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Motorcycle and Safety Barrier Crash-Testing: Feasibility Study

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Abstract

Roadside barriers are designed to enhance the safety of the road infrastructure by containing errant vehicles and reducing the severity of off-path collisions. While conventional barrier systems have performed well for the occupants of passenger cars, their effects on the safety of other road user groups, especially motorcyclists, is not well understood. The main purpose of this feasibility study was to recommend a research method for investigating the interactions between motorcycles and road safety barriers. A review of the relevant national and international literature was conducted, revealing a relative lack of published material regarding the nature of motorcycle collisions both with roadside barriers as well as motorcycle crashes in general. Various features of barrier systems were identified in the literature as providing a significant safety risk to fallen motorcyclists, particularly barrier posts. There have been numerous strategies employed, mostly in Europe, to better protect motorcyclists from impacts with barriers, including the installation of additional W-beams, using impact attenuators to cover exposed barrier posts and substituting traditional IPE posts with more forgiving "sigma" posts. In addition, there have been several new barrier designs and/or modifications that have been developed and tested in Europe with promising results. Guidelines developed for the conduct of physical crash-tests with motorcycles were reviewed, and alternative methods, such as computer/mathematical simulations and component testing, were also considered. Based on the information from the literature review and subsequent consultation with several experts and stakeholders, recommendations for a multi-stage research program were made.

Keywords

SAFETY BARRIER, CRASH-TEST, MOTORCYCLE, IMPACT, OCCUPANT PROTECTION

Contents

Figures

Tables

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1 EXECUTIVE SUMMARY

This report has been prepared for the Australian Transport Safety Bureau (ATSB) by the Monash University Accident Research Centre. It constitutes the first stage of a potential multi-stage project and takes the form of a feasibility study of motorcycle and safety barrier crash-testing.

Road safety barriers are designed to enhance the safety of the road infrastructure by containing errant vehicles and reducing the severity of off-path collisions. Experience indicates that conventional barrier systems used in accordance with specific guidelines have performed well in protecting the occupants of passenger cars. However, their effects on the safety of motorcyclists, is somewhat problematic. Given the limited available information on motorcycle-barrier interactions, and the lack of established procedures for motorcycle crash-testing, ATSB commissioned a preliminary investigation of relevant issues. This report is the principal output of these preliminary investigations.

The main purpose of this initial work was to recommend a research method for investigating the interactions between motorcycles and road safety barriers. Specific objectives were to:

- identify barrier design issues likely to impact on motorcycle rider safety;
- identify relevant rider injury mechanisms;
- identify and assess the feasibility of research methods for investigating interactions between motorcycles and safety barriers;
- recommend a research program, addressing the overall aims described above.

The study has involved a review of the international literature on relevant topics, analysis of motorcycle crash records, and consultation with technical experts and key stakeholders in three States.

1.1 LITERATURE REVIEW

1.1.1 General

A search of the relevant literature concerning road user impacts with roadside barriers revealed that there have been very few specific experiments conducted that examine the safety performance of crash barriers with regard to motorcyclists. The published literature indicates that researchers have used both a variety of physical crash-testing methods, as well as various computer and mathematical simulation techniques to investigate motorcycle crashes.

1.1.2 The Number, Nature and Severity of Injuries Resulting from Collisions with Different Barrier Types

Apart from general figures pertaining to the number of collisions between guardrails and motorcyclists for certain time periods, there is very little information available in the literature regarding the nature and severity of injuries resulting from collisions with different barrier types.

In terms of the size of the problem in Australia, Victorian crash statistics indicate that between the years of 1991 and 1995, there were 9059 accidents involving motorcyclists in Victoria, 84 of which involved the collision of the rider with a guard fence. Australian Coroner's records indicate that 2.4% of total rider fatalities involved collisions with safety barriers in 1994 and 1996.

With specific reference to the involvement of Wire Rope Safety Barriers (WRSBs) in motorcyclist casualties in Australia, ATSB (2000) reports that Australian State Road Authorities reported no such casualties, however the reporting of crashes with barriers does not necessarily accurately distinguish between different barrier types.

1.1.3 Barrier Design Features Impacting on Motorcyclist Safety

A review of the literature identified several barrier design issues which impact upon motorcycle rider safety. The literature suggests that the most dangerous aspect of guardrails with respect to motorcyclists is exposed guardrail posts. The guardrail posts present edges which concentrate the impact forces, resulting in more severe injuries to motorcyclists. This is a potential problem for any barrier system that has exposed posts. Other barrier features that are inherently dangerous to motorcyclists include:

- The jagged edges of wire mesh fences, or wire mesh topped barrier systems which provide numerous lacerating surfaces, accentuating rider injury risk;
- Upper and lower W-beam edges;
- Protruding reflectors;
- Barrier systems that are too low as motorcyclists can be catapulted over barrier systems of insufficient height;
- Discontinuous or jagged barrier surfaces, such as concrete barriers with decorative designs, which present edges to concentrate the forces of impact.
- Rigid barriers (likely to be involved in front-on collisions) which require an impacting rider to absorb virtually all of the kinetic energy at impact.

1.1.4 Safety Performance of Barrier Types with Respect to Motorcyclists

There has been no comprehensive crash-testing program that has compared the safety performance of a number of different barrier types in controlled conditions with respect to motorcyclists, therefore it is difficult to make meaningful comparisons of barrier types regarding this issue. In general, however, it appears that barriers with a smooth, continuous surface (located reasonably close, and oriented roughly parallel, to the traffic stream) represent less of a safety hazard to motorcyclists as they better allow the rider to slide along the surface of the barrier without the danger of impacting any sharp edges or corners that can concentrate the impact force. Also, barriers with high energy absorbing properties which allow for better energy dissipation would decrease the injury risk for fallen motorcyclists.

1.1.5 Review of Different Strategies for Better Protecting Motorcyclists

The three most prevalent methods of improving the design of safety barriers to better protect motorcyclists include: the replacement of traditional IPE-100 posts used in most guardrail systems with the more forgiving Sigma-Posts; covering the existing posts with additional W-beams on the lower section of the guardrail system; and covering exposed posts with specifically designed impact attenuators (Koch & Schueler, 1987; Sala & Astori, 1998).

More recently, there have been a variety of new devices developed by various companies globally that can be added to existing barrier systems to improve their safety performance with regard to motorcyclists. These include: the “Plastrail” (developed by Solidor); the “Motorail” (developed by Solosar); the “Mototub” (made by Sodirel), and; a metal plate which covers exposed guardrail posts and has a high degree of flexibility enabling it to absorb energy on impact (sold by SEC-Envel in France).

In addition, the Baltic Construction Company in Sweden has developed a device that covers the upper and lower wire rope systems of standard WRSBs. The device consists of aluminium profiles that can be fitted to existing systems. The device has been subject to computer simulations using a motorcycle, a car and a lorry with favourable indications.

1.1.6 Crash-Testing

Although physical crash-testing has not been used in the past to compare the safety performance of the main barrier types for motorcyclists, testing out new devices designed to improve the safety performance of existing barriers for motorcyclists has been carried out in a number of European countries. However, physical crash-testing is not without its limitations and other methods such as mathematical models and computer simulations are being used increasingly by researchers to overcome the financial costs and problems with repeatability that exist when conducting physical crash-tests. Although these alternatives are not without their own problems, it appears that as the technology advances in these areas, these methods are becoming increasingly more viable options and/or supplements to physical crash-testing.

1.1.7 Feasibility of Research Methods for Investigating Interactions between Motorcycles and Safety Barriers

Physical crash-tests are advantageous as they are better able to provide more realistic data for motorcycle crashes. On the other hand, the two main disadvantages of physical motorcycle crash-testing include the difficulty of reproducibility of tests as well as their relatively costly and time consuming nature (Nieboer, Wismans, Versmissen, van Slagmaat, Kurawaki, & Ohara, 1993). An alternative method, computer-aided simulation of crash-testing, makes it possible to conduct a large number of simulations at a relatively low cost, which is important considering the wide range of crash configurations the motorcycle and rider can be subjected to. Various types of mathematical models and computer simulations have been used successfully to investigate motorcyclist impacts with barriers in the past. However it must be noted that although these alternative methods are useful in terms of their repeatability and their ability to identify the *salient* aspects of injuries and injury mechanisms in crash-test situations, they are limited in various ways, including the fact that the simplification required in these models excludes a thorough analysis of the complexity of the situation.

Component testing or sub-system testing provides yet another alternative or supplementary approach to physical crash-testing and/or crash simulation. This method provides a way of testing specific parameters at a relatively low cost by focussing on specific crash components which are believed to be critical to injury severity outcomes. Component testing has been used successfully in the past for various purposes, including investigation into pedestrian/car impacts, where it can be used to help break down the complexity of the situation and identify factors influencing the injury outcome. Therefore, to overcome the cost and difficulty of full-scale motorcycle into barrier crash-testing, sub-system testing may be considered as an option for investigating these impacts.

1.1.8 The Choice of One or Several Test Set-Ups

There have been several different approaches taken by researchers in the past for the purposes of physical crash-testing. Variations between tests include the impact speed, impact angle, whether the impact occurs with the rider still on the motorcycle or with the rider having already separated from the motorcycle, and if so, with the rider head or feet first. The actual crash configuration adopted will depend on whether to investigate typical crash-test scenarios and/or worst/extreme case scenarios.

1.1.9 The Conduct of Physical Crash-Testing

In the event that a physical crash-testing program is undertaken either in isolation or in conjunction with alternative methods, there are certain guidelines developed for such purposes. Guidelines developed by a group of motorcyclist safety experts, appointed by the International Organisation for Standardisation (ISO), cover virtually all aspects of the conduct of physical crash-testing, including: suitable crash-test dummies, physical measurements to be taken, injury assessment variables, instrumentation and measurement specifications.

1.1.10 Variables to be Measured, Instrumentation & Measurement Procedures

A specialised crash-test dummy for motorcycle crash-testing has been developed and is specified in ISO 13232. The basis dummy recommended by the ISO for motorcycle crash-testing is a Hybrid III 50th percentile male dummy with sit/stand construction, standard non-sliding knees and head/neck assembly compatible with either a 3 or 6 axis upper neck load cell. However, as the Hybrid III dummy was developed for purposes other than motorcycle crash-testing eg, simulating restrained car occupants in frontal impacts, it has limited means to assess some of the main factors in motorcycle crashes due to the biofidelity characteristics being specialised for their original intended function. To turn the Hybrid III dummy into a ISO 13232 motorcyclist dummy, thereby making it useful in motorcycle crash-testing, certain modifications are required. Among the more important features of a motorcyclist dummy (compared to a vehicle occupant dummy) are the ability for the hands of the dummy to grip the motorcycle handlebars, the ability of the head of the dummy to retain a helmet, improved biofidelity of neck movements and several modifications to the biofidelity of the lower limb, including the use of frangible upper and lower leg bones, which aid in the collection of injury data specifically relevant to motorcycle crashes.

There are a number of injury assessment variables that are specified in ISO 13232, as well as guidelines regarding the instrumentation to be used, the variables that should be measured and the measurement procedures that should be followed in collecting the data. In addition, further recommendations and guidelines are provided for full-scale crash-testing and specifications regarding appropriate sensors to be used for compatiblity with the Hybrid III basis dummy (if this is to be used) are included.

1.2 CONSULTATION WITH STAKEHOLDERS

Consultation with Main Roads Queensland was conducted on Monday 10 July 2000, and provided both policy and operational perspectives from the Main Roads staff involved. Officers from VicRoads, the Victorian Motorcycle Police and the Federal Motorcycle Coalition were consulted in Victoria on Tuesday 29 August, 2000. Also, three separate consultations were held on Thursday 7 September, 2000 with stakeholders and experts in NSW including officers from the Roads and Traffic Authority and NSW Police Service, and representatives from the NSW Motorcycle Council. The main issues arising from the discussions, as they relate to the current project, are summarised in this report.

1.3 RECOMMENDATIONS FOR A RESEARCH PROGRAM

1.3.1 Research and Development Options

There are three main options for conducting research and development of safety enhancements for motorcyclists impacting roadside barriers, namely: full-scale crash-testing; crash simulation modelling; and, component testing. Any of these options, or combinations of them, could be selected to help in the development of safer barrier designs.

In light of the relative advantages and limitations, including costs, of each of these options, it is recommended that the following program of research be considered:

i) **Undertake Motorcyclist Crash Study** - Undertake an in-depth study of (selected types of) motorcyclist crashes across Australia, using crash reconstruction methods, to further our understanding of the number, nature and severity of run-off-the-road motorcyclist crashes, including crashes involving impacts with roadside barriers.

ii) **Barrier Design Criteria and Guidelines –** Establish the design features or criteria to which the designers of roadside barriers should aspire.

iii) **Develop New Barrier Designs** – Based on stages (i) and (ii) above, and in partnership with the barrier manufacturing industry, develop new barrier designs or modifications/additions to existing barriers for component testing and assessment. In addition to the development of new barrier designs and/or modifications, it would be necessary to test these barriers/modifications for compliance with existing standards. Consideration of the likely benefit-cost ratio for implementing new barrier designs could also be undertaken at this stage.

iv) **Undertake Component Testing –** New barrier designs would be evaluated using component testing to assess the human tolerance of a number of individual body parts to impact with various barrier design components. The important body parts and barrier components to be tested would be determined from the results of stages (i) and (ii), as well as from a knowledge of human biomechanics and injury mechanisms.

An important feature of component testing is that it enables an understanding to be gained, from first principles, of the interaction between individual human and barrier components, before introducing real-world complexity to a testing program. New knowledge or more sophisticated crash scenarios can then be built.

v) **Undertake Crash Simulation Modelling** – Data and knowledge gained from stage (iv) (and earlier stages) would provide input on physical measures of impacts between human body parts and barriers, for use in calibrating and developing crash simulation models.

It is also recommended that throughout any development and testing program, motorcycle riders and other road user groups and stakeholders be involved to ensure that their perspectives are adequately understood and considered in the research program.

1.3.2 Indicative Costs and Timing

On the assumption that a program, such as that described above, was to be undertaken, it is estimated that a budget of around $400,000, over a period of approximately four to five years, would be required to fund this work. The costs of individual parts of the program are detailed below.

Stage	**Indicative Cost ($000s)**
i) Undertake Motorcyclist Crash Study	150
ii) Barrier Design Criteria and Guidelines	30
iii) Develop New Barrier Designs	20
iv) Undertake Component Testing (including set-up of testing technology and equipment)	100
v) Undertake Crash Simulation Modelling (including establishment of expertise, software and hardware requirements)	80
vi) Progress Reporting to Sponsors and Dissemination of Program Findings	30
Program Total	**410**

Depending on the number of cases to be investigated and the geographic scope of the study, Stage i) of the proposed research program may be able to be completed within the period of 18 months to two years. Stages ii) and iii) could commence either after the completion of Stage i) or be done concurrently with Stage i). Thus, if Stages ii) and iii) commence after the completion of Stage i), it is estimated that Stages i) to iii) could be completed within 2.5 to three years (this period could be shortened if Stages ii) and/or iii) commenced prior to the completion of Stage i)). Stages iv) and v) could be undertaken more or less simultaneously, over a period of some 12 to 18 months. Stage vi) could occur as required throughout the life of the research program, however, most of the activity associated with dissemination of program findings would logically occur following the completion of Stages i) to v).

In summary, the total program could be undertaken progressively over a period of approximately four to five years, at a cost of around $410,000, with reporting of program findings occurring at appropriate intervals both during and after this four to five year period. The estimates of costs and timing should be regarded as indicative only, and should be subject to detailed development if further consideration of this research program is proposed.

1.3.3 Options for Sponsorship

It would be desirable to seek funding from a number of Australian jurisdictions to enable this program to be undertaken. The issue of motorcyclist impacts with roadside barriers is one of national significance, which should help in establishing a cooperative research program into which a number of jurisdictions would contribute funding and all would receive the *full benefit* of new knowledge gained in the area. Given that this problem is also one of international concern, the possibilities of seeking funding contributions from overseas agencies, especially European countries where motorcycling is very popular, might also be considered if insufficient funds were available nationally.

2 ATSB PROJECT SPECIFICATION

2.1 INTRODUCTION

This report has been prepared for the Australian Transport Safety Bureau (ATSB) by the Monash University Accident Research Centre (MUARC). It constitutes the first stage of a potential four stage project and takes the form of a feasibility study of motorcycle and safety barrier crash-testing.

2.2 KEY ELEMENTS OF ATSB PROJECT SPECIFICATION

In its project specification, the ATSB provided background to the safety issues associated with motorcyclists colliding with roadside barriers. It also set out the key elements of the project specification, which for completeness and convenience, are presented below.

2.3 BACKGROUND

Road safety barriers are designed to enhance the safety of the road infrastructure by containing errant vehicles and reducing the severity of off-path collisions. Experience indicates that conventional barrier systems used in accordance with specific guidelines have performed quite well in protecting the occupants of passenger cars. However, their effects on the safety of other road user groups, especially motorcyclists, is somewhat problematic.

Motorcycle organisations have argued that the installation of barriers can expose riders to increased risk of injury. They have expressed particular concerns about barriers which do not present a smooth face to traffic, such as wire rope safety barriers and W-beam systems with unprotected support posts. There is presently insufficient evidence to permit an objective assessment of these concerns.

The Australian Transport Safety Bureau is one of several organisations currently sponsoring a crash-test program to investigate the interactions between passenger cars, their passive safety systems and road safety barriers. This work is being conducted by the Monash University Accident Research Centre, and is expected to provide insight into design issues for manufacturers of both vehicles and barriers.

In the planning stages of this program, consideration was given to including motorcycles in the test schedule. However, it became obvious that a number of complex issues needed to be resolved before a suitable motorcycle crash-test method could be implemented. Consequently, the project sponsors agreed to deal with motorcycle testing as a separate investigation.

Given the limited available information on motorcycle-barrier interactions, and the lack of established procedures for motorcycle crash-testing, ATSB has decided to commission a preliminary investigation of relevant issues.

2.4 PROJECT DESCRIPTION

This project is envisaged as the first stage of a research program whose overall aims are to: assess and compare the safety performance of major approved barrier types (including wire rope systems); identify barrier design issues which impact on safety performance; and examine the scope for modifying barrier designs to better address the safety needs of motorcyclists.

2.5 OBJECTIVES

The main purpose of this initial work is to recommend a research method for investigating the interactions between motorcycles and road safety barriers. Specific objectives are to:

- identify barrier design issues likely to impact on motorcycle rider safety;
- identify relevant rider injury mechanisms;
- identify and assess the feasibility of research methods for investigating interactions between motorcycles and safety barriers;
    - this is expected to focus on the feasibility of physical crash-testing, but may also consider alternative (or supplementary) approaches, such as computer modelling techniques; and
- recommend a research program, addressing the overall aims described above;
    - this should include timing and cost details, and optional approaches if appropriate.

2.6 METHOD

It has been anticipated that this study will involve:

- a review of the international literature on relevant topics;
- analysis of motorcycle crash records;
- consultation with technical experts and key stakeholders as required.

2.7 REPORT

A report is to be provided at the end of the study in a form suitable for publishing in the ATSB ‘CR’ series. This report shall include:

- a succinct executive summary;
- a review of the relevant literature;
- a description of findings in relation to specified objectives; and
- conclusions and recommendations, including details of the proposed research program.

3 MUARC DESCRIPTION OF APPROACH AND METHODS

3.1 CONTEXT

Wire rope barriers, and similar types of flexible barriers with posts, are being used increasingly in Australia and elsewhere in the world to prevent death or serious injuries to road users whose vehicles leave the roadway. The performance characteristics of the new generation of barriers, in both real-world crashes and crash-testing situations, appear very promising for cars and for light trucks. However, motorcyclists have expressed concern that their safety may be compromised by the use of wire rope barriers and similar designs with exposed posts. At present, there is a lack of scientific knowledge from which to assess such concerns, and on how to improve barrier design for motorcyclists.

Major aims of proposed research in this field are to assess and compare the safety performance of major approved barrier types (including wire rope systems) when struck by a motorcyclist, and to develop possible modifications to these barrier systems to improve their safety performance and minimise any specific risks to motorcyclists.

3.2 PROJECT APPROACH

While this proposal describes four key stages required to achieve this overall aim, it primarily addresses the first stage of the research program. It has been decided that initially, funding be provided for Stage 1 only, to enable an assessment of feasibility and the development of test methods to be carried out before deciding on whether to undertake subsequent stages of an overall program of research. If the findings of Stage 1 indicate that the proposed research program is both feasible and capable of providing valuable new knowledge, Stage 1 will also define and cost the further stages required to achieve the overall research aims described earlier.

Thus, while the primary focus of this section is to address the requirements of the feasibility study, a preliminary description of possible future stages (i.e., Stages 2, 3 and 4) has been included in this proposal.

3.2.1 Stage 1: Feasibility study

Stage 1, the feasibility study, will involve a review of the international and national literature on the crashworthiness of barrier systems, with a particular focus on the injury mechanisms and their severity outcomes for motorcyclists. An important aspect of the investigation of injury mechanisms and their severity outcomes will be the identification of design features of currently approved barrier types that cause injury and/or influence injury severity.

Motorcyclist crash-testing methods will also be identified from the published literature and their feasibility in achieving the objectives of this research proposal assessed. Of particular interest will be:

- consideration of the two basic philosophies for barrier design, namely, to retain (and redirect) an impacting motorcyclist on the road or to allow the motorcyclist to pass through the barrier;
- the choice of one or several test set-ups to distinguish between different design concepts;

- the physical measurements that may be obtained from crash-test dummies to assess injury severity outcomes;
- the choice of a suitable human surrogate for the tests.

Consultation with technical experts and key stakeholders will be undertaken mainly following the completion of the literature review. It is proposed that a specific aspect of the consultation process will involve discussions with motorcyclists to ensure that their views are adequately captured during the feasibility study.

As required by the project specification, consideration will be given to alternative, or supplementary, approaches to comparing and assessing the safety performance of various barrier systems when struck by motorcyclists. Such alternative approaches might include crash simulation using computer-modelling techniques.

In the absence of relevant published information on real-world crash experience, Victorian (and if necessary, other jurisdictions) crash records may be searched and analysed to provide an indication of the number, nature and severity of injuries resulting from collisions with roadside barriers. One option would be to examine in greater detail, motorcyclist crashes investigated as part of the Victorian "Fatal single vehicle crash study" carried out by Haworth et al. (1997), though sample sizes may limit the usefulness of this approach. A decision on whether to carry out these crash analyses will be made following an initial review of the published literature.

Subject to a satisfactory assessment of the feasibility of the proposed testing and development stages of the project, a crash-testing program for subsequent stages will be defined. Definition of the overall program will include recommended test methods, study outputs, time schedule, costing for each stage and funding options for conducting the program of research.

3.3 POSSIBLE FUTURE STAGES

3.3.1 Stage 2: Crash-Testing Program

Stage 2 could involve the development of crash-testing technology, with the possibility of implementing such technology in a series of barrier crash-tests.

3.3.2 Stage 3: Development of Barrier Performance

In collaboration with barrier manufacturers, barrier designs could be developed in accordance with the research findings of Stage 2 and modified designs produced. Barrier crash-testing could then be undertaken to compare the safety performance of modified barriers with the original designs tested in Stage 2.

3.3.3 Stage 4: Promotion of Research Program Findings

Though presented as an optional stage in the overall project, it is recommended that two important further steps be undertaken. The first involves integrating all recommendations from Stage 3 and defining an improved approach to erecting and modifying barrier systems to enhance safety for all road users, including motorcyclists. The second important step relates to the transfer of knowledge so that relevant agencies, industries, community groups and individuals in society are made aware of the key findings from the study.

3.4 STUDY OUTPUTS

The main output of Stage 1 – the feasibility study – will be a report on the literature search and review, as they relate to the specific objectives of the feasibility study. That is, the report will be structured such that it:

- identifies barrier design issues likely to impact on motorcycle rider safety;
- identifies relevant rider injury mechanisms;
- identifies and assesses the feasibility of research methods for investigating interactions between motorcycles and safety barriers, including possible alternative approaches; and
- recommends a research program, which addresses the overall aims described above, as well as including timing and cost details, and optional approaches if appropriate.

Given the relatively high costs of conducting full-scale crash-testing programs, particularly where special expertise is involved, or must be developed, careful consideration will be given in the feasibility study report to costs for any testing and development research that might be recommended.

4 LITERATURE REVIEW

This chapter discusses the main findings of the literature review, as it relates to the objectives of the feasibility study. It covers, under separate headings, the key research questions defined in the project brief and in MUARC’s proposal.

4.1 THE NUMBER, NATURE AND SEVERITY OF INJURIES RESULTING FROM COLLISIONS WITH DIFFERENT BARRIER TYPES.

There are limited data available relating to motorcyclist impacts with guardrails on Australian Roads. Gowan (1996) reported that in Victoria between the years of 1991 and 1995, there were 9059 accidents involving motorcyclists, 84 of which involved the collision of the rider with a guard fence. However, no other details were given regarding the type of guardrails involved. Also, Haworth, Smith, Brumen and Pronk (1997) found that out of 222 motorcyclist casualties in metropolitan Melbourne, eight involved some type of barrier.

A report produced by ATSB (2000) summarised the additional relevant available information regarding motorcycle collisions with barriers, namely:

- The involvement of any type of barrier in motorcyclist casualties is consistently found to be less than 5% in accident studies;
- In South Australia, 2.6% of all fatal motorcycle crashes between 1985 and 1991 involved initial collision with a guardrail;
- Australian Coroner’s records indicate that 2.4% of total rider fatalities involved collisions with safety barriers in 1994 and 1996.

With specific reference to the involvement of Wire Rope Safety Barriers in motorcyclist casualties in Australia, ATSB (2000) reports that Australian State Road Authorities reported no such casualties, however the reporting of crashes with barriers does not necessarily distinguish between different barrier types.

Globally, there have been varying estimates made regarding the frequency of motorcyclist impacts with guardrails. In California, it was reported by Ouellet (1982) that out of 900 motorcycle accidents, collisions with barriers accounted for 63 somatic region injuries and 35 head-neck region injuries, totalling 98 injuries overall. In terms of the severity of injuries sustained by riders who impacted guardrails, the author reported that for 30.2% of such incidents, the maximum abbreviated injury scale (MAIS) was ≥ 3. In addition, it was reported that of the 900 cases examined in the study, “….every rider who struck either a W-beam barrier or metal mesh fencing suffered at least multiple extremity fractures; six were killed, three by partial or total decapitation.” (Ouellet, 1982, page 124).

In West Germany, 15% of all motorcycle rider or pillion deaths result from collision accidents with guardrail posts (Koch & Schueler, 1987) and 66% of motorcyclists suffer very severe trauma after impacting with guardrails.

Quincey, Vulin and Mounier (1988) reported that in a rural area of France on 940km of highway with 100% of its length with median barrier and 40% of its length with roadside guardrail, it was found that 9.5% of all motorcycle accidents involved an impact with a guardrail between the years of 1980 and 1982. In approximately 70km of road studied in an urban area of France with 100% of its length fitted with median barrier and 62% of its length fitted with roadside guardrail, it was found that 28% of motorcycle accidents involved barrier impact, accounting for two-thirds of the corresponding fatalities over a two year period (1978-1979).

4.2 BARRIER TYPES CURRENTLY IN USE IN AUSTRALIA

There are three main types of barrier used on Australian roads: rigid barriers, semi-rigid barriers and flexible barriers. Rigid concrete barriers, semi-rigid steel “W” shape beam barriers and flexible wire rope barriers (tensioned cables with frangible posts) have been satisfactorily crash tested and comply with Australian Standard AS/NZ 3845:1999 or recognised international standards (VicRoads, personal communication). These barrier types (discussed in the following sections) differ in terms of their deflection and energy absorption properties and their suitability for different road characteristics.

Once it has been established by road authorities that installation of a barrier is, in fact, warranted for a particular location, there are several factors that need to be considered in choosing an appropriate barrier system. Installation cost, maintenance cost, rigidity (containment performance, deflection), site conditions, particularly ground slope, distance from the travelled roadway, feasibility of providing impact absorbing end-treatments and, in some situations aesthetics, are all taken into account when making a choice of one barrier type over another. In many cases, however, there may be a choice between barrier types (or a wide median) subject to individual detailed design possibilities (VicRoads, personal communication).

4.2.1 Rigid Barriers

Rigid barrier systems have the lowest deflection properties of the three types of barrier systems, exhibiting very little, if any deflection on impact. Therefore, during a collision, energy dissipation is achieved through deformation of the vehicle and raising and lowering of the vehicle body. They are most suitable in locations where there is limited space for barrier deflection and perform optimally in collisions where the impact angle is 15° or less (Main Roads, Queensland, 2000).

Concrete Barriers

Generally concrete barrier systems are made up of separate interlocking sections joined together to make a rigid, continuous smooth surface. Traditionally, the most common concrete barrier type used was the “New Jersey” barrier, however, more recent variations on the design include the ‘F’ Shape, constant slope and vertical face concrete barriers which have less of a propensity to cause vehicles to overturn on impact (VicRoads, 2000). In Australia, concrete barriers are mainly used for median barriers on divided high-speed arterials or as bridge railings (Cunningham, 1993). They are only suitable for low impact angles and they are not suitable for placement away from traffic lanes.

4.2.2 Semi-rigid Barriers

Semi-rigid barrier systems have greater deflection properties than rigid systems, but still less than those of flexible barrier systems. Redirection of errant vehicles following impact is achieved through the transfer of energy to the support posts and barrier rails (or an analogous feature) (Main Roads, Queensland, 2000).

W-Beam

As the name suggests, W-beam guardrails have a 'W' profile that can be used with a variety of post configurations depending on the particular characteristics of the site for which the system is intended. They are not suitable for potential right angle impacts. W-beam barrier systems are comprised of several components, including:

- The W-beam rail, which must be strong enough to withstand the high axial tensile and bending stresses that occur in the event of vehicle impact.
- The posts, which can be made of timber or steel and provide rigidity to the entire system. They also hold the W-beam rail at the correct height.
- The blocks which prevent snagging of the posts and aid in the prevention of vehicle roll-over by providing restraining forces above the centre of gravity of the vehicle.
- The anchorages which provide restraining forces at either end of the W-beam and enable the system to develop its full tensile strength (Cunningham, 1993).

VicRoads (personal communication) advises that W-beam barriers, which were extensively used before the advent of other barrier types, are now rarely used over extensive lengths in new median installations due to the superior performance of other barrier types. They are also the least effective of the three barrier types in containing heavy vehicles.

Pipe-fence/Tubeprofile

The Pipefence system, manufactured by Blue Systems, Sweden, consists of an upper and lower rail generally made of steel. The rails are held in place by support posts that are fixed into the ground 1.2m. The Pipefence barrier system causes minimum sight obstruction and allows simple, flexible installation. Other similar barrier types such as Tubeprofile (manufactured by Varmforzinkning, Sweden) are also being used increasingly in Europe.

4.2.3 Flexible Barriers

Flexible barriers have the greatest deflection and energy absorption properties of the three types of barriers, providing significant lateral deflection and thus resulting in the lowest deceleration forces on vehicles, such as cars, and their occupants. In Australia, there are two types of flexible barriers in use, both of which are comprised of a wire rope system held in position by support posts. The first flexible barrier type to be used in Australia, was the Wire Rope Safety Fence, manufactured and distributed by *Brifen*. The other form of flexible barrier was approved for use by VicRoads in 1997 (VicRoads, 1998). It is known as 'Flexfence' and is manufactured by Ingal Civil Products in Australia.

Flexible barriers are now used to various extents in all Australian states and territories (ATSB, 2000), however there are specific guidelines for assessing their suitability for installation at particular locations. For example, due to their high lateral deflection properties, they are not used in situations where large defections would result in contact with objects or oncoming vehicles. They also have limited effectiveness on the inside of curves and cannot be used on smaller radius curves (VicRoads, personal communication).

Wire Rope Safety Barrier (WRSB)

Although there are slight variations in design, generally, WRSBs are comprised of a three or four ‘woven’ rope system, which are fixed to frangible posts and the ends of the wire rope are fixed into the ground. The cables are made from galvanised steel, are approximately 19mm in diameter and are held under tension. The Brifen WRSB system, comprised of four ropes, has an upper and lower rope system whereby two parallel ropes, vertically displaced from each other, are situated at the top of the posts, while the lower two ropes are at the same height as each other and crossed over in the horizontal plane from one support post to the next (VicRoads, 2000). The upper and lower steel rope pairs are approximately 585mm and 490mm above ground level respectively and are tensioned to 22kN (VicRoads, 2000). Alternatively, the Flexfence system consists of either three or four galvanised ropes that are vertically displaced from each other and do not cross over, however, only the four rope design has been used in VicRoads projects (VicRoads, 2000). The standard distance between each of the posts is 2.5 metres (Schmidt, 1997), although this can be modified to increase or decrease the deflection properties of the system. The posts are frangible, galvanised sigma shaped posts set in concrete footings (VicRoads, 2000). However, it should be noted that the concept of “frangibility” obviously depends on the characteristics (i.e. mass) of the body impacting the post.

Wire Mesh Fences (or Wire Meshed Topped Barriers)

Although not a conventional barrier system, wire mesh fencing, consisting of a body of wire mesh usually supported by thin steel posts, has been identified in the literature as being hazardous to motorcyclists when used in the same way as other barrier systems. Such fencing may consist of various barrier bases that are topped with wire mesh.

4.2.4 End-Treatments (Terminals)

Safety barriers systems require an end-treatment (terminal) or an impact attenuator (also known as energy attenuators or crash cushions) in order to terminate the system so as to avoid any part of the end of the barrier system from penetrating the passenger compartment or causing intolerable deceleration on impact (VicRoads, 2000). These devices are designed to either: allow deceleration of a vehicle to a safe stop within a relatively short distance; permit controlled penetration of the vehicle behind the device; contain and redirect the vehicle; or a combination of the aforementioned functions. In addition, no part of the end-treatment should spear, vault, snag or roll an impacting vehicle (VicRoads, 2000).

End-Treatments

Current end-treatments are classified as either gating or non-gating systems. Gating systems are designed to break away, hinge or pivot on impact, allowing an errant vehicle to pass behind the barrier system. Gating systems therefore require an obstacle free area beyond the barrier in which the vehicle can safely come to a stop (VicRoads, 2000). Alternatively, non-gating systems do not allow the vehicle to pass behind the barrier, rather they allow for safe deceleration of a vehicle in the case where the vehicle impacts the “nose” of the end-treatment. Thus, they do not require a runout area beyond the barrier system (VicRoads, 2000).

Impact Attenuators

Impact attenuators are designed to reduce the deceleration forces of an impacting vehicle and may be either non-redirective or redirective (VicRoads, 2000). As implied by the name, a non-redirective impact attenuator is unable to redirect an impacting vehicle back into its intended direction, but rather functions by absorbing the kinetic energy of the vehicle on impact. A redirective attenuator has both energy absorbing properties to slow vehicles that hit the attenuator head-on, as well as being able to redirect impacting vehicles back into their original direction when hit on an angle or during glancing impacts (VicRoads, 2000).

4.3 ROADSIDE BARRIER DESIGN FEATURES AND INJURY MECHANISMS

The fact that many roadside objects, such as guardrails and/or their posts, tend to be hit with a very high proportion of the total speed perpendicular to the impact surface means that the injuries sustained by motorcyclists who have collided with guardrail systems are usually severe and often lethal (Ouellet, 1982). Accident analysis has shown that severe injuries are sustained by two out of three motorcyclists who collide with guardrails (Domhan, 1987) with the most dangerous feature of guardrail systems being the guardrail posts.

As it is common for motorcyclists to slide along the road surface after leaving their vehicles, exposed guardrail posts can prove to be especially dangerous as they are often hit by wayward riders (cited in Koch & Schueler, 1987). Similarly, motorcyclists thrown from their vehicles onto the top of the guardrail can also be severely injured after tumbling along the tops of the exposed posts. Both the tops and bottoms of the posts present edges and corners which act to concentrate the impact forces and thus, increase the severity of the injuries sustained (Ouellet, 1982). Impacts with guardrail posts are especially harmful to motorcyclists as they cause injuries that are five times more severe than an average motorcycle accident (Pieribattesti & Lescure, 1999).

In the case of metal mesh fencing, once again the supporting posts are the main source of injury through either deceleration of the torso, fracture of the extremities, or occasionally, decapitation (Ouellet, 1982). In addition, the metal edges of the barrier, especially the top of the barrier which is at approximately rider head height, provide numerous lacerating surfaces accentuating rider injury risk (Ouellet, 1982). This is also the case with other barrier systems that are topped with wire mesh (Ouellet, 1982).

The height of guardrail systems is another important consideration for motorcyclist safety. In the event of a motorcyclist colliding with a barrier that is too low, the rider may be catapulted over the top of the guardrail. In a review of 375 motorcycle accidents in Los Angeles, at least 10 resulted in a rider being catapulted over the top of a barrier that was too low (Ouellet, 1982). It was suggested by the author that a barrier which is slightly higher than the riders centre of mass (around four and a half feet) would prevent such incidents.

Although the greatest perceived concern for motorcyclists with respect to WRSBs is their potential to induce injuries through the so called ‘cheese-cutter effect’, the fact that the posts are left exposed means that they may also pose a similar safety risk as other barrier systems with exposed posts (ATSB, 2000). While WRSB posts are designed to be frangible when struck by a car, it is unknown how these properties would affect the safety risk for motorcyclists.

4.4 SAFETY PERFORMANCE OF BARRIERS TYPES WITH RESPECT TO MOTORCYCLISTS.

In the International testing standards for the evaluation of safety barriers, motorcyclists have not been explicitly considered as test vehicles (Gowan, 1996). This has been justified based on the following three arguments:

1. That the concept of redirecting the vehicle, namely the motorcycle, has little meaning in safety terms;

2. That any collision of the rider with any given rigid object will result in great trauma for the motorcyclist;

3. That the probability of crashes of motorcyclists into safety barriers is low.

Given this stance on crash-tests between motorcyclists and safety barriers, there is very limited existing information relating to the safety performance of different barrier types with respect to motorcyclists. However, in a general sense, whether or not a barrier system has a continuous surface could be expected to have a large impact on the safety performance where motorcyclists are concerned. For example, although the rigidity of concrete barriers is inherently hazardous in terms of not absorbing the force of impact, for motorcyclists, their continuous surface is preferable to the non-continuous surfaces of W-beam and wire rope systems at low impact angles. This is due to the fact that barriers with a continuous surface enable sliding and “soft” redirection of the victim and allow for greater distribution of contact forces over a large body area (Sala and Astori, 1998). Alternatively, direct victim–post interaction in the case of non-continuous barriers results in concentrated loads acting on the body, generating high flexion/extension movements of the body, high decelerations and high inertial loads (Sala and Astori, 1998). However, sharp decorative edges on concrete barriers (such as sound fence), which transform the surface into a non-continuous barrier, are not desirable in terms of motorcycle safety (Ouellet, 1982). In terms of energy absorbing properties of barrier systems, those which have the capacity to dissipate impact energy through deformation or alternate mechanisms present less of an injury risk to motorcyclists (Sala & Astori, 1998).

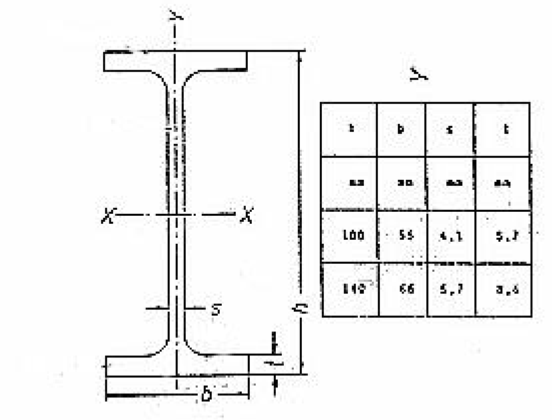
4.5 REVIEW OF DIFFERENT STRATEGIES FOR BETTER PROTECTING MOTORCYCLISTS.

Most of the initiatives taken to improve road safety barrier performance for motorcyclists of late have taken place in Europe, particularly in Germany and France. The three most prevalent methods of achieving this aim are all based on modifying existing barrier types and include: the replacement of IPE-100 posts (refer to Figure 1) traditionally used in European guardrail systems with the more forgiving Sigma-Posts (refer to Figure 2); covering the existing posts with additional W-beams on the lower section of the guardrail system; and covering exposed posts with special impact attenuators (Koch & Schueler, 1987; Sala & Astori, 1998).

4.5.1 Sigma Posts

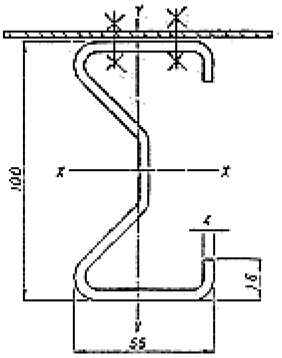
Sigma (Σ) posts (figure 2), as opposed to IPE-100 posts (Figure 1), are more compliant and less harmful to motorcyclists as they have a large, thin walled, Σ-shaped cross section with rounded edges (Koch and Scheuler, 1987; Sala and Astori, 1998). As noted above, these posts are used predominantly in a number of European countries, while Australian practice in these situations is to use “C-posts”.

Figure 1: Schematic diagram of IPE post.



h	b	s	t
[illegible]	[illegible]	[illegible]	[illegible]
100	55	4,1	5,7
140	66	5,7	8,6

Figure 2: Schematic diagram of Sigma post.



4.5.2 Additional W-Beams

The installation of additional W-beams to the lower section of the guardrail system has proven to be an effective method of reducing the severity of injuries sustained by motorcyclists as they aid in distributing the energy of impact over a larger surface (Koch and Scheuler, 1987; Sala and Astori, 1998). They also serve to protect victims from directly impacting the guardrail posts.

Quincey *et al.* (1988) conducted several crash-tests involving a dummy ejected from a moving platform. Tests were carried out using two modifications to a metal beam standard guardrail and a comparative test on a standard concrete barrier was also conducted, however, no comparison was made with a standard W-beam configuration. The two modifications to the metal beam guardrail included (1) the addition of an upper and lower beam to the existing guardrail, and (2) the removal of the upper beam and the reduction of the lower beam stiffness (to facilitate fitting onto existing barrier). The dummy impacted the barrier at a speed of 55 km/h and at an angle of 30°. The platform was stopped short of the barrier and the dummy impacted the target after sliding along the ground for two metres. The tests showed that the accelerations and the head injury criteria (HIC) were lower than the limit values, and thus, the French Transport Ministry approved the barrier modifications for use.

Similar devices which incorporate the addition of lower beams to existing W-beam barrier systems have been developed and tested by other research groups and authorities worldwide and evaluations have found similar favourable results (see, for example, Pieribattesti & Lescure, 1999). Similarly, computer/mathematical simulations have been carried out on W-beam barrier systems with additional lower W-beams (see section 4.5.5).

4.5.3 Impact Attenuators

Impact attenuators, or dampers, that are fitted to existing guardrail posts, also serve to increase the impact surface and, due to their deformation properties, increase energy absorption on impact (Koch and Schueler, 1987; Sala and Astori, 1998). They are made from a variety of synthetic materials. Impact attenuators have proven to be popular due to their relative cost-effectiveness compared to other intervention types, however, they are susceptible to rodent attack and weathering (Domhan, 1987). In addition, their effectiveness decreases with speed and are generally only acceptable for impacts at a maximum of 50 - 60km/h (Domhan, 1987).

Tests have been carried out using impact attenuators made of various types of polyetheylene foam with favourable results. Schueler (1985, cited in Koch and Schueler, 1987) and Jessl (1985, cited in Koch and Schueler, 1987) carried out tests on IPE-100 posts covered with an impact attenuator and uncovered IPE-100 posts as well as covered sigma posts. The tests involved investigating the damage caused to cadavers and body parts projected onto barrier posts. Cadavers were fixed to a sled and slid into the barrier posts at approximately 32km/h, lying face up and feet first at an angle of 15°. The tests showed that the presence of an impact attenuator reduced the maximum abbreviated injury scale (MAIS) from 3, in the case of the uncovered IPE-100 posts, to MAIS = 1 for the covered IPE-100 post, and MAIS = 2 for the covered sigma post. Impact with the uncovered IPE post caused arm amputation, the sigma post caused arm fractures while the covered IPE post caused only contusions. In light of these results, it was recommended by German authorities that impact attenuators be installed at accident black spots.

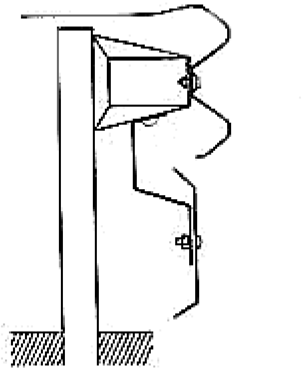
4.5.4 Additional Measures Taken to Reduce Risks to Motorcyclists

A report by the Federation of European Motorcyclists Associations (FEMA, 2000) described four additional measures that have been used in France to reduce the risks that safety barriers pose to motorcyclists. All of the devices were tested and approved for use using the LIER/INRETS homologation procedure described in section 4.7.3. These measures include:

- Ecran Motard (Figures 3 and 4): a metal shield or plate that can be fixed under existing guardrails to cover the barrier posts. It differs from the addition of extra W-beams described above as it has a flat surface with a high degree of flexibility enabling it to absorb energy on impact. It is sold by SEC-Envel in France.

Figure 3: Photograph of the 'Ecran Motard" fitted to an existing guardrail.

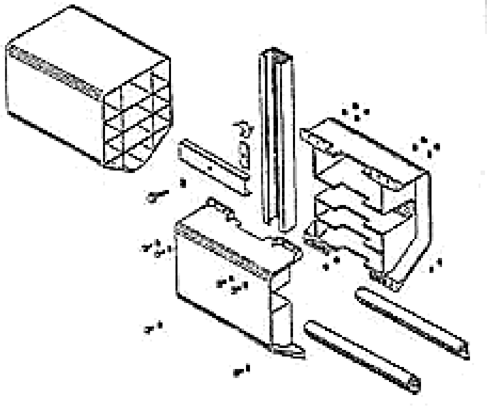
Figure 4: Schematic drawing of "Ecran Motard" fitted to an existing guardrail.



- A plastic rail named “Plastrail” (Figures 5 and 6) developed by the French company Solidor. The device consists of soft plastic fence covering barrier posts that can be fitted to existing barrier systems. It aims to combine both energy absorption properties and impact spreading properties.

Figure 5: Photograph of the “Plasti-rail” fitted to existing barrier system.

Figure 6: Schematic Diagram of the “Plasti-rail” components.



- A device known as “Motorail” (Figures 7 and 8) which is a barrier with a built-in secondary rail. It has been designed with minimal aggressive shapes and has turned in edges. It was designed and is sold by Solosar.

Figure 7: Photograph of the “Motorail”.

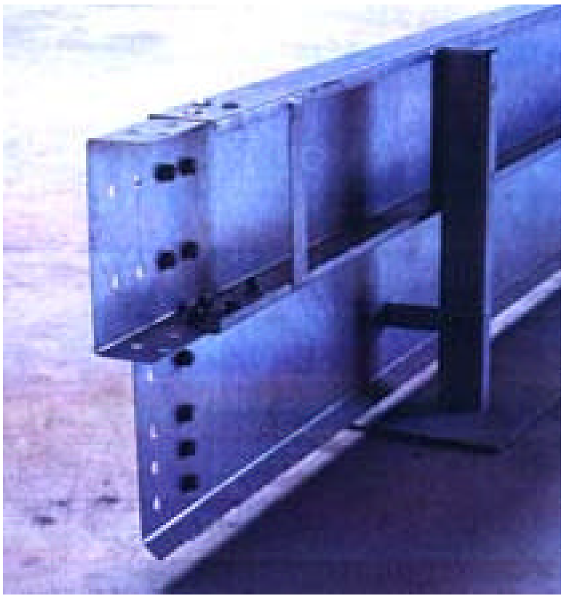
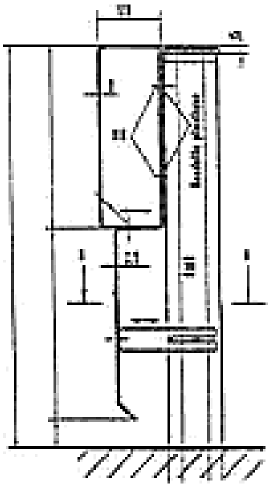


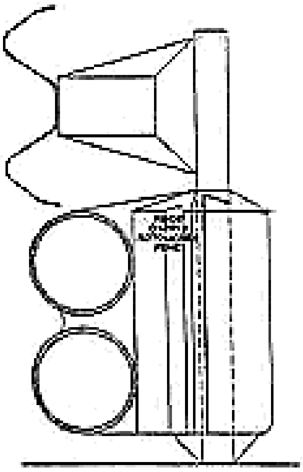
Figure 8: Schematic drawing of the “Motorail”



- The “Mototub” (Figures 9 and 10) made by Sodirel, which is similar to the Plastrail except that it is made from 70% recycled material. It is apparently also able to be adapted to cover WRSB types and is now being sold in Australia by L.B. Wire Ropes.

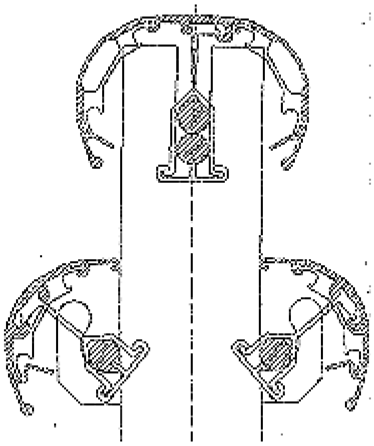
Figure 9: Photograph of “Mototub” fitted to existing barrier system.

Figure 10: Schematic drawing of “Mototub” fitted to existing barrier system



In addition, the Baltic Construction Company in Sweden has developed a device that covers the upper and lower wire rope systems of standard WRSBs (Figure 11). The device consists of aluminium profiles that can be fitted to existing systems. Computer simulations were conducted to assess the safety performance of the device using the Finite Elements Program, LS-DYNA, and included tests using a 16 ton lorry, a 900kg car and a motorcycle (Baltic Construction Company, 1999).

Figure 11: Schematic drawing of aluminium profile covering WRSB



The simulation was set up according to the following conditions:

1. 16 ton lorry – initial velocity of 80km/h, impact angle 20°;

2. 900kg car – initial velocity 100km/h, impact angle 20°, and;

3. Motorcycle – initial velocity 100km/h, impact angle 20°.

The Acceleration Severity Index (ASI), Theoretical Head Impact Velocity (THIV), Post Impact Head Decelerations (PHD), working width and the dynamic deflection (i.e. deflection of the fence) were measured for each configuration. The results, in terms of the safety performance of the device for motorcyclists, showed that the motorcycle was redirected by the device and that, as the motorcycle and its rider slid along the fence, the aluminium guides protected the rider body parts against the wires. In addition, no part of the fence penetrated the motorcycle or the rider. The simulations involving the car suggested that all measured variables were within acceptable levels, however, in the simulation involving the lorry, the vehicle was found to run over the fence, and hence, not all variables could be recorded, although it was found that no fence parts became detached and penetrated the vehicle.

On the basis of these results, this device appears promising in terms of its potential to reduce injuries to motorcyclists through the so-called “cheese-cutter” effect of WRSBs, however, it does not protect motorcyclists from injuries resulting from impact with the posts of WRSBs. Also, it should be noted that a standard WRSB (without the aluminium guides) was not included for comparison purposes in the simulation.

4.5.5 Data From Computer and Mathematical Based Simulation Studies

There is additional evidence for the aforementioned interventions from computer and mathematical simulation studies. Using a *multi-body* numerical method, Sala & Astori

(1998) conducted a simulation study of motorcyclist impact on three different types of conventional barriers: steel with a rubbing rail (a rail with a flat, smooth surface); steel with no rubbing rail; and a concrete barrier. The input parameters for the model were derived using finite element analysis and from experimental testing. Data relating to the type and severity of injuries that motorcyclists would be likely to sustain after colliding with the three barrier types were obtained. In light of the results from the study, a new protection device was designed, tested and compared with the three types of barriers listed above.

The new device took the form of a lower rail that could be added to the conventional metallic guardrail and was made from *pultreded* continuous glass fibres and polyester resin. The composite materials used for the new barrier rail are characterised by low elastic modulus (however, this can be tailored), high damping co-efficients and do not suffer corrosion. The rail is “U” shaped so as to decrease the possibility of motorcyclists sliding under or being thrown over the rail. In order for impact energy to be absorbed, a deformable steel spacer must be used to bolt the rail into the guardrail posts.

The results gave further support for the use of barriers with continuous surfaces (such as the barrier with the new lower rail added and the concrete barrier) as they were found to be much safer for motorcyclists than non-continuous barriers (such as the steel barriers with and without rubbing rails). In addition, the energy absorbing spacers used to secure the new rail and its low flexural stiffness reduced the risk parameters to minimum values.

4.6 CRASH-TESTING

As is evident from the preceding sections of this report, physical crash-testing has been used in the past as a successful method for testing new devices designed to improve the safety performance of existing barriers for motorcyclists. There are, however, alternative approaches to physical crash-testing, such as computer modelling and crash simulation, that are being used increasingly to investigate various safety issues with respect to motorcyclists.

4.6.1 The Feasibility of Physical Crash-Testing and Possible Alternative or Supplementary Approaches

Physical crash-tests are advantageous as they provide more realistic data for motorcycle crashes. On the other hand, the two main disadvantages of physical motorcycle crash-testing include the difficulty of reproducibility of tests as well as their relatively costly and time consuming nature (Nieboer, Wismans, Versmissen, van Slagmaat, Kurawaki, & Ohara, 1993). For these reasons, there has been increased interest in the development of computer-aided simulation of crash-testing. With simulations, it is possible to conduct a large number of simulations at a relatively low cost which is important considering the wide range of crash configurations the motorcycle and rider can be subjected to. Computer simulations are also useful in terms of their repeatability and their ability to identify the *salient* aspects of injuries and injury mechanisms in crash-test situations, however, the simplification required excludes a thorough analysis of the complexity of the situation.

One of the major problems associated with conducting an accurate simulation of a crash between a motorcycle and another object, is that motorcycles and their riders behave in an extremely complex way following impact. The motorcycle rider interacts with the motorcycle, the motorcycle interacts with the collision partner (e.g., passenger car, barrier, etc.) but the motorcycle rider also interacts directly with the collision partner (Nieboer *et* *al.*, 1993). The complex movements are, in part, due to the fact that the masses of the motorcyclist and of the rider are the same order of magnitude as opposed to that of cars and their occupants (Yettram, Happian-Smith, Mo, Macaulay & Chinn, 1994). Hence, there are a large number of degrees of freedom in the real life situation, whereas, in a computer model there must be a finite number of degrees of freedom (Yettram *et al.*, 1994).

4.6.2 Computer Simulation Studies of Motorcycle Impacts

In the paper by Nieboer *et al.* (1993) the development and validation of a 3D mathematical model of a motorcycle and rider is presented. The modelling and simulations were made with MADYMO. It is a simulation program in world-wide use, specially designed for the study of the complex dynamic response of humans or human surrogates under extreme loading conditions (Lupker, de Coo, Nieboer & Wismans, 1991, cited in Nieboer *et al.*, 1993). Three full-scale motorcycle to load-cell barrier crash-tests were performed to obtain dynamic input data and two motorcycle to car crash-tests were performed to validate the mathematical model. The tests were performed at the laboratories of the TNO Crash-Safety Research Centre. In the first stage of model construction the motorcycle model was developed and validated against the three full-scale barrier tests. In the second stage the motorcycle model was adjusted to take rider interaction into account and the rider model was added. The MADYMO model of the motorcycle consists of seven bodies linked to each other by joints and spring-damper type elements. The dummy representation was an updated version of an already existing model.

The simulation of crashes involving motorcycle, rider and vehicle proved to be substantially more difficult than crashes involving cars and occupants. The difficulties were due to the three involved objects moving at the time of the crash and the complicated way motorcycles and riders behave after a crash. The simulation results were however, considered very promising by Nieboer *et al.* (1993); even time-histories of dummy and motorcycle acceleration showed an acceptable correlation. The only drawback was that the energy absorption in the crash was underestimated in cases of large motorcycle deformation.

Extra measurement results from additional tests and the use of recent features of the MADYMO program will improve the simulation results in the future. Nieboer *et al.* (1993) believe that simulating crash events involving rider, motorcycle and collision partner is a research activity worthwhile exploring and that the riders involved in crash events will directly benefit from the research.

Another simulation, conducted by Yettram *et al.* (1994), utilised computer/mathematical simulations to investigate full-scale crash-tests of motorcycles with dummy riders. The riders were impacted into flat rigid vertical barriers inclined at various angles to the motorcycle direction of travel. The 3D models used in the simulations consisted of three main physical components: the motorcycle, the dummy rider and the target (for example, a barrier or a moving car).

Due to the necessary simplifications that need to be made to models Yettram *et al.* (1994) found that some are more significant and need to be considered when comparing analytical results with the corresponding experimental values.

Also, the sensitivity increases with impact speed, making simulation difficult at velocities greater than about 56 km/h. This is due to the coalescing of critical events at such high speeds.

Yettram *et al.* (1994) found that with accurate values for the input data the program will produce overall displacements and velocities to within an acceptable tolerance.

Another study, conducted by Chinn, Okello, McDonough and Grose (1996) in the United Kingdom, successfully used a combination of, among other things, computer simulation (using MADYMO), initial sled tests and full-scale impact tests to develop a testing program for a purpose-built airbag restraint system for motorcycles.

MADYMO was used to investigate rider kinematics at impact using load and acceleration impact test data information that had been supplied by the Transport Research Laboratory, UK. The sled tests were conducted in order to evaluate the test system, with a dummy rider, over a range of parameters covering speed, angle and seating positions. The final phase of the project, which was incomplete at the time of publication of the report, was full-scale crash-testing, carried out in accordance with the current standards for conducting motorcycle crash-tests (ISO DIS 13232) (Van Driessche, 1994). The crash-tests were conducted at the Transport Research Laboratory using a computer controlled hydraulic motor-drive system with the capacity to achieve highly accurate test speeds with low acceleration of the trolley (Chinn *et al.*, 1996).

The authors conclude that the process of development, which begins with computer simulation and proceeds to design, development and evaluation using tests such as sled tests and full-scale crash-tests, has proven to be very efficient and effective.

4.6.3 Sub-system/Component Testing

Another alternative or supplementary approach to physical crash-testing and/or crash simulation is sub-system or component testing. This method focuses on specific crash components, of both the human body and isolated barrier parts, which are believed to be critical to injury severity outcomes. Hence, it provides a way of testing specific parameters at a relatively low cost. It is also a way of breaking down a very complex problem into “easy to handle” parameters, which is useful when certain criteria need to be measured.

In the case of motorcycle riders interacting with roadside barriers, it is important to identify the specific injury mechanisms that may cause death or serious injury to the rider. Once this is done, a number of sub-system tests can be developed to measure what is found to be important indicators of injury, such as head acceleration.

To be able to determine what type of injuries riders sustain when they come into contact with roadside barriers, it is important to look at real world crashes. Only real world crashes produce the necessary injury statistics that can be used to identify the specific injury producing factors that play a part in the interaction between rider and barrier. When the injury producing factors have been found, it is possible to set up a number of guidelines, which aim to reduce or eliminate the potential of serious injury or death. A number of sub-system tests can then be designed around the guidelines in order to be able to measure the performance and possible benefits from different barrier designs.

Sub-system testing is used in many ways, for example, in motorcycle helmet testing. Helmets are tested on the specific, potential injury producing factors for which they are designed to address. With special tools, helmets are tested on their ability to absorb energy and protect from penetration. The same principle of testing is used in sub-system testing of cars to measure their potential injury producing effect in collisions with pedestrians.

In a report by Grösch and Hochgeschwender (1989), sub-system testing of car/pedestrian collisions is described. One of the reasons why the authors chose to do component testing is that the large number of impact configurations requires an inordinately large number of tests. This problem can also be found in motorcycle crash-testing, indicating some similarities with pedestrian testing. Certain parameters, which may also be useful in barrier testing, are measured in, for example, the head to bonnet component test. The aims of the parameters are:

- Maximum deformation of the component;
- The smallest possible peak force;
- The most even distribution of forces possible.

All of the different parameters are measured with relevant parts of the dummy mounted to the pendulum of the impactor. The relevant dummy parts were, in this case, the head, lower leg and femur. The results of these tests are recognised as only a rough guide to the injury risk of a human in a comparable accident situation.

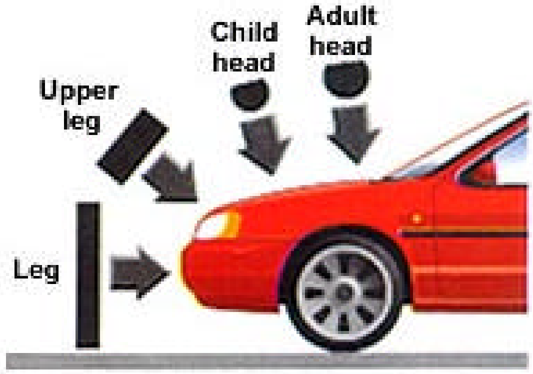
Another sub-system test was done by MacLaughlin and Kessler (1990). The report describes a head impact test with a uniaxial head impactor. The impactor was able to identify which of nine passenger cars and three light trucks would cause pedestrian head impact injury in the event of a car/pedestrian collision.

Ishikawa, Yamazaki, Ono and Sasaki (1991) conducted parametric studies with sled tests and computer simulations in order to understand pedestrian kinematics in car/pedestrian collisions. Ishikawa *et al.* (1991) also looked at accident analyses and full-scale tests to obtain data for considering sub-system test methods for pedestrian protection.

Component testing with leg impactors was carried out by Sakurai, Kobayashi, Ono and Sasaki (1994), to determine the influence of upper body mass on leg impact and to compare direct and indirect measuring methods when determining potential leg injury.

In 1987 the European Experimental Vehicles Committee (EEVC) set up Working Group 10 (WG10) which presented a proposal for a test method to evaluate pedestrian protection for cars (Harris, 1991). The work of WG10 was finalised in 1994.

Figure 12: Sub-system tests.



The tests have been developed by a European Consortium acting under contract to the European Commission. The test consists of three sub-system tests to separately assess the bumper, the leading edge of the bonnet and the top of the bonnet. (Figure 12). Each of the tests is based on a car to pedestrian impact speed of 40 km/h. The sub-system testing allows for testing of any area that is likely to be struck by pedestrians of any height and at any location across the width of the car. This type of testing also allows assessment to be either to a complete car, or to the parts of a car considered necessary in order to evaluate the interactions that may result in injury.

Improvements have continually been made to the design of the impactors and to the test procedures. According to Janssen (1996), the procedures seem easy to follow and the test methods appear to be reproducible and sensitive to vehicle design changes. The headform and upper legform impactors are available on a commercial basis.

When considering the complexity and variety of possible impact scenarios, there are some similarities between the interaction between pedestrian/car and barrier/motorcycle rider. In the case of pedestrian impacts with cars, EEVC chose to handle the complexity with sub-system testing of identified factors influencing the injury outcome. To deal with the cost and difficulty of full-scale motorcycle into barrier crash-testing, sub-system testing may be considered as an option.

4.7 THE CHOICE OF ONE OR SEVERAL TEST SET-UPS TO DISTINGUISH BETWEEN DIFFERENT DESIGN CONCEPTS

4.7.1 Previous Approaches Used for Physical Crash-Testing

There have been various techniques used by researchers in physical motorcycle crash-tests. Variations in the designs of the different crash-test procedures reported in the literature are described in Table 1 below:

Table 1: Physical Crash-Testing Configurations Previously Used by Researchers

Authors	Human Surrogate	Design Summary
Jessl (1985) (cited in Koch & Brendicke, 1988)	Sierra Hybrid II/Part 572 dummy	• Impact velocity approximately **32km/h** • Impact angle **15°**
Schueler (1985) (cited in Koch & Schueler, 1987)	Cadaver/Body parts	• Cadavers projected onto guardrail posts. • Impact velocity approximately **32km/h**
Quincey *et al.* (1988)	Dummy (type not specified)	• Dummy **ejected** from **moving platform** • Impact speed of **55km/h** • **30°** impact angle • dummy **sliding** for **2 metres** prior to impact • dummy lying on **back** with **head forward**

4.7.2 Typical Crash Scenarios

There is a significant absence of information in the literature regarding the nature of motorcyclist crashes, especially those involving guardrails. One exception to this is a study done by Quincey *et al.* (1988) who reported various crash conditions of motorcyclist accidents that occurred over a period of two years (1978 – 1979) in the Paris area (urban). The paper reported that the 38 barrier impacts that were investigated in the study could be broken up into the following categories:

- 34% (13 cases) involved road sliding and barrier impact with the rider still on the motorcycle;

- 24% (9 cases) involved pavement sliding and barrier impact with the rider having been ejected from the motorcycle during sliding, and;

- 42% (16 cases) involved barrier impact without sliding.

The authors note that the injury severity was higher following ejection of the rider and that crashes most commonly occured on curves with the motorcyclist hitting their head on the guardrail posts.

Ouellet (1982) suggests that motorcyclists tend to impact barriers at a very shallow angle, however, there are no data presented in the report to back up this suggestion.

4.7.3 Review of Homologation Procedures of Crash Barrier Protectors

The FEMA (2000) report reviews the different methods of assessing the effectiveness of different safety devices and 'homologation' procedures used by various testing laboratories globally. A summary of this section of the report is contained below:

- **LIER/INRETS homologation test for secondary rail**: a dummy is thrown, head first sliding on its back, against a fitted barrier with an impact speed of 60km/h ± 5% at a 30° angle ± 0.5°. The criterion for homologation is HIC < 1000 (note: the surface of the road was required to be made slippery for the dummy to actually reach the barrier due to the significant reduction of speed caused by the motorcyclist sliding along the ground prior to impact).

- **German Federal Bureau for Road Safety (BASt) homologation procedure for impact protector**: Deceleration against crash barrier protector during impact, which should not exceed 60g as a peak value and 40g over a 3ms interval, is measured. The report states that different methods are used to assess two classes of devices (class one are tested with an impact speed of 5.5m/s or 20km/h, and class 2 with an impact speed of 9.7m/s or 35km/h), however, it does not divulge the nature of these two classes of devices or any other details of the method used.

The FEMA (2000) report acknowledges the difficulty in comparing the effectiveness of different safety devices used due to the fact that the devices have been tested with different methods and criteria. The document reports on a discussion held with Dr. Michelle Ramet from INRETS in France who points out the need for a study that compares different types of barrier and barriers fitted with safety devices in comparable conditions.

4.8 THE CONDUCT OF PHYSICAL CRASH-TESTING

4.8.1 Crash-Testing Guidelines

In the event of a decision to conduct physical crash-testing either in isolation or in conjunction with computer or mathematical modelling techniques, there are certain guidelines that have been developed for such purposes. Guidelines were developed by a group of motorcyclist safety experts, appointed by the International Organisation for Standardisation (ISO) in response to the need for an internationally recognised research methodology to be developed regarding motorcycle safety research (see Van Driesseche, 1994). The guidelines cover factors such as suitable crash-test dummies, physical measurements to be taken, injury assessment variables, instrumentation and measurement specifications. Although the recommendations apply primarily to the evaluation of specific devices to be fitted to motorcycles for the protection of riders, many of the recommendations apply to other crash-testing programs. Relevant sections of the report are outlined below.

4.8.2 The Choice of a Suitable Human Surrogate for Testing

A specialised crash-test dummy for motorcycle crash-testing has been developed and is specified in ISO 13232. The basis dummy recommended by the ISO for motorcycle crash-testing is a Hybrid III 50th percentile male dummy with sit/stand construction, standard non-sliding knees and head/neck assembly compatible with either a 3-or 6-axis upper neck load cell. However, the Hybrid III dummy was developed for purposes other than motorcycle crash-testing, for example, simulating restrained car occupants in frontal impacts. The Hybrid III dummy has limited means to assess some of the main factors in motorcycle crashes due to the biofidelity characteristics being specialised for their original intended function. To transform the Hybrid III dummy into an ISO 13232 motorcyclist dummy, thereby making it useful in motorcycle crash-testing, certain modifications are required. These include:

1. **Motorcyclist dummy head skins** must be extended to provide surfaces for the helmet retention strap under the chin and the back of the neck-helmet contact.

2. **Motorcyclist dummy neck components**, including: a neck shroud, which provides an appropriate reaction surface between the neck and external objects. A lower neck mount, which is needed to increase the neck extension adjustment possibilities to accommodate forward leaning riding styles. A modified nodding joint, which with the modified lower neck mount, provide maximum adjustability for the positioning of the dummy head and improved upper neck torsional characteristics.

3. **Motorcycle dummy thorax components**, including provisions for a replacement thoracic spine, which is compatible with the internal data acquisition system. A slightly modified chest skin and a modified straight lumbar spine are important for many reasons such as e.g., provide an upright seating position on a motorcycle and provide appropriate weight for maintaining the proper Hybrid III centre of gravity and mass.

4. **Motorcycle dummy abdominal insert**, which provides a physical record of maximum residual deformation. The deformation allows the dummy to show the potential abdominal injuries as a result of penetration into the abdominal insert.

5. **Sit/stand pelvis**, which may contain parts of the internal data acquisition system. Even if part of the system is located in the pelvis it is a requirement that the Hybrid III sit/stand characteristics remain unchanged.

6. **Modified elbow bushing** allowing for proper positioning of the elbow and preventing over-centre locking of the elbow, which would distort realistic torso motion.

7. **Motorcyclist dummy hand components** with deformable aluminium wires as internal structure, which allow the dummy to ‘grasp’ the handlebars, and hence, aid in stabilising the dummy on the vehicle as well as providing realistic dummy to handlebar force properties.

8. **Motorcyclist dummy upper-leg components** including a frangible femur bone and associated mounting hardware. In order to achieve human-like impact force levels up to fracture point and human-like trajectory after fracture, it is necessary to have frangible bones with human-like stiffness and strength. The bones used in the ISO 13232 motorcyclist dummy are composite bones described in St Laurent Shewchenko and Szabo (1989) and Newman, Zellner and Wiley (1991). The rigid metal leg bones used in the Hybrid III are inappropriate to use in motorcycle crash research because they were designed with a very different type of crash in mind. The Hybrid III leg bones are designed to measure frontal impacts most often to the knee but in motorcycle crash-testing the leg bones are exposed to multiple impacts from all directions.

   Another problem with the Hybrid III leg bone is large overestimation of fracture potential. In comparison with human cadaver lower leg bone or frangible composite lower leg bone, the rigid metal lower leg bone of the Hybrid III can result in a 100%, or more, overestimation of impact forces i.e., fracture potential. As a result of the Hybrid III leg bones not fracturing the dummy motions may, in some cases, be distorted as compared to the motions produced with frangible human or dummy leg bones.

9. **Motorcyclist dummy frangible knee assembly**, which is included to measure the possibility of knee ligament injuries in lateral bending and monitor torsion relative to the tibia. A frangible knee assembly also provides realistic movement and allows for measuring of the forces between the lower and upper legs, as well as providing enhanced biofidelity with regards to the potentially large torsional load in the femur.

   For this frangible knee concept, a failure of an internal shear pin is interpreted as an injury of the respective knee ligament.

10. **Leg retaining cables** to prevent the loss of the dummy legs in the case of frangible bone fracture because the loss of a leg during a crash-test may influence the overall movement of the dummy.

11. **Motorcyclist dummy lower-leg components**, which includes a frangible tibia bone. The same issues are relevant here as in the case of the frangible femur bone except for the tibia axial characteristics.

12. **Modified lower leg skin**, which is needed in order to provide for the removal and installation of the skin on the frangible leg bones.

13. **Sampling of frangible components,** to allow for performance specification of potentially different frangible component designs and to ensure that the variability in frangible components is controlled to a feasible minimum.

A full description of the recommended dummy with all of the relevant modifications as well as its electronic configuration can be found in Zellner *et al.* (1996).

4.8.3 Review of the Physical Measurements that may be Obtained from Crash-Test Dummies to Assess Injury Severity

This section reviews the injury assessment variables that are required for quantifying the probability of injury for the various parts of the body.

Head

The injury assessment variables for the head include; the maximum generalised acceleration model for brain injury tolerance (GAMBIT), which is used to quantify combined linear and angular acceleration effects as related to the probability of brain injury; Head Injury Criteria (HIC); and the maximum resultant linear acceleration, which should be taken for reference with, and comparison to, computer simulation research.

Chest

For the chest, the injury assessment variables are the upper and lower sternum maximum normalised-compression and the upper and lower sternum maximum velocity-compression injury variables. These are considered to be preferable to acceleration-based chest impacts because they are more directly related to observed injury mechanisms in humans.

Abdomen

The maximum residual deformation is the injury assessment variable for the abdomen.

Neck

Extra injury assessment variables (including the x – z trajectory of the helmet, the resultant velocity at first helmet/opposing vehicle contact and longitudinal, lateral and vertical velocities at first helmet/opposing vehicle contact) are suggested for research into head protective devices. However, as neck trauma is claimed to be relatively infrequent in normal accident data (Van Driesseche, 1994), these variables may not be required in the proposed research project.

Lower Extremity Injuries

Displaced and non-displaced bone fractures and, knee partial and complete dislocation.

Injury Severity Probabilities

Weibull functions are used to model the probability associated with each AIS level for a given body region.

Injury Indices

The injury indices include: the probability of each discrete AIS injury severity level for the head, thorax, abdomen and lower extremities; the probability of fatality; the risk of life threatening brain injury based on HIC; the medical and ancillary costs associated with injuries to each of the four body regions; the probable AIS for each body region based upon the weighted average of each AIS probability; the normalised injury costs of survival and fatality; and the total normalised injury cost.

4.9 VARIABLES TO BE MEASURED, INSTRUMENTATION & MEASUREMENT PROCEDURES

4.9.1 Electronic Recorded Variables

For full-scale impact tests, it is recommended that the entire impact sequence be recorded, including: time of first motorcycle/opposing object (MC/OO) impact; nine linear head accelerations (in order to compute the three linear and three angular accelerations of the head centre of gravity); and four sternum displacements (two upper, two lower).

Head protective device research: the upper neck x, y z forces and y and z movements are required to provide some indication for the potential for neck injury.

Leg protective device research: the upper femur axial force and the lateral and antero-posterior (AP) bending movements and the upper-tibia lateral and AP bending movements are required for both legs. The leg sensors are required to provide information regarding cause/effect relationships rather than as an injury index, as this is indicated by frangible bone fracture.

Other variables that may be recorded include: upper neck forces and movements; lumbar spine forces and movements; upper and lower femur lateral and AP bending movements;

torsional movement and axial force; upper- and lower-tibia lateral and AP bending movements, torsional movement and axial force.

Due to biofidelity limitations of the dummy, it is recommended that chest and pelvic acceleration not be recorded, as it may lead to misleading data.

4.9.2 Mechanically Recorded Variables

In full-scale tests the following mechanical variables must be recorded and photographed: abdomen maximum penetration, left and right femur fracture occurrence; left and right femur fracture occurrence; left and right knee varus valgus and torsional dislocation occurrence; and left and right tibia fracture occurrence.

4.9.3 Photographic Targets To Be Digitised

In order to quantify head injury potential variables, the helmet centroid point (the centre of a circle circumscribed about the helmet) during the primary impact period is required. In addition, in order to provide measurements and verification that the speeds and contact points are within the specified tolerances, the targets on the opposing vehicle, dummy joints, and the ground prior to the first MC/OO impact are required. These targets are to be digitised.

4.9.4 Sensor Specifications

The specific electronic sensors required include: head accelerometers; upper-neck load cell, chest potentiometers; lumbar load cell; upper-femur load cells; and frangible load cell strain gauges. The sensors used should be compatible with the Hybrid III basis dummy (if this is to be used). Mechanical sensors include: the abdominal foam insert; frangible femur and tibia bones; knee compliance elements; and knee sheer pins.

5 CONSULTATION WITH STAKEHOLDERS

5.1 QUEENSLAND

Attendees: Main Roads Queensland (Lloyd Davis, Senior Multidisciplinary Engineer, Transport Technology Division; Mark Olive, Engineer (Traffic), Transport Technology Division; Paul Grice, Assistant to Principal Engineer (Development Control), Metropolitan District.)

These discussions were held on Monday 10 July 2000, and provided both policy and operational perspectives from the Main Roads staff involved. The *main* issues arising from the discussions, as they relate to the current project, may be summarised as follows:

- Useful sources of information include:
    - Australian Standard (AS/NZS 3845: 1999) for Road Safety Barrier Systems;
    - Austroads Guide to Traffic Engineering Practice, Part 15 (initial release May 2000);
    - INRETS Website;
    - Motorcycle Riders Association Website in Australia and the UK;
    - NCHRP Report 350 (US crash-testing standard);
    - PREN 1317 (European crash-testing standard);
    - Main Roads Design Guide;
    - Barrier manufacturers for their crash records;
    - Motorcycle racing videos to observe the range of crash scenarios that occur in this sport, that might also be expected on public roads.
- The design objective for barrier systems in impacts with motorcyclists should be for motorcyclists to be contained and redirected by the barrier, rather than be allowed to pass under, through or over the barrier. The main reason for this is to prevent subsequent impact with hazards that lay beyond the barrier;
- The preferred strategy is to manage motorcyclist injury risk by redirecting riders. This has been attempted by using a (lower) rubbing rail fitted below the main rail to prevent riders going underneath the barrier and suffering injuries while, or after, passing under the barrier (for example, the snagging of a rider helmet between the barrier and the road surface causing severe head injuries was noted as an injury mechanism). Such a feature also has the potential to reduce injury severity due to contact with barrier posts. In French designs, the rubbing rail presents a flat, smooth surface, in the Austroads

guide, a second W-shaped beam is recommended, while in some German experiments, twin tubes (possibly of the Mototub design described in section 4.5.4) have been installed by riders themselves, with approval by road authorities;

- The majority of motorcyclist impacts with barriers involve riders sliding across (or otherwise traversing) the pavement after leaving their motorcycles. Therefore, any future research should focus on this scenario rather than the situation where the rider and bike together strike the barrier, with the bike more or less upright. Typical impact angles are around 12°, though US and European test standards might involve impact of around 20-25° for general barrier testing, thereby capturing information on more severe crash scenarios.

- A particular safety concern with barriers is the use of reflectors which sit above or out from the barrier (known as “butterfly” reflectors). This problem is being addressed through the use of reflector types which are fitted within the middle “V” of the W-beam or, alternatively, reflectors fitted to a frangible mounting pipe have been used to allow the reflectors to break off if struck during impact.

- Posts used to support wire rope barriers have been made more frangible by reducing design thickness of the s-shaped cross-section to 6mm. Barrier manufacturers have indicated that no further reduction can occur without overall performance of the barrier being compromised. With regard to posts used to support W-beam barriers, there is little scope to reduce their dimensions without affecting post installation practices (posts are driven into the ground and may be damaged if weaker designs are used).

- A number of practical considerations, believed to contribute to crash and injury risk for motorcyclists, include:

    - Arrows and other pavement markings, as well as use of pavement crack sealant, especially in the vicinity of curves or other areas where high levels of skid resistance are required;

    - Optimal placement of noise walls (for successful noise attenuation) along high-speed roads such as freeways/expressways, can interfere with optimal placement of roadside barriers for safety reasons. In such cases, safety barriers may need to be located within the desirable minimum 9m clear zone. Similarly, the achievement of grades of less than 10%, as specified by barrier designs, can also result in placement of barriers closer than the desired 2m minimum offset.

- Motorcyclist involvement in any future research activities in this field is encouraged to obtain direct user input, while helping to ensure that the requirements of all road users (truck drivers, bus passengers, other vehicle occupants, etc.) receive due recognition. The Harley Owner’s Group (HOG) and Ullysses (motorcyclists aged 50 years and over) were mentioned as potential groups with whom to consult in any future stages of this research.

5.2 VICTORIA

Attendees: VicRoads (Warwick Pattinson, Sam Pirotta and Rod Howard), Victoria Police (Sergeant Steve Lomas, Senior Constable Colin Chamings), Representative from the Federal Motorcycle Coalition (Michael Czajka).

These discussions were held on Tuesday 29 August 2000. The *main* issues arising from the discussions, as they relate to the current project, may be summarised as follows:

CRASH PROBLEM

- VicRoads reported that wire rope barriers have been used overseas for over 30 years with few reported injuries from impacts and that there are no known cases of casualty crashes in Victoria.

- There is a problem of under-reporting of run-off-the-road motorcycle crashes in general, which may in turn suggest that there is under-reporting of motorcyclist impacts with barriers. However, it is probable that the crashes that are not being reported (if this is the case) are of a less serious nature due to the fact that any crash requiring medical assistance will be reported. Further, when crashes are actually reported, identification of barrier type tends to be inadequate for detailed study.

- Despite the potential for under-reporting of crashes, the problem of motorcyclist impacts into barriers appears to be a relatively small part of the total road safety problem. However, among motorcycle crashes, rider impacts with barriers, particularly barrier posts, are a serious concern in terms of the potential for serious injuries.

- There is a distinct lack of data available for an adequate understanding to be developed regarding the nature of motorcyclist impacts with barriers (i.e., the identification of one or more “typical” crash scenarios). It was suggested that video footage of motorcyclist crashes in motorcycle races such as the Grand Prix could be studied to gain further insight into the nature of motorcycle crashes. Another suggested source of information was the study conducted by Haworth, *et al.*, (1997).

- It was also suggested that crash data could be investigated to identify where motorcycle crashes typically occur on Victorian roads. Potential sources of information include: Corben, Gelb, Pronk and Fitzharris (1999), and the Motorcycle Countermeasures report (Haworth *et al.*,1997). Also, the VicRoads Road Crash Information System, available on-line and which provides details of accidents including exact locations, may be another possible source of information.

REDIRECT THE RIDER OR ALLOW RIDER TO PASS THROUGH BARRIER

- The issue of when and where to install barriers was discussed in terms of ensuring that the installation of barriers should be limited to locations where the injury consequences of hitting the barrier will be less than if there were no barrier installed. In addition, the issue of alternative types of barriers was discussed, for example, the use of small shrubs and sand arrestor-beds, either between the road and the barrier or in lieu of the barrier itself. It was acknowledged that there are practical issues with these interventions, however.

- The general views expressed were that barriers should be designed to retain riders rather than allow them to pass through, over or under the barrier. The two main reasons for this view were:

    1. It is reasonable to expect that if a barrier has been installed, that there is some sort of serious hazard beyond the barrier. Therefore, retaining and redirecting the rider should protect him/her from the hazardous environment beyond the barrier.

    2. It is believed that it is unlikely that a sliding or tumbling motorcyclist (having separated from their bike) would have enough control to successfully avoid impacting with a post on the way through/under the barrier system.

- Also, it was felt that as riders generally impact barriers at shallow angles, the likelihood of the rider eventually hitting a post will be high, despite the fact that there are some barrier systems that allow for greater spacing between posts.

DESIGN FEATURES/INJURY MECHANISMS

- The barrier posts were regarded as the most dangerous feature of guardrail systems. The sharp edges along the top and sides of W-beam barriers were also considered particularly hazardous.

- Despite the rigidity of concrete barriers, they were considered to be preferable to other barrier types when hit at a shallow angle, as they have a smooth continuous surface and have the potential to distribute forces over a larger surface area. This was also the view expressed in Czajka (2000), where it was mentioned that the absence of protrusions and the smooth surface of concrete barriers makes them preferable to motorcyclists than other barrier types. However, adding holes or protrusions to this barrier type increases the possibility of vehicles or riders becoming caught on them, thus decreasing barrier safety performance.

- A suggestion that would possibly improve existing W-beam systems was to add a smooth-surfaced rail or cap to the top of the W-beam barriers and to make the railing continuous all the way to ground level. Also, in the case of WRSBs, it was suggested that a continuous sheath that covers the barrier system could be developed to help reduce injures that result from sliding along the ropes or into the posts.

- The height of guardrail systems was also identified as a potentially hazardous feature of barriers especially when riders hit the barriers while still on their motorcycle and there is a hazardous environment on the other side of the barrier (for example, it was mentioned that a situation exists where trees have been planted on the “non-traffic” side of concrete barriers which may pose a threat to any motorcyclist that is catapulted over the top of the barriers). However, no specific solutions were offered regarding the height issue.

TEST PROCEDURES AND PHYSICAL MEASURES

- Angles of impact in real-world crashes were generally believed to be quite shallow, usually around five to ten degrees with a maximum of about 15°.

- The more speed that can be shed by a rider prior to impact, the less severe the injuries are likely to be.

- It was suggested that measurement of the injury severity of body areas such as limbs should be considered in addition to head, neck and chest injury measurement.

- There may be some value in looking at the types of injuries sustained by riders who have hit other types of objects such as trees, poles, embankments etc., in order to further understand the injury mechanisms.

TEST CONFIGURATION

- In answer to the question of whether the worst-case scenario or, one or several typical crash scenarios, should be investigated in physical crash-testing, it was felt that a more detailed understanding of crash scenarios may be required before a decision can be made.

HUMAN SURROGATE

- The crash-test dummy modified for motorcycle crash-testing, as specified in ISO 13232, was thought to be the best option for use in a crash-testing program.

- It was suggested that careful thought should be given to the clothing worn by the dummy in the crash-tests. The dummy could wear full-leathers, including boots and gloves, or more commonly worn attire such as motorcycle rider jackets (other than leather) and jeans. Clearly, numerous possibilities exist.

CRASH-TESTING AND CRASH SIMULATION MODELLING

- Due to the expensive nature of physical crash-testing, it may be more viable to concentrate on crash simulation modelling approaches and use a smaller physical crash-testing program for validation purposes only.

5.3 NEW SOUTH WALES

Attendees: Roads and Traffic Authority, NSW (James Holgate, Ross Dal Nevo, Colin Jackson, Steve Williamson and Michael Brauer), NSW Police Service (Sergeant Peter Jenkins), NSW Motorcycle Council (Paul Wilton, Greg Hirst).

These discussions were held on Thursday 7 September 2000. For logistical reasons, three meetings were held addressing each group separately. In addition, telephone discussions were held with Derek Wainohu Laboratory Manager, RTA CrashLab. The *main* issues arising from these discussions, as they relate to the current project, may be summarised as follows:

CRASH PROBLEM

- No scientifically-based information exists on the comparative performance for motorcyclists of the main barriers types in use, namely concrete, steel W-beam and wire rope. Such information is needed to guide future use of barrier types to enhance the safety of motorcyclists, as well as other road user groups.

- There is a lack of specificity with current crash coding and reporting. In terms of barrier systems, the current method distinguishes between only concrete/New Jersey kerbs and guardrails/fences. More specific coding and reporting rarely occurs.

- The RTA and the NSW Police expressed the view that, in road safety terms, the problem of motorcycle impacts with barriers appears to be relatively small.

- It was the opinion of all three groups consulted that a study designed to gather more information regarding the details of motorcycle crashes (especially run-off-the-road crashes) would be of great benefit. All three groups expressed support for such a study, however the NSW Motorcycle Council representatives stressed their preference that such a study should not take precedence over an investigation into the safety of barriers for motorcyclists. It is understood that the NSW Motorcycle Council has engaged Human Impact Engineeering to analyse NSW Coroner's records of motorcyclist crashes over a five-year period in an effort to better define the crash problem and hence provide guidance on the focus of future testing.

- RTA found no match between motorcycle crash sites and road locations with WRSBs, although this has not been done for other barrier types, such as W-beam guardrail.

- It was suggested that more information regarding the extent to which guardrails may have been involved in previous motorcycle crashes may be gained by closer examination of Police crash records on a case-by-case basis. Peter Jenkins indicated his willingness to assist, where possible.

REDIRECT THE RIDER OR ALLOW RIDER TO PASS THROUGH BARRIER

- It was generally agreed by all parties that barriers should be designed to retain and redirect the rider rather than to allow them to pass through, based on the assumption that the barrier has been installed to protect road users from a potential hazard that exists beyond the barrier. This was especially relevant for median barriers where allowing a rider to pass to the other side of a barrier may place them in the path of oncoming traffic.

DESIGN FEATURES/INJURY MECHANISMS

- The RTA believed that the poor energy transfer properties of concrete barriers may be underestimated by motorcyclists, especially at higher impact angles. In addition, other road users would experience higher injury severity from the substitution of concrete barriers in the place of WRSBs. The Motorcycle Council believed that the problems with energy-sharing properties (such as with concrete barriers) presents less of an injury risk to motorcyclists than barrier types that do not have a smooth continuous surface (such as W-beam and WRSBs).

- In terms of WRSBs, it was the opinion of the RTA that the posts of this barrier type would be more dangerous to riders than the ropes themselves. The Motorcycle Council expressed concern regarding both of these features, noting that while there is no existing data to suggest that the wire ropes cause severe injuries when struck by riders, they believe the ropes would be abrasive and concentrate impact forces over a small area.

- The sharp edges and the tops and bottoms of W-beam barriers were identified as inherently dangerous features for motorcyclists.

- It was suggested by the RTA that the posts of WRSBs could be made more forgiving for motorcyclists by making them out of a frangible material and/or by flattening out the posts to increase their surface area in the direction that they are most often hit by motorcyclists.

- The concept of covering WRSBs with some sort of sheath (possibly made of a rubber/plastic compound) was suggested to improve the safety performance of this barrier type.
- Reflectors that protrude from various barrier types were also identified as a dangerous feature for impacting motorcyclists.

TEST PROCEDURES AND PHYSICAL MEASURES

- The Police believed that most motorcycle impacts with barriers occur at shallow angles. Experienced riders would be more likely to separate themselves from the bike if given sufficient time and would therefore be more likely to slide into the barrier.
- The Motorcycle Council representatives stated their preference for the inclusion of tests in which the rider is still on the bike *and* with the rider separated from the bike.
- Another important issue for full-scale crash-testing is the type of test dummy to be used and whether available dummies (e.g., modified Hybrid III, Thor, etc.) are sufficiently biofidelic to achieve the test objectives.

TEST CONFIGURATION

- The RTA suggested that a more detailed knowledge of the crash problem is required before an accurate/suitable test configuration could be developed. Others consulted agreed that defining appropriate test configurations is both complex and difficult to achieve, given the large number of possible crash scenarios. Therefore, it is important that a manageable, affordable research program be developed, in recognition of the limited resources available for such testing.

CRASH-TESTING AND CRASH SIMULATION MODELLING

- Full-scale physical crash-testing was not considered to be the most appropriate option by the RTA, due to its high cost and the problems with reliability and repeatability. Also, due to the extremely variable nature of motorcycle crashes, it is unlikely that crash-testing will be sophisticated enough to handle the complexity of important situations encountered in real-world crashes.
- Computer simulation was considered by all groups to be a viable method. The RTA suggested such a method could be used to help understand the injury mechanisms of various barrier designs, which could then be used to develop guidelines for design features in a general sense. Modifications could then be made to existing barrier systems to improve their safety performance with respect to motorcyclists, without altering their performance for other vehicle types.
- The Motorcycle Council suggested that computer simulation could be used to test “typical” scenarios and then used to extrapolate findings to examine more severe cases.

6 SUMMARY AND RECOMMENDATIONS

This section of the report incorporates and synthesises the information contained in the previous sections of the report according to the objectives stated in the ATSB project specification.

6.1 BARRIER DESIGN ISSUES AND RIDER INJURY MECHANISMS

6.1.1 Contain and Redirect the Rider or Allow the Rider to Pass Through?

There are two basic philosophies for barrier design, namely, to retain (and redirect) a vehicle on the road or to allow the vehicle to pass through the barrier. With regard to vehicles other than motorcyclists, the main aim of roadside barriers or guardrails is the former: to retain and redirect errant vehicles, which should ultimately prevent the vehicle from impacting with potentially more dangerous roadside objects beyond the barrier system. With regard to motorcyclists, it is our recommendation that barriers should be designed with the aim of containment in mind, as long as the containment of the rider does not result in more severe injuries than would be sustained if the rider were to pass over, through or under the barrier. This view is consistent with that of all of the authorities and stakeholders consulted where it was generally agreed that containment and redirection of the rider will prevent subsequent impact with hazards that lay beyond the barrier.

6.1.2 Barrier Design and Injury Mechanisms

A review of the literature identified several barrier design issues which impact upon motorcycle rider safety. The literature suggests that the most dangerous aspect of guardrails with respect to motorcyclists is exposed guardrail posts. Both the tops and bottoms of the posts present edges and corners which act to concentrate the impact forces and thus, increase the severity of the injuries sustained. Impacts with guardrail posts can cause serious injuries through deceleration of the torso, fracture of the extremities, or occasionally, decapitation. In addition, the jagged edges of wire mesh, or wire mesh topped barrier systems provide numerous lacerating surfaces which serve to accentuate rider injury risk. Barrier systems of insufficient height can also pose a threat to riders as they can be catapulted over the top of barrier systems. Alternatively, barrier systems such as W-beam barriers and WRSBs that leave a space between the road surface and the bottom of the barrier, potentially allow riders to slide under the barrier into contact with roadside hazards. Rigid barriers cause the rider to absorb virtually all of the kinetic energy at impact thus increasing injury risk for riders, particularly as the impact angle increases.

6.2 FEASIBILITY OF DIFFERENT RESEARCH METHODS

Although physical crash-testing has not been used in the past to compare the safety performance of the main barrier types for motorcyclists, testing out new devices designed to improve the safety performance of existing barriers for motorcyclists has been carried out in a number of European countries. However, physical crash-testing is not without its limitations and other methods such as mathematical models and computer simulations are being used increasingly by researchers to overcome the financial costs and problems with repeatability that exist when conducting physical crash-tests. Although these alternatives are not without their own problems, it appears that as the technology advances in these areas, these methods are becoming increasingly more viable options and/or supplements to physical crash-testing.

6.2.1 Physical Crash-Testing

In the event of conducting a physical crash-testing program, a decision will be required regarding the issue of whether the tests adopt the configuration of a "typical" crash-test scenario or a "worst-case" scenario.

Likely Crash-Test Scenarios

The task of defining one or several 'typical' motorcycle crash scenarios that are most appropriate for inclusion in a crash-test program is difficult. This is due to a significant absence of information pertaining to the specifics of real-world motorcycle crashes. Details including the speed, location, road characteristics (including the presence or absence of horizontal and/or vertical road curvature), the impact angle (in the case of impact with a barrier), whether separation of the rider and motorcycle occurs, and if so, whether the rider is sliding or is upright immediately prior to impact are all pertinent to defining such scenarios.

There are a limited number of articles that isolate certain scenarios that are common in motorcycle crashes, and discussions with stakeholders have also provided some clues as to the most likely crash scenarios for use in crash-test modelling. These are summarised below:

Impact Angle

- Ouellet (1982) makes the claim that motorcyclists tend to impact barriers at a very shallow angle, however, no data are provided to support this claim.

- Discussions with Queensland Main Roads representatives, Victorian authorities and the NSW Police suggest that typical impact angles are relatively shallow (around 10°), although US and European test standards might involve impact angles of around 20-25° for general barrier testing, thereby capturing information on more severe crash scenarios.

- The homologation procedure used by INRETS, France, as described in the FEMA (2000) report, utilises an impact angle of 30° (± 0.5°).

- The Quincey *et al.* (1988) study utilised an impact angle of 30°.

Approach to Impact

- Discussions with Queensland Main Roads and NSW Police suggest that the vast majority of motorcyclist impacts with barriers involve riders sliding across (or otherwise traversing) the pavement *after* leaving their motorcycles. Queensland road authorities recommend, therefore, that any future research should focus on this scenario rather than the situation where the rider and bike together strike the barrier, with the bike more or less upright.

- Representatives from the NSW Motorcycle Council stated their preference for the inclusion of tests in which the rider is still on the bike *and* with the rider separated from the bike.

- The study by Quincey *et al.* (1988) reported that over half of the accidents involving barrier impacts in an urban area involved sliding prior to impact, with 34% of the accidents occurring with the rider still on the bike and 24% with the rider having been ejected from the bike.

- In terms of whether the dummy should impact the barrier head-first or otherwise, again Quincey *et al.* (1988) adopted a configuration where the dummy was projected head-first into the barrier. This is also the method reported to be used by INRETS, France in their homologation procedure (FEMA, 2000).

Impact Speed

- Jessl (1985) (cited in Koch & Brendicke, 1988) utilised an impact speed of approximately 32km/h as did Schueler (1985) (cited in Koch & Schueler, 1987).

- The homologation procedure used by INRETS, France, as described in the FEMA (2000) report, utilises an impact speed of 60km/h (± 5%), while the BASt homologation procedure for impact protectors utilised impact speeds of 20km/h and 35km/h.

- The impact speed used by Quincey *et al.* (1988) was 55km/h.

It is evident from this summary, that there is a variety of crash configurations that have been used by researchers investigating motorcyclist impacts with guardrails. The choice to adopt a particular crash-test configuration will be dependent on the decision of whether to investigate the "worst-case" scenario of motorcycle crashes or to investigate "typical" scenarios. Defining typical scenarios remains problematic, though different scenarios might exist for different road situations (e.g. freeway, rural undivided highways, tourist routes, etc.).

Protocol for Motorcycle Crash-Testing (Physical Crash-Testing)

As discussed in sections 4.8 and 4.9 of this report, guidelines have been developed by a group of motorcyclist safety experts, appointed by the International Organisation for Standardisation (ISO) for the conduct of physical motorcycle crash-testing. The guidelines are extremely comprehensive, covering factors such as suitable crash-test dummies, physical measurements to be taken, injury assessment variables, instrumentation and measurement specifications. Although the recommendations apply primarily to, and have been used successfully in, the evaluation of specific devices to be fitted to motorcycles for the protection of riders, it is our understanding that the guidelines could be adapted for the purposes of a physical crash-testing program investigating motorcyclists impacts with guardrails.

Use of Suitable Crash-Test Dummy (Physical Crash-Testing)

The ISO standard for crash-testing, as described directly above and in sections 4.8 and 4.9 of this report, include the specifications for a suitable crash-test dummy for motorcycle crash-test research. Among the more important features of a motorcyclist dummy (compared to a vehicle occupant dummy) are the ability for the hands of the dummy to grip the motorcycle handlebars, the ability of the head of the dummy to retain a helmet, improved biofidelity of neck movements and several modifications to the biofidelity of the lower limb, including the use of frangible upper and lower leg bones, which aid in the collection of injury data specifically relevant to motorcycle crashes.

6.2.2 Physical Crash-Tests or Computer Simulation

As reported in section 4.6.2, Nieboer *et al.*(1993) have confidence in the validity of using computer simulation and modelling stating that extra measurement results from additional tests and the use of recent features of the MADYMO program will improve the simulation results in the future. They believe that simulating crash events involving rider, motorcycle and collision partner is a research activity worth exploring and that the riders involved in crash events will directly benefit from the research.

Therefore, when considering the relative merits and drawbacks of both physical crash-testing and computer simulation, as well as the difficulties regarding the isolation of one or several crash scenarios for crash-testing, the approach that is most likely to provide the greatest amount of relevant (cost-effective) information may be a combination of both physical crash-testing and computer modelling techniques. Such an approach was used successfully by Chinn *et al.* (1996) in their work on development and evaluation of airbags for motorcyclists. Data obtained from physical crash-testing could be used within a computer modelling package, such as MADYMO, to extrapolate the crash-test findings to a variety of other crash scenarios.

6.2.3 Component Testing

An alternative or supplementary approach to physical crash-testing and/or crash simulation is sub-system or component testing. This method focuses on specific crash components, of both the human body and isolated barrier parts, which are believed to be critical to injury severity outcomes. Hence, it provides a way of testing specific parameters at a relatively low cost. Component testing has been used successfully in the past for various purposes, including investigation into pedestrian/car impacts, where it can be used to help break down the complexity of the situation and identify factors influencing the injury outcome. Given the similarities of pedestrian/car impacts and motorcyclists/barrier impacts in terms of the complexity of the situation and the multitude of possible impact scenarios, sub-system testing may be considered as a viable option.

6.3 RECOMMENDATIONS FOR A RESEARCH PROGRAM

This section describes the recommended options for further research to address the problem of motorcyclists impacting with roadside barriers. It presents the main options, recommends a feasible program of research, which attempts to both focus on the central issues leading to injury among motorcyclists and to produce practical solutions. Finally, indicative cost, timing and funding possibilities are presented and discussed.

6.3.1 Research and Development Options

There are three main options for conducting research and development of safety enhancements for motorcyclists impacting roadside barriers. They are:

- full-scale crash-testing;
- crash simulation modelling;

- component testing.

Any of these options, or combinations of them, could be selected to help in the development of safer barrier designs.

Full-scale crash-testing has been successfully conducted to quantify the safety performance of new barrier designs. These tests examined only a very small number of crash scenarios and are therefore of limited value in adding new knowledge in this field. In real-world motorcyclist crashes into barriers, there is an unlimited number of crash possibilities, with speed, angle, impact location and orientation being among the main crash variables. Full-scale crash-testing is, therefore, extremely complex and relatively costly, and yields results on only a very limited set of possible crash scenarios. It is also difficult to achieve satisfactory levels of repeatability, even when testing methods are quite precise in terms of test conditions.

Crash simulation modelling contrasts with full-scale crash-testing in that it is much less costly and is able to address many more crash-test scenarios than full-scale testing, for given project resources. While its repeatability is high, it is, by definition, attempting to simulate real-world outcomes through simplified mathematical and physical models which tend to focus on major outcomes. In doing so, simulation modelling may fail to take full account of real-world complexities, such as interactions between test variables and second-order effects. Furthermore, complex simulation involving simulated crash dummies would have to be validated in actual crash-tests.

Component testing (or sub-system testing) has the advantages over full-scale crash-testing of being less costly, able to cover more crash scenarios and focussed on specific crash components which are believed to be critical to injury severity outcomes. Component testing might, for example, concentrate on measuring accelerations acting on a motorcyclist head form propelled into, or dropped onto, various components of a barrier to assess whether critical acceleration levels are reached or, indeed, exceeded. Other motorcyclist components might include the chest, neck, lower or upper leg or arm. Barrier components to be tested might include, in the case of wire rope barriers, the ropes, or the posts, and in the case of concrete barriers, the rigid face of the barrier at a number of representative locations throughout its profile.

Having regard to the above discussion, it is recommended that the following program of research be considered and that, throughout any development and testing program, motorcycle riders, other road user groups and other stakeholders be involved to ensure that their perspectives are adequately understood and considered in the research program.

i) **Undertake Motorcyclist Crash Study** - Undertake an in-depth study of (selected types of) motorcyclist crashes across Australia, using crash reconstruction methods, to:

  - define the magnitude and nature of motorcyclist crashes where riders leave the roadway, including where they impact roadside barriers and other objects.

  - determine worst-case crash scenarios and/or a number of typical/common scenarios to help in establishing test set-ups for both crash simulation modelling and component testing (limited full-scale testing might also be considered later, if required). This would include defining speed and angle of impact, as well as rider orientation at impact, barrier component struck, injury mechanisms, etc.

ii) **Barrier Design Criteria and Guidelines –** Either after completion of Stage i) above, or concurrently with Stage i), establish interim design features or criteria to which the designers of roadside barriers should aspire. For example, an enhanced barrier might be free of sharp edges and protruding, rigid parts, possess a smooth flat surface to allow riders to slide and have beneficial energy dissipation characteristics for riders and for other road users, as well.

The specification of such barrier performance criteria would provide a basis for the development of barrier design enhancements that could then be tested using component testing methods and/or crash simulation modelling. In addition, these new barriers/modifications would be required to be fully tested for compliance with existing standards. Consideration of the likely benefit-cost ratio for implementing new barrier designs would also be undertaken at this stage.

iii) **Develop New Barrier Designs –** Based on stages (i) and (ii) above, and in partnership with the barrier manufacturing industry, develop new barrier designs for component testing and assessment. New barrier designs should be defined to include:

- modifying existing barrier designs;
- adding components to existing barrier designs or to barriers already installed;
- developing entirely new barrier designs for future installation, according to safety-based guidelines.

It is especially important that this stage of the research program be undertaken in close consultation with motorcyclists to ensure that rider views, along with those of other affected road user groups, are understood.

iv) **Undertake Component Testing –** New barrier designs would be evaluated using component testing to assess the human tolerance of a number of individual body parts to impact with various barrier design components. The important body parts and barrier components to be tested would be determined from the results of stages (i) and (ii), as well as from a knowledge of human biomechanics and injury mechanisms.

For example, a test program might include propelling, at known speed and angle, human surrogates of the head, leg (upper and lower), arm, hip, etc., into various barrier components. Physical measurements, such as acceleration experienced by the human components would be collected and these levels assessed against known limits of human tolerance. Findings could then be used to modify barrier design features to further improve performance at impact.

The value of this method is that it starts from “first principles” in building knowledge about a very complex crash situation by first understanding how the simpler, but critical, individual components of the system behave under specific crash situations. Once an understanding has been gained of the basic principles involved, it should be feasible to gradually increase the complexity of testing to examine the effects of impact on combinations of body parts, such as head, neck and upper body. To attempt to move directly to the testing and understanding of real-world crash kinematics and injury outcomes is unlikely to be successful and could only be carried out at high cost.

v) **Undertake Crash Simulation Modelling –** Data and knowledge gained from stage (iv) (and earlier stages) would provide input on physical measures of impacts between human body parts and barriers, for use in calibrating and developing crash simulation models.

Once developed, these models offer a vast expansion in the range of crash scenarios which can be investigated. The potential also exists to develop more complex mathematical models to more comprehensively cover the complexities of real-world motorcyclists' impacts with other objects, including barriers. Such models could become powerful and cost-efficient methods for motorcyclist crash research.

6.3.2 Indicative Costs

On the assumption that a program, such as that described above, was to be undertaken, the following indicative costs have been estimated:

Stage	Indicative Cost ($000s)
i) Undertake Motorcyclist Crash Study	150
ii) Barrier Design Criteria and Guidelines	30
iii) Develop New Barrier Designs	20
iv) Undertake Component Testing (including set-up of testing technology and equipment)	100
v) Undertake Crash Simulation Modelling (including establishment of expertise, software and hardware requirements)	80
vi) Progress Reporting to Sponsors and Dissemination of Program Findings	30
Program Total	**410**

An additional stage (vi), progress reporting to sponsors and dissemination of program findings, has been included in the cost estimates. Its main purpose is to ensure that research program sponsors and key stakeholders are fully informed of the results of the research, thereby helping to ensure the translation of best practice into new barrier design and into possible modification of existing barriers. This stage might, for example, involve the conduct of seminars and workshops, as well as the presentation of findings at one or two key conferences.

6.3.3 Indicative Timing

Depending on the number of cases to be investigated and the geographic scope of the study, Stage i) of the proposed research program may be able to be completed within the period of 18 months to two years. Stages ii) and iii) could commence either after the completion of Stage i) or be done concurrently with Stage i). Thus, if Stages ii) and iii) commence after the completion of Stage i), it is estimated that Stages i) to iii) could be completed within 2.5 to three years (this period could be shortened if Stages ii) and/or iii) commenced prior to the completion of Stage i)). Stages iv) and v) could be undertaken more or less simultaneously, over a period of some 12 to 18 months. Stage vi) could occur as required throughout the life of the research program, however, most of the activity associated with dissemination of program findings would logically occur following the completion of Stages i) to v).

In summary, the total program could be undertaken progressively over a period of approximately four to five years, at a cost of around $410,000, with reporting of program findings occurring at appropriate intervals both during and after this four to five year period. The estimates of costs and timing should be regarded as indicative only, and should be subject to detailed development if further consideration of this research program is proposed.

6.3.4 Options for Sponsorship

The estimated cost of the project in present day dollars (year 2000) is around $410,000, with a proposed research program duration of some four to five years. Given that motorcyclist injuries due to impacts with roadside barriers are a relatively small, though high severity, proportion of the total road safety problem, it may be that individual states or territories of Australia will be reluctant to expend funds of this magnitude. On this assumption, and in order to ensure that high quality research and testing standards are achieved, it may be desirable to seek funding from a number of Australian jurisdictions to enable this program to be undertaken. A cooperative research program into which a number of jurisdictions contribute funding has the unique advantage that all would receive the full benefit of new knowledge gained in the area.

Given that this problem is also one of international concern, the possibilities of seeking funding contributions from overseas agencies, especially European countries where motorcycling is very popular, might also be considered if insufficient funds were available nationally. The notion of contributions from a number of Australian jurisdictions is compatible with a proposed national in-depth study of motorcycle crashes (Stage i) above). Conducting such a study nationally will accelerate progress in collecting an adequate number of cases, as well as ensuring that state agencies with safety responsibilities in this area are actively involved and committed to the final outcomes of the research.

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