be concerned and therefore they should be invited to take part in the development of barrier-use on high-speed roads in Victoria.

*Traffic Operations*

No change in capacity is expected. Road closures due to severe traffic crashes will decrease although there will be an increase of minor disturbances due to crashes into barriers. This would be expected to be similar in number to the current situation of incidents and crashes.

Introducing mid-barriers will require modification of the existing delineation to create narrower lanes, with usage of the shoulders to accommodate the 1.25 m working width of the barrier. The shoulders will need to be constructed to its full load-bearing capacity.

*Vehicle Speeds and Travel Times*

There is likely to be no significant change to the vehicle speeds and travel times. Reduction in travel times due to drivers being more cautious within the narrower lanes is likely to be minimal.

*Emergency Service Access*

Permanent emergency openings are to be established every 3-5 km in the flexible barriers to allow emergency vehicles to U-turn. Part of the barrier can be dismantled quickly should the need arise to get across to the other side of the road.

*Road and Barrier Maintenance and Repairs*

Work zone area safety is a major concern. Repair work is to be conducted with a TMA-closing one lane with full traffic in the other lane.

*Access To and From Properties and Intersections*

The number of access roads should be minimised where possible.

### 5.1.3 1+1 undivided roads in Victoria

*Typical Cross-sections and Examples of Roads*

Can be B or C standard roads

- One lane in each direction
- Generally 3.3 m wide lanes
- 2.0 m outer shoulders, could be sealed
- Some delineation
- Could have direct access on to roads

*Typical Examples of Roads: Parts of the Midland Highway*

*Treatment 2+1*

Placing continuous barriers along the centre of the road and roadsides will provide the highest level of road performance according to crashworthiness. Given the widths of these roads are generally around 10 m in width as opposed to Sweden's 13 m roads, the 2+1 barrier layout cannot be conveniently adopted on to Victorian undivided two-lane, two-way roads. It is therefore possibly more suitable and cost effective to place barriers along the centre and sides of the undivided two-lane, two-way roads and utilise the existing overtaking lanes rather than providing continuous overtaking lanes as with the Swedish layout. The shoulders will need to be strengthened to their full-bearing capacity to accommodate the 1.25 m width required for the central barrier.

1+1 designs could be used on long bridges, which are expensive to widen, and on sections of road with frequent access roads or pedestrians and bicyclists where separation is costly or impossible, the extra lane used to cater particularly for these road-users. 2+2 sections could also be needed to avoid one-lane sections on inclined road sections and to improve traffic performance on segments with low costs for widening.

As with the other two formats, trees and other rigid objects can remain within the roadside, as long as they are not within the working width of the flexible barrier, which is very positive for the environment and the landscape.

*Effect*

It is anticipated that the road toll (for targeted crash types), would decrease by up to 75% when the road is converted into a road divided and lined with barriers. Head-on collisions and ROR crashes will now be crashes against the median with slight or no injuries. Rear-end crashes will not be addressed by this treatment.

*Public Opinion - Drivers Attitudes*

Changing the existing road design to a road divided with barriers is likely to generate concern among road users. It is important therefore to launch an information campaign to inform the public of the benefits of the design concept. Motorcyclists are particularly likely to be concerned and therefore they should be invited to take part in the discussion and development of barrier use on high-speed roads in Victoria.

*Traffic Operations*

It is expected that there will be a slight decrease in road capacity - the capacity is estimated to be about 1550 veh/h (90 km/h) and 1500 veh/h (110 km/h) in one direction, some 400-450 veh/h less than for say, an ordinary 13 m road.

Road closure due to severe traffic crashes will decrease. An increase of minor disturbance due to crashes into the barrier will occur similar to the current situation of incidents and crashes.

*Vehicle Speeds and Travel Times*

Speed performance will remain virtually unchanged on these sections of road lined with flexible barrier.

*Emergency Service Access*

Permanent emergency openings are to be established every 3-5 km in the flexible barrier to allow rescue vehicles to turn. Part of the barrier can be dismantled quickly should the need arise to get across to the other side of the road. Broken down vehicles can be moved aside on to shoulders to allow the passing of other vehicles.

*Road and Barrier Maintenance and Repairs*

Work zone area safety is a major concern. Repair work is so far conducted from a TMA – closing the overtaking lane with full traffic along one lane in both directions. There is some concern with emergency blockages and emergency vehicle operation that can be solved in cooperation with rescue forces.

*Access to and from Properties and Intersections*

Access roads should be minimised and pedestrians and cyclists separated where possible.

In general, issues of major concern regarding the barriers along undivided, two-lane, two-way roads are the situation for access traffic, effect on vulnerable road users such as motorcyclists, and the narrow one-lane sections. In Sweden, the case of narrow one-lane sections, some 5 m, if the road is not widened, can create road blockages at emergency truck stops, and adversely affect emergency services and conditions for maintenance.

To address these issues, it is proposed that generous shoulder widths be provided and sealed to allow broken down vehicles to be removed from the direct flow of traffic. These shoulders will also somewhat protect repair workers. Regular breaks in the barriers will allow access for emergency vehicles as well as property access. It should be noted that as the barrier is installed in sections it can be easily and quickly dismantled if required. Working widths can be reduced by placing the cable posts closer together thereby reducing deflection and minimising any concerns regarding the narrow widths of lanes.

*Environmental Sustainability*

The use of flexible barriers in general is a more "environmentally friendly" alternative to clear zones, as it saves a large number of trees from being removed in order to protect the occupants of errant vehicles. The 2+1 format and its adaptations in particular optimises existing road configurations therefore reducing the acquisition of land that would otherwise be required to provide a median.

## 5.2 IMPACTS OF FLEXIBLE BARRIERS ON MOTORCYCLISTS

Concerns have been raised that flexible barriers can have a "cheese cutter" effect or that posts could snag motorcyclists impacting the barriers, some believing therefore, that these barriers should not be installed on roads until a superior design is developed.

Based on Swedish experience and the study by Duncan, Corben, Truedsson and Fitzharris (2001), this section will briefly discuss research on the inherent risk associated with flexible barriers for motorcyclists and provide a recommendation as to the appropriateness of the use of flexible barriers with respect to motorcyclists.

A human being is crashworthy up to the level that the body can tolerate external forces and impact with any kind of object. After impact, trajectory is common, leading to additional, often very severe injuries for motorcyclists. Therefore, almost regardless of the type of countermeasure used, serious injury to the motorcycle rider is quite likely in the event of a single-vehicle crash.

As mentioned previously, motorcyclists are around 30 times more likely to be involved in a serious or fatal crash. When it comes to motorcyclists it is fair to say that it is very difficult, if not impossible, to protect a "pedestrian with a helmet", travelling at more than 30 km/h in a crash situation.

With respect to the safety risks associated specifically with flexible barriers for motorcyclists, as no directly relevant research has been done in this area and there have been very few known crashes involving motorcyclists and flexible barriers, it is difficult to make a definitive assessment of the safety risk that this barrier type poses to motorcyclists. However, the concerns raised are generally centred on the potential for flexible barriers to induce injuries through the "cheese-cutter" effect and through impact with the exposed steel posts of the barriers. Both these features of flexible barriers present a safety risk to fallen motorcyclists; however, the extent of these risks relative to other barrier types (or, indeed, the situation of no barrier) cannot be determined with the information available at the current time. In comparison, there are safety risks associated with other barrier types, namely W-beam and concrete, which may prove to be worse for motorcyclists than the potential problems with flexible barriers. For example, the posts of W-beam systems are also exposed and may even pose a greater risk to motorcyclists as they are usually made from wood or galvanised steel (compared to frangible steel posts used in flexible barrier systems). Having said that however, as noted in Duncan, et al., (2001), the posts of flexible barriers are frangible in terms of impacts with vehicles such as cars and larger vehicles; their frangible properties may be much less effective in the case of impacts with object of lesser mass and rigidity, such as a human body (or body part).

With respect to the fate of the motorcyclist if no barrier existed, given the proportion of ROR crashes that involve fixed roadside objects, it is very likely that an out-of-control motorcyclist will impact against a fixed object such as a tree or concrete light pole, or collide with on-coming vehicles and receive serious injury. Insufficient data are available to conclude whether the risk of serious injury is more or less compared with the serious injury risks associated with flexible barrier impacts.

However, Sweden, with over 600 km of flexible barriers on its roads does not have any records of motorcycles being "sliced" by the barriers. No other records indicate that flexible barriers are potential "cheese cutters" or that they are particularly hazardous to motorcyclists when compared with the alternatives. This experience is also consistent with the findings of Duncan et al. (2001).

Given the large crash reduction factors for passenger vehicles; the proportion of single-vehicle crashes involving motorcyclists being very small - 55 single-vehicle crashes on Eastern Freeway and 279 single-vehicle crashes on Geelong Road involved a total of only 6 motorcyclists; and there being no substantial evidence to indicate that flexible barriers are inherently more dangerous to motorcyclists than the available alternatives, it was recommended by Duncan et al. (2001) that flexible barriers continue to be used along roadways.

Concurrent research however needs to be undertaken to improve barrier designs for motorcyclists, collaboration with motorcyclist organisations to discuss both crash and especially pre-crash factors being a vital step in improving motorcycle safety. Questions such as the speed up to which the infrastructure should aim to protect a motorcyclist in a crash needs to be asked as there is great potential based on pre-crash findings for motorcyclists to avoid a crash. In 85% of the cases studied the onus was in the hands of the rider.

Alliance with motorcycle manufacturers is necessary to assist in addressing pre-crash factors such as speeding and driving under the influence of alcohol - "motorcycle rider fatalities with a blood alcohol concentration over (0.05) are more likely than those with lower blood alcohol concentrations to have been killed in single-vehicle crashes or accidents on curves" (Inquiry into Motorcycle Safety in Victoria, 1993).

Similarly, collaboration with barrier manufacturers is crucial for achieving the best possible result in developing the least harmful barrier for motorcyclists.

Developments, such as seat belts for the motorcyclist, might increase the crashworthiness of the rider and motorcycle, in the event of a collision with roadside furniture.

The interaction between the driver, the vehicle and the road has to be developed rapidly.

When introducing new elements into road infrastructure, it is not only valuable to evaluate the crash performance for different road users; it is also of value, especially with motorcyclists, to be aware of the choice of driving speed in different situations based on the existence of road features such as stones, trees and barriers along the road. This could be done in a simulator with a test group of motorcyclists.

Similarly, constructing a test road that will provide only safe infrastructure for motorcyclists is a possible way of gaining more information on creating a safer environment overall, for all road users.

## 5.3 IMPACTS OF FLEXIBLE BARRIERS ON HEAVY VEHICLES

As the wider-spread introduction of flexible barriers on Victorian roads is relatively recent, records of collisions with heavy vehicles are limited, thereby hindering the drawing of conclusions on the safety performance of flexible barriers in impacts with heavy vehicles. Corben et al. (2003) found that, "... although flexible barriers were not designed specifically to restrain heavy vehicles, they appear to have performed well in heavy vehicle impacts and tests around the world; (one particular barrier make) designed specifically to contain a tensile force of two tonnes, has contained heavy vehicles imposing tensile forces of over 11 tonnes on the wire ropes".

## 5.4 COST-EFFECTIVENESS OF FLEXIBLE BARRIERS

Costs associated with collisions with roadside objects account for 34% of total costs for all regional casualty crashes (Delaney et al., 2002). At present, as the use of extended lengths of flexible barrier treatments is relatively new in Victoria, the costs associated with preventing death and serious injury through their use is also proving quite significant, although this is likely to change as large programs are implemented.

Currently, there does not appear to be a substantial quantity of research into the cost-effectiveness of flexible barriers. To ensure that this form of treatment is a cost-viable option, more research is required in this area. Sweden is currently evaluating the cost-effectiveness of flexible barriers.

Although limited quantitative evaluation exists on the cost-effectiveness of in-situ barriers, some findings from a predictive study undertaken on the flexible barriers installed on the Eastern Freeway and Geelong Road are provided below (Duncan et al., 2001):

Flexible barriers are predicted to save over 30 of 35 median encroachments in a ten-year period along the Eastern Freeway. In the same time frame, three median encroachments involved motorcyclists.

More than 150 median encroachments not involving motorcyclists can be prevented through the use of flexible barrier along Geelong Road. In the case of motorcyclists losing control into the median, 13 such riders over a ten-year period would be exposed to possible injuries due to contact with WRSBs.

A projective estimate was also provided by Corben et al., (2001) for three routes in Victoria along which flexible barriers have been installed: Monash Freeway, Frankston/Mornington Peninsula Freeway and Western/Metropolitan Ring Road. Table 3 provides indicative costs and BCR (based on a 15-year life span, although life spans of 20 years or more is likely) to save one fatality through the use of flexible barriers.

*Table 3: Costs and BCR of preventing a single fatality through the installation of median barriers*

| | **Estimated Cost to Save One Fatality ($M) (BCR)** | | |
|---|---|---|---|
| | **Barrier Cost Scenario** | | |
| | **$50/m** | **$100/m** | **$130/m** |
| **1. Monash Freeway** | 2.36 (7.8) | 4.72 (3.9) | 6.14 (3.0) |
| **2. Frankston/Mornington Peninsula Freeway** | 3.18 (3.2) | 6.36 (1.6) | 8.26 (1.2) |
| **3. Western/Metropolitan Ring Road** | 1.74 (7.9) | 3.48 (4.0) | 4.52 (3.1) |

Table 3 indicates that even using the $130/m cost estimate, flexible barriers are a cost-effective means of improving safety.

Comparatively, the cost of W-beam steel barriers range from $60/m to $150/m and concrete barriers from $120/m to $500/m (Working Party Report, 2000). Although based on 1987 values, costs from Pak-Poy and Kneebone (1988) have also been quoted to provide further indication of costs per km for the countermeasure option for W-beam guardrail and concrete barriers: double-sided concrete barriers $110-130,000 per km and double steel W-beam guardrail is estimated to cost between $61-65,000 per km. Though comparable in terms of costing, concrete and guardrail barriers are not considered to have as large a crash severity reduction rate as flexible barriers and so are unlikely to be as cost-effective as flexible barriers.

Indicative maintenance costs for the three types of barriers are quoted as $50/m for flexible barrier; $80-$100/m for guardrail and generally no maintenance takes place on concrete barriers, (Working Party Report, 2000).

These figures are presented to provide some indications of relative costs. A thorough cost-effectiveness study is required, taking into account also factors such as damage to vehicles as a result of impact with barriers and the relative reduction of installation prices through large-scale implementation, before clear conclusions on comparative cost-effectiveness of the different countermeasures can be made.

## 5.5 LARGE-SCALE IMPLEMENTATION OF BARRIERS AND CONSTRUCTION VERSUS RETROFITTING COMPARISONS

Inadequate data are currently available to provide quantitative comparisons in this study of the savings to be gained through the large-scale implementation of flexible barriers in Victoria. Similarly, there appears to be little documentation of the costs and benefits of installing barriers at the construction stage, as opposed to retrofitting the barriers. VicRoads' regional offices have only recently commenced keeping records of associated costs. Definitive information in this regard is more likely to be available perhaps, at the end of 2004.

However, it is reasonable to assume that implementation of flexible barriers on a large-scale will reduce the per-kilometre manufacturing and erection costs. Victoria-wide programs to introduce these barriers systematically on to our roads will also provide some surety to manufacturing companies about on-going contracts, reducing insurance premiums and, ultimately, costs to the customer.

## 5.6 IMPROVING SAFETY ON VICTORIAN ROADS (FUTURE WORK)

To provide safety for the vast majority of users of the road-transport-system on high-speed roads, the use of mid and side barriers should increase rapidly, and be a standard solution, starting with roads with the highest traffic volumes. Preferably, flexible barriers should be used along the centre and sides of all high-speed roads with high traffic volumes.

There are, however, areas where more research, with a highly practical focus, is required in order to maximise the safety improvements to be obtained through the use of flexible barriers:

- Determining the locations of greatest potential for barriers and how many lives and serious injuries can be prevented
- Selecting a "test" undivided, two-lane, two-way road to introduce central barriers without a median and analyse its impact on safety as well as traffic operations
- Conducting further research into more motorcycle-friendly barriers
- Conducting more research into the impacts of heavy vehicles with flexible and other barrier types, including the conduct of a crash-based, before-and-after evaluation of road lengths where barriers have been installed
- Once adequate crash records become available, determining actual cost effectiveness of flexible barriers

Identifying key motorcycle crash causes through model section simulator drives as suggested below, will increase opportunities to design barriers with some of these crash factors in mind:

- Constructing, as a demonstration project, a model road that will incorporate safe features for motorcyclists to increase knowledge of hazards typical to motorcyclists
- Conducting simulation rides with motorcyclists to be more aware of approach speeds to different hazards

## 5.7 IMPROVING SAFETY ON VICTORIAN ROADS (CONCLUSIONS)

In order to address up to 40% of Victorian fatalities, namely run-off-road crashes, this paper explores the possibilities of introducing, on a large scale, flexible barriers based on Swedish practices. Swedish research and experience suggest up to a 90% crash reduction in targeted fatalities through the use of flexible barriers

Swedish results indicate that in over 600 km of flexible barrier, no death has occurred as a direct consequence of a barrier impact and severe injuries have significantly reduced.

Existing infrastructure allows the introduction of flexible barriers along the roadsides and centre with minimal modification, hence providing a significant cost advantage. Predictive studies have indicated the treatments would be cost-effective, though more research is required before these findings can be conclusive.

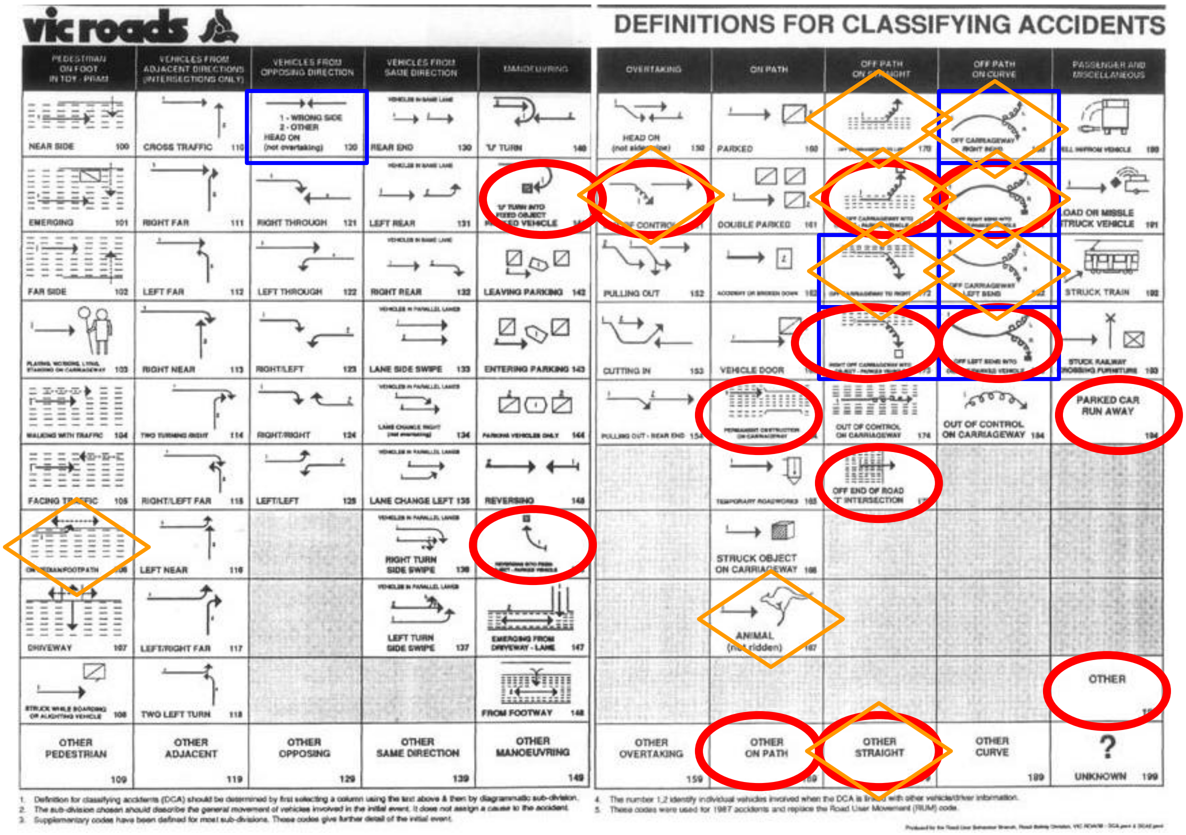
Although some concern has been expressed regarding the use of flexible barriers and its potential to cause injury to motorcyclists who impact with them, no evidence exists to indicate that riders who leave the roadway will be at greater risk of injury striking a flexible barrier than if there were either no barriers or barriers of a different type. As motorcyclists represent less than 1% of distance travelled on the roads, and given the large potential benefits for the remainder of the road users, it is considered appropriate to continue the use of these barriers in Victoria, while concurrently undertaking research, in collaboration with stakeholders, to improve the crashworthiness of barriers for all road users, including motorcyclists.

The predicted safety benefits of large-scale use of flexible barriers is overwhelming, and despite some issues relating to its use, the opportunity exists to utilise this treatment to reduce dramatically the incidence of single-vehicle fatalities in Victoria.

# APPENDICES

- *Appendix A - DCA Codes Included in the Various Studies*
- *Appendix B – Crash Analysis*
- *Appendix C– Detailed Findings from Road Safety Study in Sweden*
- *Appendix D – Performance Criteria Tables*

## Appendix A - DCA Codes Included in the Various Studies




-Urban Arterial Clear Zone Guidelines

-Crash Analysis for the Review of Guidelines for Median Barriers

- A Study of Run-Off the Road Left Crashes

Road Environment Safety included collisions with fixed roadside objects based on DCA codes and police crash report descriptions

# Appendix B – Crash Analysis

## B.1 EXTENT OF PROBLEM

Vehicles losing control and running off the road is a significant problem in Victoria. Victoria-wide crash data for the five-year period of 1993-1997 indicate that a total of 12,632 casualty crashes involved vehicles leaving the roadway and hitting an object on the median or within the roadside (Wilson, Corben & Narayan, 1999). Higher figures were found for the five-year period of 1996-2000, where 15,556 collisions with fixed roadside objects were recorded Victoria wide, accounting for 16-19% of total casualty crashes (Delaney, Langford, Corben Newstead, & Jacques, 2002).

Despite current treatment measures, the number of collisions with roadside objects has been increasing over the last decade, as Figure B1 demonstrates. Current crash data (July 1997 – June 2002) though not yet complete, confirm this general trend.

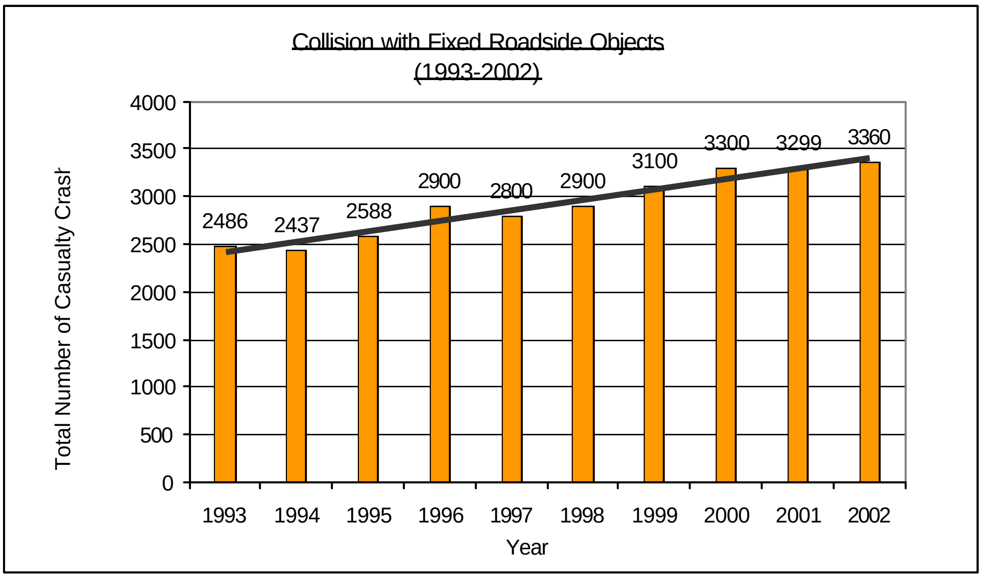



*Figure B1 – Number of reported casualty collisions in Victoria that have involved fixed roadside objects*

Another study found that between the years 1991 and 2000, 3,603 casualty crashes Victoria-wide involved vehicles that encroached the median, (Corben, Tingvall, Fitzharris, Newstead, Les & Johnston, 2001) while over 23,000 run-off-the-road-left casualty crashes occurred in the same ten-year period, some six times greater than median encroachment crashes, (Delaney, Jacques, Corben and Newstead, 2002).

## B.2 SPATIAL DISTRIBUTION

Studies have found that metropolitan Melbourne has slightly more occurrences of ROR crashes than has rural Victoria. Figures for collisions with fixed roadside objects between 1993-1997 indicate that 6,708 of 12,632 crashes in to fixed roadside objects (53%) were in metropolitan Melbourne (Wilson et al., 1999) while 1996-2000 data have 60% of collisions with fixed roadside objects occurring in metropolitan Melbourne (Delaney et al., 2002). Present figures confirm that a greater percentage of collisions with roadside objects occur in metropolitan Melbourne.

Similarly for median encroachments, a greater proportion of crashes occurred in metropolitan Melbourne, figures for the ten-year period of 1991-2000 indicating that almost 80% of vehicles encroaching into the median occurred in urban surroundings (Corben et al., 2001). Corben et al. (2001) also found that median encroachments tend to be highly concentrated along high-speed, high-volume, divided roads, conservatively estimating that at least 40% of median encroachments occur on Victorian freeways and State highways.

Delaney et al. (2002), found that the problem of run-off road-left crashes however, was quite evenly distributed between metropolitan Melbourne and rural Victoria, the concentration of crashes depending more on volumes than location, roads with high volumes having the greatest concentration of crashes. Figure B21 indicates the spatial distribution throughout Victoria of two categories of ROR crashes (run-off-road left and median encroachment crashes) for the ten-year period 1991-2000, showing that the issue of out-of-control vehicles is a significant one and all major routes are involved.

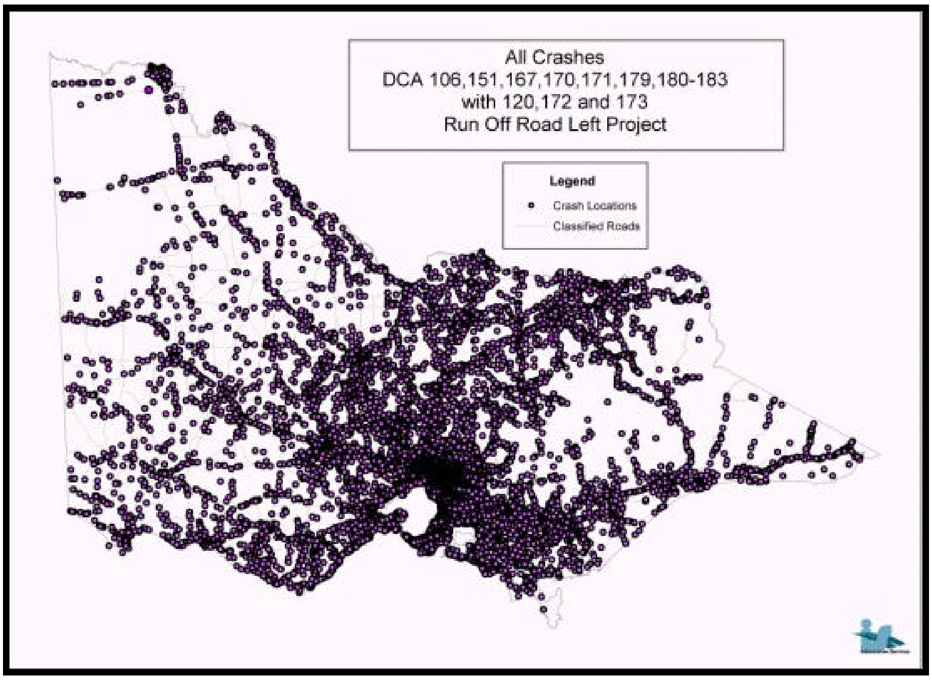



*Figure B2 - Location of run-off road left and median encroachment crashes in Victoria from 1991-2000*

Although figures indicate that there is a greater number of ROR crashes in the metropolitan Melbourne, the proportion of ROR crashes to total casualty crashes is higher in rural areas. Of the average annual number of casualty crashes occurring between 1996-2000 (17710), 26% occurred in rural Victoria (4518). Of these, 28% were roadside collisions. In contrast, of the 74% of crashes occurring in the metropolitan Melbourne, only 14% involved roadside casualty crashes (Delaney et al, 2002), suggesting the problem of ROR crashes in rural areas is, in proportional terms, double that of metropolitan areas.

## B.3 PREDOMINANT CRASH TYPES

In rural Victoria, very definite trends exist in terms of vehicles that run off the road. Of the total number of crashes involving vehicles striking fixed roadside objects between the years of 1993 and 1997, 96% resulted in vehicles travelling off the carriageway to the left or right into a fixed object – that is, DCA codes 171, 173, 181 and 183 were the predominant crash types (see FigureB 3, cited in Wilson et al., 1999). “arrive alive!” Strategy 2002-2007 indicates also that 91% of fatal ROR crashes involved a fixed roadside object.

DCA 173 similarly, was found to be involved in median encroachments crashes between 1991 and 2000, 80% of these crashes involving DCA codes 173 and 120 - right off carriageway into an object on a straight path and head-on collisions (Corben et al., 2001). Within the same time period, DCA 171 was reported to be the most frequent run-off-road-left crash type in rural Victoria, followed by 181 and 183 – off a bend in the road and hitting a roadside object (Delaney et al., 2002). Current statistics also indicate that DCA codes 171 and173 are highly represented in ROR crash statistics.

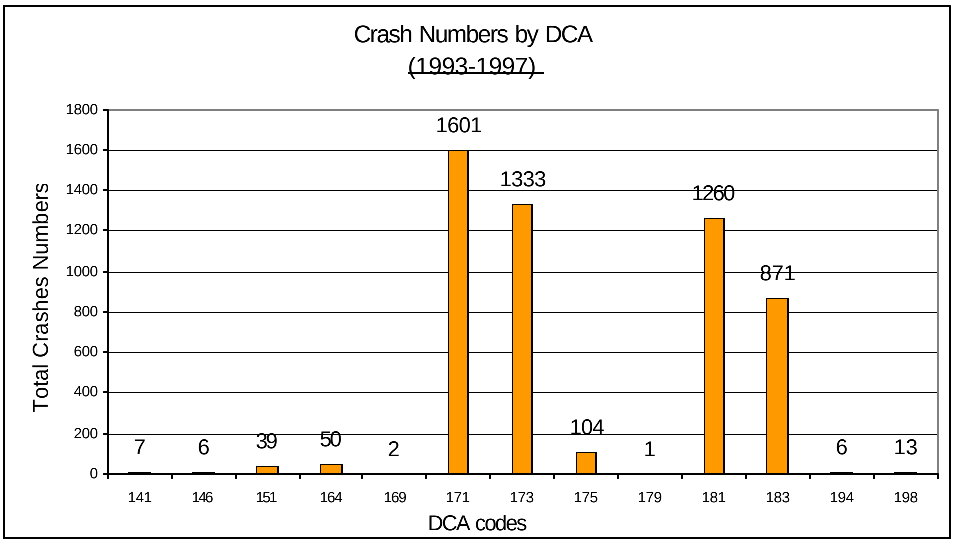



*Figure B3 - Predominant Crash Types, (Wilson et al, 1999)*

## B.4 SEVERITY

Injuries resulting from ROR crashes are likely to be more serious in nature than from the average crash. Although crashes into fixed roadside objects represent 16-19% of all casualty crashes Victoria-wide, 32% of all fatalities between 1996-2000 resulted from this type of crash (Delaney et al., October 2002). Current data indicate similar percentages.

Of all run-off-road-left crashes in rural surroundings with speed limit of 100+ km/h, 43% resulted in serious or fatal injuries (Delaney et al., 2002); almost half of all median encroachment crashes resulted in death or serious injury (Corben et al., 2001); and 46% of crashes into fixed objects resulted in death or serious injury (Wilson et al., 1999). These figures are considerably higher than death and serious injury proportions when total casualty crashes are considered. Based on figures in Delaney et al., (October 2002), 30% of all casualty crashes result in serious and fatal injuries, compared to 41% of all roadside crashes resulting in serious and fatal injuries.

The proportion of fatalities resulting from collisions with fixed roadside objects on 110 km/h, 100 km/h and 60 km/h speed zones in rural Victoria were 7.2%, 5.8% and

2.1% respectively (Delaney et al., October 2002), clearly indicating that travel, and hence impact speed, influence injury severity.

## B.5 SPEED

It appears that the problem of ROR crashes is the most significant on roads of 100 km/h followed by 60 km/h. In rural Victoria, 77% of run-off-road-left crashes occurred in 100 km/h zones (Delaney et al., September 2002). Of collisions involving fixed roadside objects in rural Victoria, 67% occurred on roads with speed limits of 100 km/h, followed by roads of 60 km/h (Delaney et al., 2002). Corben et al., (2001) found that within all of Victoria, 38% and 30% of median encroachments respectively were on roads with speed limits of 60 km/h and greater than 100 km/h.

## B.6 PREDOMINANT VEHICLE INVOLVEMENT

Given that cars and car derivatives are the most common types of vehicles on the road network, it is not surprising that these are the most likely to be involved in median encroachment crashes, with 86% being passenger vehicles, 9% heavy vehicles and 3% involving motorcyclists (Corben et al., 200l). Delaney et al. (October 2002), also found that cars are the most likely to hit fixed roadside objects in rural Victoria but with station wagons, utilities and motorcycles also contributing to overall numbers.

On roads of greater than 100 km/h, 82% of run-off-road-left crashes involved passenger vehicles, 11% motorcycles and 6% heavy vehicles.

To assist with understanding the effects of flexible barriers on motorcyclists, a section of this appendix is devoted to their crash characteristics.

### B.6.1 Motorcycle Involvement in Run-Off-Road Crashes

Motorcycle crashes contribute significantly to the overall road toll in Victoria. According to the Transport Accident Commission (TAC), although motorcyclists represent less than 1% of travel on the road, they accounted for 14% of the road toll in 2001.

Of total casualty motorcycle crashes, around one third are single-vehicle crashes (Haworth, Smith, Brumen and Pronk, 1997 cited in Duncan, et al., 2001). Delaney et al., (September 2002) also found motorcyclists to feature prominently in ROR crashes, contributing to 3% of median encroachment crashes and 11% of run-off-road-left crashes.

Moreover, the consequences of crashes are a lot more severe for motorcyclists. In Victoria during the period from 1991 to 2000, motorcycle crashes accounted for 12% of fatalities although they are involved in only 6% of casualty crashes (Delaney et al., September 2002). According to the Motorcycle Council of NSW, although motorcycles are no more likely to be involved in a crash than are passenger cars (crash rate for motorcycles and cars being 272.1 and 272.9 respectively), 90% of reported motorcycle crashes involve injury compared to only 40% of car crashes.

The Australian Transport Safety Bureau (ATSB), Monograph 12 – Motorcycle Safety, found that motorcyclists are around 29 times more likely to be fatally injured than operators of other vehicles travelling the same distance. In another study, Diamantopoulou, Skalova and Cameron, 1996 (cited in Duncan, et al., 2001) found that in Victorian rural towns, motorcyclists are 30 and 34 times more likely to be involved in a serious and fatal crash, respectively, than car drivers although on rural highways, risks of serious and fatal crashes for motorcyclists are only slightly higher than for car drivers, 1.4 and 1.3 times, respectively.

The ATSB, Monograph 12 - Motorcycle Safety also found that the popularity of motorcycling appears to be increasing significantly among the 40 years and over age group, resulting in an increase in fatalities among this age group of motorcyclists from 14% in 1991 to 27% in 2001. Despite the significant increase in older rider fatalities however, the risk of fatal injury to motorcycle riders per distance travelled is still significantly higher among younger riders.

The National Highway Traffic Safety Administration in the US found 46% of motorcyclist fatalities involved single-vehicle crashes and that speed contributed to 39% of all motorcyclist fatalities.

## Appendix C– Detailed Findings from Road Safety Study in Sweden

*Roads with speed limits of 90 and 110 km/h constitute 29% of the total road length but account for no less than 49% of the fatal crashes.* When undertaking remedial road works, priority should thus be given to stretches where the speed limit is 90 or 110 km/h.

*More than half of the 290 crashes occurred on outer curves, a little more than a third on straight stretches and a few on inner curves.* The percentage of vehicles that ran off the road in outer curves was greater on low traffic volume roads, which often are narrow and winding. *On roads with an AADT of 4000-5999, 65% of the crashes occurred on straight stretches.*

When examining the accident material, the side of the road that vehicles ran off was also noted. Vehicles ran off the road almost as frequently to the left as to the right*: 41% to the left and 49% to the right. Only 10% of the crashes involved a vehicle that exited and re-entered the road more than once before coming to a final stop*.

*70% of the crashes involved collisions with various kinds of fixed objects, with trees accounting for a little more than half. Other fixed objects included light/sign posts, rock faces or boulders.* These fixed objects were standing an average of 4.7 m away from the road, with half of them either in or immediately after an outer curve. This would indicate that measures should primarily be aimed at outer curves and the length of road immediately after the curve. *In 25 crashes it was collision with a post that produced the greatest force.* Eight of these columns were on roads where the AADT was 2000-3999. It was found that rigid columns could penetrate deeply into the occupant compartment, especially those of a lattice design. The more modern, “collapsible” or frangible posts would probably have saved lives in 10 of the 25 crashes.

*Using a seat belt would not have been able to save the lives of the vehicle occupants in 116 of the 171 crashes (motorcycles excluded) involving collision with a fixed object as the occupant compartment had been crushed too badly by trees, columns, rock, etc.*

In 188 crashes, the vehicle came to a halt at the far edge of the verge or even further away. The median (range) for the estimated width of the verge in these crashes was four metres (0.5-16 m). The median (range) for the distance between the edge of the road to the place where the vehicle came to a standstill was six metres (0.5-36 m) and 43 m (1-218 m) for the distance beyond the carriageway to where the vehicle landed. *In other words, in a total of 70% of the crashes, the verge was so narrow that the vehicle did not stop until it reached the far edge of it or even beyond.* This clearly shows that the verges on today’s roads are altogether too narrow in relation to the speeds driven.

The “flat” verges currently referred to at the SNRA (in Road Design Specifications ’94) entail a slope of 1:4 or better, and a width of eight to ten metres. Further, all fixed objects must be cleared away. *All in all, “flat” verges were only found in four instances of the 290 crashes included in the study.* This is probably more due to the fact that there are not especially many kilometres of road with flat verges rather than that few fatal crashes occur where verges are flat.

The study also shows how poorly cars are designed in relation to travel speeds and the physical road environments through which they drive. *In 104 of the 234 crashes involving a* *car, the vehicle was so badly crushed that a seat belt would not have saved the life of the occupant.* This applied to both new and old cars. Particularly serious was roof or side impact by a narrow object. At speeds as low as 70 km/h the collision force is enough for a column to penetrate right through the side of a car as far as the gear shift. Hence, it is important that there are no trees or lighting columns close to the edge of the carriageway even where the speed limit is as low as 50 km/h. Another alternative could be to replace old columns with modern collapsible ones.

*Two hundred and seventy two people travelled under conditions in which a seat belt was available. Of these, 83 were using it, which corresponds to 31%. Despite this, all of these 83 people died because of the violence of the crash.* If seat belt usage had been 100% in the crashes examined, 49% of those killed would probably have survived. This figure would be 70% for those who were not using their seat belt. The simplest and most obvious way to substantially reduce the number of road traffic fatalities is therefore to increase seat belt usage. This would require some type of effective seat belt reminder system.

*Sixty-eight of the 84 people, who were killed when their vehicle rolled over in the ditch without hitting a fixed object, were not wearing their seat belt. It was estimated that a seat belt would have saved the lives of 66 of these 68 people.* This means that almost 80% would have survived if there had been 100% seat belt usage in vehicles that rolled over in the ditch without hitting a fixed object. Where these kinds of accident were fatal despite seat belt usage, it was usually because the roof of the vehicle had been crushed in. The foregoing shows that as long as the vehicle does <u>not</u> hit any fixed object and that the seat belt is being used, there is quite a good chance of surviving a rollover accident with the ditch design we have today. In certain cases, however, a rollover in the ditch forces in the roof to the extent that the seat belt does not help.

A flexible barrier alone would probably have saved lives in no less than 72% of the crashes. Since more than half the crashes occurred at an outer curve, priority should be given to setting up barriers on outer curves and immediately after them. In practice, this means that the barrier should be extended in both directions since almost as many cars run off the road to the left as to the right at outer curves.

*In 145 of the 290 cases studied, it was found that the driver was under the influence (DUI) of alcohol or drugs (19 were on drugs).* This means that alcohol/drugs had been detected in 50% of the single-vehicle crashes on the rural road network that ended in death. *In the crashes occurring on roads with an AADT of 1000-1999 this was as high as 63%.* In general, it seems that there are more DUI drivers on low traffic volume roads than on busy roads. *The introduction of alcohol ignition interlocks would probably have a considerable effect on reducing the number of people killed in single-vehicle crashes.*

*It was estimated that four of ten had kept within the posted speed limit, two of ten had driven fast enough to be fined and almost four of ten had driven at a speed that would have cost them their driving licence.* The number of those who drive between 11 and 30 km/h over the speed limit (interval entailing a fine) decreases with an increase in traffic volume, while those who drive faster than 30 km/h above the speed limit (grounds for driving licence revocation) tends to increase on higher traffic volume roads.

*On summing up, conclusion appears to be that a combination of 100% seat belt usage, and flexible barriers or wide, cleared, flat verges would reduce the number of people killed in single-vehicle crashes by up to about 100%.* There are, however, cases where the speed and angle are such that a guardrail would not help or where the vehicle would continue beyond the safety zone even at wide verges. *Therefore, if the speed limit were respected, if everyone used a seat belt and if there were a flexible barrier or wide, cleared, flat verges, a fatal outcome could probably be avoided in almost all single-vehicle crashes.*

## Appendix D – Performance Criteria Tables

The table below presents the criteria for each crash test level along with the working width. Working width is defined as the deformation of the barrier upon impact. That is, the distance between the edge of the barrier facing the traffic prior to impact and the maximum lateral deflection of the barrier or vehicle. The W1, W2 in the working width table do not correlate with the T1, T2 categories but simply define the deformation levels.

| Containment level | Test | Speed (km/h) | Weight (kg) | Angle (deg) |
|---|---|---|---|---|
| T1 | TB 21 | 80 | 1 300 | 8 |
| T2 | TB 22 | 80 | 1 300 | 15 |
| T3 | TB 21 | 80 | 1 300 | 8 |
| | TB 41 | 70 | 10 000 | 8 |
| N1 | TB31 | 80 | 1 500 | 20 |
| N2 | TB 11 | 100 | 900 | 20 |
| | TB 32 | 110 | 1 500 | 20 |
| H1 | TB 11 | 100 | 900 | 20 |
| | TB 42 | 70 | 10 000 | 15 |
| H2 | TB 11 | 100 | 900 | 20 |
| | TB 51 | 70 | 13 000 | 20 |
| H3 | TB 11 | 100 | 900 | 20 |
| | TB 61 | 80 | 16 000 | 20 |
| H4a | TB 11 | 100 | 900 | 20 |
| | TB 71 | 65 | 30 000 | 20 |
| H4b | TB 11 | 100 | 900 | 20 |
| | TB 81 | 65 | 38 000 | 20 |

| Working width | |
|---|---|
| W1 | <= 0.6 m |
| W2 | <= 0.8 m |
| W3 | <= 1.0 m |
| W4 | <= 1.3 m |
| W5 | <= 1.7 m |
| W6 | <= 2.1 m |
| W7 | <= 2.5 m |
| W8 | <= 3,5 m |

| Impact severity level | |
|---|---|
| A | Very good |
| B | Good |

# REFERENCES

Brannolte, U. et al (1993) Sicherheitsbewertung von Querschnitten ausserörtlicher Strassen. BAST Verkehrstechnik Heft V5

Bergh, T. (1997) 13 m roads – alternative traffic safety counter measures (in Swedish). SNRA memo (unpublished)

Berge, T (1998) 2+1 roads with cable barrier for improved traffic safety. Proceedings of the third international symposium on highway capacity volume 2. Copenhagen 1998

Berge, T (1999a) Traffic safety counter measures on rural roads (in Swedish). VTI Proceedings Transportforum 1999

Berge, T et al (1999b) 2+1 roads with cable barriers – a new safety measure. 2nd European Road Research Conference Proceedings. Brussels June 1999

Berge, T et al (1999c) 2+1 roads with cable barriers – a new safety measure. 10th International Conference of Traffic Safety on two Continents. Malmö September 1999

Berge, T and Carlsson, A (2000) 2+1 roads with and without cable barriers-speed performance. Proceedings of the fourth international symposium on highway capacity Maui, Hawaii 2000

Brude, U. and Larsson, J. (1996) Wide lanes - safety effects (in Swedish). VTI Meddelande 807

Brude, U. and Larsson, J. (1997) Summary - effects of 2+1-design (in Swedish). VTI memo (unpublished)

Brude, U. and Carlsson, A. (1997) Alternative performance of 13 m roads and semi motorways – Overall effects (in Swedish), VTI memo

Carlsson, A et al (2000). Evaluation of alternative 13 m roads- Half year report 2000:1 (in Swedish). VTI Notat 67-2000

Carlsson, A et al (2001) Evaluation of alternative 13 m roads- Half year report 2000:2 (in Swedish). VTI Notat 23-2001

Corben, B., Tingvall, T., Fitzharris, M., Newstead, S., Les, M., and Johnston, I. (2001) Crash Analysis for the Review of Guidelines for Median Barriers. Monash University Accident Research Centre, Prepared for VicRoads

Corben, B., Tingvall, C., and Wilson, N. (1999) Urban Clear Zone Study, Identification of Potential Roadside Barrier Types for Urban Tree Crashes. Monash University Accident Research Centre

Delaney, A., Langford, J. Newstead, S., and Jacques, N. (2002) Roadside Environment Safety, Monash University Accident Research Centre, Report to RACV

Delaney, A., Jacques, N., Corben, B. and Newstead, S. (2002) A Study of Run-Off-the-Road-Left Crashes – Stage 1, A description of the Crash and Injury Problem and an assessment of the Effectiveness of Clear Zone Guidelines. Monash University Accident Research Centre, Prepared for VicRoads

Duncan, C., Corben, B., Truedsson, N. and Fitzharris, M. (2001) Motorcyclists and Barriers. Monash University Accident Research Centre, Report prepared for VicRoads

Ibitoye, A.B., Wong, S.V., Umar, R.S., Hamouda, A.M.S., and Law, T.H. (2002) Harmful Effects of Guardrail Features to Motorcyclists, Road Engineering Association of Malaysia

Jacques, N., Franklyn, M., Corben, B., and Candappa, N. (2003) The Investigation of the Performance of Safety Barriers in Relation to Heavy Vehicle Crashes, Report prepared for VicRoads

National Cooperative Highway Research Program - Research Results Digest (2003) Application of European 2+1 Roadway Design

Pak-Poy and Kneebone Pty Ltd (1988), Road Safety Benefits from Rural Road Improvements Transport and Communications – Federal Office of Rad Safety

Parliament of Victoria (1993)- Inquiry into Motorcycle Safety in Victoria

SNRA, (1994). VU94-SNRA guidelines on geometric design (in Swedish). SNRA

SNRA, (2000). Investment- and improving measures (in Swedish). SNRA

Szwed, N. (2002). Wire Rope Barriers in Victoria. Proceedings of ITE Conference, March 24-27, 2002; Palm Harbor, Florida, USA

The Australian Transport Safety Bureau, Monograph 12 – Motorcycle Safety, (http://www.atsb.gov.au/road/stats/pdf/monograph_12.pdf)

Wilson, N., Corben B., and Narayan, S. (1999) Urban Arterial Clear Zone Guidelines – Stage 1: Literature Review. Monash University Accident Research Centre, Prepared for VicRoads

Working Party Report (June 2000) Review of Wire Rope Barriers Online http://www.atsb.gov.au/road/pdf/wrbarrier.pdf