FEASIBILITY OF OCCUPANT PROTECTION MEASURES

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Abstract

Benefit cost analysis is often used in setting road safety priorities. The concept of ***Harm*** *was developed for assessing injury mitigation benefits from vehicle safety improvements. This study builds upon previous work in the area. Harm reductions were determined for a range of vehicle safety measures for front seat occupants involved in frontal crashes. These included supplementary driver and passenger airbags (both fullsize and facebags), belt tighteners and webbing clamps, seatbelt warning systems, improved seat and seatbelt geometry, padded steering wheels, better design of lower instrument panels, kneebars, padded head protection, and structural improvements. Injury reductions were estimated by body region and AIS improvement using available literature, unpublished data, and where necessary, expert group assessment. Likely costs for these measures were determined from discussions with local automobile manufacturers, part suppliers, and vehicle importers, from overseas prices costed for Australian vehicles, and derived from first principles. Industry plans for the introduction of these measures were also sought from the automotive industry. Likely BCR's, NPW's, and percent of total trauma were then determined for each countermeasure and for packages of vehicle safety measures.*

Keywords

SAFETY, ACCIDENT, VEHICLE OCCUPANT, INJURY, COUNTERMEASURE, COST-BENEFIT, ECONOMIC, HARM, EVALUATION

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EXECUTIVE SUMMARY

INTRODUCTION

This study provided a cost-benefit analysis of a range of frontal crash vehicle safety measures recommended in the Federal Office of Road Safety's recent report CR 95 on passenger cars and occupant injury (Fildes, Lane, Lenard and Vulcan 1991). In addition, it sought to identify the most cost beneficial mix of measures to guide future policy decisions in the preparation of Australian Design Rules for passenger cars. As previously, this study was primarily concerned with front seat occupants involved in frontal crashes.

A experienced international consortium was established to undertake this work. The Monash University Accident Research Centre was ably assisted by Ernst & Young Consultants (Canberra) and Kennerly Digges & Associates (Virginia) in the conduct of this work. A number of international vehicle safety experts also provided advice on the likely effectiveness of many of these measures.

COUNTERMEASURES AND PACKAGES

The first task was to review which countermeasures were suitable for inclusion in this study, taking into account recent information on satisfactory performance and acceptability overseas. This task also involved consideration of complementary *Packages* of countermeasures and options when there were conflicting alternatives.

The countermeasures included restraint system improvements such as seatbelt tighteners, webbing clamps, improved seatbelt geometry, and a seatbelt warning system; supplementary airbags [both fullsize and facebags] for drivers and front seat passengers as well as energy-absorbing steering wheels, better instrument panel design for front seat occupants, and improved padding and structures.

INDUSTRY'S PLANS

Discussions were arranged with the Federal Chamber of Automotive Industries and with individual vehicle manufacturers to undertake an assessment of plans for the possible introduction of these measures and any potential difficulties associated with their requirements. Information was also gained from a number of contacts outside Australia regarding these matters.

COUNTERMEASURE COSTS

Several approaches were necessary to establish the likely costs to the consumer of the various measures. First, information was sought from local automotive manufacturers and part suppliers where available. In addition, overseas costs were provided for some of the componentry and these were adjusted for fitting into Australian vehicles as required.

For devices where no costs were available, cost estimates were compiled from first principles using the experience of team members and subsequently adjusted after discussions with people within the vehicle industry. Ranges of costs were provided when particular measures were seen to be sensitive to volume. In some instances, these ranges were then adjusted into a single cost using weightings derived from current make and model sales volumes.

ESTABLISHING NATIONAL DATA

An Australia-wide database was necessary to assess the likely injury reductions for each measure. The Crashed Vehicle file from the previous study offered the most appropriate source of data for this purpose [it contained both injuries and their contact source], but on closer examination, was shown to be representative of Victoria but not Australia.

Converting these data into national statistics was achieved by adjusting the Crashed Vehicle file to take account of national accident frequencies and injury levels, assuming that the adjusted injury levels were derived from similar sources of injury to those observed initially.

HARM INJURY MITIGATION

Countermeasure benefits were estimated using "*Harm Reductions*" [where Harm is the total cost of injury based on frequency and cost of treatment to the community]. Australian Harm figures were determined from national estimates of the frequency of injury by body region and contact source. Injury costs were based on those provided by Steadman and Bryan (1988) for each Abbreviated Injury Scale (AIS) level and adjusted for particular body regions by relative rates reported by Miller (1991).

Estimates of the likely injury reduction for each measure were made using performance or test results published in the international road safety literature or from unpublished information known about by the investigating team. Where performance results were unknown, best estimates of the likely injury reeductions had to be made by an *Expert Panel*.

While reliable data were available on fullsize airbag performance in the US, there was little information in the literature on facebag injury reductions. The expert panel's views on the expected performance of these smaller airbag units ranged from a conservative to an optimistic expectation. Sensitivity analyses were subsequently conducted on their likely performance under these differing scenarios.

Harm calculations included the benefits to be derived from airbags for the small proportion of front seat occupants in Australia who do not wear seatbelts (6%). The proportion of persons killed or hospitalised who are not wearing belts in a crash is higher (17%) than the proportion in the driving population as a whole. Belted occupants account for most of the total Harm reductions estimated for airbags (77%).

COUNTERMEASURE BENEFITS

Detailed calculations were undertaken of the likely Harm reduction for each measure by body region of injury, contact source within the vehicle, and restraint condition. These figures were then summarised to provide the total Harm benefit (in 1991 A$ million) for each measure and the Unit Harm per car for the total Australian passenger car fleet.

The *Discounted Present Value* method was used to establish these Unit Harm benefits for each measure. While a 7% discount rate is generally adopted for these calculations nationally, sensitivity analysis for a 4% discount rate was shown to yield higher benefits [the latter has been recommended for use by Victorian government agencies].

The calculated benefits were considered *conservative* because of the conservative assumptions made regarding the cost of injury, effectiveness for each measure, and the discount rates used in the analysis.

BENEFITS AND COSTS

Benefit Cost Ratios (BCR) and Net Present Worth (NPW) figures were calculated for each measure. To supplement these calculations, the percent of vehicle occupant trauma likely to be saved was also calculated for each measure. This enabled a broad assessment of the importance of each measure to be calculated.

The economic worthiness of *three* countermeasure packages was also considered, involving (1), a fullsize airbag package, (2), a facebag package, and (3) a non-airbag package of measures. These were judged to be the most appropriate packages of measures to optimise front seat occupant safety, given today's available technology.

INDIVIDUAL COUNTERMEASURES

Table 1 illustrates the rank order of measures in terms of their Benefit Cost Ratio. Their Net Present Worth and likely percent vehicle occupant trauma saved is also shown.

TABLE 1
INDIVIDUAL COUNTERMEASURE ECONOMIC ANALYSIS

MEASURE	*BCR*	*NPW*	*%TRAUMA SAVED*
Belt geometry & seats	*7.3*	*$27 million*	*1.7%*
Energy-Absorbing steering wheel	*3.2-16*	*$23 to 32 million*	*1.9%*
Seatbelt warning device	*4 1-7.2*	*$46 to 53 million*	*3.4%*
Knee bolsters	*2 9-4.3*	*$62 to 73 million*	*5.3%*
- - - - - - - - highly beneficial [BCR > 3] - - - - - - - -			
Lower instrument panels	*1.8-18*	*$21 to 45 million*	*2.6%*
Fullsize driver airbag (electro-mech)	*1.2*	*$36 million*	*14 9%*
Webbing clamp	*1.1-3.5*	*$0 to 16 million*	*1 2%*
Seat pretensioner	*0 8-1.1*	*-$12 to +$4 million*	*2.7%*
- - - - - - - - break-even [BCR = 1] - - - - - - - -			
Maximum driver facebag	*0.98*	*-$5 million*	*11.5%*
Fullsize driver airbag (electronic)	*0.77*	*-$80 million*	*15 1%*
Minimum driver facebag	*0.58*	*-$91 million*	*6.8%*
Shoulder pretensioner	*0.46*	*-$33 million*	*1 6%*
Padded upper areas	*0.3-0.4*	*-$19 to -31 million*	*0.7%*
Fullsize passenger airbag (electro-mech)	*0.18*	*-$192 million*	*2.4%*

The majority of the injury reduction benefits would accrue to **restrained** vehicle occupants. For airbags and facebags, the restrained benefit varied from 73% to 81% of total benefit, depending on which injury reduction scenario was assumed (refer Table 6.14 in Chapter 6).

COUNTERMEASURE PACKAGES

Table 2 shows the *three* options of countermeasure packages and their likely economic benefits to the community. All of these packages were cost-beneficial and would result in marked reductions in vehicle occupant trauma. Most notable, however, was the *fullsize airbag package* (Package 1) which had a nominal to moderate BCR, a highly beneficial NPW, and would produce a 25% reduction in vehicle occupant trauma when fitted to the total vehicle fleet in this country. Package 1 comprised:

. a fullsize driver airbag,
. an energy-absorbing steering wheel,
. a front passenger side [seat attached] seatbelt pretensioner,
. a front passenger [inertia reel attached] seatbelt webbing clamp,
. improved seatbelt geometry and seat design, and
. a knee bolsters across the full lower dash area.

TABLE 2
ECONOMIC ANALYSIS OF COUNTERMEASURE PACKAGES

PACKAGE	*BCR*	*NPW*	*%TRAUMA SAVED*
Package 1 - Fullsize airbags *Fullsize driver airbag (electro-mech)* *Energy-Absorbing steering wheel* *Seat pretensioner (passenger side)* *Webbing clamp (passenger side)* *Improved seatbelt geometry & seat design* *Knee bolsters*	*1.4-1 6*	*$133 to 168 million*	*25%*
Package 2 - Facebags (Minimum Benefits)* *Driver facebag (Minimum Benefit*)* *Energy-Absorbing steering wheel* *Seatbelt warning device* *Seat pretensioner (passenger side)* *Webbing clamp (passenger side)* *Improved seatbelt geometry & seat design* *Knee bolsters*	*1.2-1 3*	*$53 to 94 million*	*20%*
Package 3 - No airbags *Energy-Absorbing steering wheel* *Seatbelt warning device* *Seat pretensioner (both sides)* *Webbing clamp (both sides)* *Improved seatbelt geometry & seat design* *Knee bolsters*	*2.1-3.4*	*$156 to 214 million*	*17%*

* Three injury reduction scenarios were used for comparing facebag benefits in the text (see Chapters 6 to 8). However, the **minimum** scenario was the one which the team felt was most appropriate.

CONCLUSIONS AND RECOMMENDATION

The study concluded with a discussion of the desirability of the various countermeasure packages and highlighted the conservative nature of many of the assumptions and assessments involved in the study. *Four* recommendations were made from the findings of this study:

1. *that due consideration be given to the introduction of the measures outlined above in Table 2 as packages of vehicle safety improvements. [Trauma reduction would be greatest with the introduction of Package 1 which will eventually lead to a 25% reduction in vehicle occupant trauma].*

2. *that consideration also be given to ways of reducing vertical and lateral steering column intrusions and floor and toe pan intrusions as a matter of priority.*

3. *that further consideration be given on how to encourage vehicle manufacturers to improve the crashworthiness of lower instrument panels.*

4. *that further research be undertaken to examine why the estimated BCR of padding the header rail, A-pillar, side rails, and B-pillar is considerably less in this country than in the USA.*

1. INTRODUCTION

The recently released report by the Federal Office of Road Safety on ***Passenger Cars and Occupant Injury, CR 95***, (Fildes, Lane, Lenard and Vulcan 1991) identified a number of potential frontal crash countermeasures to minimise injury to front seat occupants. Furthermore, this report also noted the need for further cost-benefit analysis for each of these measures to demonstrate their beneficial effects for the community as a means for prioritising their implementation.

This subsequent report was commissioned by the Federal Office of Road Safety in response to this call and provides a cost-benefit analysis of the vehicle safety measures listed in CR95, as well as details on any automotive industry's plans for their introduction in the foreseeable future.

1.1 PROJECT OBJECTIVES

The project specification nominates ***two*** objectives for this study:

1. To identify the most cost beneficial mix of countermeasures,

2. To provide a sound basis for policy decisions in the preparation of Australian Design Rules.

It was assumed that the soundest basis for these policy decisions is economic cost-benefit analysis, based on scientific injury mitigation assessments, but taking into account relevant local industry issues and priorities, international developments, and other likely community benefits.

1.2 COUNTERMEASURE SELECTION

The project specification nominated the total list of countermeasures for cost-benefit analysis, including:

. improvements to restraint systems (belt tensioners, force limiters, webbing clamps, and improved seat belt geometry),

. anti-submarining devices, such as seat improvements and knee bolsters,

. padded steering wheels,

. improvements to dashboards, instrument panels, and parcel shelf areas to reduce the injurious nature of contacts,

. padding of windscreen header and door surrounds, and

. air bags.

. the influence of extending ADR 10/01 to include maximum vertical and lateral steering column movements,

. replacing the steering wheel with a smaller hand control arrangement (eg; a joy-stick controller),

. seat belt interlocks,

. other restraint improvements (wider belts, inflatable seat belts, etc.)

. reduced floor and toe pan intrusions,

. windscreen laminates, and

. the various packages of countermeasures associated with meeting a barrier crash test requirement, similar to Federal Motor Vehicle Safety Standard (FMVSS 208).

It is noted that while a number of these measures are mutually exclusive, some are likely to have interactive effects with others (eg, restraint improvements and anti-submarining devices). Thus, it was important in this study for these effects to be quantified and the results presented as a series of vehicle safety options or packages of options.

The study was to take account of current industry plans for the development and implementation of these countermeasures, as well as recent international developments and latest test findings in its deliberations. This information was necessary in refining the final list of countermeasures and package options for inclusion in the study and for describing suitable timelines for the final ranking of suitable measures.

1.3 THE PROJECT STRUCTURE

A number of tasks were undertaken during the course of this research and an overview of these are detailed below.

1.3.1 Countermeasures and Packages

One of the earlier tasks undertaken in this study was to evaluate the current suitability of the full range of countermeasures listed in CR95 and to outline a number of countermeasure option packages that would be possible in the implementation of these measures into Australian passenger cars. Details on the resultant list of countermeasures and packages that were considered in this study are included in Chapter 2.

1.3.2 Assessing Industry Plans

Discussions were undertaken with the Federal Chamber of Automotive Industries (FCAI) as well as visits to a number of local vehicle manufacturers, vehicle importers, and part suppliers. In addition, information was sought from various overseas and other sources regarding future plans for safety features in vehicles. This is described in full in Chapter 3.

1.3.3 Costs of Countermeasures

It was necessary to provide realistic likely in-vehicle costs to society for the range of countermeasures or countermeasure packages. In some cases, this was difficult without a detailed design plan for the particular countermeasure. While most of these measures are presently available in many overseas vehicles, they have a variety of different designs and are not always readily applicable to Australian vehicles.

In assessing the costs of the various countermeasures singly and as desirable packages, therefore, information needed to be gathered from local vehicle and component manufacturers and overseas sources. Where current costs could not be determined or countermeasures needed local adaptation, best estimates were derived using the experience of the study team, supplemented with the views of producers. The resultant derived costs and the rationale for these is described in Chapter 4.

1.3.4 National Data and Injury Costs

The report on Passenger Cars and Occupant Injury, Number CR 95, was based on data collected, either for the state of Victoria [Transport Accident Commission (TAC) data], or from a limited number of patients admitted to a sample of Metropolitan hospitals in Melbourne [the *"Crashed Vehicle study"* comprising approximately one-third rural and two-thirds metropolitan crashes]. These figures need to be adjusted into national statistics to allow a full account of the total safety benefits for all Australians. This process is described in Chapter 5.

1.3.5 Assessing Injury Reductions

An essential part of this evaluation was the assessment of injury reductions likely from the introduction of these countermeasures across the whole new vehicle fleet. The concept of *"Harm"* was developed in the US and applied to National Accident Sampling System (NASS) database by the National Highway Traffic Safety Administration (NHTSA) as a means of determining benefits for road safety programs (eg, Malliaris, Hitchcock and Hedlund 1982; Malliaris, Hitchcock and Hansen 1985; Malliaris and Digges 1987). Harm is a metric for quantifying the total cost of road trauma.

In its original form (stage of development) it was not immediately applicable for use with these data. However, after modification to local conditions, it was able to be used for this study. The development and use of Harm, is also explained in Chapters 5 and 6 of this study and represented a significant international advancement in the ability to assess injury mitigation effects of vehicle countermeasures. To the authors' knowledge, this level of detailed analysis has never been attempted before.

1.3.6 Estimation of Countermeasure Benefits

In developing the concept of Harm analysis, it was necessary to develop a basic Body Region by Abbreviated Injury Scale (AIS) Harm matrix, that could be applied to Australian costs and injury patterns for use in this analysis. This process is described fully in Chapter 5.

There is debate about what are the real costs of road injuries in this country (essentially involving "human capital" or "willingness to pay" methods of costing benefits). To avoid this study being delayed while this debate takes its course, the injury costs (by AIS level of severity) outlined in Steadman and Bryan (1988) were adopted. It should be recognised, however, that this approach is conservative (Steadman and Bryan 1988; Motha 1990) and that published willingness to pay estimates give much higher values to human life. However, the validity of these estimates is subject to debate as is their applicability to studies of mandatory safety features.

A second issue of importance in assigning vehicle safety benefits was in the means of computing Unit Harm benefits for each vehicle in the total vehicle fleet. The traditional method for this uses the "*Discounted Present Value*" (DPV) approach. Alternatively, the "*Equilibrium*" method, which is a measure of the annual maintenance expenditure needed to keep the total stock of vehicles equipped with safety features, has been used in the US for similar exercises (Kahane 1981).

On the advise of the Bureau of Transport and Communications Economics (BTCE), the DPV method was adopted for use in this study with a 7 percent discount rate. Again, it should be pointed out that this method also produces a lower estimate of vehicle safety measure benefits. The full account of the reasoning behind these decisions as well as a summary of the resultant cost-benefits is found in Chapter 6.

1.3.7 Benefit-Cost and Other Economic Comparisons

As noted earlier, one indication of implementation priority was the likely Benefit Cost Ratios (BCR's) for all measures. This is simply the benefits accruing to each vehicle (Unit Harm) divided by the economic cost of fitting the device to a vehicle (the retail price minus sales tax and import duty). In addition, the Net Present Worth (NPW) and the percent of vehicle occupant trauma saved were also considered to be useful measures of the full economic impact of the measures under consideration.

The resultant BCR summary is described fully in Chapter 7, along with their Net Present Worth (NPW) and percent of vehicle occupant trauma saved.

1.3.8 Conclusions and Recommendations

The conclusions and recommendations emanating from this study, along with the strengths and limitations of the research, are discussed in the final Chapter 8.

1.4 RESEARCH TEAM MANAGEMENT & STRUCTURE

A list of members of the Research Team is provided at the front of this report.
In providing the best available expertise to conduct this study, a comprehensive multi-disciplinary research team and management structure was assembled, comprising the following organisations and experts.

1.4.1 Monash University Accident Research Centre

The primary consultant (Performing Organisation) for the project was the Monash University Accident Research Centre (MUARC), comprising Peter Vulcan, Director, Brian Fildes and Max Cameron (Senior Research Fellows of the Centre). MUARC's tasks and responsibilities included overall responsibility for the conduct of the study, as well as responsibility for the data and analyses, and compiling the project report.

1.4.2 Ernst and Young Consultants

Ernst and Young (Canberra) were represented on the study team by Douglas Taylor, Director, and Mike Stacy, Consultant Engineer, and were responsible for discussions with the vehicle industry and deriving the costs of the various countermeasures and packages.

1.4.3 Professor Kennerly Digges & Associates

Professor Kennerly Digges of Kennerly Digges and Associates directed the development of the Australian Harm matrix as well as providing the logic, relevance, and assessments of benefits for each countermeasure. His vast international knowledge was especially helpful in providing the assumptions necessary for prescribing countermeasure benefits, documented in Chapters 2 and 6.

1.4.4 Expert Group Discussions

Expert group discussions were held on occasions throughout the duration of the study to establish the final list of countermeasures of relevance in this study and to assign relevance factors to countermeasures for which performance data was not available from tests or crash data published in the international road safety literature.

Professor Murray Mackay, Director, University of Birmingham Accident Research Unit, kindly contributed to the former task by providing details on European countermeasure development and other relevant experience during his brief stay in Australia during July. Dr. Ralph Hitchcock, Deputy Associate Administrator (Research), NHTSA, also kindly participated in expert group discussions during his timely visit to Australia. Expert group discussions were aimed at establishing unknown injury relevance factors.

1.4.5 Economic Consultant

Professor Ross Parish, Faculty of Economics, Monash University, acted as Economic Consultant for the project. Professor Parish's specialist background in cost-benefit analysis was useful in advising on benefit-cost analysis methods used in the study (including the suitability of using the human capital versus willingness to pay costing basis and the discounted present value approach). He further audited the methods adopted for this study and provided general economic advice as required. Two papers were prepared by Professor Parish during the course of this study and are included as an Appendix to this report.

1.4.6 Project Steering Committee

Several project steering committee meetings were convened during the course of the study for comment and discussion on the conduct and progress of the research. The committee comprised members of the Federal Office of Road Safety, the Bureau of Transport and Communications Economics, as well as senior members of the project team. Participants in the Project Steering Committee are also listed at the front of this report.

2. COUNTERMEASURES AND PACKAGES

As noted in the Introduction of this report, one of the earlier tasks undertaken in this study was to evaluate the current suitability of the full range of countermeasures listed in CR95. This was necessary to ensure that the final list of countermeasures was relevant based on the latest available test results in the international literature and recent developments overseas on these measures.

2.1 EXPERT GROUP DISCUSSIONS

An expert group meeting was called at the commencement of the study to review the list of countermeasures for detailed consideration in the study. As noted earlier, this expert group comprised road safety experts from Europe and the United States, as well as local road safety people. In addition, visits were made to a number of vehicle showrooms to see how many of these measures were currently available on the seven most popular vehicles in this country.

A number of issues were relevant for this task. First, were any of these countermeasures currently available in all modern passenger cars in Australia and thus required no further consideration. Second, was there any recent local or overseas evidence on performance testing of any of these measures that showed them to be less effective than first thought. Third, what was the international experience in introducing these measures and how relevant would this be for their introduction in to Australia.

The deliberations of the expert group are described below, along with the ultimate list of frontal crash countermeasures for front seat occupants that were considered valid for this study.

2.2 COUNTERMEASURES NOT RELEVANT AT THIS STAGE

The full list of countermeasures was detailed in the Introduction. From this list, the following countermeasures were eliminated for the reasons outlined below. It should be stressed, though, that while these measures did not receive detailed consideration in this project, this does not mean that they do not have potential to reduce vehicle occupant trauma. Rather, they are currently implemented in vehicles or require substantial further development or testing at this time.

2.2.1 Adjustable D-Ring Belt Supports

These devices were initially proposed as a safety feature for passenger car occupants. Indeed, the group felt that there was considerable merit for the device to be fitted to vehicles for smaller sized adult occupants [adjusting the D-ring down aligns the belt more desirably across the shoulder for people of small stature]. However, if they are left in the down position, they may then produce misalignments for people of large stature.

The group consensus was that these devices were generally viewed in the industry as a comfort rather than a safety device, and besides, many current model vehicles available in Australia already had these devices fitted. Hence, it was decided not to consider this countermeasure any further here.

2.2.2 A No Steering Wheel Option

There are a number of current developments locally and overseas towards providing an alternative vehicle controller to the steering wheel. SAAB in Sweden, for instance, have a prototype for a computerised steering system operated by a single hand controller located in the vehicle console. In addition, there are several other developments in Australia and overseas of a similar kind principally aimed at providing vehicle control for handicapped drivers.

The universal application of these devices, however, was considered to be a long way off yet, given the general public acceptance of the steering wheel as the preferred means of steering the vehicle at this time. It was unanimously agreed by the group that a major behavioural change would be required before these devices would be generally preferred to the steering wheel by the motoring community. While accepting that there would be merit if these devices were generally available in Australian passenger cars, further consideration of the implementation of this measure was premature for this study.

2.2.3 Other Restraint Improvements

Given the number of vehicle occupant injuries from the seatbelt itself reported in CR95, a need was identified for further improvements in the design and structure of seatbelts. Wider (and possibly) inflatable belts were proposed as two improvements worthy of further consideration.

Inflatable belts have been tested in the US but found to require further development at this stage before introduction into the passenger car fleet. This countermeasure was subsequently not considered further in this study.

It was generally agreed that wider belts would offer some reductions in belt loading on the chest. However, there was debate among the expert group about their development and effectiveness. The major problem was whether wider belts could be made to remain flat on loading and not "curl" into a rope-like structure. [This had apparently been a problem early in belt development which reduced their effectiveness, although it was also noted that economics was the prime reason that one European manufacturer choose not to proceed with 7.5cm (3") belts as a standard feature on their cars]. Furthermore, the issue of increased belt stiffness to prevent curling might present a new problem for occupants using wider belts.

It was agreed, therefore, to not include this item at this stage, given the current state of knowledge and development on this issue. However, there was consensus about the need for further research into wider belts for future deliberations about the effectiveness of ADR standards in this country.

2.2.4 Windscreen Laminates

Laminates on the inside of the windscreen were trialled overseas to reduce glass splintering (a significant problem for minor injuries to vehicle occupants) and to minimise partial ejections from the vehicle. The evidence from Europe and the USA was not promising at this time; there were difficulties in bonding laminates on the inside of the windscreen and visibility defects had been reported.

While not wanting to stifle further developments of this potentially important (minor) injury countermeasure, the expert group considered it was not worthy of inclusion in this study at this time.

TABLE 2.1
LIST OF COUNTERMEASURES FOR THE FEASIBILITY PROJECT

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1. IMPROVED RESTRAINT SYSTEMS

. belt pretensioners (seat and reel attached)

. webbing clamps

. improved seatbelt geometry & seats (reduced submarining)

- *in-board anchorage (improved stalk position)*
- *anti-submarining seat cushion*
- *out-board anchorage (seat attached)*

. seatbelt warning system (not an engine interlock)

. fullsize passive restraint airbag (US style)

. supplementary facebag (Eurobag)

2. STEERING ASSEMBLIES

. energy-absorbing (padded) steering wheels

. reduced vertical and lateral column movements

3. INSTRUMENT PANEL

. improved panel structure and materials

. improved padding

. knee bars or bolsters

. reduced protrusions

4. WINDSCREEN, HEADER & FLOOR

. improved upper head padding

. better floor & toe pan structure

2.3 COUNTERMEASURES RELEVANT FOR THIS STUDY

The countermeasures listed in Table 2.1 were those that the expert group considered relevant for inclusion in this cost-benefit study. As noted earlier, relevance was decided on the basis of consensus on the likely effectiveness of these measures to reduce injury based on overseas experience, as well as their current availability, either because they are presently being offered in production vehicles outside Australia, or that a suitable device or design is available for use in this country.

Many of the measures could be immediately grouped into packages because they formed logical combinations. For example, improved seatbelt geometry (more appropriate seatbelt angles across the occupant's abdomen) could be achieved by mounting the belt anchor points (both in-board and out-board) on the lower frame of the seat in conjunction with a more inclined seat pan angle. Hence, this combination represented an immediate pre-grouping of countermeasures into appropriate packages.

2.4 COUNTERMEASURE PACKAGES

While the combination of countermeasures into various packages might seem almost limitless at first glance, in fact there were only a very small number of countermeasure package options actually appropriate on closer inspection. Many of the measures were complementary (eg, padded steering wheels and airbags) while others were alternatives (eg, airbags, belt clamps and pretensioners). These countermeasure packages are discussed below.

2.4.1 Airbags and Padded Steering Wheels

These two countermeasures are, in fact, complementary. Energy-Absorbing (padded) steering wheels offer essentially face protection in low speed crashes when the airbag may not be deployed [impact speeds up to 32km/h (20mph), Pintar et al 1988], while airbags provide head, face, and chest protection for restrained drivers beyond 16-24km/h (10-15mph). This is even allowing for the fact that the heavily padded hub of the acknowledged padded steering wheel (TRRL and Volvo designs) would be lost from having to fit the airbag in this region. Thus, together, they form a logical combination or package of measures for improved protection from contacts with the steering wheel.

2.4.2 Fullsize Airbag versus Facebag

Both these airbags [fullsize airbag in the USA and facebag under development in Europe] offer protection from the steering wheel. For the designs currently in production or being developed, they differ in terms of their size [fullsize = 60-70litre, facebag = 30-40litre], threshold for deployment [fullsize = approximately 16km/h (10mph), facebag = approximately 24km/h (15mph)], and rate of deployment [fullsize = 30msec, facebag = 40-60msec]. In addition, the sensors vary both within and between these different airbag designs for reasons of cost and sensitivity and reliability.

All speed and delta-V figures are shown in kilometres per hour (km/h) and miles per hour (mph) in recognition of the fact that US data has been used in many of these comparisons.

The amount of occupant protection, therefore, differs between these two airbags. Facebags essentially offer head, face, and some chest protection from contacts with the steering wheel up to 56km/h (35mph) and are more effective for pure head-on crashes (i.e., 12 o'clock or straight ahead). Fullsize airbags, on the other hand, offer head, face, chest, and some abdominal injury protection up to 64km/h (40mph) at least, and provide greater protection in offset and oblique angled crashes than do facebags.

At present, the minimum performance of the fullsize airbag is defined by the US Federal Motor Vehicle Safety Standard 208. There are no government standards for performance criteria for facebags (essentially a European initiative]. Therefore, the performance may vary significantly from manufacturer to manufacturer until such standards become available.

Moreover, fullsize airbags also provide passive restraint benefits for unrestrained occupants in minimising injuries from being thrown around inside the passenger compartment and contacting the steering assembly, A-pillar, instrument panel, and the windscreen, as well as from ejection and exterior contacts. There is no evidence (or expectation) at this time of any likely benefit to unrestrained drivers from the facebag, except for reduced steering wheel contacts.

This does not preclude the possibility of some form of compromise between these two airbag systems. A manufacturer could choose to opt for a 60 to 70litre bag for instance but use facebag sensing criteria thereby gaining improved supplementary (and possibly some passive) injury benefits while keeping costs to a minimum.

2.4.3 Seatbelt Warning Devices

Unrestrained occupants were shown to be 3 to 4 times more likely to be hospitalised or killed in frontal crashes than those restrained [Fildes et al 1991; McLean et al 1979]. While this may be in part a function of increased risk of accident involvement for unrestrained drivers, it almost certainly reflects the degree of improved protection for restrained occupants as well.

Seatbelt interlocks [where the car engine will not start unless all seated occupants have their belts on] were mandatory for some 1974 model cars in the US and occupant protection improvements were subsequently noted (NHTSA 19 cities observation data, Digges 1991). However, this requirement was eventually retracted as there was strong opposition and motorists disregarded the law for a variety of reasons, most of which would not be relevant in Australia today.

A highly visible and audible warning device could be installed in a vehicle as a seatbelt warning device would seem to be a viable alternative to a full engine interlocks to remind (embarrass) those who forget to put on their belt. (For full effects, the alerting system should be ***both*** internal and external). Alternatively, the warning device could operate the car's 4-way hazard flashers until all seated occupants are belted, although this may require a legislative change. Such a device would lead to benefits in improved protection for unrestrained occupants.

2.4.4 Reduced Seatbelt Slack

A number of seatbelt enhancements are available to reduce the amount of slack or reel-out prior to loading. These include webbing clamps (at the buckle loop, D-ring loop, or at the inertia reel) and pretensioners (mechanical or pyrotechnic) at the stalk or inertia reel.

Clamps act to reduce reel-out by gripping the belt during the early stages of impact. Shoulder pretensioners, on the other hand, remove the slack by actually reeling in up to 12.5cm (5") of the belt on impact, thereby reducing occupant movement and belt loads on the occupants chest. Seat pretensioners replace the seatbelt stalk and, on impact, pull down the lap and lower part of the sash to remove any slack in the lap section of the belt system.

These systems are most likely to be of benefit to drivers by reducing chest and abdominal contacts with the steering wheel (mainly pretensioners) and possibly some lower leg contacts with the instrument panel and steering assembly (seat pretensioners and webbing clamps). Left front passengers would also derive benefit from reduced head and face contacts with the windscreen, header rail, and instrument panel.

A combination of belt clamps and pretensioners was considered a desirable package of measures to minimise seatbelt injuries and reduce contacts with the steering wheel, instrument panel, A-pillar, and the floor. It was acknowledged that in some cases, though, these features may only change the contact point with the steering wheel for drivers rather than prevent injuries entirely. It can be argued that these systems should be incorporated in conjunction with E-A wheels and airbags to optimise occupant protection. A padded wheel and airbag for the driver and a seat pretensioner and/or webbing clamp system for the front left passenger would seem to be a minimum package for improved front seat passenger safety.

2.4.5 Submarining Reductions

Current seatbelt and seat designs do not necessarily prevent submarining (Fildes et al 1991). Hence, there is clearly a need for improved seatbelt angles and anti-submarining seat pans to reduce the incidence of these occupant movements under the lap section of the seatbelt.

The attachment of the lower belts on the seat (inner and outer) rather than the floor and a steeper angled solid seat pan wedge under the seat would seem to constitute a minimum package to reduce belt related injuries to the abdomen/pelvis and thigh/knees injuries from contacts with the steering assembly, instrument panel, and the A-pillar.

2.4.6 Lower Instrument Panel Contacts

Even with airbag, seatbelt, and seat improvements noted above, further lower limb injury benefits would be gained by better design, less injurious materials, and fewer protrusions on the lower instrument panel.

Kneebars are installed in many passenger cars in the USA to help meet femur load requirements in FMVSS 208. If kneebars were standard equipment in Australian passenger cars too, there would also be lower limb benefits for restrained and unrestrained front seat occupants from reduced thigh/knee and leg/foot contacts with the steering assembly, instrument panel, and the floor.

Kneebars would (to some degree) alleviate concern with poorly designed instrument panels as noted earlier. However, there may be grounds for some concern if these devices are fitted without airbags or seatbelt improvements in terms of their consequences on unrestrained occupants. In any event, it would still be desirable if a lower limb injury prevention package contained both of these improvements to optimise occupant safety. Indeed, it could be said that the improvements listed in the lower instrument panel are simply a matter of good engineering practice.

2.4.7 Steering Column Intrusions

Fildes et al (1991) reported generally satisfactory performance as specified by ADR 10/01 for longitudinal movement of the steering column in the vehicles they inspected. However, vertical and lateral movements were associated with injury to front seat occupants (notably the driver) from intrusions into these spaces as the occupant is thrown forward during head-on crashes.

Benefits in reduced head, face, chest, and some injuries to the spine from contact with the steering wheel and column would accrue if these intrusions were minimised (at least to the level specified for longitudinal movement). Given head and torso trajectories in frontal crashes, vertical restrictions would seem to require early attention.

2.4.8 Intrusion Control

Floor and toe pan, and instrument panel intrusions were especially associated with injuries to the lower limbs for restrained and unrestrained front seat occupants. While major vehicle structural improvement beyond that available overseas might be difficult to specify locally, nevertheless, lower limb injury reductions would result from fewer (and less severe) of these intrusions, especially in offset frontal crashes and pole collisions.

2.4.9 Head Impact Padding

Head contacts with the header rail and A-pillar were evident in Fildes et al (1991) for both restrained and unrestrained occupants. A countermeasure package comprising 2.5cm (1") of suitable padding in these regions would lead to a 50% reduction in these injuries (Willke and Gabler 1991). Recent tests of Australian and US sunvisors by Kennerly Digges and Associates in the United States showed that significant improvements in head protection safety already exist in visors on sale in Australia which meet ADR 11/00.

3. INDUSTRY DEVELOPMENTS AND PLANS

3.1 INTRODUCTION

As structural change is occurring in the Australian motor vehicle manufacturing industry, Australians are becoming more heavily dependant on imported technology and products. The Australian car market is highly fragmented with the ten top selling cars accounting for around 56% of annual sales. Only the Falcon is a uniquely Australian vehicle. Industry commentators recognize that the "end of the line [has come] for the Aussie car".

Consequently, the costs and timing of introduction of "countermeasure" technology is likely to be heavily dependant on international developments with some local input possible to suit Australian conditions and taste.

3.2 INTERNATIONAL OVERVIEW - THE AUTO INDUSTRY

The world's largest manufacturing industry, the automobile industry, is undergoing major structural change.

Major differences have been reported in the efficiency of international vehicle manufacturers, reflected in their capacity to respond to market and regulatory changes. Differences have been documented by the Massachusetts Institute of Technology International Motor Vehicle Program 1985-1989. (MIT IMVP)

Key differences include:

- the product life cycle; 4 years for a typical Japanese vehicle compared with 8 to 10 years for European and US manufacturers;
- annual production volumes; 125,000 for a typical Japanese vehicle compared with 200,000 plus for typical western vehicles;
- new product design time; in the mid 1980s 46 months for a Japanese vehicle, 60 months or longer for a western vehicle;
- average rates of shared parts (with previous models); 18% of Japanese vehicle, 28% - 30% for European vehicles, 38% for US vehicles;
- design inputs to a new vehicle; 1.7 million man-hours of engineering effort for a Japanese vehicle, 3 million man-hours inputs for a European or US vehicle.

This chapter is based on material collected by Ernst and Young from discussions with the automobile industry and other sources in the third quarter of 1991.

Best practice is being set by leading Japanese manufacturers in terms of cost, quality and product cycles.

These differences have been attributed to the adoption of "lean production" systems in place of the more traditional western mass production systems. By the use of "lean production" systems, manufacturers have been able to obtain most of the economies of scale associated with the traditional western mass production systems at much lower volumes.

The Toyota production system introduced in the 1960s and refined , has been recognized by the MIT study as the industry bench mark. Similar systems have been introduced by Mazda (post 1973) and some other Japanese manufacturers. A number of plants have been established in the US by local and foreign manufacturers but none have been reported in production in Europe or Korea. Japanese manufacturers are planning to open new plants in the UK and Europe over the coming decade.

Despite the presence of Japanese producers in Australia, the MIT IMVP surveys found Australian "productivity and quality levels far off the standard set by lean producers in Japan and North America." Since the IMVP surveys, Nissan, for example, reported in October 1991 that it had reduced the average built time (assembly hours per car) from 35 hours to 26 hours in the last 18 months.

The international competitiveness of Australian manufacturers is indicated by comparison with information obtained by the IMVP World Assembly Plant survey aspects of which are provided in the following table.

TABLE 3.1
COMPARATIVE EFFICIENCY - SELECTED MOTOR VEHICLE PLANTS 1987

	Plant 1	Plant 2	Plant3
Assembly hours per car	31	16	19
Assembly defects per 100 cars	135	45	45
Average inventory of parts	2wks	2hrs	2day
(Measured in production requirements)			

* Plant 1 is an aged US plant. (GM Framingham which was subsequently closed.)

* Plant 2 is a plant using the Toyota Production System, (Takaota Japan built in 1966 with "average" automation.)

* Plant 3 is an old US plant (built in 1966) but adopting the Toyota Production System, United Motor Manufacturing Incorporated, Freemont California.

In view of the relative cost disadvantage of the Australian industry it is unlikely that it will invest heavily in unique research and development into countermeasure technologies. The technology is likely to be imported from the international parent company or "bought in" from specialist component manufacturers. The technology will reflect the experience of the large volume US market, the only large existing airbag market in the world currently.

Importers with access to advanced countermeasure technology in "left hand drive" configuration are likely to have a competitive advantage over Australian manufacturers with "unique" or somewhat "unique" local products. Accordingly, timing of introduction in Australia is likely to depend on international developments.

Ernst & Young, in association with the University of Michigan, have recently completed a report, *The Car Company of the Future: A Study of People and Change* (1991) which provides a perspective on efforts car companies are making to become more competitive internationally. The report concludes that while Japanese manufacturers will maintain a competitive advantage in the year 2000, GM is expected to make the largest improvement in overall relative competitiveness to be on a par with Ford (Refer Table 3.2). Of the big 3 US manufacturers, GM has yet to offer airbags in vehicles to the extent of its competitors.

TABLE 3.2
RELATIVE OVERALL COMPETITIVENESS RATINGS

1990 Manufacturer	1990 Relative Rating	2000 Manufacturer	2000 Relative Rating
Toyota	1.5	Toyota	1.1
Honda	1.6	Honda	1.4
Nissan	2.3	Nissan	1.9
Mazda	2.5	Ford	2.0
Mercedes Benz	2.5	GM	2.0
Ford	2.6	Mazda	2.3
GM	3.0	Mercedes Benz	2.5
Chrysler	3.6	Chrysler	3.9

Indexed Scale: 1 to 5; 1=highest rating

It can be concluded from this information that the major differences in the efficiency of motor vehicle manufacturers internationally could be expected in the short term to have a direct bearing on their ability to respond to market and regulatory requirements for improved vehicle safety and the introduction of "countermeasures".

3.3 INTERNATIONAL COUNTERMEASURE DEVELOPMENTS OF POTENTIAL CONSEQUENCE FOR THE AUSTRALIAN MOTOR VEHICLE MARKET

Significant recent developments have occurred in Japanese industry that will be of direct consequence for Australian new car buyers. Advice obtained from the US is provided below;

. HONDA - advice dated 22 December 1990
"....driver-side and passenger-side airbags for all passenger cars sold in the US by the 1994 model year" (US market)

. MAZDA - advice dated 20 November 1990
airbags as "standard equipment for both driver and passenger by the 1994 model year" (US market).

- NISSAN - advice dated 26 November 1990
  "by 1992, most of our passenger cars sold in the United States will come with a driver, side airbag as either standard or optional equipment", "Passenger side airbags will be available in nearly all Nissan models sold in the United States in 1994".

- TOYOTA - advice dated 23 November 1990
  "By 1992 we plan to make drivers side air bag available on almost all our passenger vehicles in Japan and the US. We also expect to add passenger seat airbags beginning in 1992"

- ISUZU - advice dated 16 November 1990
  "Isuzu Motors is planning that airbags will be available in all its next model passenger cars for the Japanese market".

- DAIHATSU - advice dated 4 December 1990.
  "Tentative plans call for us to introduce the driver side airbag system on vehicles sold in the United States beginning with the 1994 model passenger cars." "Passenger side airbags system..... possible introduction in the United States beginning with the 1996 model year". "We hope to follow this same timetable for introduction of an airbag system on vehicles sold in the Japanese domestic market".

These manufacturers supply similar vehicles but in Right-Hand drive configuration into the Australian market. In recent months, countermeasure technology (as listed in Table 2.1) has become available on some models sold in Australia.

In the United States, Ford, General Motors, and Mitsubishi/Chrysler have advanced countermeasure technology available. Airbags are standard on many vehicles and optional on others. The number of vehicles equipped with airbags has been forecast to increase rapidly in the US from 4 million in 1990 to 15 million in 1993.

European manufacturers of luxury vehicles are providing airbag and other countermeasure technology in vehicles sold in the US and have in recent months introduced it into vehicles sold in Australia.

Considerably less of this technology is to be found in general in vehicles currently manufactured and sold in the UK and Europe, industry sources have indicated that European manufacturers are expected to be offering airbags and other features on "mass produced" cars by the 1994 model year.

Countermeasure technology is also readily available from specialist component manufacturers, eg. Autoliv, who are established in Australia and the US Breed Corporation. A range of well developed value engineered products are available, including seat belt webbing clamps and pretensioners and US airbags and facebags.

It can be concluded that countermeasure technology is available now to Australian manufacturers and many importers through their international parent companies and component manufacturers. The timetable for its introduction in Australian vehicles is primarily related to introducing the technology into particular models.

3.4 LIKELY LEAD TIMES FOR THE INTRODUCTION OF COUNTERMEASURE TECHNOLOGY IN PARTICULAR MODELS

3.4.1 Airbag Systems, Pretensioners, Webbing Clamps.

Information provided by Japanese auto manufacturers in 1990 indicates a 2 to 4 year period for the introduction of airbags. In view of the typical Japanese product cycle of 4 years, it is clear a number of manufacturers propose to introduce the new features into new models.

In 1983 the US National Highway Traffic Safety Administration (NHTSA) considered submissions from key manufacturers and importers and concluded lead times for various features as:

- "detachable automatic belts" requiring seat, door, pillar and floor pan reinforcements - approximately 24 months.
- driver air bag requiring steering column modification - at least 36 months and longer for small cars.
- passenger air bag requiring instrument panel and glove box relocations - approximately 24 months. Additional time of 36 to 48 months would be required for testing and development, and longer for small cars.

These NHTSA assessments are based on implementation across the full range of passenger vehicles then on sale by US manufacturers.

The modifications to vehicles required for "detachable automated belts" are not unlike those which would be required for inclusion of seat belt pretensioners and webbing clamps and provide a broad indication of the likely time for their incorporation in Australian vehicles. Depending on the type of webbing clamps and the nature of the vehicle, a lead time of 18 months may be feasible.

Recent advice received from industry suggests a 32 month period may typically be required to introduce airbags into a vehicle. This timetable is based on the ready availability of computer simulation facilities, and extensive experience in the design and manufacture of airbag systems. The various stages and related timing include:

Phase 1	System analysis/computer simulation, prototype design manufacture and testing - 8 months.
Phase 2	Design modifications, prototype tooling, manufacturing and testing, production planning - 9 months.
Phase 3	Design refinement, production tooling, production equipment, additional testing, first part out of tools - 10 months.
Phase 4	Production planning, pre production, try-out series, verification testing - 5 months.

Opportunities exist for a shortened timetable where airbags are already provided in left hand drive configurations of vehicles also manufactured in a right hand drive configuration.

Provided vehicles were similarly equipped (engine/drive train and equipment) Phases 1 and 2 offer the potential time savings as much of "crash pulse" information and tooling, production planning and manufacturing information would be available.

Provided difficulties during testing do not arise, manufacturers could move quickly to Stages 3 and 4 which again could also be reduced. In these circumstances an overall best lead time of 15-18 months may be achieved. This is unlikely to apply to smaller vehicles where only limited LHD configurations include airbags and difficulties are likely to be experienced.

The reduced estimates for "overall best lead time" for right hand drive configuration when air bags are already fitted to left hand drive configuration is consistent with the information provided by leading Japanese manufacturers in late 1990, and other "intelligence" gained from local sources.

3.4.2 Improved Padding

An independent assessment of the lead times to introduce improved pillar padding was completed for NHTSA in August 1991. NHTSA were advised that lead time of 12 months would be required for US manufacturers to provide improved levels of padding to the A, B and C pillars roof headers and roof rails for a range of vehicle configurations (sub compact, compact, full size vehicle and other larger vehicles. The padding had been specifically designed to reduce head injury.

3.4.3 Padded Steering Wheels

An independent assessment of the lead times to introduce padded steering wheels was completed for NHTSA in February 1989. NHTSA were advised that a lead time of 28 months would be required by US manufacturers to introduce a soft steering wheel (similar to the Sheller Clifford design) which would reduce the likelihood of driver head injuries in frontal collisions.

3.5 THE AUSTRALIAN INDUSTRY POSITION

The Federal Chamber of Automotive Industries (FCAI) was provided with a draft list of occupant protection countermeasures in the ***third quarter of 1991*** for their consideration and comment. A broad specification of each countermeasure was provided so as not to preclude potential innovation and new developments through unnecessary prescription.

Arrangements were made with the FCAI to meet with its representatives and representatives of "Motor Plan" manufacturers and a number of the larger vehicle importers. The FCAI endeavoured within the short time frame available to provide an industry position. They presented an industry refinement of the specification of each countermeasure to reflect industry views, and provided minimum lead times for introduction of the measures. The efforts of the FCAI are greatly appreciated.

A comparison of the information provided by the FCAI with consultant estimates is provided in Table 3.3. The FCAI position paper is reproduced as Appendix 1 to this report. Consultant estimates were derived from research undertaken for the NHTSA in the US, from discussions with industry sources and suppliers, and from first hand knowledge of the Australian motor vehicle industry.

TABLE 3.3
COMPARISON OF LEAD TIMES FOR INTRODUCTION OF VARIOUS COUNTERMEASURES.

Countermeasure	FCAI position*1	Consultants assessments	
Seat belt pretensioners	36 months min	24 mths or less	*2*5
Seat belt webbing clamps	36 months min	18 mths or less	*2*4
Improved seat belt geometry	36 months min	18 mths or less	*3*5
Anti-submarining seat cushion	36 months min	18 mths or less	*5
Seat belt interlocks	no advice	18 mths or less	*6
Supplemental restraint system			
- US type Driver Side airbag	48 months min	32 months	*7
- US type Pass. Side airbag	60 months min	32 months	*7
- Euro type Drivers Side	48 months min	32 months	*7
- Euro type Pass Side	no advice		
Padded steering wheels	no advice	28 months	*8
Improved padding upper areas	no advice	12 months	*9
Reduced instrument panel intrusions	36 months min	n.a.	
Improved instrument panel materials	no advice	n.a.	
Improved padding of lower areas	36 months min	n.a.	
Knee bolsters	no advice	n.a.	
Reduced intrusion	no advice	n.a.	
Adoption of US Standard FMVSS 208	36 months min	n.a.	

*1 FCAI have based minimum lead times generally on the introduction of a new model

*2 may be reduced if modifications to vehicle are not required (industry sources) This assumes no further engineering of the system or vehicle equipment (eg. steering wheel) to optimise with other elements of the restraint system.

*3 generally will require seat re-design

*4 modifications to B pillar likely to be required

*5 major seat redesign likely to be required

*6 will depend on type selected

*7 may be reduced if a system is already available in LHD configuration (industry sources)

*8 information provided to NHTSA

*9 information provided to NHTSA

The FCAI estimates are considered conservative in view of other information provided by industry sources. However it must be recognized that the cost penalties associated with introducing these measures into existing vehicles may prove to be prohibitive. As the FCAI notes the lead time estimates it has provided "are generally based on new model introductions". It could be expected some manufacturers and importers would be better placed than others to introduce "countermeasures" within a shorter time frame.

It is expected that Japanese vehicles imported into Australia will increasingly include countermeasure features from 1992 onward, in view of the Japanese manufacturers public commitments to provide them on right hand drive vehicles sold in the home market. Industry observers believe that competition in the market place is likely to result in some local plan producers providing countermeasure features in vehicles sold in 1993.

For competitive and other reasons, some plan producers are expected to incorporate countermeasure technology as "running changes" or at "face lift" rather than await the introduction of new models. With Ford Falcon, Holden Commodore and Mitsubishi Magna not expected to be replaced before 1995, upgrading of current models can be expected.

The introduction of the new Camry (thought by industry observers to be late 1992 or early 1993) will provide an opportunity to include countermeasures. SRS is reportedly available on Camry models sold in Japan (ie RHD configuration). For other lower volume plan producer models, FCAI estimates appear more appropriate. Some importers may have difficulty achieving the FCAI minimum lead time estimates, and may find it uneconomic to continue to sell into the Australian market.

In relation to the potential for advancing industry plans, Australian plan producers and importers have not made public commitments to a timetable for the introduction of many of the countermeasures reviewed in this report. This is in marked contrast to the position of manufacturers supplying the US market. As discussed in Section 3.3, Japanese manufacturers have made commitments in relation to the US market and in some cases their home market.

3.6 CURRENT AVAILABILITY OF COUNTERMEASURE TECHNOLOGY IN VEHICLES SOLD IN AUSTRALIA

An inspection was made of vehicles on exhibition at the Sydney Motor Show (October 1991) to identify the introduction of countermeasure technology. Assistance from sales representatives was sought and reference was also made to publicly available material. Where features were positively identified or recorded in brochures, they have been noted in the attached Table 3.4. (The absence of information against a particular model does not necessarily mean that the items were not included in the vehicles on display).

The survey revealed that European manufacturers had incorporated improved seat belt technology and seating into many of the models imported into Australia. Airbags were offered as options by an increasing number of European manufacturers.

Airbag technology was available in luxury or sporty Japanese imports. Improved seat belt technology was also in evidence in most Japanese imports including the lower priced Mazda 626. Very few small cars exhibited countermeasure technology.

Australian manufacturers offered ABS braking as optional on some models but there was little apparent evidence of the countermeasure technology discussed in this report at this time in locally manufactured vehicles. Improved seatbelt geometry of a limited nature was evident in one or two models.

A number of motor vehicle sales representatives indicated that safety was not a strong selling feature and suggested that the Australian public did not have a strong understanding of countermeasure technology and its safety benefit. Exhibits by foreign vehicle manufacturers involved working and stationary displays of airbags, seat belt pretensioners and other items and drew strong public interest.

In April 1992, some selected technology (excluding airbags) was introduced into selected Ford Falcon and Holden Commodore ranges.

TABLE 3.4 A survey of vehicles on exhibition at the Sydney Motor Show, October 1991 - Examples of vehicles incorporating countermeasure technology.

Countermeasure	Lexus ES400	Honda Prelude SRS	Honda Accord	Honda Legend	Mazda 929	Mazda 626	Nissan	Volvo 960	Audi V6
seat belt pretensioners	-	-	-	-	-	-	-	yes	yes
seat belt webbing clamps	-	-	-	-	-	-	-	yes	yes
improved seat belt geometry	yes*1	yes *1	yes*1	yes *2	yes*1	yes*1	yes*1	yes*2	yes
adjustable upper sash guides	-	-	-	-	yes	yes	-	yes	yes
anti submarine seat cushions	-	-	-	-	yes	yes	-	-	-
seat belt warning system	-	-	-	-	-	-	-	yes	-
supplementary restraint system									
- fullsize driver airbag	avail.	option	-	option	-	-	-	opt. *4	-
- fullsize pass. airbag	-	-	-	-	-	-	-	-	-
padded steering wheels	-	-	-	-	-	-	-	-	yes
improved padding of upper areas	-	-	-	-	-	-	-	yes	-
reduced instrument panel intrusions	yes	yes	yes	yes	yes	yes	yes	yes	yes
improved instrument panel materials	yes	yes	yes	yes	yes	yes	yes	yes	yes
improved padding of lower areas	yes	yes	-	yes	-	-	-	yes	yes
knee bolsters	yes	yes	-	yes	-	-	-	yes	-
reduced intrusions	-	-	-	-	-	-	-	-	-

*1 inboard anchorages attached to seat

*2 inboard and outboard anchorages attached to seat.

*3 limited improved seatbelt geometry on one or two models

*4 a standard feature in 1992

TABLE 3.5 Examples of vehicles incorporating countermeasure technology

Countermeasure	BMW models	SAAB 9000	Mercedes Benz	VW Golf	Ford	General Motors	Mitsu-bishi	Toyota
seat belt pretensioners	yes	yes	yes	-	-	-	-	-
seat belt webbing clamps	yes	yes	yes	-	-	-	-	-
improved seat belt geometry	yes *2	yes *2	yes	yes *1	-	-	-	-
adjustable upper sash guides	yes	yes	yes	-	-	-	-	-
anti submarine seat cushions	yes	-	-	yes	-	-	-	-
seatbelt warning system	-	-	-	-	-	-	-	-
supplementary restraint system - fullsize diver airbag - fullsize passenger airbag	airbags available in '92 on some models	airbag video but no evidence of option	airbags optional on some models	-	-	-	-	some discuss. of airbags in a high tech present.
padded steering wheels	yes	yes	yes	-	-	-	-	-
improved padding of upper areas	yes	-	yes	-	-	-	-	-
reduced instrument panel intrusions	yes	yes	yes	yes	yes	yes	yes	yes
improved instrument panel materials	yes	yes	yes	yes	yes	yes	yes	yes
improved padding of lower areas	yes	-	yes	yes	-	-	-	-
knee bolsters	-	-	yes	yes	-	-	-	-
reduced intrusions	-	-	yes	yes	-	-	-	-

*1 inboard anchorages attached to seat
*2 inboard and outboard anchorages attached to seat.
*3 limited improved seatbelt geometry on one or two models
*4 a standard feature in 1992

4. COSTS AND PRICES OF COUNTERMEASURES

4.1 INTRODUCTION

In developing the assessment of the likely costing and prices of the countermeasures for the Australian market, a range of information was utilised, including:

. information supplied by individual Australian motor manufacturers covering most countermeasures (Section 4.2),

. international retail price comparisons such as those provided on airbags by the National Highway Traffic Safety Administration (NHTSA) and the Insurance Institute for Highway Safety (IIHS).

. information from local and overseas component manufacturers (adjusted for the Australian market) for a number of measures.

An assessment of the likely costs of each countermeasure assuming it would be a mandatory requirement has been undertaken to provide an estimate of the likely best retail price. This is reported in Section 4.5. A summary of industry estimates and the likely best retail price estimate is provided in Table 4.1.

4.2 INFORMATION FROM THE AUSTRALIAN MOTOR INDUSTRY.

While providing a coordinated industry response, the FCAI submission provided in the third quarter of 1991 did not include costing or pricing information due to the *"complexity of the requirements for specific manufacturers models and the costs related to locally made vehicles and imported vehicles"*.

Discussions were held with individual companies, many of whom provided valuable information on a strictly confidential basis. In providing the information, companies were required to make a number of assumptions regarding the timing of introduction of the various countermeasures in the product life cycle, the sourcing of components, the costs of testing to ensure compliance, exchange rates and likely market acceptance.

Manufacturers indicated that most vehicles sold in Australia had not specifically been designed to meet US standard FMVSS 208 and the nature of a testing program required to fit airbags for example was unknown. Performance and/or compliance testing for the various countermeasures had yet to be determined for Australian vehicles.

They also claimed that modifications would be necessary to most vehicles including modifications to B pillars for webbing clamps, to seat belt anchorages and other components for pretensioners, and to steering wheels and components for airbags. While some countermeasures could be economically fitted as running changes or at model face lift, manufacturers indicated most would be more economical if introduced on new models. [In April 1992, selected countermeasure technology (excluding airbags) was introduced into Ford Falcon and Holden Commodore ranges].

Many companies approached provided an assessment of the likely retail price of countermeasures if introduced into their vehicles. Considerable differences existed between companies reflecting their assumptions and assessments [refer Table 4.1]. It should be noted that this information may include import duty where appropriate and sales tax.

TABLE 4.1
ESTIMATED RETAIL PRICE * OF MEASURES TO NEW CAR BUYERS

Countermeasure	Industry estimates $	Est. best retail price for plan producer (New model) $ *(Refer Section 4.5)
seat belt pretensioners	140, 150-190, 230	100-140*1
seat belt webbing clamps	30, 85, 100-130, 150	15 basic 50 deluxe
improved seat belt geometry	25	marginal, say $10
anti-submarine seat cushions	27, 35-45	marginal, say $10
seat belt warning device	50-80	20 basic 35 deluxe
supplementary restraint system - Fullsize driver airbag	500*2-1500*3, 1000-1500, 1000-2000,	528*9 - 800*3
supplementary restraint system - Fullsize passenger airbag	1800*4, 2200*5, 2500*6 470*5, 1000-1500, 1400	528*9 extra
supplementary restraint system -Fullsize airbag system [driver and passenger]	1500*7-3000*3, 2700, 3200	1156*9
supplementary restraint system -Driver facebag	500 plus	478*9
supplementary restraint system -Passenger facebag	n/a*8	
Padded steering wheel	n/a	5-25
Improved padding upper areas	n/a	70-100
Reduced panel intrusions	n/a	0-30
Improved panel materials	n/a	zero
Improved padding lower areas	n/a	0-60
Knee bolsters	n/a	50-75
Reduced intrusions	n/a	u/k
Compliance with FMVSS208	760	u/k

* 1991 prices and exchange rates

NOTES:
1. Retail price allowance of $40 has been made for vehicle modification, In a new model, this may not be appropriate as seat may be designed to accommodate pretensioners. In these circumstances, the likely retail price would be $100
2. Single-sensor mechanical control system.
3. Multi-sensor electronic control system
4. US airbag with multi-sensor electronic system
5. Based on adaptation of US system to a passive restraint system for Australian conditions. Passenger side bag shown as an additional cost to the driver side bag ($2200).
6. US specification from a European manufacturer
7. Basic mechanical control system
8. Industry estimates not available
9. These prices are for locally produced vehicles corresponding to an annual volume of the weighted mean for the 8 plan production models. Refer Sect. 4.5.12 and 4.5.13.

4.3 INTERNATIONAL PRICE COMPARISONS

Very limited information was readily available to provide an international comparison of the prices charged for most countermeasures. However information has been assembled in relation to driver side airbags as an option from a range of sources, including manufacturers and car sales outlets in Australia, US and Japan. A summary is provided in Table 4.2.

TABLE 4.2.
INTERNATIONAL RETAIL PRICE* COMPARISONS FOR DRIVER SIDE AIRBAGS (AS AN OPTION)

MANUFACTURER	MODEL	CONFIGURATION	MARKET	PRICE
Ford US	Various	LHD	US	US$500-$800
GM US	Various	LHD	US	US$500-$800
Chrysler	Most	LHD	US	Standard
Isuzu	Stylus	LHD	US	Standard
Nissan	300ZX	LHD	US	US$500
Toyota	Celica	RHD	Japan	Y55,000(A$550)
Honda	Prelude	RHD	Australia	$1500
Volvo	960	RHD	Australia	$1500
Mercedes	Various	RHD	Australia	$2656

* 1991 prices

Allowing for exchange rate differences, import duty and sales tax (where appropriate), prices quoted by major US manufacturers are generally much lower than those *estimated* by the Australian industry. This may be explained (in part) by the US experience. In 1983, US manufacturers and importers supplied information to NHTSA indicating the retail price of airbags would be between US$500 and US$900 [refer Table 4.3].

TABLE 4.3.
MANUFACTURER/SUPPLIER ESTIMATES FOR AIRBAG SYSTEM VEHICLE PRICE* INCREASES [OVER MANUAL BELT SYSTEM] $US 1983, NHTSA

	Driver Airbag US $	Driver & Pass. Airbag US $
GM US	510*1	838
Ford US	n/a	807
Chrysler	500*2	800
Mercedes	880*3	n.a.
Renault	n.a.	1000
Jaguar	900	1800
ADPA	n.a.	185*4
Breed	45*5	141
Komeo Kojyo	150	n.a.

**prices are US$ 1983*

1. GM based on 3million units
2. Chrysler based in 1million units
3. Mercedes includes pretensioner passenger seatbelt plus driver lap/shoulder belt
4. Based on supply of components only for retrofit
5. Based on supplying components only.

In March 1984, the US Insurance Institute for Highway Safety published a cost volume relationship for airbag systems covering sensors, diagnostic equipment, inflator bags, housings, decorative coverings, wiring, labour and profit for the auto manufacturers and dealers. The retail price almost halved as the volume increased from 100,000 to 1million units [refer Table 4.4].

TABLE 4.4.
COSTS OF AIRBAG SYSTEMS FOR DIFFERENT PRODUCTION VOLUMES, INSURANCE INSTITUTE FOR HIGHWAY SAFETY, MARCH 1984

Volume	Price per Car (US $)
2,000,000	185
1,000,000	240
500,000	280
100,000	500
10,000	1100

NB : Figures cover the cost of the entire airbag system (driver side only) including sensors, diagnostic equipment, inflator bags, housings, decorative covers, wiring, labour, and profits for auto manufacturers and dealers.

The number of vehicles equipped with airbag systems in the US has increased significantly since 1984. It has been forecast to increase from 4million in 1990 to 15million by 1993 (Hitchcock 1991).

The economies of scale forecast in 1984 appear to have been realised as in 1991, driver airbag systems can be purchased on popular US cars for around US$500. *If forecasts for 1993 materialise, further cost savings would be expected and these savings could be available to Australian vehicle manufacturers also.*

4.4 INFORMATION FROM COMPONENT MANUFACTURERS

Countermeasure technology is available to Australian motor vehicle manufacturers from their parent companies or from specialist manufacturers.

Specialist manufacturers who provide a wide range of componentry include Autoliv International (including an Australian operation) Breed Corporation, Delco Corporation, Nippon-Denso and TRW-Technar.

Componentry available includes ranges of seatbelt pretensioners, webbing clamps, fullsize airbags, and driver facebags.

The information used in this report is based on that obtained in relation to Autoliv and Breed componentry. Both companies offer highly sophisticated computer simulation services and have extensive experience in the application of this technology.

The authors are most grateful to these manufacturers for their willingness to provide prices of this componentry. However, it should be stressed that the use of these prices in no way implies preference for these goods over others that might be available.

4.5 INVESTIGATION OF THE COSTS OF INTRODUCING COUNTERMEASURE TECHNOLOGY

An independent assessment has been undertaken to examine the likely costs of introducing countermeasure technology assuming that ***these features would be standard on all vehicles, rather than optional.***

The assessment was based on published NHTSA investigations, price lists for various components, information provided by experienced industry sources and from knowledge and understanding of the Australian motor vehicle industry. This price is based on best estimate of present day costs and technology for a hypothetical current model which can be modified relatively easily to accommodate the technology. It does not allow for progressive future reductions resulting from improvements in design, technology, value engineering or productivity.

4.5.1 Seatbelt Pretensioners

Seatbelt pretensioners currently available range from those which are mechanically operated (torsion bar or loaded spring) to those activated by pyrotechnics.

Reliable well engineered mechanically operated devices which provide substantial shortening of the lap and sash part of the seatbelt are available from a component manufacturers. The likely net additional cost is estimated at $35 per unit.

Installation of these devices may require changes to front seatbelt anchorage arrangements in particular models. Seat and seat track modifications may also be required if inadequate clearance is available between seats and the transmission tunnel.

For a new model manufactured by a plan producer, the likely best retail price is estimated to be $140. Industry estimates range from $140 to $230.

4.5.2 Webbing Clamps

A range of seat belt webbing clamps are available from high specification proven devices to highly value engineered seat belt anchorage housings incorporating a clamp device. The performance of this latter basic device is yet to be established.

The net additional cost of the high specification device is estimated at around $10 to $20 per unit. (This replaces existing seat belt anchorage/spool/housing etc.) The product also offers potential for further development and value engineering.

The estimated net additional cost of the highly value engineered product is around $3 per unit. Installation of these devices will require modifications to the B pillar on most vehicles as the housings are generally larger than current types.

For a new model manufactured by a plan producer, the likely best retail price is estimated to be $15 for the basic device to around $50 for the higher specification device. Industry estimates range from $30 to $150.

4.5.3 Improved Seatbelt Geometry

The mounting of inboard seatbelt anchorage on the seat is becoming an increasing standard feature on imported Japanese vehicles and luxury European imports. Some Australian manufacturers, too, have incorporated these on particular models.

Mounting of the outboard lower anchorage on the seat is included on fewer vehicles, although this feature is not yet apparent on locally manufactured vehicles. These improvements will require redesign of seats, tracks and anchorages but are unlikely to require significant additional componentry or materials.

Only one manufacturer provided an estimate of cost, the estimate being $25.

The costs of these improvements are likely to be included in the overall cost of designing the new model, and would only lead to a marginal (a few dollars) increase in the retail price.

4.5.4 Anti-Submarine Seats

Anti-submarine seats and seat pans are available on a limited number of Japanese and European imports. Locally produced vehicles do not include this feature. Redesign of the seat is required. Additional componentry and materials are unlikely to be required.

The costs of anti-submarining seat design are likely to be included in the overall cost of designing the new model and are expected to increase the retail price only marginally (a few dollars). Two manufacturers provided estimates of $27 to $45 increase in the retail price.

4.5.5 Seatbelt Warning Device

Industry representatives reported that seatbelt interlocks were marketed in the USA during the 1970's but were withdrawn due to consumer resistance. These interlocks did not permit the starting of a car unless occupants connected the belts. They reported that motorists frequently disconnected the interlock.

Time limited seatbelt advisory lights are now provided in some US vehicles. A continuous audible reminder system is included in a number of Volvo models in Australia.

Installation of simple advisory lights may require redesign of dash board instrumentation. Additional componentry and design would also be required to incorporate a Volvo type system for front seats.

For a new model manufactured by a plan producer the likely best price for a basic advisory system is estimated at $20, and for a higher specification system $35.

4.5.6 Padded Steering Wheels

FCAI reported that many Australian passenger cars are currently equipped with energy absorbing steering wheels. TRRL style steering wheels, however, are generally not available on vehicles sold in Australia.

A steering wheel weight and cost analysis conducted by NHTSA June 1987 concluded that a steering wheel based on the Sheller Clifford design could be "*manufactured at no additional cost to the consumer*". Cost estimates were not provided by Australian manufacturers.

Additional materials may be required and Australian manufacturers could be expected to match mouldings to interior styling of other components. For a new model manufactured by a plan producer, the likely best retail price is estimated in the range $5 to $25.

4.5.7 Improved Padding of Upper Areas

FCAI reported that members were not aware of any world wide regulations regarding improved padding of upper areas. They indicated that many passenger cars sold in Australia may well meet a performance standard without any additional padding.

An examination of the cost estimates of improved pillar padding is currently being conducted by NHTSA. This involves the assessment of 0.5 and 1.0 inch polyurethane padding materials added to A, B and C pillars, roof headers and roof rails of 7 generic vehicle configurations.

Preliminary estimates indicated that price increases ranging from US $29 - $46 could be expected for passenger cars.

Allowing for exchange rates, sales tax, and the differing economies of scale between the Australian and US industry, this may equate to a likely best retail price of A$70 - $100 for a new model manufactured by a plan producer.

4.5.8 Reduced Instrument Panel Intrusions & Protrusions

FCAI have reported that this may require revision to knobs and controls and could be most effectively achieved when a vehicle manufacturer changes the design of the instrument panel of a particular model.

If components from the previous model were intended for use in a new model but were replaced because of this requirement, then the likely upper retail price increase for a plan producer vehicle is estimated at $30. If this were not the case the cost of meeting this requirement would be included in the overall cost of designing the new model and need not lead to an increase in the retail price.

4.5.9 Improved Instrument Panel Materials

Manufacturers claim that current locally manufactured vehicles generally incorporate advanced instrument panel and other materials. An increase in retail price, therefore, would not be expected.

4.5.10 Improved Padding of Lower Areas

Any requirement for improved padding of lower areas will vary between vehicle models.

Some vehicles may not require additional materials, others may require redesign and additional mouldings. Rough estimates suggest an increase in retail price in the range zero to $60.

4.5.11 Knee Bolsters

Knee bolsters have been included by manufacturers to enable vehicles to meet the injury criteria of FMVSS 208. Examples can be seen in imported luxury vehicles, and also the VW Golf.

NHTSA investigations have indicated that the cost to manufacturers of including bolsters is less than US$10 for relatively high volume vehicles. This does not include manufacturers profits and overheads, nor retail markups.

Australian manufacturers are unlikely to be able to achieve comparable economies of scale and rough estimates suggest the increase in retail price may be in the range $50 to $70 for a new Plan Producer model.

4.5.12 Supplementary Restraint Systems

In developing supplementary restraint systems [ie. airbag systems designed to work in conjunction with seatbelts], some manufacturers have modified components used in the US passive restraint system, while others have elected to adopt more recently developed facebag componentry.

The fullsize US restraint system is designed to provide an inflatable occupant restraint system. Driver airbags are typically around 60 litres and inflation rates are relatively rapid. Deployment occurs for a delta-v of 16km/h (10mph). Fullsize passenger side airbags are a requirement in a passive restraint system and are incorporated into a wide range of vehicles.

By comparison, there is less reliance on an airbag if used in a supplementary restraint system. Its major objective is to reduce the incidence and severity of head, face, chest and abdominal injuries to drivers by cushioning the impact with the steering wheel. Accordingly, the airbag need not be as large, typically around 40 litres and need not be deployed as soon and therefore the sensory mechanism may be simpler.

A wide range of airbag technology is available to Australian motor vehicle manufacturers, either from their parent company or from specialist manufacturers. Airbag technology and systems have undergone significant development and change since their initial introduction into US vehicles. Typical airbag system components include crash sensor(s), gas generator, and fabric airbag.

In the *traditional* US airbag system, multiple sensors are used requiring extensive wiring and electrical connections. Two or three "crash" sensors are located in the crush zone to discriminate between significant collisions (where an airbag is required to be deployed) and minor impacts. Additionally, at least one "safer" sensor is usually located in the passenger compartment to help prevent unwanted deployment caused by abuse or localised impacts.

Incorporation of these systems may require extensive modification to existing vehicles and may also involve additional costs associated with their installation in the vehicle. Sensors may be mechanical, electro-mechanical or electronic. *In general, the more sophisticated the sensor system, the greater the cost as reported in Table 4.5.*

The component costs include driver airbag module, multiple sensors and diagnostic equipment, and clock spring (where required), but does not include system costs, such as wiring, connections, and assembly and installation. These data were provided by the US Breed Corporation to NSW Crashlab.

TABLE 4.5.
COST COMPARISON OF COMPONENTS FOR BREED DRIVER SIDE AIRBAG ONLY US FULLSIZE AIRBAG SYSTEM WITH FACEBAG SYSTEM

Type	Control systems		
	Mechanical	Electro-mech.	Electronic
US fullsize airbag system	\$140	\$225	\$240
Facebag system	\$125	\$170	\$190

NB: Costs are in US dollars.

To develop these prices into a final retail price to the consumer, it is necessary to add the cost of vehicle modification, a testing program, and assembly to derive a "*total variable cost*" which, when factored by the ratio of retail price to total variable cost, provides for manufacturers overheads, profits, and dealer margins.

It is understood that these prices are US factory door and do not include handling, freight (of dangerous goods), warehousing or duty, and are for "generic" systems. Additional costs will also be incurred to adapt a "generic" module which fits into the steering wheel to meet the requirements of particular manufacturers' concerns of styling and modification for other controls (eg. the horn button).

Local industry sources suggest that depending on the pricing policy of the supplier, these factors may add A\$40 - A\$80 to the cost of the systems delivered to a local manufacturer.

Single sensor airbag systems which may be included in a module for installation in a steering wheel offer potential cost savings compared with traditional systems. The costs associated with multiple sensors, extensive wiring, electrical connections, and vehicle modifications are avoided and installation costs reduced.

A *new generation of single sensor* airbag systems are available from Breed Corporation and Autoliv International. The new generation Breed All Mechanical Airbag System (AMS) is offered as a facebag or fullsize airbag and utilizes mechanical energy, rather than electrical energy for airbag initiation. Further details are provided in Attachment 2.

Breed Corporation have reported that NHTSA have approved their AMS and that the driver side AMS was incorporated into the Jaguar XJS and 3 Toyota models sold in the US in 1990.

Autoliv are also able to provide a highly sophisticated electronically controlled single sensor facebag system. It incorporates a micro processor which compares an impact with preset parameters to determine the severity of the crash and deployment of the airbag. Further details are provided on this system also in Attachment 2.

Published cost information on the Autoliv single sensor system is not currently available.

Inquiries made to a number of sources indicated that a thoroughly reliable proven single sensor facebag system incorporating a micro processor would be available to Australian motor manufacturers for around A$240 (FIS) and possibly less. Industry advice also suggested that a fullsize single sensor version was unlikely to add more than A$50 *retail* to the price of a facebag system.

The Team is satisfied that local manufacturers are able to buy a sophisticated proven facebag system incorporating single electro-mechanical sensors for A$240 and that a similar fullsize system would most probably be available for around A$265 from specialist component manufacturers.

In view of the highly competitive nature of the motor industry and related cost pressures, manufacturers may ultimately choose to adopt a product that is available from their parent company when it was less costly or more expedient in the context of overall development costs, expected unit costs, and company policy.

For the purpose of this evaluation, however, the most simple effective system available is most relevant. The best likely "in-vehicle" retail price for the supply of components to vehicle manufacturers has been taken as A$240 (FIS) for the facebag system and A$265 (FIS) for the fullsize airbag system.

4.5.13 Calculation of the Likely Best Retail Price of an Airbag System on a Popular Locally Manufactured Passenger Vehicle.

Information obtained from Australian industry, product suppliers, NHTSA reports and direct knowledge of US retrofit programs has been drawn together to provide an estimate of the likely best retail price for the inclusion of a driver side airbag as a supplemental restraint system in a popular Australian car.

To derive this estimate, assumptions have been made in relation to annual production volumes, testing requirements for compliance, configuration, modifications to vehicle, component costs and the ratio of final retail price to manufacturers variable cost. It has been assumed for the purpose of this calculation that the SRS airbag system is supplied as a standard feature on all passenger vehicles.

For estimating purposes, an annual production volume of 30,000 vehicles and a 6 year product cycle have been assumed.

Estimates have been prepared based on an extensive testing program, involving around 150 sled tests using fully instrumented dummies and around 60 barrier crash tests, complemented by extensive computer simulation, as outlined in the following description.

For each model variant, a standard testing procedure has been assumed based on our knowledge of the certification process adopted to enable the retrofitting of driver side airbags as supplemental restraint systems to 2 US car fleets involving around 7000 vehicles (including 4500 Ford Tempo's).

Based on these case studies a testing program for each model variant was assumed to require:

- up to 7 barrier crash tests to enable the airbag Manufacturers to simulate the crash pulse to enable simulation and testing

- computer simulation

- up to 25 sled tests with fully instrumented dummies for experimental testing

- a minimum of 3 barrier crash tests for prototype testing.

Advice obtained from Australian industry indicates that barrier crash tests cost up to $70,000 per test, including the vehicle. Sled testing could be conducted in Australia at a cost of around $4,000 per test and computer simulation may cost up to $50,000. On this basis the cost of a testing program for a single model variant would amount to up to $0.85m.

Testing requirements for additional model variants will depend on the particular model and range. If comprehensive certification rather than just worst case compliance testing is required, manufacturers are likely to test vehicles for engine type (4/6 or 6/8 cylinder) and transmission type (manual/automatic). On this basis around 40 barrier crash tests would be an expected requirement of certification of a sedan.

Industry sources suggest economies in testing could be made in relation to testing of station wagon and utility variants. An additional 20 barrier crash tests may be required.

As previously indicated, a total of 60 barrier crash tests and 150 sled tests have been assumed for preparing this estimate. The total cost of the testing program on these assumptions is around $5m.

The unit cost based on a typical annual production volume of 30,000 vehicles over 6 years is around $30.

Rough estimates of the cost of vehicle modifications have been developed from NHTSA information. The US firm of Corporate Tech Planning Inc and Pioneer Engineering and Manufacturing Co provided evidence to NHTSA in August 1985 on Cost and Weight Analysis of the Thiokol-Breed Airbag system.

For a production volume of 300,000 vehicles total over 8 years they itemised the costs of modifications to the vehicle. Costs included modification to incorporate both driver and passenger side airbags.

For the combined system, the cost of modifications was $US25.66. For driver side bags of the electro-mechanical type (single sensor in the steering column) the cost of modifications were $US3.83 for revisions to steering wheel covers, the steering wheel, steering wheel assembly and slip-ring assembly.

The fixed costs amortised over a total production volume of 180,000 would have resulted in a unit cost of $US6.35. For a total production volume of 60,000 the unit cost would have been US$20.

Manufacturers' overheads and profits and dealer margins must be incorporated in estimates of the retail price. In cost breakdown information provided to NHTSA in its July 1983 Regulatory Analysis for FMVSS 208 GM figures indicate the ratio of retail price increase to variable cost to be in the range 1.62 to 1.68.

Information informally supplied by some manufacturers suggested in Australia the ratio may be around 1.7 depending on the pricing strategy of a particular company. (This included 15% sales tax).

Where models manufactured in Australia have been developed overseas and include provision for SRS, then the testing program would need only reflect vehicle modifications made for the Australian market. Hence a less extensive program could be anticipated.

4.5.14 Estimate of Best Retail Price for Driver Facebag

An estimate of the likely best retail price for a driver facebag system installed in a popular locally manufactured vehicle is provided in Table 4.6.

TABLE 4.6
ESTIMATE OF BEST LIKELY RETAIL PRICE DRIVER FACEBAG

Estimated Cost	180,000 total units over 6 years
Fully integrated single sensor facebag system	$240
Full testing program of 150 sled tests, 60 barrier tests and computer simulation	$ 30
Modifications to hypothetical vehicle (NHTSA report)	$ 13
Assembly costs	$ 10
Total cost of elements	**$293**
Manufacturers oncosts, profits etc. and retailers margins and sales tax*1	$207
Estimated retail price	**$500**

**1 ratio of retail price increase to manufacturers variable cost has been assumed as 1.7*

The following assumptions were made in making this estimate:

. that facebags are fitted as standard equipment,

. that the facebag consists of a proven single sensor system located in the steering wheel,

. that the price for the supply of the fully integrated facebag system is for small volumes and discounts may be expected for larger volumes,

. that the testing program assumes a full testing program for each variant which may prove unnecessary,

. that the costs of barrier crash tests of $70,000 per test (this is considered high and costs could be expected to be markedly cheaper),

. that testing of more than 3 prototypes in barrier crash tests may be required if difficulties occur (and these may be expected in smaller vehicles not designed to meet FMVSS 208),

. that modifications to particular models may be more costly than those reported to NHTSA,

. that NHTSA modification costs are in 1985 US$ and have been indexed by 56% to provide 1991 estimates,

. that an exchange rate of $US 0.80 has been assumed for $A.,

. that import duty of around 2% is appropriate in pricing the facebag system [local manufacturers may have offsets to avoid paying further import duties], and

. that Australian sales tax of 15% is appropriate for calculating the ratio of retail price to manufacturers variable cost.

Where models manufactured in Australia have been developed overseas and include provision for SRS, then any testing program would need only to reflect vehicle modifications made for the Australian market. Hence, a less extensive testing program could be anticipated.

In order to calculate the ***weighted mean*** for the eight plan production models, the 1990 sales volumes listed by Paxus were used, namely:

Laser/Capri	37,700
Corolla/Nova	35,600
Pulsar	27,700
Camry/Apollo	35,600
Pintara/Corsair	21,300
Magna	31,800
Falcon	61,800
Commodore	73,800
Total	**329,000**
Weighted mean	**41,125**

Using these annual production figures, the weighted mean best estimate retail price of a facebag for the eight models would reduce to A$478. [This estimate would be even lower if the Nissan Pulsar and Pintara models, recently announced not to be manufactured locally, were omitted].

Information was not available regarding the suitability and likely cost of a passenger facebag. However, it is expected that a design for a passenger side facebag should be commercially available within the next 2 to 3 years.

4.5.15 Estimate of Best Retail Price for Supplementary Driver Airbag

As noted earlier, industry sources indicated that a fully integrated single sensor fullsize airbag system is unlikely to add more than A$50 to the retail price of a facebag system, similar to that used as the basis of cost estimates in Table 4.6. On this basis, the best likely retail price for a fullsize driver side only supplementary airbag *single sensor* system in this country would be expected to be A$550 for a typical production volume of 30,000 cars annually.

Again, using a weighted mean of the eight plan production models, the fullsize driver airbag with a single sensor could be expected to have a best estimated retail price of A$528.

Based on Breed airbag prices and NHTSA data, a multi-sensor electronically controlled fullsize airbag could be expected to cost around A$800 for a typical 30,000 annual production volume. It is not possible to estimate a plan production weighted price for these units as not all producers would necessarily fit these units to their vehicles.

Information provided by the NHTSA [reported Table 4.3] and the local industry indicated that the cost of a combined fullsize driver and passenger airbag system was between 1.6 and 2.0 times the cost of a driver side airbag only.

Assuming a factor of 2.0 is therefore applicable, the best estimated retail price of a fullsize driver **or** passenger airbag system in Australian cars is estimated to be $550 for 30,000 cars per year and $528 using a weighted mean of the eight plan producers.

4.5.16 Compliance with FMVSS 208

The FCAI have advised their "total support for an injury criteria based occupant protection performance as specified for frontal impact tests in FMVSS 208". In this way "Manufacturers' discretion" will then be exercised in selection of countermeasure technology to be incorporated.

As Australian manufactured vehicles have not been required to met this standard, little information is available on the need for modification if any and associated cost. One manufacturer indicated a cost of $760 per vehicle to achieve certification/compliance.

5. NATIONAL STATISTICS AND HARM ESTIMATES

This chapter describes the procedures used to obtain national estimates of the number of vehicle occupant casualties annually, and the frequency and costs of their injuries. These estimates form the basis of the potential savings of injury costs from new occupant protection countermeasures aimed at reducing or preventing injury.

The objectives were to provide Australia-wide estimates per annum (averaged over 1988 to 1990) of:

i. Numbers of occupants of passenger cars and car derivatives killed, hospitalised (admitted), and medically treated (not admitted to hospital) disaggregated by key factors related to specific circumstances in which particular countermeasures operate or are likely to be effective (eg. seating position, restraint use, and impact direction)

ii. Frequencies of injuries to these occupants, categorised by the body region and Abbreviated Injury Scale (AIS) severity level disaggregated by the same factors as the occupants (in (i) above) and also by the contact source of the injury where appropriate for particular countermeasures

    The AIS scale is a "threat to life" scale applied to individual injuries by experienced coders using a handbook developed by the Association for the Advancement of Automotive Medicine (1990). The injuries are coded on a six point scale as follows:

    1. Minor
    2. Moderate
    3. Severe (not life threatening)
    4. Serious (life threatening, survival probable)
    5. Critical (survival uncertain)
    6. Maximum (potentially non-survivable)

iii. Costs of these injuries ("Harm") in 1991 Australian dollars, categorised and disaggregated by the same factors as the raw injury frequency estimates. Harm was calculated by multiplying injury frequencies by the unit cost of each injury (described by its AIS and body region) and summing these to give the total cost of road trauma.

5.1 DATA SOURCES AND OCCUPANT CASUALTY NUMBERS

The injury data needs for the second objective dominated the estimation process. Two of the suitable data files (the MUARC Crashed Vehicle Study File and a file of Transport Accident Commission injury compensation claims) were from Victoria and there was a need to check their representativeness against occupant casualties in Australia as a whole. The injury data files were compared with national crash data in terms of occupant seating position, restraint use, impact direction, car weight, crash type, and speed zone. This check led to a decision to adjust the data from each of these two files by the speed zone of the crash location in order to produce injury frequencies which were nationally representative (see Section 5.2).

These two files were supplemented by the Fatal File (Australia 1988) provided by FORS, which included injury details of all killed occupants of cars and car derivatives.

The national estimates of the average numbers of occupant casualties per annum during 1988-90, based on the FORS monthly fatality reports, ABS Serious Injury Statistics and New South Wales police accident reports, were:

- 1612 killed
- 17134 hospitalised
- 58448 medically treated (not admitted to hospital)

- 77194 total casualties.

Details of the procedures used to obtain these estimates can be obtained from the Federal Office of Road Safety or the Monash University Accident Research Centre for those interested. It should be noted that the estimates were based on reported injury crashes. The casualties may be substantially underreported, particularly at lower levels of injury severity. The estimated numbers of occupant casualties were disaggregated by restraint use, seating position, impact direction and speed zone.

5.2 ESTIMATES OF INJURY FREQUENCIES

National estimates of the injury frequencies by body region and AIS sustained by the estimated 77194 occupants of cars and car derivatives killed or injured per annum were then prepared. A computer spreadsheet was developed to combine the injury frequencies from the 1639 killed occupants in the Fatal File (covering Australia-wide fatalities), the 369 hospitalised occupants in the Crashed Vehicle Study File (adjusted for the speed zone imbalance) and the 31177 medically treated occupants in the TAC claims file (also adjusted for a speed zone imbalance). While these three data elements differed substantially in the number of occupant casualties on which they were based, it should also be noted that the Crashed Vehicle Study File and the Fatal File contained greater amounts of detail on the occupant injuries (9.9 and 6.1 injuries per casualty, respectively) compared with the TAC claims file (2.0 injuries per casualty).

The injury frequencies from each source were inflated by the ratio of the national estimated number of occupant casualties to the number of occupants on which the injury frequencies were based. This was done separately within each speed zone category (except for the Fatal File), and then summed across speed zones, in order to provide the necessary adjustment for the speed zone imbalances. Finally, the estimated injury frequencies for the killed, hospitalised and medically treated occupants were summed (Table 5.1).

Table 5.1: National estimates of injury frequencies sustained by occupants of cars and car derivatives in all types of impact (average per annum during 1988-90).

	INJURY SEVERITY							
BODY REGION	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS =3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown	**TOTAL**
External*	0	521	7	0	10	19	0	557
Head	6201	11890	5395	3127	1599	149	0	28360
Face	48167	8193	742	52	0	0	456	57611
Neck	9731	1438	638	12	150	8	0	11977
Chest	21678	7709	6000	2637	869	205	2	39101
Abdomen-Pelvis	23518	7854	3864	562	425	6	3	36233
Spine	2467	2832	571	7	77	55	2	6011
Upper Extremity	31205	10198	2495	0	0	0	6	43904
Lower Extremity	41586	13055	6122	10	2	0	10	60786
TOTAL	184553	63690	25835	6407	3132	441	481	284540
No. Occupants Sustaining Injury								77194

* Injuries to the external parts of the body which were not assigned to specific body regions (Fatal File only).

For all occupants of cars and car derivatives, there were an estimated 284,540 injuries at a rate of 3.7 injuries per occupant casualty. It should be noted that it was not possible to estimate the AIS One injuries for killed occupants due to the absence of these injuries in the Fatal File. This was not considered to be an important omission because these injuries could be expected to be relatively few in number compared with AIS One injuries to the much larger numbers of hospitalised and medically treated occupants. Thus the absence of these injuries was expected to have a very minor effect on the estimates of the total cost of the occupant injuries.

5.3 ESTIMATES OF INJURY COSTS

To estimate the total cost of injury within each cell of the matrix of injury frequencies (body region by AIS), it was necessary to estimate the average cost of each specific injury. This was based on a matrix of average injury costs in the USA developed by Miller (1991).

Miller used the human capital approach to estimate injury costs per person categorised by the AIS and body region of the most severe injury of the victim. Forgone income of the killed and permanently disabled was discounted to present values using a 4% discount rate. No allowance for pain and suffering was included. In a report to the US National Highway Traffic Safety Administration, Data Link (1991) have applied Miller's injury cost estimates to individual injuries to calculate Harm.

The US average injury costs were interpreted to match the body regions and AIS levels shown in Table 5.1. Average costs for AIS 3-6 injuries to the Brain were used for injuries of corresponding severity to the Head region, and the average costs for AIS 3-6 injuries to the Spinal Cord were used for the severe injuries in the Spine region. Where no US cost for a specific body region and AIS was provided, the minimum value of the available corresponding values was generally used. The substitute average costs are shown in italics in Table 5.2.

Table 5.2: Average cost per injury (1988 $US '000's) [following Miller 1991].

	INJURY SEVERITY						
BODY REGION	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS =3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown
External	*3*	*16*	*45*	*73*	*106*	*644*	*3*
Head	4	19	78	180	636	644	*3*
Face	4	19	78	103	211	644	*3*
Neck	4	19	78	103	211	644	*3*
Chest	3	16	45	73	106	644	*3*
Abdomen-Pelvis	3	16	45	73	106	644	*3*
Spine	3	16	105	905	1082	644	*3*
Upper Extremity	4	28	66				*3*
Lower Extremity	3	28	84	124	*211*		*3*

A correction factor was derived for the US average injury costs to convert these figures into Australian average injury costs (in 1991 $A). This was done by:

(a) calculating the total cost of all injuries to occupant casualties, using the injury frequencies of all occupants in Table 5.1, weighting each injury by its US average cost in Table 5.2,

(b) adjusting the total injury cost of all road users (excluding vehicle damage costs) in 1985, given as $3166.5 million (1985 $A) by Steadman and Bryan (1988), by:
- estimating the proportion of the total cost due to car occupants in 1985, within each injury level and overall
- adjusting this total cost to the injury frequencies of car occupants in 1988-90
- adjusting the car occupant total injury cost to 1991 $A using the Consumer Price Index for all Australian capital cities (index = 1.519).

The estimated total injury cost to car occupants during 1988-90 was $3142.6 million per annum in 1991 prices.

(c) dividing (b) by (a) to derive a scaling factor for the US average injury costs.

The rescaled average injury costs per injury are given in Table 5.3. These average costs were applied to the injury frequencies in Table 5.1 to calculate the total injury cost ("Harm") to all occupant casualties in Australia (Table 5.4). It can be seen that this method produces the same total injury cost ($3142.6 million) as the Steadman and Bryan adjusted figure, since this was intended through rescaling the US figures.

Table 5.3: Average cost per injury (1991 $A '000's), after rescaling of Miller (1991).

	INJURY SEVERITY						
BODY REGION	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS =3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown
External	1 5	8.3	23.2	37.7	54.7	332.3	1.5
Head	2.1	9.8	40.3	92.9	328.2	332.3	1.5
Face	2 1	9.8	40.3	53.2	108 9	332.3	1.5
Neck	2 1	9.8	40 3	53.2	108 9	332.3	1.5
Chest	1.5	8.3	23 2	37.7	54.7	332.3	1.5
Abdomen-Pelvis	1.5	8.3	23.2	37 7	54.7	332.3	1.5
Spine	1.5	8.3	54.2	467 0	558.4	332.3	1.5
Upper Extremity	2 1	14.4	34.1				1.5
Lower Extremity	1.5	14.4	43.3	64.0	108.9		1.5

Table 5.4: Total injury cost ("Harm") to occupants of cars and car derivatives in all types of impact (1991 $A millions, average per annum during 1988-90).

	INJURY SEVERITY							
BODY REGION	Minor (AIS = 1)	Moderate (AIS = 2)	Serious (AIS =3)	Severe (AIS = 4)	Critical (AIS = 5)	Maximum (AIS = 6)	Unknown	**TOTAL**
External	0.0	4.3	0.2	0.0	0.5	6.2	0.0	11 2
Head	12.8	116.6	217 2	290.4	524.9	49.4	0.0	1211 2
Face	99.4	80.3	29 9	2.8	0.0	0.0	0.7	213 1
Neck	20.1	14.1	25.7	0.6	16.3	2.6	0.0	79.5
Chest	33.6	63.7	139.3	99.4	47.5	68.0	0.0	451.4
Abdomen-Pelvis	36.4	64.8	89.7	21.2	23.3	2.0	0.0	237.4
Spine	3.8	23.4	30 9	3 5	42.8	18.3	0.0	122.7
Upper Extremity	64.4	147.4	85.0	0 0	0.0	0.0	0 0	296.7
Lower Extremity	64.4	188.6	265.4	0.6	0.2	0.0	0 0	519.3
TOTAL	334.9	703.2	883.3	418.4	655.6	146.4	0.7	3142.6
No. Occupants Sustaining Injury								77194

5.4 DISAGGREGATED ESTIMATES

The injury frequencies and total harm in Tables 5.1 and 5.4, respectively, were disaggregated by seating position, restraint use and impact direction by using the same procedures for subsets of the injury and occupant casualty data. Table 5.5 contains the disaggregated total harm estimates by body region for the four combinations of restrained and unrestrained drivers and front left passengers involved in front impacts. This table provides fundamental total injury cost data for establishing the potential cost savings benefits of countermeasures aimed at reducing the injuries of front seat occupants in front impacts.

Table 5.5: Total injury cost ("Harm") to front seat occupants of cars and car derivatives in front impacts (1991 $A millions, average per annum during 1988-90).

	Restrained		Unrestrained	
BODY REGION	**Drivers**	**Front Left Passengers**	**Drivers**	**Front Left Passengers**
External	2.0	0.2	1.4	0.3
Head	277.8	112.7	77.4	72.1
Face	86.1	20.0	22.5	6.7
Neck	16.4	23.0	2.4	0.1
Chest	136.7	31.2	32.8	13.4
Abdomen-Pelvis	64.1	25.4	10.6	7.3
Spine	27.5	15.6	12.4	4.0
Upper Extremity	96.9	32.4	13.5	11.7
Lower Extremity	208.0	71.1	54.2	7.1
TOTAL	915.4	331.7	227.2	122.8
No. Occupants	19441	7304	3948	1450

Each injury in the Crashed Vehicle Study File was associated with a contact source of the injury. For the hospitalised occupants included in this file it was possible to disaggregate the injury frequencies and total harm by the contact source. However, neither the Fatal File nor the TAC claims records contained injury contact sources to allow similar disaggregation of the injuries of the killed and medically treated occupants.

To achieve this disaggregation, data was selected from the full Crashed Vehicle Study File to act as proxies for the killed (the proxy was those hospitalised for more than 20 days, plus the 23 actual fatalities) and the medically treated but not admitted to hospital (the proxy was those hospitalised for less than 3 days). The injury frequencies from these proxies were adjusted within each AIS severity level by body region category to match the principal estimates forming components of Table 5.1. Where the proxy occupants did not sustain any injuries in an injury category for which harm was estimated by the principal method, the distribution of harm by contact source was estimated from the contact source distribution of the next lowest injury severity level within the same body region.

Tables 5.6 and 5.7 contain the total harm within each body region of the front seat occupants involved in front impacts, disaggregated by contact source of the injury, for restrained and unrestrained occupants respectively. The total harm estimated in these tables via the proxy method is within 2% of the total estimated by the principal method (Table 5.5). These figures represent the potential cost savings benefits of countermeasures aimed at treating specific contact sources to protect occupants involved in front impacts.

Table 5.6: Total injury cost ("Harm") to restrained front seat occupants of cars and car derivatives in front impacts (1991 $A millions, average per annum during 1988-90).

	BODY REGION								
CONTACT SOURCE	Head	Face	Neck	Chest	Abd.-Pelvis	Spine	Upper Extr.	Thigh-Knee	Leg-Foot
Windscreen	1.1	3.5	0.0	0.0	0.0	0.0	2.8	0.0	0.0
Header	11.0	1.1	2.5	0.0	0.0	0.0	0.4	0.0	0.0
Steering Assembly	190.2	74.4	4.9	78.2	18.3	0.4	11.5	19.2	0.1
Instrument Panel	86.7	16.2	6.1	18.2	12.2	9.8	76.5	94.3	12.8
Console	0.0	0.0	0.0	0.0	0.0	0.1	0.0	1.4	0.0
A-pillar	25.7	5.8	0.0	0.0	3.2	0.0	5.6	5.9	0.0
Other Pillar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sideglaze	0.0	0.2	0.0	0.0	0.0	0.0	2.4	0.0	0.0
Door Panel	0.0	0.0	0.0	12.0	13.5	0.0	2.6	2.3	0.8
Roof Surface	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seats	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Seat Belts	0.0	0.0	4.5	64.1	45.5	0.0	20.5	0.0	0.0
Other Occupant	18.6	0.0	0.0	0.1	0.6	10.3	0.9	0.0	0.0
Floor	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.1	130.1
Exterior	63.3	4.2	0.0	0.1	0.0	0.0	2.6	0.0	0.0
Non-contact	3.5	1.4	20.2	0.3	0.0	17.3	2.3	0.0	0.0
Other and Not Known	0.9	1.6	0.0	0.6	0.1	1.0	5.0	0.2	0.9
TOTAL	401.1	108.3	38.2	173.7	93.4	38.9	133.9	123.4	144.7
No. of Occupants Sustaining Injury									26745

Table 5.7: Total injury cost ("Harm") to <u>unrestrained</u> front seat occupants of cars and car derivatives in <u>front impacts</u> (1991 $A millions, average per annum during 1988-90).

	BODY REGION								
CONTACT SOURCE	Head	Face	Neck	Chest	Abd.-Pelvis	Spine	Upper Extr.	Thigh-Knee	Leg-Foot
Windscreen	10.3	11.6	0.1	0.0	0.0		2.1	0.0	0.0
Header	0.0	0.2	0.0	0.0	0.0		0.0	0.0	0.0
Steering Assembly	44.3	13.5	1.5	13.8	4.2		3.0	12.2	2.0
Instrument Panel	22.5	0.7	0.0	12.7	11.5		6.4	11.3	7.9
Console	0.0	0.0	0.0	0.0	0.0		0.0	0.1	0.0
A-pillar	1.0	0.4	0.0	0.0	0.0		0.7	0.0	0.0
Other Pillar	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Sideglaze	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Door Panel	0.0	0.0	0.0	0.0	0.0		1.7	0.0	0.0
Roof Surface	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Seats	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Seat Belts	0.0	0.0	0.0	0.1	0.1		0.1	0.0	0.0
Other Occupant	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
Floor	0.0	0.0	0.0	0.0	0.0		0.0	0.1	26.7
Exterior	88.9	2.9	2.0	15.3	0.1		5.2	0.2	0.0
Non-contact	0.5	1.1	0.0	0.7	0.0		0.7	0.0	0.0
Other and Not Known	0.0	0.0	0.0	0.0	0.0		3.1	0.0	0.1
TOTAL	167.4	30.3	3.6	42.7	15.9	*	23.0	23.8	36.6
No. of Occupants Sustaining Injury									5398

* No spinal injuries to unrestrained front seat occupants involved in front impacts appeared in the Crashed Vehicle Study File to allow estimation of the contact source distribution of the spinal harm estimated by the principal method ($16.4 million).

6. ESTIMATES OF COUNTERMEASURE BENEFITS

This chapter describes the approach adopted for estimating the likely benefits of the full range of countermeasures relevant in this study. As noted in the Introduction, Chapter 1, the approach adopted for assessing injury mitigation in this study used the "***Harm***" approach to calculate benefits.

The concept of "Harm" was first developed in the US and applied to National Accident Sampling System (NASS) database by the National Highway Traffic Safety Administration (NHTSA) as a means of determining countermeasure benefits for road safety programs (Malliaris, Hitchcock and Hedlund 1982; Malliaris, Hitchcock and Hansen 1985; Malliaris and Digges 1987).

In its original form, it was not suitable for immediate application to these data as it lacked an Australian cost basis. Moreover, it had never quite been used previously for itemising injury reductions by body regions as was envisaged here. Thus, the development and use of Harm in this study represented a significant international advancement in the ability to assess injury mitigation effects of vehicle countermeasures.

It should be noted that the benefit analysis conducted in this study was restricted to front seat occupants involved in frontal crashes. While this was necessary because of constraints on time and resources, it should be recognised that these injury reductions will be conservative as some of the countermeasures also reduce injury in side impact and rollover crashes.

6.1 HARM AND INJURY MITIGATION

Harm is a metric for quantifying injury costs from road trauma, involving both a frequency and a unit cost component. In its most general form, it is used as a measure of the total cost of road trauma. [In Steadman and Bryan's (1988) publication, for instance, total cost of road trauma (Harm) was listed as $5 Billion]. Harm can also be broken down by type of road user, body region injured and severity of the injury sustained. The fundamental matrix of harm for vehicle occupants by body region and injury severity to be used in this analysis was derived in the previous Chapter and is shown in Table 5.4.

6.1.1 The Harm Method

The Harm method allows for different types or levels of calculations in estimating injury mitigation. The most simple global approach (when suitable data are available) takes reported reductions in road trauma attributed to a particular countermeasure and simply expresses these as an expected level of trauma reduction among vehicle occupants. An example of this method is found in Section 6.4.1 where a 40% Harm benefit is claimed to unbelted front seat occupants from the installation of a seatbelt warning device in all cars leading to a Harm mitigation of $97m for vehicle occupants in this country.

However, not all of the countermeasures examined here have data available on expected injury reductions of this kind (most have only specific test results for particular body region and contact source benefits). For these measures, the basic Harm approach can be adopted to piece together a picture of the expected overall benefit from a series of individual body region and restraint condition savings using a more detailed (building block) approach. An example of this method is given below.

FIGURE 1 SAMPLE HARM SPREADSHEET: FACE INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE A HARM DIST. BY CONTACT

				COUNTERMEASURE OPPORTUNITIES			
CONTACT	FRONTAL HARM	% HARM FT. OCC.		DRIVER AIRBAG	PASS. AIRBAG	DRIVER FACEBAG	E-A WHEEL
STEER A	74.45	68.72%		68.72%		68.72%	68.72%
INS.PANEL	16.15	14.91%					
WINDSCR.	3.48	3.21%		3.21%	3.21%		
A PILLAR	5.85	5.40%		5.40%	5.40%		
B PILLAR	0.00	0.00%					
HEADER	1.09	1.01%					
FLOOR	0.00	0.00%					
BELT	0.00	0.00%					
NON-CONT.	1.37	1.26%					
OTHER	5.95	5.49%					
TOTAL	108.34	100.00%		77.33%	8.61%	68.72%	68.72%
SENSITIVITY ANALYSIS			-2 AIS	70.5	1.5	42.6	6.6
			-1 AIS	61.3		36.9	5.8

TABLE B SAMPLE HARM CALCULATION - AIRBAG FOR STEERING ASSEMBLY CONTACTS

INJURY SEVERITY DISTRIBUTION			INJURY REDUCTION		RESIDUAL
AIS	DIST.	% DIST.	RELEVANCE	BASIS	-2 AIS
1	30.5	40.9%	0.80	0.33	0.01
2	27.7	37.2%	0.90	0.33	0.00
3	16.0	21.5%	0.95	0.20	0.00
4	0.2	0.3%	0.95	0.00	0.00
5	0.0	0.0%	0.95	0.00	
6	0.0	0.0%	0.95	0.00	
UNK.	0.0	0.0%			
TOTAL	74.4	100.00%		0.87	0.01
			HARM UNITS REMOVED		63.95

TABLE C SAMPLE INJURY REDUCTION ASSUMPTIONS

1. 20% OF AIS 1 INJURIES OCCUR BELOW 10 MPH
2. 80% OF AIS 1 INJURIES OCCUR BETWEEN 10 AND 40 MPH
3. 90% OF AIS 2 INJURIES OCCUR BETWEEN 10 AND 40 MPH
4. 95% OF AIS 3+ INJURIES OCCUR BETWEEN 10 AND 40 MPH
5. INJURY REDUCTION FOR ALL RELEVANT CRASHES IS -2 AIS
6. FULLSIZE AIRBAG DEPLOYS AT 10 MPH
7. RELEVANT INJURY RANGE FOR FULLSIZE AIRBAG = 10 TO 40 MPH

TABLE D HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	DRIVER FACEBAG	PASS. AIRBAG	E-A WHEEL
STEER A	74.45	68.72%	63.9	42.6		5.8
INS.PANEL	16.15				0.6	
W'SCREEN	3.48	3.21%	2.4		1	
A PILLAR	5.85	5.40%	4.1			
HEADER	1.09	1.01%				
NON-CONT	1.37	1.26%				
OTHER	5.95	5.49%				
TOTAL	108.34	100.00%	70.4	42.6	1.6	5.8
BENEFIT ASSUMED			2 AIS	2 AIS	2 AIS	1 AIS

6.1.2 The HARM Spreadsheet

A computer spreadsheet was developed for making the detailed Harm calculations by body region and restraint condition. Figure 1 shows a typical summary page for a Harm spreadsheet for face injuries to restrained occupants. The first table (Table A) shows the adjusted national distribution of face injury Harm by contact sources and the opportunities available for each countermeasure to reduce face injury Harm to restrained occupants in frontal crashes in Australian vehicles. For example, it is argued that fullsize driver airbags offer opportunities for face injury reductions to restrained drivers from steering assembly, windscreen, and A-pillar, contacts.

The likely injury reductions for each of these opportunities was then analysed separately in another section of the spreadsheet. Table B shows a sample of one such calculation (fullsize driver airbags with the steering assembly) and Table C, the assumptions made in that calculation. The opportunity for injury reduction at each AIS level was reduced through the use of a *relevance* factor (0.8 for AIS 1 up to 0.95 for AIS 3 and above injuries). This relevance factor is used to include only that Harm which is within the injury mitigation capability of the measure and is determined by the proportion of Harm within the crash severity range for which the measure is judged to be effective.

The *Basis* column is the product of relevance and % Harm and is the actual Harm expected to be saved by the measure for that particular AIS level. However, as the Harm reduction in this example is a shift in the Harm distribution of -2 AIS rather than a total mitigation of injury, the *basis* therefore needs to be corrected for the *Residual Harm*. This is done in the column headed *-2 AIS* where the Residual of existing AIS 3 is shifted to AIS 1 injuries and adjusted to reflect reduced cost of injury at that level (0.20 basis at AIS 3 is shifted to AIS 1 and multiplied by 4/78 which is the cost of AIS 1 over AIS 3 injuries to the face). Thus, the total *Harm Units Reduced* is then the product of the total Harm experienced ($74.4million) by the difference between the total basis and the residual Harm:

$$\text{i.e., } 0.87 - 0.01 = 0.86 \times 74.4 = \$63.95\text{million}$$

The assumptions in Table C show that the airbag was expected to reduce injuries for the specified body regions and vehicle contacts. The injury reduction was assumed to occur over the crash severity range of 16 to 64k/h (10-40mph). Ninety-five percent of AIS 4 and above injuries for the body regions and vehicle contacts specified occur over this severity range. It was assumed that 95% of these AIS 4 and above injuries would be reduced by 2 AIS. A relevance factor of 0.95 was therefore used in Table B. It is recognised that some injuries will be reduced more, and others, less. However, based on airbag crash tests with dummies, injury measures corresponding to 2 AIS levels are common. Accident experience supports this order of injury reduction. Relevance factors were selected for the other AIS levels in a similar way. The airbag had the lowest relevance factors (0.8) for AIS 1 injuries because many of them occur below 16k/h, the threshold for airbag deployment.

The benefit for each measure for that particular body region and restraint condition is finally summarised in Table D, where the Harm mitigated by each individual contact source was added to provide total Harm saved for that body region and restraint condition. Again for the fullsize driver airbag, Table D shows that this measure was judged likely to save A$70.4million annually from reduced face injuries to restrained front seat occupants, most of which would be derived from reduced contacts by the driver with the steering wheel (A$63.9million).

The total Harm reduction for each countermeasure was eventually obtained by adding together the results of all the body region and restraint conditions applicable for each measure (this is shown in Tables 6.14 and 6.15 at the end of this section). The summary sheet of each body region and restraint condition spreadsheet is shown in Tables 6.1 to 6.13 detailing the injury mitigation benefits for each countermeasure where Harm reduction was computed this way. (It was not possible to include the full set of spreadsheets in this report and those interested in this level of detail should contact the Federal Office of Road Safety or the Monash University Accident Research Centre to obtain copies of them).

6.1.3 Benefit Assumptions

The project specification called for all benefit assumptions to be derived from the best available objective source of information. For the most part, this meant internationally published figures of injury mitigation effects for the various countermeasures under consideration. However, it was ambitious to expect detailed crash or crash test results for all these countermeasures, given that many of these are recent developments in improved vehicle safety. Where injury mitigation effects were not available, a panel of experts made estimates of their likely effects (relevance) by body region and contact source. Details of the expert group are provided at the front of this report. Naturally, any assessment of relevance was based on local incidence data and the Australian fleet of vehicles.

6.2 DETAILED INJURY MITIGATION CALCULATIONS

The detailed assumptions (and information source) used for Harm reduction by each body region injury, contact source, and measure are outlined below.

FULLSIZE DRIVER AIRBAG - Harm calculations for fullsize driver airbag benefits are shown in Tables 6.1 to 6.9. Relevant data sources for these injury mitigations come from Zuby and Saul (1989), Highway Loss Data Institute (1991), Zador and Ciccone (1991) and Yoganandan, Sances, Pintar, Reinartz and Haffner (1991). From these reports, the following assumptions were made:

. that these 70 litre airbags would reduce injuries to front seat occupants in frontal crashes from 16-64km/h (10-40mph),

. that injury reductions to restrained occupants would come from fewer head and face contacts with the steering wheel, instrument panel, windscreen, and A-pillar,

. that there would be fewer injuries from chest contacts with the steering wheel, instrument panel, and seatbelt, and abdominal contacts with the steering assembly,

. that injury reductions for restrained and unrestrained occupants involved the same body areas and contacts plus reduced contacts from exterior objects,

. that benefits would be mainly to the driver, except for front passenger contacts with the steering wheel,

. that AIS 1 and 2 injuries were concentrated at lower impact speeds while AIS 3's and above were more common at higher delta-V's, and

. that airbags as a supplementary restraint would produce a 2 AIS injury reduction to restrained occupants, and a 3 AIS reduction for head and chest injuries to unrestrained occupants.

TABLE 6.1
HARM ANALYSIS - HEAD INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.	COUNTERMEASURE OPPORTUNITIES DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	FLP WEBBING CLAMP	HEAD PADDING	FLP SHOULDER PRE-TEN.
STEER A	190.19	47.41%	47.41%		47.41%	47.41%	47.41%	47 41%			
INS.PANEL	86.66	21.60%	21.60%	21 60%	21.60%	21.60%			21.60%		21.60%
WINDSCR	1.12	0.28%	0 28%	0.28%	0.28%	0 28%					
A PILLAR	25.69	6.40%	6 40%	6.40%	6.40%	6.40%			6.40%	6 40%	6.40%
B PILLAR	0.00	0.00%									
HEADER	11.05	2.75%							2.75%	2.75%	2 75%
FLOOR	0.00	0.00%									
BELT	0.00	0 00%									
NON-CONT	3 54	0 88%									
EXTERIOR	63.29	15 78%									
OTHER	19.60	4.89%									
TOTAL	401.14	100 00%	75 70%	28.29%	75 70%	75.70%	47.41%	47.41%	30.76%	9.16%	30 76%
SENSITIVITY ANALYSI		-2 AIS	192 7	23 8	146.3	120.1	102 6	56.2	15.4	16.6	15.4
		-1 AIS	143.6				76.7	42.3		13 0	6 8

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS	ALL	% HARM DRIVERS	PASS.	ALL
1	2 3	1 5	3 8	0.57%	0.37%	0.95%
2	30.3	8 0	38.3	7.55%	1 99%	9.55%
3	56.0	20 2	76 2	13.96%	5 04%	19.00%
4	62.6	37.8	100 4	15.61%	9 42%	25 03%
5	116.8	41.1	157.9	29.12%	10 25%	39 37%
6	9.8	4.0	13.8	2.44%	1 00%	3.44%
UNK.	5.4	5 3	10.7	1.35%	1.32%	2.67%
TOTAL	283.2	117.9	401 1	70 61%	29 39%	100 00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	10%	10%
11-25	17-40	35%	45%
26-35	41-56	30%	75%
36-45	57-73	20%	95%
46+	73+	5%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	PASS AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	WEBBING CLAMP (FLP)	HEAD PADDING	SHOULDER PRE-TEN. (FLP)
STEER A	190 19	47.41%	134.5		102.6	102 6	102.6	42.3			
INST PAN	86.66	21.60%	44.2	18 1	33.2	13 3			11.5		11.5
WINDSC	1 12	0 28%	0.6	0.2	0.4	0.2					
A PILLAR	25 69	6 40%	13.4	5 5	10.1	4			3.8	11 8	3 8
HEADER	11 05	2 75%							0.1	4.8	0 1
NON-CONT	3 54	0.88%									
EXTERIOR	63 29	15.78%									
OTHER	19.6	4.89%									
TOTAL	401 14	100.00%	192 7	23.8	146.3	120.1	102.6	42 3	15.4	16.6	15.4
BENEFIT ASSUMED			2 AIS	2 AIS	2 AIS	2 AIS	2 AIS	1 AIS	2 AIS	2 AIS	2 AIS

TABLE 6.2
HARM ANALYSIS - HEAD INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.	COUNTERMEASURE OPPORTUNITIES: DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	HEAD PADDING
STEER. ASY	44.33	26.48%	26.48%		26.48%	26.48%	26.48%	26.48%	
INS.PANEL	22.47	13.42%	13.42%	13.42%	13.42%	13.42%			
WINDSCR.	10.25	6.12%	6.12%	6.12%	6.12%	6.12%			
A PILLAR	0.98	0.59%	0.59%	0.59%	0.59%	0.59%			0.59%
B PILLAR	0.00	0.00%							
HEADER	0.00	0.00%							0.00%
FLOOR	0.00	0.00%							
BELT	0 00	0.00%							
NON-CONT	0.54	0.32%							
EXTERIOR	88.85	53.07%	53.07%	53.07%	53.07%	53.07%			
OTHER	0.00	0.00%							
TOTAL	167 42	100.00%	99.68%	73.20%	99.68%	99.68%	26.48%	26.48%	0 59%
SENSITIVITY ANALYSIS		-3 AIS	56.5	20.6	47.5				
		-2 AIS	51.8			34.5	28.3	12.6	0.4
		-1 AIS	39.8				22.3	9.9	0.3

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM: DRIVERS	PASS	ALL	% HARM: DRIVERS	PASS	ALL
1	1 3	0.4	1.7	0.78%	0.24%	1.01%
2	11.9	5.0	16.9	7 10%	2.99%	10.09%
3	15.1	6 4	21.5	9.01%	3.82%	12 84%
4	7.6	25.0	32.6	4.54%	14.93%	19 46%
5	38.1	34.9	73.0	22.75%	20.84%	43 58%
6	3.4	0.5	3.9	2.03%	0 30%	2.33%
UNK.	9.0	8.9	17.9	5 37%	5.31%	10.69%
TOTAL	86.4	81.1	167.5	51.58%	48.42%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	10%	10%
11-25	17-40	35%	45%
26-35	41-56	30%	75%
36-45	57-73	20%	95%
46+	73+	5%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	HEAD PADDING
STEER A	44.33	26.48%	34.1		30.9	28.3	28.3	9.9	
INST PAN	22.47	13 42%	9.1	8.4	6.9	2 5			
WINDSC	10.25	6.12%	3.9	3.6	2.9	1.2			
A PILLAR	0.98	0.59%	0.4	0.3	0.3	0.1			0.4
HEADER	0	0.00%							0
NON-CONT	0.54	0.32%							
EXTERIOR	88.85	53.07%	9	8.3	6.5	2.4			
OTHER	0	0.00%							
TOTAL	167.42	100.00%	56.5	20.6	47.5	34.5	28.3	9.9	0.4
		BENEFIT ASSUMED	3 AIS	3 AIS	3 AIS	2 AIS	2 AIS	1 AIS	2 AIS

TABLE 6.3
HARM ANALYSIS - CHEST INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

			COUNTERMEASURE OPPORTUNITIES						
CONTACT	FRONTAL HARM	% HARM FT. OCC.	DRIVER AIRBAG	PASS AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	SHOULDER PRE-TEN.	WEBBING CLAMP
STEER A	78.24	45 04%	45.04%		45.04%	45 04%	45 04%	45.04%	45 04%
INS.PANEL	18.16	10 45%	10 45%	10.45%	10.45%	10.45%			
WINDSCR	0.00	0 00%	0.00%	0.00%	0.00%	0 00%			
A PILLAR	0 00	0 00%	0.00%	0.00%	0 00%	0 00%			
B PILLAR	0 00	0.00%							
HEADER	0 00	0.00%							
DOOR	11.99	6.90%							
BELT	64.14	36 92%	36 92%	36.92%	36.92%	36 92%	36 92%	36.92%	36.92%
NON-CONT.	0.34	0.20%							
EXTERIOR	0.10	0.06%							
OTHER	0.74	0.43%							
TOTAL	173.71	100.00%	92.42%	47 38%	92.42%	92.42%	81.96%	81.96%	81 96%
SENSITIVITY ANALYSIS		-2 AIS	92.9	10.0	67.4		31 6	35.7	
		-1 AIS	69 8			31.5	26.4	29.9	19.8

TABLE II HARM DISTRIBUTION BY AIS

	TOTAL HARM			% HARM		
AIS	DRIVERS	PASS.	ALL	DRIVERS	PASS	ALL
1	11 5	4.9	16.4	6.62%	2 82%	9 45%
2	31 5	6 0	37 5	18.15%	3 46%	21 60%
3	31.0	9 4	40.4	17.86%	5.41%	23 27%
4	28 7	2.6	31.3	16.53%	1.50%	18 03%
5	17 6	4.2	21 8	10.14%	2.42%	12 56%
6	16.4	4.0	20 4	9.45%	2.30%	11 75%
UNK	2.9	2.9	5 8	1 67%	1.67%	3.34%
TOTAL	139.6	34 0	173.6	80.41%	19.59%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	SHOULDER PRE-TEN.	WEBBING CLAMP
STEER A	78.24	45 04%	50 4		37.7	11 4	11 4	11.4	8
INST PAN	18 16	10.45%	9.9	2.3	7.5	2.4			
DOOR	11.99	6.90%							
A PILLAR	0	0.00%							
BELT	64.14	36.92%	32.6	7.7	22.2	17.7	15	18.5	11 8
NON-CONT	0.34	0 20%							
EXTERIOR	0.1	0.06%							
OTHER	0.74	0.43%							
TOTAL	173.71	100.00%	92.9	10	67.4	31.5	26.4	29.9	19.8
		BENEFIT ASSUMED	2 AIS	2 AIS	2 AIS	1 AIS	1 AIS	1 AIS	1 AIS

TABLE 6.4
HARM ANALYSIS - CHEST INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.	COUNTERMEASURE OPPORTUNITIES DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG
STEER. ASY	13.77	29 81%	29.81%		29.81%	29.81%	29.81%
INS.PANEL	12.74	27.58%	27.58%	27.58%	27.58%	27.58%	
WINDSCR.	0.00	0.00%	0.00%	0.00%	0.00%	0 00%	
A PILLAR	0.00	0.00%	0.00%	0 00%	0.00%	0.00%	
B PILLAR	0.00	0.00%					
HEADER	0.00	0.00%					
FLOOR	0.00	0.00%					
BELT	0 14	0.30%					
NON-CONT.	0.75	1.62%					
EXTERIOR	15.27	33.06%	33 06%	33.06%	33 06%	33 06%	
OTHER	3.52	7.62%					
TOTAL	46.19	100.00%	90.45%	60.64%	90.45%	90.45%	29.81%
		-3 AIS	19	6.2	14 2		
SENSITIVITY ANALYSIS		-2 AIS	14.8			4.3	3.7
		-1 AIS	6.4				2.2

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	1.3	0.5	1.8	2.81%	1 08%	3.90%
2	3.5	0.6	4.1	7.58%	1.30%	8.87%
3	7.6	3.2	10.8	16.45%	6.93%	23 38%
4	6 1	3.2	9.3	13.20%	6 93%	20.13%
5	4 0	0.6	4.6	8.66%	1 30%	9.96%
6	10.2	5 4	15.6	22.08%	11.69%	33.77%
UNK.	0.0	0 0	0.0	0.00%	0.00%	0.00%
TOTAL	32.7	13.5	46.2	70.78%	29 22%	100 00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG
STEER A	13.77	29.81%	9 3		7	2 6	2.6
INST PAN	12.74	27.58%	7.6	2.8	5.6	1	1.1
WINDSC	0	0 00%					
A PILLAR	0	0.00%					
BELT	0.14	0.30%					
NON-CONT	0.75	1.62%					
EXTERIOR	15.27	33 06%	2.1	3.4	1.6	0.7	
OTHER	3.52	7.62%					
TOTAL	46.19	100.00%	19	6.2	14.2	4.3	3.7
		BENEFIT ASSUMED	3 AIS	3 AIS	3 AIS	2 AIS	2 AIS

TABLE 6.5
HARM ANALYSIS - ABDOMINAL & PELVIC INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT OCC.	COUNTERMEASURE OPPORTUNITIES: DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	SEAT PRE-TEN	BELT/SEAT DESIGN
STEER A	18.27	19.57%	19.57%		19.57%	19 57%	19 57%
INS PANEL	12.20	13.07%	13 07%	13.07%	13 07%	13 07%	13 07%
WINDSCR	0 00	0.00%	0.00%	0.00%	0 00%		
A PILLAR	3.20	3.43%					
B PILLAR	0 00	0.00%					
HEADER	0.00	0 00%					
FLOOR	0.00	0.00%					
BELT	45 50	48.73%				48 73%	48.73%
NON-CONT	0 00	0 00%					
EXTERIOR	0.00	0 00%					
OTHER	14 20	15.21%					
TOTAL	93 37	100.00%	32.63%	13 07%	32 63%	81 36%	81.36%
SENSITIVITY ANALYSIS		-2 AIS	9.1	1.2	6 9	19.3	16 3
		-1 AIS	6.4			14.6	12.5

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	10 4	3 8	14.2	11 15%	4 07%	15 22%
2	21.9	6 6	28 5	23.47%	7 07%	30.55%
3	24.0	9.5	33 5	25 72%	10.18%	35.91%
4	5 2	4.6	9.8	5.57%	4 93%	10 50%
5	1.7	0.5	2 2	1.82%	0.54%	2 36%
6	0.8	0.4	1 2	0 86%	0.43%	1.29%
UNK	2.0	1.9	3.9	2 14%	2 04%	4.18%
TOTAL	66 0	27 3	93 3	70.74%	29 26%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S OCC.	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	SEAT PRE-TEN.	BELT/SEAT DESIGN
STEER A	18.27	19.57%	6		4.5	4.1	3
INST PAN	12 2	13.07%	3.1	1.2	2.4	2.2	3.1
WINDSC	0	0 00%					
A PILLAR	3.2	3.43%					
BELT	45.5	48.73%				8 3	10.2
NON-CONT	0	0.00%					
EXTERIOR	0	0 00%					
OTHER	14.2	15.21%					
TOTAL	93.37	100.00%	9 1	1.2	6.9	14 6	16.3
		BENEFIT ASSUMED	2 AIS	2 AIS	2 AIS	1 AIS	2 AIS

TABLE 6.6
HARM ANALYSIS - ABDOMINAL & PELVIC INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.	COUNTERMEASURE OPPORTUNITIES DRIVER AIRBAG	PASSENGER AIRBAG	MAXIMUM FACEBAG
STEER ASY	4.20	23.35%	23.35%		23 35%
INS.PANEL	11.55	64.20%	64.20%	64 20%	64 20%
WINDSCR.	0.00	0.00%			
A PILLAR	0.00	0.00%			
B PILLAR	0.00	0.00%			
HEADER	0.00	0 00%			
FLOOR	0.00	0 00%			
BELT	0.07	0.39%			
NON-CONT	0 00	0.00%			
EXTERIOR	0.00	0.00%			
OTHER	2 17	12.06%			
TOTAL	17 99	100.00%	87.55%	64 20%	87.55%
SENSITIVITY ANALYSIS		-2 AIS	7.5	3.2	5.6
		-1 AIS	5.3		

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	0.8	0.6	1.4	4.47%	3.35%	7.82%
2	2 7	1.0	3.7	15.08%	5.59%	20.67%
3	5.1	5.2	10 3	28.49%	29.05%	57.54%
4	0.6	0 1	0.7	3 35%	0.56%	3.91%
5	1.4	0 4	1.8	7 82%	2.23%	10.06%
6	0.0	0 0	0.0	0.00%	0.00%	0.00%
UNK.	0.0	0.0	0.0	0.00%	0.00%	0.00%
TOTAL	10.6	7.3	17.9	59.22%	40 78%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	PASSENGER AIRBAG	MAXIMUM FACEBAG
STEER A	4.2	23.35%	2.8		2.1
INST PAN	11.55	64 20%	4.7	3.2	3.5
WINDSC	0	0.00%			
A PILLAR	0	0.00%			
BELT	0.07	0.39%			
NON-CONT	0	0.00%			
EXTERIOR	0	0.00%			
OTHER	2.17	12.06%			
TOTAL	17.99	100.00%	7.5	3 2	5.6
		BENEFIT ASSUMED	2 AIS	2 AIS	2 AIS

TABLE 6.7
HARM ANALYSIS - FACE INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT OCC.	COUNTERMEASURE OPPORTUNITIES: DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	FLP SHOULDER PRETENS.	FLP WEBBING CLAMPS	HEAD PADDING
STEER A	74 45	68.72%	68.72%		68 72%	68.72%	68 72%	68 72%			
INS PANEL	16.15	14.91%							14.91%	14.91%	
WINDSCR	3 48	3.21%	3.21%	3 21%	3 21%	3 21%					
A PILLAR	5 85	5.40%	5 40%	5 40%	5.40%	5.40%			5.40%	5.40%	5.40%
B PILLAR	0.00	0.00%									
HEADER	1.09	1 01%							1.01%	1 01%	1 01%
FLOOR	0 00	0 00%									
BELT	0.00	0 00%									
NON-CONT	1.37	1 26%									
EXTERIOR	0 00	0 00%									
OTHER	5 95	5.49%									
TOTAL	108.34	100.00%	77.33%	8.61%	77.33%	77 33%	68 72%	68.72%	21 31%	21.31%	6.41%
SENSITIVITY ANALYSIS		-2 AIS	70 5	1.5	52.8	44.6	42.6	6.6			5 8
		-1 AIS	61.3				36 9	5 8			5.1

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM: DRIVERS	PASS.	ALL	% HARM: DRIVERS	PASS.	ALL
1	32 0	9.7	41.7	29 55%	8 96%	38 50%
2	36.9	8 0	44 9	34 07%	7 39%	41.46%
3	16 7	2.3	19.0	15 42%	2.12%	17.54%
4	0.3	0.0	0 3	0.28%	0.00%	0.28%
5	0.0	0 0	0 0	0.00%	0.00%	0 00%
6	0.0	0 0	0.0	0 00%	0.00%	0.00%
UNK	1.2	1.2	2 4	1.11%	1.11%	2.22%
TOTAL	87.1	21 2	108 3	80.42%	19.58%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U S DATA % HARM	CUM. HARM US DATA
0-10	0-16	10%	10%
11-25	17-40	50%	60%
26-35	41-56	35%	95%
36-45	57-73	5%	100%
46+	73+	0%	100%

TABLE IV HARM DIST BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S OCC.	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	SHOULDER PRETENS. FLP	WEBBING CLAMP FLP	HEAD PADDING
STEER A	74 45	68.72%	63 9		48	42.6	42 6	5 8			
INST PAN	16.15	14.91%							2 4	2 4	
WINDSC	3.48	3.21%	2 4	0.5	1.7	0.8					
A PILLAR	5.85	5 40%	4.2	1	3.1	1.2			0.9	0 9	4.9
HEADER	1.09	1.01%							0.2	0.2	0 9
NON-CONT	1.37	1 26%									
EXTERIOR	0	0.00%									
OTHER	5.95	5 49%									
TOTAL	108.34	100 00%	70.5	1.5	52 8	44.6	42 6	5.8	3.5	3.5	5.8
		BENEFIT ASSUMED	2 AIS	2 AIS	2 AIS	2 AIS	2 AIS	1 AIS	2 AIS	2 AIS	2 AIS

TABLE 6.8
HARM ANALYSIS - FACE INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.	COUNTERMEASURE OPPORTUNITIES DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL	FACE PADDING
STEER. ASY	13.48	44.50%	44.50%		44.50%	44.50%	44 50%	44.50%	
INS.PANEL	0.66	2.18%	2 18%	2.18%	2 18%	2.18%			
WINDSCR.	11.58	38.23%	38.23%	38.23%	38 23%	38 23%			
A PILLAR	0.44	1.45%	1.45%	1.45%	1.45%	1.45%			1 45%
B PILLAR	0.00	0 00%							
HEADER	0.00	0.00%							0 00%
FLOOR	0.00	0.00%							
BELT	0.00	0.00%							
NON-CONT	1.05	3.47%							
EXTERIOR	0 00	0.00%							
OTHER	3.08	10.17%							
TOTAL	30.29	100.00%	86.37%	41.86%	86.37%	86.37%	44.50%	44.50%	1.45%
SENSITIVITY ANALYSIS		-2 AIS	19.9	2.5	14.9	10.3	7.8	1.1	0.6
		-1 AIS	17.4				6.7	1.0	0.6

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	8 8	2.9	11.7	28.95%	9.54%	38 49%
2	9.2	3.9	13.1	30.26%	12.83%	43.09%
3	4.3	0.0	4 3	14.14%	0 00%	14.14%
4	0.2	0.0	0.2	0.66%	0.00%	0 66%
5	0 0	0.0	0.0	0.00%	0.00%	0.00%
6	0.0	0.0	0.0	0.00%	0.00%	0.00%
UNK.	0 6	0.5	1.1	1.97%	1.64%	3.62%
TOTAL	23 1	7.3	30.4	75 99%	24.01%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	10%	10%
11-25	17-40	50%	60%
26-35	41-56	35%	95%
36-45	57-73	5%	100%
46+	73+	0%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER FACEBAG	MINIMUM FACEBAG	E-A WHEEL	FACE PADDING
STEER A	13.48	44.50%	11.6		8 7	7 8	7.8	1	
INST PAN	0.66	2 18%	0.4	0.1	0 3	0.1			
WINDSC	11.58	38 23%	7 6	2.3	5.7	2.3			
A PILLAR	0.44	1.45%	0.3	0.1	0.2	0.1			0.4
HEADER	0	0 00%							0.2
NON-CONT	1.05	3.47%							
EXTERIOR	0	0.00%							
OTHER	3.08	10.17%							
TOTAL	30.29	100 00%	19.9	2.5	14 9	10.3	7.8	1	0 6
BENEFIT ASSUMED			2 AIS	2 AIS	2 AIS	2 AIS	2 AIS	1 AIS	2 AIS

TABLE 6.9
HARM ANALYSIS - UPPER EXTREMITY INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

			COUNTERMEASURE OPPORTUNITIES					
CONTACT	FRONTAL HARM	% HARM FT. OCC.	DRIVER AIRBAG	PASS AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL
STEER A	3.04	13.21%	13.21%		13.21%	13 21%	13.21%	13 21%
INS.PANEL	6 44	27.99%	27.99%	27 99%	27.99%	27.99%		
WINDSCR.	2 12	9 21%						
A PILLAR	0 65	2 82%						
B PILLAR	0.00	0 00%						
HEADER	0.00	0 00%						
DOOR	1.68	7 30%	7.30%	7.30%	7.30%	7.30%		
BELT	0 00	0 00%						
NON-CONT	0 65	2.82%						
EXTERIOR	5.19	22 56%	22 56%	22.56%	22.56%	22.56%		
OTHER	3.24	14.08%						
TOTAL	23 01	100 00%	71.06%	57 84%	71.06%	71 06%	13.21%	13.21%
SENSITIVITY ANALYSIS		-2 AIS	7.6	4.8	5 7	2.7	1.0	0.6
		-1 AIS	6.2				0 8	0.5

TABLE II HARM DISTRIBUTION BY AIS

	TOTAL HARM			% HARM		
AIS	DRIVERS	PASS.	ALL	DRIVERS	PASS.	ALL
1	3.9	1 1	5.0	15.48%	4 37%	19 84%
2	6.1	6.6	12 7	24.21%	26.19%	50 40%
3	3.5	4.0	7.5	13 89%	15.87%	29 76%
4	0 0	0.0	0.0	0.00%	0.00%	0 00%
5	0 0	0.0	0 0	0.00%	0.00%	0 00%
6	0.0	0.0	0 0	0.00%	0.00%	0 00%
UNK.	0 0	0.0	0 0	0.00%	0.00%	0.00%
TOTAL	13.5	11.7	25.2	53 57%	46.43%	100 00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	10%	10%
11-25	17-40	35%	45%
26-35	41-56	30%	75%
36-45	57-73	20%	95%
46+	73+	5%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	DRIVER AIRBAG	PASS. AIRBAG	MAXIMUM FACEBAG	INTER. FACEBAG	MINIMUM FACEBAG	E-A WHEEL
STEER A	3.04	13.21%	2.1		1.6	1	1	0.5
INST PAN	6.44	27.99%	2.3	2	1.8	0.7		
W'SCREEN	2.12	9.21%						
A PILLAR	0.65	2.82%						
DOOR	1.68	7.30%	0 7	0.6	0.5	0 2		
NON-CONT	0.65	2.82%						
EXTERIOR	5.19	22.56%	2 5	2.2	1 8	0 8		
OTHER	3.24	14.08%						
TOTAL	23 01	100 00%	7.6	4.8	5 7	2.7	1	0.5
		BENEFIT ASSUMED	2 AIS	2 AIS	2 AIS	2 AIS	2 AIS	1 AIS

TABLE 6.10
HARM ANALYSIS - THIGH & KNEE INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.		COUNTERMEASURE OPPORTUNITIES SEAT PRE-TEN.	BELT/SEAT DESIGN	KNEEBAR
STEER. ASY	19.24	15.59%		15.59%	15.59%	15.59%
INS.PANEL	94.34	76.42%		76.42%	76 42%	76.42%
WINDSCR.	0.00	0 00%				
A PILLAR	5.20	4.21%		4 21%	4.21%	4.21%
B PILLAR	0.00	0 00%				
HEADER	0.00	0.00%				
FLOOR	0.07	0.06%				
BELT	0.00	0.00%				
NON-CONT.	0.00	0.00%				
EXTERIOR	0.00	0.00%				
OTHER	4.60	3.73%				
TOTAL	123.45	100.00%		96.22%	96.22%	96.22%
SENSITIVITY ANALYSIS			-2 AIS	34.9	36.9	93.7
			-1 AIS	28.1	31.5	74.9

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	20.4	7 0	27.4	7 31%	2 51%	9.82%
2	85 3	25.2	110.5	30 59%	9.04%	39.62%
3	102 1	38.7	140.8	36.61%	13.88%	50.49%
4	0.1	0.1	0 2	0.03%	0.04%	0.07%
5	0.0	0.0	0 0	0.00%	0.00%	0.00%
6	0.0	0.0	0.0	0.00%	0.00%	0 00%
UNK.	0.0	0 0	0.0	0.00%	0.00%	0.00%
TOTAL	207.9	71.0	278.9	74.54%	25.46%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	SEAT PRE-TEN.	BELT/SEAT DESIGN	KNEEBAR
STEER A	19.24	15.59%	4 6	5.8	15.1
INST PAN	94.34	76.42%	22 3	30	74
WINDSC	0	0.00%			
A PILLAR	5.2	4.21%	1.2	1.1	4.6
FLOOR	0.07	0.06%			
NON-CONT	0	0.00%			
EXTERIOR	0	0.00%			
OTHER	4.6	3.73%			
TOTAL	123.45	100.00%	28.1	36.9	93.7
		BENEFIT ASSUMED	1 AIS	2 AIS	2 AIS

TABLE 6.11
HARM ANALYSIS - THIGH & KNEE INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.		COUNTERMEASURE OPPORTUNITIES KNEEBAR
STEER. ASY	12.20	51.28%		51 28%
INS.PANEL	11.29	47 46%		47.46%
WINDSCR	0.00	0.00%		
A PILLAR	0.00	0.00%		
B PILLAR	0.00	0 00%		
HEADER	0.00	0 00%		
FLOOR	0.07	0.29%		
BELT	0.00	0.00%		
NON-CONT.	0.00	0 00%		
EXTERIOR	0 00	0.00%		
OTHER	0.23	0.97%		
TOTAL	23 79	100 00%		98.74%
SENSITIVITY ANALYSIS			-2 AIS	18 4
			-1 AIS	14.3

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS	ALL	% HARM DRIVERS	PASS.	ALL
1	4 6	1 2	5.8	7.49%	1 95%	9.45%
2	15.6	2 6	18 2	25.41%	4.23%	29.64%
3	34 0	3.2	37 2	55 37%	5 21%	60.59%
4	0 1	0.1	0 2	0.16%	0 16%	0.33%
5	0.0	0.0	0.0	0.00%	0 00%	0.00%
6	0.0	0 0	0 0	0.00%	0.00%	0.00%
UNK	0.0	0 0	0.0	0.00%	0.00%	0.00%
TOTAL	54 3	7.1	61.4	88.44%	11.56%	100.00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	KNEEBAR
STEER A	12.2	51 28%	9.6
INST PAN	11.29	47 46%	8.8
WINDSC	0	0 00%	
A PILLAR	0	0.00%	
FLOOR	0 07	0.29%	
NON-CONT	0	0.00%	
EXTERIOR	0	0.00%	
OTHER	0.23	0.97%	
TOTAL	23 79	100.00%	18 4
		BENEFIT ASSUMED	2 AIS

TABLE 6.12
HARM ANALYSIS - LEG & FOOT INJURIES TO RESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT. OCC.		COUNTERMEASURE OPPORTUNITIES SEAT PRE-TEN.	INTRUSION CONTROL	KNEEBAR
STEER ASY	0.07	0.05%		0 05%	0.05%	0 05%
INS.PANEL	12.82	8 86%		8.86%	8.86%	8 86%
WINDSCR	0.00	0.00%				
A PILLAR	0.00	0.00%				
B PILLAR	0.00	0.00%				
DOOR	0.77	0 53%				
FLOOR	130 13	89.92%		89.92%	89 92%	89.92%
BELT	0 00	0.00%				
NON-CONT.	0.00	0.00%				
EXTERIOR	0.00	0.00%				
OTHER	0.93	0.64%				
TOTAL	144.72	100.00%		98.83%	98.83%	98 83%
SENSITIVITY ANALYSIS			-2 AIS	42.1	112 4	43.3
			+1 AIS	33.9	90.3	36.4

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	na	na	10.4	na	na	7 19%
2	na	na	64.3	na	na	44.43%
3	na	na	70 0	na	na	48 37%
4	na	na	0 0	na	na	0.01%
5	na	na	0.0	na	na	0.00%
6	na	na	0.0	na	na	0.00%
UNK.	na	na	0.0	na	na	0.00%
TOTAL	107.9	36.8	144.7	74 56%	25 44%	100 00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC.	SEAT PRE-TEN.	INTRUSION CONTROL	KNEEBAR
STEER A	0.07	0.05%	0.02	0.04	0.02
INST PAN	12 82	8 86%	3 8	10.2	5.6
WINDSC	0	0.00%			
A PILLAR	0	0.00%			
FLOOR	130.13	89.92%	38.3	102.2	37.7
DOOR	0.77	0.53%			
EXTERIOR	0	0.00%			
OTHER	0.93	0.64%			
TOTAL	144.72	100.00%	42.1	112.4	43.3
		BENEFIT ASSUMED	2 AIS	2 AIS	2 AIS

TABLE 6.13
HARM ANALYSIS - LEG & FOOT INJURIES TO UNRESTRAINED FRONT SEAT OCCUPANTS IN FRONTAL CRASHES

TABLE I HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	% HARM FT OCC		COUNTERMEASURE OPPORTUNITIES INTRUSION CONTROL	KNEEBAR
STEER. ASY	1 96	5.36%		5 36%	5.36%
INS PANEL	7.92	21.64%		21 64%	21.64%
WINDSCR.	0 00	0.00%			
A PILLAR	0 00	0.00%			
B PILLAR	0.00	0.00%			
DOOR	0 00	0.00%			
FLOOR	26.65	72 81%		72.81%	72 81%
BELT	0.00	0.00%			
NON-CONT	0 00	0.00%			
EXTERIOR	0.00	0 00%			
OTHER	0.07	0 19%			
TOTAL	36 60	100.00%		99.81%	99 81%
SENSITIVITY ANALYSIS			-2 AIS	27.6	10.2
			-1 AIS	21.6	7.9

TABLE II HARM DISTRIBUTION BY AIS

AIS	TOTAL HARM DRIVERS	PASS.	ALL	% HARM DRIVERS	PASS.	ALL
1	na	na	2 1	na	na	5 74%
2	na	na	12.7	na	na	34 70%
3	na	na	21.7	na	na	59 29%
4	na	na	0.1	na	na	0 16%
5	na	na	0.0	na	na	0 00%
6	na	na	0 0	na	na	0 00%
UNK	na	na	0.0	na	na	0.00%
TOTAL	27 3	9.3	36.6	74 56%	25.44%	100 00%

TABLE III HARM DISTRIBUTION BY DELTA V

DELTA-V MPH	KPH	NASS U.S. DATA % HARM	CUM. HARM US DATA
0-10	0-16	5%	5%
11-25	17-40	25%	30%
26-35	41-56	40%	70%
36-45	57-73	20%	90%
46+	73+	10%	100%

TABLE IV HARM DIST. BY CONTACT

CONTACT	FRONTAL HARM	%HARM F.S.OCC	INTRUSION CONTROL	KNEEBAR
STEER A	1.96	5 36%	0 6	0.4
INST PAN	7.92	21.64%	6 2	2.4
WINDSC	0	0.00%		
A PILLAR	0	0 00%		
FLOOR	26 65	72.81%	20.8	7.4
DOOR	0	0.00%		
EXTERIOR	0	0.00%		
OTHER	0.07	0.19%		
TOTAL	36 6	100.00%	27.6	10.2
		BENEFIT ASSUMED	2 AIS	2 AIS

PASSENGER AIRBAG - Harm calculations for the passenger side airbag (US size bag) are described in Tables 6.1 to 6.9 and were based on the same data sources and assumptions listed above for the driver side airbag. In determining the Harm mitigation for these units, however, only front passenger side Harm was judged relevant for these calculations.

DRIVER FACEBAG (EUROBAG) - There were very few data available on the likely injury reduction effectiveness of these units in real world crashes (there are relatively few of these airbags available in production models). Hence, expert group assessments were necessary for determining likely injury reductions of driver facebags. These Harm calculations are shown in Tables 6.1 to 6.9.

There was a range of divergent views among the expert panel on body region by contact source mitigation and the likely size (relevance) of these reductions. Moreover, while these units have a notional design deployment threshold of 24km/h (15mph), there does not seem to be any technical reason why they could not be deployed at a similar level as fullsize airbags (16km/h or 10mph). Such a reduction in deployment would lead to a significant increase in Harm mitigation. Thus, ***three*** benefit scenarios were developed for the facebag, based on different assumptions about their use and likely injury reduction effects.

***Minimum* Facebag Benefit** - Minimum facebag benefits were based on expected performance of facebags in the absence of safety standards. Under such conditions, economic and styling considerations dominate the design in the direction of smaller bags with higher deployment thresholds. Zuby and Saul (1989) reported that a large proportion of facial Harm occurred at speeds between 16-24km/h (10-15mph) from a data analysis of facial injuries suffered by restrained drivers in the US. This analysis suggested that the deployment speed can have a significant influence on its effectiveness in reducing facial injuries.

The minimum facebag benefit were based on the assumption that these units would only provide protection essentially from the steering wheel and hub (the fundamental design philosophy behind facebags as a supplementary restraint). Thus, injury mitigations were confined to the head, face, and chest only for both restrained and unrestrained front seat occupants (and upper extremities for unrestrained occupants). In addition, minimum facebag benefits came predominantly from contacts with the steering wheel, although there were some additional chest benefit from reduced seatbelt (restrained) and instrument panel (unrestrained) contacts. Exterior contact benefits were not permitted for unrestrained occupants under this scenario. Finally, the deployment threshold was set at 24km/h (15mph), the level commonly accepted as appropriate in Europe to ensure a softer (less injurious) inflation.

***Intermediate* Facebag Benefit** - A less conservative scenario of facebag injury mitigation assumed a greater benefit for both restrained and unrestrained occupants than previously by allowing some additional injury reductions from contacts with instrument panel, windscreen and header, and A-pillar, as well as a minor restraint benefit from reduced ejections to unrestrained occupants. These assumptions include:

. a lower deployment threshold of 16km/h (10mph),

. the same reduction in head, face, and chest injuries from contact with the steering wheel as the minimum facebag, but an added 30 percent reduction in additional body region contacts allowed for fullsize airbags, except for abdominal injuries, and

. a less conservative injury reduction of 2 AIS for unrestrained head and chest injuries but a similar 1 AIS for restrained face injuries.

***Maximum* Facebag Benefits** - The most optimistic prediction of facebag performance assumed that these units would be three-quarters as effective as fullsize driver airbags for both restrained and unrestrained drivers and (where relevant) front seat passengers. This view has been expressed by a number of commentators in Europe.

The assumptions for this scenario, therefore, were similar to those expressed for fullsize airbags, except that a 75 percent relevance factor was applied to the subsequent benefits calculated for each body region and contact source. Implicit with this scenario is the major assumption that facebags will offer a sizable passive benefit for unrestrained occupants (75% of that offered by fullsize airbags), which is not normally associated with these units.

ENERGY-ABSORBING PADDED STEERING WHEEL - Harm savings for the padded steering wheel (E-A Wheel) are found in Tables 6.1, 6.2, 6.7, 6.8 and 6.9. Relevant data sources included Yoganandan et al (1988), Zuby and Saul (1989), Dal Nevo, Griffiths and Dowdell (1991), and Yoganandan et al (1991). The assumptions regarding effectiveness of these units included a 0-32km/h (0-20mph) speed range relevance for drivers only, a benefit for steering wheel contacts only, and likely to produce a 1 AIS injury mitigation.

WEBBING CLAMP & PRETENSIONER - Harm reductions from fitting webbing clamps and pretensioners are summarised in Tables 6.1, 6.3, 6.5, 6.7, 6.10 and 6.12. Apart from the recent Australian study by Dal Nevo et al (1991) and an older study by Bacon (1989) both of which used dummies, likely injury mitigation effects for humans were not found for these devices, hence assumptions were primarily based on expert panel assessments. Relevance range was assumed to be 24-40km/h (15-25mph), major benefits would accrue to lower severity injuries, and that a 2 AIS injury mitigation would be possible for both front occupants from steering assembly contacts with the torso and abdomen. [The Australian study showed little benefit for head and face contacts using these devices].

HEAD & FACE PADDING - Harm savings for head and face padding are listed in Tables 6.1, 6.2, 6.7 and 6.8. Relevant data sources were from Monk and Sullivan (1986), Wilke and Gabler (1989), and other miscellaneous NHTSA information. The assumptions made about the likely benefits to be derived from head padding included a 0-40km/h (0-25mph) relevant speed range, a 2 AIS reduction in head and face injuries only, that most relevance would be at the lower injury levels, and that benefit would accrue from all front seat occupant contacts with the header rail and A-pillar.

KNEEBAR - Limited relevant data on injury mitigation for these units came from DeLays (1980) so the expert panel used these test results and knowledge from accident experience in arriving at their findings. Harm mitigation from the fitting of kneebars in cars is summarised in Tables 6.10 to 6.13. The benefit assumptions included a 0-64km/h (0-40mph) relevant speed range, an 80% relevance for all severity injuries, and a 2 AIS mitigation for lower extremity contacts with steering assembly, instrument panel, and the floor.

INTRUSION CONTROL - HARM benefits from reduced intrusions of the floor and toe pan and instrument panel are shown in Tables 6.12 and 6.13. Again, these benefits needed to be assessed by the expert panel as there was little quantitative information available to judge the likely injury savings from reduced intrusions.

The assumptions made included a 16 to 48km/h (10-30mph) relevant speed range for floor intrusions, a 32-80km/h (20-50mph) relevant speed range for instrument panel intrusions, and a 2 AIS benefit for lower leg injuries from these contacts. Relevance factors were judged to be higher for instrument panel than floor contacts.

6.3 SUMMARY OF DETAILED INJURY MITIGATIONS

Injury reductions varied for each countermeasure depending on the assigned body region and restraint condition relevance. There were no benefits claimed for upper extremity injuries to restrained occupants as the expert group felt that none of the measures evaluated here would reduce injuries to this particular body region.

The results of these individual analyses are summarised in Tables 6.14 and 6.15. The Total Harm savings for each countermeasure (in millions of A$ 1991) is shown in the second last line of each Table. These figures show the expected return in reduced trauma each year. For example, in Table 6.14, the Total Harm saved for a driver airbag is estimated to be $479million, that is, the installation of US style fullsize driver airbag as a supplementary restraint in all Australian passenger cars would lead to a reduction in vehicle occupant trauma of approximately 15%.

The Unit Harm (A$'s saved per car) on the last line of the Table is the Harm saved per vehicle based on a *discount method* of ascribing future benefits (this is described more fully in the next Chapter). In essence, the Unit Harm figure is the maximum cost allowable of fitting these devices into passenger cars to *"break-even"*, that is, for a Benefit-Cost-Ratio of 1.

Three Harm reductions were derived for facebag benefits because of the lack of a firm design concept and performance data. On balance, the expert panel considered that the likely Harm mitigation of units frequently discussed in the context of *"Eurobag"* would be nearer to those of the *minimum* benefits specified. However, for the purpose of this analysis, both the minimum and maximum benefit scenarios will be examined further.

6.4 GLOBAL INJURY MITIGATION CALCULATIONS

6.4.1 Seatbelt Warning Device

It was possible to use the more simple global method of calculating Harm for the benefits that would accrue from the seatbelt warning device, given that these devices had been in use in the USA in the early 1970's. However, care needed to be taken in not assuming the full benefits reported from this experience as the American version was a full ignition interlock [which ultimately led to its downfall] and seatbelt wearing rates were particularly low in the USA during this period.

Several studies have shown that the probability of death or serious injury in a crash can be reduced by 40% to 50% if a seatbelt is worn (eg, Campbell et al 1988; Zador and Ciccone 1991). Early experience in the USA during the 1970's showed that an ignition interlock which prevented a vehicle from being started unless the driver's (and when occupied) the front seat passenger's belt was fastened, was effective in increasing seatbelt usage rates by up to 80%. Difficulties, however, were experienced with this device in several emergency cases and the requirement for the device was subsequently repealed.

TABLE 6.14
SUMMARY OF HARM BENEFITS
FULLSIZE AIRBAG AND 3 FACEBAG SCENARIOS
A$ million

BODY REGION	DRIVER AIRBAG	PASSENGER AIRBAG	MAXIMUM FACEBAG	INTERMEDIATE FACEBAG	MINIMUM FACEBAG
HEAD - restrained	192.7	23.8	146.3	120.1	102.6
HEAD - unrestrained	56.5	20.6	47.5	34.5	28.3
CHEST - restrained	92.9	10	67.4	31.5	26.4
CHEST - unrestrained	19	6.2	14.2	4.3	3.7
ABDOMEN - restrained	9.1	1.2	6.9	0	0
ABDOMEN - unrestrained	7.5	3.2	5.6	0	0
FACE - restrained	70.5	1.5	52.8	44.6	42.6
FACE - unrestrained	19.9	2.5	14.9	10.3	7.8
UPPER EXT - unrestrained	7.6	4.8	5.7	2.7	1
REST. HARM ($million)	365	37	273	196	172
UNREST. HARM ($million)	111	37	88	52	41
TOTAL HARM ($million)	476	74	361	248	212
UNIT HARM ($ per car) (7% discount method)	515	80	391	268	230

TABLE 6.15
SUMMARY OF HARM BENEFITS FOR
OTHER THAN FACEBAGS AND AIRBAGS
A$ millions

BODY REGION	E-A WHEEL	BELT PRETEN. [shoulder]	BELT PRETEN. [seat]	BELT ANGLE+ SEATPAN	BELT WEBBING CLAMP	HEAD PADDING	KNEEBAR	INTRUSION CONTROL
HEAD - restrained	42.3	15.4	0	0	15.4	16.6	0	0
HEAD - unrestrained	9.9	0	0	0	0	0.4	0	0
CHEST - restrained	0	29.9	0	0	19.8	0	0	0
ABDOMEN - restrained	0	0	14.6	16.3	0	0	0	0
FACE - restrained	5.8	3.5	0	0	3.5	5.8	0	0
FACE - unrestrained	1	0	0	0	0	0.6	0	0
UPPER EXT - unrestrain.	0.5	0	0	0	0	0	0	0
THIGH/KNEE - restrained	0	0	28.1	36.9	0	0	93.7	0
THIGH/KNEE - unrestrain.	0	0	0	0	0	0	18.4	0
LOWER LEG - restrained	0	0	42.1	0	0	0	43.3	112.4
LOWER LEG - unrestrain.	0	0	0	0	0	0	10.2	27.6
REST. HARM ($million)	48	49	85	53	39	22	137	112
UNREST. HARM ($million)	11	0	0	0	0	1	29	28
TOTAL HARM ($million)	60	49	85	53	39	23	166	140
UNIT HARM ($'s per car) (7% discount method)	64	53	92	58	42	25	179	151

A warning device which would operate the 4-way emergency flasher system whenever the ignition was on and the driver or front seat passenger seatbelt was not in use is likely to increase usage rates of this belt, at least among drivers who are too lazy or forget to put to put their seatbelt on (ie, estimated to be about 40% of those who are still unrestrained).

Injury mitigation for this device, therefore, was based on the assumption of a 40% reduction in Harm for unrestrained front seat occupants but only a 40% relevance factor (as noted above, an 80% was experienced during the 1970's in the USA for the ignition interlock). When these factors are applied to the total Harm reduction of $607million for unrestrained drivers and front seat passengers in all crashes, an estimate of the Harm benefit is $97m with a Unit Harm saving of $115.00 per car.

This figure is based on savings for all crash configurations because of the use of global Harm assessment and overstates frontal benefits. However, its effect would be of benefit beyond frontal crashes and can be justified accordingly. These benefits, though, would need to be adjusted downward if the seatbelt warning device benefits are mitigated by other devices (eg; facebags) in any ultimate package of measures.

6.4.2 Reduced Vertical Column Intrusions

A 19% intrusion rate was observed in Fildes et al (1991) by vertical movement of the steering column in frontal crashes. In many instances, these movements far exceed the regulated distance for longitudinal intrusions in ADR 10/01.

There was no evidence readily available on the potential injury benefits for a 127mm maximum displacement distance vertically at 48km/h (30mph). However, the expert panel's best judgement was that head and face injuries could be reduced by 2 AIS especially at the higher impact speeds. This would lead to a total Harm saving of $58million or $62 per car.

6.4.3 Improved Lower Instrument Panels

Contacts with the lower regions of the instrument panel led Fildes et al (1991) to call for improvements in the type of materials used in this region to reduce injury and for dangerous protrusions to be eliminated.

Again, little information was available on what the likely injury mitigation effects of these improvements would be. However, it would be related to the benefits that would accrue from kneebars, albeit at a lesser benefit rate, given the difficulties of ensuring a uniform design and structure across vehicle models.

The expert panel considered that these benefits would be of the order of 50% of those possible with a knee bolster. Naturally, the need for greater attention to the lower dash area would be alleviated substantially if knee bolsters became standard fittings in Australian passenger cars.

Injury mitigation effects for this device, therefore, were based on this assumption (ie, 50% of the kneebolster Harm reduction) for both restrained and unrestrained vehicle occupants involved in frontal crashes. This results in an injury benefit estimate of $83 million or $90 per car.

7. BENEFIT AND COST COMPARISONS

This chapter integrates all the preceding information on countermeasure costs and benefits to provide likely benefit-cost comparisons with particular interest on those likely to produce BCR's greater than 1 that are suitable for immediate implementation. As there are several somewhat contentious issues surrounding this process, these need to be discussed fully along with the various assumptions made in the process and their consequences for BCR analysis.

7.1 DIFFERENT APPROACHES TO COSTING CRASHES

7.1.1 Human Capital Costs

Steadman and Bryan (1988) note that there are two basic approaches that exist on costing road crashes. The first can be called the ***Human Capital*** method (HC) where crash costs are derived historically from summary records of the costs involved in treatment, compensation and repair to the individuals involved and their property.

It should be noted that there are particular variants of this approach, as discussed more fully in Steadman and Bryan (1988) but these all involved issues of what should be included and relative worth, that is, they are all fundamentally based on what it actually costs society.

7.1.2 Willingness To Pay

The alternative method is the ***Willingness to Pay*** approach (WTP) where costs are determined from estimates of what the community are prepared to pay to avoid or reduce road crashes in future. This method makes no assumptions about the actual costs involved, other than where this information might be used by individuals as a basis for their willingness to pay assessments.

Parish (1991) argued that the WTP approach is typically based on theoretical welfare economics and would be the preferred method on purely theoretical grounds. However, he points out that reservations must be made about the means by which WTP estimates are made and their rationality. [He noted that in estimating willingness to pay values, there is considerable variation reported in the literature, because of the means used in eliciting these judgements]. Thus, he maintained that the HC method at this time is a more rational and appropriate means for governments to use in making policy decisions about road safety countermeasures.

What Parish did point out, though, was that the HC approach will result in relatively low values of life, compared with the WTP method. Miller et al (1988) too, argued for the need for governments to use more appropriate values of human life (5 to 9 times what the current practice is in the USA). He did note, however, that there were signs in some states in the USA of a movement towards using WTP approaches in countermeasure benefit-cost analysis.

7.1.3 Comment

The project submission called for this project to adopt HC values for injury reduction as specified in Steadman and Bryan (1988). Values derived from their adjusted income method were used in deriving the Australian body region by injury severity Harm matrix in Chapter 5, the basis for estimating Harm reductions per countermeasure. However, from the preceding discussion, it is obvious that these benefits will be at best conservative estimates and that these savings could at least double using WTP methods.

7.2 CALCULATION OF BENEFIT-COST RATIOS

There are a number of ways in which the Benefit-Cost Ratio (BCR) of a measure which is applied to only new vehicles can be calculated. The first method set out below was adopted for use in this project after consultation with Professor Parish and the Bureau of Transport and Communications Economics.

7.2.1 Discount Present Value Method

The discount present value method sums the average Harm attributed to the measure for one car over its life and then discounts the benefits in future years back to the present. For the purpose of this calculation, it is assumed that percentage of total Harm reduction for all cars of a certain age group is equal to the percentage of total relevant casualty crashes involving that age group. This is detailed further below:

$$\frac{H_1}{H} = \frac{F_1}{F} \qquad \text{or} \qquad H_1 = \frac{F_1}{F} \times H$$

Where H_1 = Harm reduction for all cars in their first year

H = total Harm reduction for all cars in one year

F_1 = number of cars involved in casualty crashes in first year

F = total number of cars involved in casualty crashes in one year

Note: Both F_1 and F have been derived from frequency distributions of crashed cars involving fatal, hospitalised, and medically treated occupants, weighted according to their average cost at each severity level. First year means in the calendar year in which the vehicle was manufactured. For instance, a car showing 12/89 on its compliance plate as its date of manufacture would be in its first year for less than one month.

Then, the average Harm reduction for any one car in its first year would be:

$$\frac{H_1}{V_1} \qquad \text{where } V_1 = \text{number of new cars registered that year.}$$

The total benefit B attributed to the measure for one car is then obtained by adding up the Harm reduction in each year of its life, discounted back to the first year. [No discount is applied back to the first year because both the costs and benefits accrue progressively during the year].

$$B = \frac{H_1}{V_1} + \frac{H_2}{V_2[1+d]} + \frac{H_3}{V_3[1+d]^2} + \cdots\cdots\cdot \frac{H_n}{V_n[1+d]^{n-1}}$$

Where H_n = reduction in Harm by the measure for cars in their nth year

V_n = number of new cars registered n years ago

d = discount rate (.07 equals 7%)

It should be noted that this calculation assumes that the involvement rate in three years time of cars which were new this year can be estimated by the involvement rate of three year old cars this year [where involvement rate is measured as crashes per thousand new cars originally registered three years ago]. This allows for scrapping some cars each year and for the fact that as new vehicles become older, their crash involvement rate may be different to that when new.

Then, if the economic cost of the measure is $C per car, the Benefit-Cost-Ratio is:

$$BCR = \frac{1}{C}\left[\frac{H_1}{V_1} + \frac{H_2}{V_2[1+d]} + \frac{H_3}{V_3[1+d]^2} + \cdots\cdots \frac{H_n}{V_n[1+d]^{n-1}}\right]$$

This equation can be simplified to:

$$BCR = \frac{H}{C.V}\left[\frac{f_1}{v_1} + \frac{f_2}{v_2[1+d]} + \frac{f_3}{v_3[1+d]^2} + \cdots\cdots \frac{f_n}{v_n[1+d]^{n-1}}\right]$$

Where $f_n = \frac{F_n}{F}$ = proportion of total crashes involving cars in their nth year

$v_n = \frac{V_n}{V}$ = correction factor for new car registrations "n" years ago

V = average number of new cars registered per annum over the past 15 years [this was the best estimate of the number of new registrations per annum necessary to produce the current fleet mix on which the Harm reduction calculations is based].

C = the economic cost [the retail cost of the measure at present day prices but excluding import duty and sales tax].

Table 7.1 shows the number and percentages of cars in which an occupant was either killed or injured from one to 25 years old, and the cumulative percentage. It is interesting to note that the total number of new cars registered during the past 25 years [12.95million] is considerably greater than the number estimated in the fleet today [8.4million].

TABLE 7.1
NUMBERS AND PERCENTAGES OF CARS CONTAINING OCCUPANT CASUALTIES IN AUSTRALIAN STATES BETWEEN 1965 AND 1990

DF=1.07	Cars with Killed or Injured Occs.			New Registrations		Discounted
	Raw Total		Cum.		Relative	Cum. Factor
Car Age	(4 States)	Percent	Percent	Number	to Av.	Percent
26 & Above	589	0.70%	100.00%			
25	239	0.28%	99.30%	378816	0.71	57.97%
24	272	0.32%	99.02%	365844	0.69	57.90%
23	373	0.44%	98.70%	369447	0.69	57.81%
22	613	0.72%	98.26%	402955	0.76	57.67%
21	815	0.96%	97.53%	437278	0.82	57.46%
20	1163	1.37%	96.57%	461443	0.87	57.17%
19	1611	1.90%	95.20%	470873	0.88	56.76%
18	2047	2.42%	93.29%	470709	0.88	56.17%
17	2307	2.73%	90.87%	500906	0.94	55.36%
16	3067	3.62%	88.15%	542856	1.02	54.44%
15	3899	4.61%	84.52%	551400	1.03	53.23%
14	4162	4.92%	79.92%	536433	1.01	51.62%
13	4401	5.20%	75.00%	535054	1.00	49.72%
12	4405	5.21%	69.80%	518697	0.97	47.57%
11	4694	5.55%	64.59%	537112	1.01	45.19%
10	4928	5.82%	59.04%	525945	0.99	42.58%
9	4731	5.59%	53.22%	547352	1.03	39.58%
8	4933	5.83%	47.63%	571299	1.07	36.61%
7	4921	5.82%	41.80%	549569	1.03	33.45%
6	4747	5.61%	35.98%	553937	1.04	29.93%
5	5412	6.40%	30.37%	610982	1.15	26.34%
4	5267	6.22%	23.98%	556125	1.04	22.36%
3	4473	5.29%	17.75%	428708	0.80	17.80%
2	3996	4.72%	12.46%	432316	0.81	12.44%
1	4614	5.45%	7.74%	520243	0.98	7.35%
0	1937	2.29%	2.29%	574256	1.08	2.13%
Total	84616	100.00%		12950553		
	Av. New Regs. p.a. (last 15 years)			533202		

The last column shows that the cumulative sum of the terms $\dfrac{f_n}{v_n(1.07)^{n-1}}$ using a discount rate of 7% (the value recommended by the Commonwealth Treasury) equals 0.5768 after 25 years.

DISCOUNT RATE - Selection of an appropriate discount rate is really a matter of opinion [there is no magic number]. The Commonwealth Treasury uses 7% which is around the long-term bond rate, minus a little for inflation. Other state governments, however, choose different values [the Victorian Government, for instance, use 4%. A smaller discount rate gives greater weight to benefits received in the distance future.

It should be noted that the choice of the discount rate has a marked effect on the calculation. Not only does it influence the BCR, but also the cost of injury [Steadman and Bryan 1988 used a 7% discount rate in determining the cost of injury for each injury severity level and noted that a 4% rate would increase the cost of injury overall by 17%].

7.2.2 Equilibrium Method

An alternative approach used by the US Federal Government titled the "***equilibrium***" method simply assumes that an equilibrium state has been reached where the device is fitted to all vehicles in the fleet. At this stage, the benefit equals the total Harm reduction resulting from the measure for all cars (in one year) and the on-going cost is the annual cost of fitting the new vehicles each year. The BCR is determined by:

$$BCR = \frac{H}{C \times V}$$

This method yields results which are 1.734 [1/.577] higher than those calculated by the Discounted Present Value method with a 7% discount rate. It was considered not suitable for this analysis, though, as it does not take into account the difference in time when the costs of the measure are initially incurred (as the measure was progressively introduced into the car fleet) and the time when the benefits accrue.

The equilibrium method is used by the National Highway Traffic Safety Administration in the USA for cost-benefit analysis (Kahane 1981; NHTSA 1983). They argue that it is appropriate because it places value on the benefits for all future generations for simply an annual maintenance cost. As this method does not discount future benefits, it also does not reduce future costs resulting from improvements in design, technology, and productivity.

Furthermore, they claim that the DPV method [with a 7% discount rate] fails to take into account the long-term associated Harm benefits [investments in protecting the ozone layer or in disposing of radioactive waste, which have extremely long-term Harm benefits, could never be justified without equilibrium assumptions].

7.2.3 Comment

It is worth noting that the difference in outcome using both methods is substantial; Benefit Cost Ratios derived using the discount present value method are only 58% of the values computed using the equilibrium method.

Thus, adopting this method has again led to a more conservative assessment of the cost-benefits of the various vehicle safety measures than would be the case elsewhere. It should be noted, though, that the differential between the two methods would be substantially less if a discount rate less than 7% were used.

7.3 APPROPRIATE COUNTERMEASURE COST

Parish (1991b) describes the rationale for choosing the appropriate cost for each countermeasure under consideration. In essence, he maintains that in calculating the cost of each countermeasure, the "***economic cost***" should be used, comprising the retail price less sales tax and duty.

7.4 BENEFIT-COST-RATIO RESULTS

Tables 7.2 and 7.3 show the summaries of the cost and benefit calculations for each of the countermeasures included in this feasibility study.

The first column shows the manufacture's retail costs (or ranges of costs) for each countermeasure which were provided by the automotive industry where available. Column 2 lists the best estimate of retail costs derived by the study team, based on various sources of information. The background to these figures was documented in detail in Chapter 4.

Column 3 shows the "*economic cost*" for each measure which is effectively the net value of column 2, that is, the retail price minus duty (where relevant) and sales tax. It was argued above that this was the appropriate cost to use for benefit-cost analysis. Column 4 is the annual Harm reduction figure per car discounted to present day values that was computed for each countermeasure in Chapter 6. The Benefit-Cost Ratio was calculated simply by dividing the annual Harm per car in column 4 by the economic cost in column 3 as is listed in the final column of the Tables. The final column lists the likely Benefit-Cost Ratio outcome for each countermeasure.

It should be noted that there is likely to be some statistical variance in these figures, given the amount of estimation necessary in deriving many of the benefits and costs. This is not uncommon in these economic exercises and should not be interpreted as degrading the value of these indicators in guiding implementation decisions. Rather, they may need further refinement in the light of additional information becoming available.

The following ranking of countermeasures in terms of their likely Benefit-Cost-Ratio was obtained from Tables 7.2 and 7.3 where those likely to return a BCR equal to or greater than 1 are shown above the cut-off line.

. improved seatbelt geometry & seats (7.3)
. energy absorbing steering wheel (3.2 - 16.0)
. seatbelt warning device (4.1 - 7.2)
. knee bolsters (2.9 - 4.3)
- - - - - - - - - highly beneficial [BCR > 3] - - - - - - - - - -
. improved lower instrument panels (1.8 - 18.0)
. electro-mechanical fullsize driver airbags (1.2)
. seatbelt webbing clamps (1.1 - 3.5)
. seat attached seatbelt pretensioners (0.8 - 1.1)
- - - - - - - - - break even [BCR = 1] - - - - - - - - - - - - -

TABLE 7.2

COST AND BENEFIT SUMMARY FOR AIRBAGS AND FACEBAGS

ITEM	MANUFACTURER'S COSTS	BEST ESTIMATE RETAIL PRICE	ECONOMIC COST (1)	UNIT HARM (2) [$'s per car]	LIKELY BCR OUTCOME
FULLSIZE DRIVER AIRBAG [Electronic sensors]	$500 - $2500 (3)	$800 approx (4)	$665 approx	$515	0.77
FULLSIZE DRIVER AIRBAG [Electro-Mechanical sensors]		$528 (5)	$440	$508 (8)	1.15
FULLSIZE PASSENGER AIRBAG [In conjunction with driver airbag] [Electro-Mechanical sensors]	$500 plus (7)	$528 (5)	$440	$80	0.18
DRIVER FACEBAG - MAXIMUM BENEFITS [Electro-Mechanical sensors]	$470 - $3200 (6)	$478 (5)	$400	$391	0.98
DRIVER FACEBAG - MINIMUM BENEFITS [Electro-Mechanical sensors]	$470 - $3200 (6)	$478 (5)	$400	$230	0.58

NOTES:
1. Economic cost equals Ernst & Youngs estimate of consumer cost minus sales tax and less duty on any imported items
2. Harm reduction is the estimated safety benefit per vehicle over its life (discounted to present day values)
3. Various control systems used varying from simple to multi-sensors involving mechanical, electronic or electro-mech.
4. Electronic control multi-sensor systems could add up to $250 [Ernst & Young Consultants]
5. Price based on a weighted mean of the 8 Plan Production models using 1990 sales volumes listed in Paxus
6. Features of systems not specified
7. The additional cost of adding a passenger airbag to a driver airbag - features of the system not specified
8. Harm mitigation reduced by 2% for the fullsize electro-mechanical airbag to account for occasional non-firing

TABLE 7.3
COST AND BENEFIT SUMMARY FOR NON-AIRBAG COUNTERMEASURES

ITEM	MANUFACTURER'S COSTS	BEST ESTIMATE RETAIL PRICE	ECONOMIC COST (1)	UNIT HARM (2) [$'s per car]	LIKELY BCR OUTCOME
SEATBELT PRETENSIONER (Seat)	$140 - $230	$100 - $140	$85 - $115	$92	0.8 - 1.1
SEATBELT PRETENSIONER (Shoulder)	n.a.	> $140	> $115	$53	0.5
SEATBELT WEBBING CLAMP	$30 - $150	$15 (basic) - $50 (delux)	$12 - $42	$42	1.1 - 3.5
IMPROVED BELT GEOMETRY & SEATS	$50 - $70	$ marginal ($10)	$ marginal ($8)	$58	7.3
SEATBELT WARNING DEVICE	$50 - $80	$20 (basic) - $35 (delux)	$16 - $28	$115	4.1 - 7.2
E-A PADDED WHEEL	n.a.	$5 - $25	$4 - $20	$64	3.2 - 16.0
VERTICAL & LATERAL COLUMN INTRUSIONS	n.a.	n.a.	n.a.	$62	unknown
PADDED UPPER AREAS	n.a.	$70 - $100	$60 - $83	$25	0.3 - 0.4
IMPROVED LOWER PANELS	n.a.	$6 - $60	$5 - $50	$90	1.8 - 18.0
KNEE BOLSTERS	n.a.	$50 - $75	$42 - $62	$179	2.9 - 4.3
REDUCED FLOOR & TOEPAN INTRUSIONS	n.a.	n.a.	n.a.	$151	unknown

NOTES: 1. Economic cost equals Ernst & Youngs estimate of consumer cost minus sales tax and less duty on any imported items
2. Harm reduction is the estimated safety benefit per vehicle over its life (discounted to present day values)

- - - - - - - - - break even [BCR = 1] - - - - - - - - - - - - -

. *maximum* driver facebags (0.9)
. electronic fullsize driver airbags (0.8)
. *minimum* driver facebags (0.6)
. shoulder seatbelt pretensioners (0.5)
. padded upper areas (0.3 - 0.4)
. fullsize passenger airbags (0.2)

7.5 NET PRESENT WORTH

It is customary when considering which safety measures should be adopted to consider both the Benefit Cost Ratio and the Net Present Worth (defined as benefit minus cost, expressed in present day values) of each proposed countermeasure.

The Net Present Worth of applying the countermeasures to all new cars in one year is shown in Table 7.4. The NPW for one car has been calculated from the benefits and costs listed in Tables 7.2 and 7.3 by subtracting the economic cost (column 3) from the break-even cost (column 4 - Harm reduction for the countermeasure per car over its life, discounted to present day values). The NPW for all new cars registered in one year is calculated by multiplying the NPW for one car by 533,202 (the average number of new cars registered p.a.).

The following ranking of countermeasures in terms of their Net Present Worth was obtained from Table 7.4. Those likely to return a positive NPW are shown above the cut-off line.

. knee bolsters ($62 to 73 million)
. seatbelt warning device ($46 to 53 million)
. electro-mechanical fullsize driver airbags ($36 million)
. improved lower instrument panels ($21 to 45 million)
. energy absorbing steering wheel (S23 to 32 million)
. improved seatbelt geometry & seats ($27 million)
. seatbelt webbing clamps ($0 - 16 million)
. seat attached seatbelt pretensioner (-$12 to 4 million)

- - - - - - - - - cut-off line [NPW = 0] - - - - - - - - - -

. *maximum* driver facebags (-$5 million)
. padded upper areas (-S19 to -31 million)
. shoulder seatbelt pretensioner (-$33 million)
. electronic fullsize driver airbags (-$80 million)
. *minimum* driver facebags (-$91 million)
. fullsize passenger airbags (-$192 million)

7.6 PERCENT OF VEHICLE OCCUPANT TRAUMA SAVED

The final analysis undertaken was to express the potential injury savings (Harm) of each countermeasure as a percentage of the total Harm attributed to vehicle occupant road trauma each year. It should be noted that the total Harm figures (in $'s million) listed for each measure in Chapter 6 are, in fact, estimates of the total cost savings to the community from the introduction of that measure, assuming that these devices are fitted to the whole vehicle fleet.

TABLE 7.4

BCR, NET PRESENT WORTH & PERCENT TOTAL HARM FOR COUNTERMEASURE BENEFITS

ITEM	LIKELY BCR OUTCOME	LIKELY NPW OUTCOME	PERCENT REDUCTION VEHICLE TRAUMA
FULLSIZE DRIVER AIRBAG (electronic)	0.77	-$80 million	15.1%
FULLSIZE DRIVER AIRBAG (electro-mech)	1.15	$36 million	14.9%
FULLSIZE PASSENGER AIRBAG (electro-mech)	0.18	-$192 million	2.4%
MAXIMUM FACEBAG (electro-mech)	0.98	-$5 million	11.5%
MINIMUM FACEBAG (electro-mech)	0.58	-$91 million	6.8%
SEATBELT PRETENSIONER (Seat)	0.8 - 1.1	-$12 to $4 million	2.7%
SEATBELT PRETENSIONER (Shoulder)	0.46	-$33 million	1.6%
SEATBELT WEBBING CLAMP	1.1 - 3.5	$0 to $16 million	1.2%
IMPROVED BELT GEOMETRY & SEATS	7.30	$27 million	1.7%
SEATBELT WARNING DEVICE	4.1 - 7.2	$46 to $53 million	3.4%
ENERGY ABSORBING WHEEL	3.2 - 16.0	$23 to $32 million	1.9%
VERTICAL & LATERAL COLUMN INTRUSIONS	unknown	unknown	1.8%
PADDED UPPER AREAS	0.3 - 0.4	-$19 to -$31 million	0.7%
IMPROVED LOWER PANELS	1.8 - 18.0	$21 to $45 million	2.6%
KNEE BOLSTERS	2.9 - 4.3	$62 to $73 million	5.3%
REDUCED FLOOR & TOEPAN INTRUSIONS	unknown	unknown	4.4%

Hence, the proportion of Harm saved can be expressed as:

$$\text{Harm saved} = \frac{\text{Annual Harm from measure}}{\text{Total Vehicle Occupant Trauma}}$$

and is an expression of the relative worth of a particular measure in terms of its potential savings in reduced vehicle occupant trauma each year to society [$3.143 billion from Table 5.4 in Chapter 5]. Table 7.4 also shows the proportion of total vehicle occupant trauma likely to be saved by each measure.

7.6.1 Countermeasure Ranking by Vehicle Occupant Trauma Saved

The following ranking of countermeasures in terms of their likely reduction in vehicle occupant trauma was obtained from Table 7.4.

. electronic fullsize driver airbag (15.1%)
. electro-mechanical fullsize driver airbag (14.9%)
. *maximum* driver facebag (11.5%)
. *minimum* driver facebag (6.8%)
. knee bolsters (5.3%)
. reduced floor & toepan intrusions (4.4%)
. seatbelt warning device (3.4%)
. seat attached seatbelt pretensioner (2.7%)
. improved lower instrument panels (2.6%)
. fullsize passenger airbag (2.4%)
. energy absorbing steering wheel (1.9%)
. vertical & lateral column intrusions (1.8%)
. improved seatbelt geometry & seats (1.7%)
. shoulder seatbelt pretensioner (1.6%))
. seatbelt webbing clamps (1.2%)
. padded upper areas (0.7%)

8. DISCUSSION AND CONCLUSIONS

The last chapter elaborates on the total potential benefits to the community from the introduction of these measures and describes further desirable packages of measures aimed at mitigating injury to vehicle occupants.

It addresses some of the critical issues and limitations raised throughout this report and concludes with a recommendation for the introduction of additional safety performance regulations to ensure that the more promising of these measures become standard features on passenger cars sold in this country. It is important to stress that the calculations of percent trauma saved are based on the assumption that the whole vehicle fleet is fitted with these measures.

8.1 MEASURES WORTHY OF IMMEDIATE CONSIDERATION

Three indicators were used in the previous chapter to arrive at rankings of the value of the nominated vehicle safety measures, namely Benefit Cost Ratio [BCR], Net Present Worth [NPW] and Percent of Vehicle Occupant Trauma saved. These are *complementary* indicators which show the value of these measures using somewhat different selection criteria.

This report does not attempt to nominate which of these criteria is more appropriate for government decision making, but rather presents the value for each. Clearly, any measure which ranks highly with all three would seem to be highly desirable for immediate introduction. Table 8.1 compares the three sets of rankings of these measures.

8.1.1 Knee Bolsters

Knee bolsters were shown to be of considerable worth in terms of their BCR [Moderate: 2.9 to 4.3], Net Present Worth [High: $62 to 73 million], and % trauma saved [5.3% vehicle occupant trauma]. This is because of the high number of lower limb injuries presently sustained by front seat occupants in frontal crashes and the relatively expensive treatment costs associated with these injuries.

8.1.2 Seatbelt Warning Device

There are considerable benefits still to be gained from increased seatbelt wearing rates for front seat occupants. There is a considerable body of evidence that shows that the probability of death or serious injury will be reduced by 40% to 50% if front seat occupants are properly restrained. A simple modification that ensures that the 4-way hazard flasher system (or other visible and auditory warning device) operates if a seated occupant is unbelted with a running engine would result in a Moderate to High BCR [4.1 to 7.2], a High NPW [$46 to $53 million] and would lead to a 3.4% reduction in vehicle occupant trauma.

8.1.3 Energy-Absorbing Steering Wheel

Energy-Absorbing (padded) steering wheels are being introduced by some manufacturers overseas, predominantly in the UK and Sweden. They are of considerable benefit in reducing mainly face injuries from contacts with the steering wheel at relatively low impact speeds. The results show that this measure would return a Moderate to High BCR [3.2 to 16], would produce a Moderate NPW [$23 to 32 million] and would reduce occupant trauma by 1.9%.

TABLE 8.1
RANKINGS OBTAINED USING THE 3 ECONOMIC INDICATORS

BCR	NPW	% TRAUMA SAVED
belt geometry & seats	knee bolster	fullsize airbag (E)
E-A steering wheel	seatbelt warning device	fullsize bag (E/M)
seatbelt warning device	fullsize airbag (E/M)	maximum facebag
knee bolster	lower instrument panels	minimum facebag
- - - - highly beneficial - - - -	- - - - highly beneficial - - - -	knee bolster
lower instrument panels	E-A steering wheel	reduced intrusions
fullsize airbag (E/M)	belt geometry & seats	seatbelt warning device
webbing clamp	webbing clamps	seat pretensioner
seat pretensioner	seat pretensioner	lower instrument panel
- - - - - break even - - - - - -	- - - - - break even - - - - -	passenger airbag
maximum facebag	maximum facebag	E-A steering wheel
fullsize airbags (E)	padded upper areas	vert & lat column
minimum facebag	shoulder pretensioner	belt geometry & seats
shoulder pretensioner	fullsize airbag (E)	shoulder pretensioner
padded upper areas	minimum facebag	webbing clamps
passenger airbags	passenger airbags	padded upper area

8.1.4 Driver Airbags

A number of different airbag options were highlighted during the course of this study. However, the benefits of a fullsize (US style) airbag far outweighed those of the facebag currently being developed in Europe. Given that these measures would be used as *supplementary* restraints [to the seatbelt], there is, however, less need for a full electronic sensing system as is current practice in most US *passive* airbag systems. If all new Australian vehicles had a fullsize airbag fitted for the driver, this would result ultimately in a 15% reduction in vehicle occupant trauma. Moreover, it would be cost-beneficial [BCR = 1.2 with electro-mechanical single sensors], and accrue a Moderate NPW value of $36million.

8.1.5 Improved Lower Instrument Panels

While knee bolsters would go some of the way to alleviating injuries to the lower limbs, there would still be worthwhile benefits in improving the structure, materials, and layout of the lower instrument panel. On its own, this would lead to a Moderate BCR [1.8 to 18], a High NPW [$21 to 45 million], and would result in a reduction in vehicle occupant trauma of 2.6%.

8.1.6 Improved Seatbelt Geometry & Seats

Improved seatbelt geometry was called for to reduce the instances of submarining under the seatbelt for front seat occupants. This could be achieved by attaching the lower belt supports to the seat frame and providing a more inclined and robust seat pan. These improvements would result in a High BCR [around 7.3], a Moderate NPW of $27 million, and would lead to a 1.7% reduction in vehicle occupant trauma.

8.1.7 Webbing Clamps

Webbing clamps which clasp the belt on impact and reduce the amount of seatbelt slack are relatively cheap devices that offer some chest protection from the steering wheel for restrained drivers and head, face and chest benefits for restrained front seat passengers. The analysis showed that they are likely to be cost-beneficial [BCR 1.1 to 3.5], produce a modest NPW of $0 to 16 million, and reduce vehicle occupant trauma by 1.2%.

8.1.8 Pretensioners (Seat Attached)

There are at least two different types of seatbelt pretensioners used overseas. One is a pyrotechnic devices that attaches to the inertia-reel and winds in the slack on impact, the other a mechanical device that replace the fixed seatbelt stalk and pull down the buckle thereby tightening the lap section of the belt around the occupant's pelvis with some minor tightening of the torso section.

Because of the large number of abdominal and thigh/knee injuries sustained by restrained front seat occupants, seat attached pretensioners would be close to cost-beneficial [BCR = 0.8 to 1.1], would result in around break-even NPW, and reduce vehicle occupant trauma by 2.7%. Hence, a small reduction in the cost of these units would make the device economically worthwhile.

8.2 LOWER PRIORITY COUNTERMEASURES

There were a number of measures that with today's costs and technology did not produce benefit cost ratios above unity. Some of these, however, would still lead to significant injury benefits and hence, sizable reductions in vehicle occupant trauma and should not be dismissed easily.

8.2.1 Facebag

Some European manufacturers and administrators are convinced that the facebag is a viable countermeasure for head and face contacts with the steering wheel for restrained drivers. Unfortunately, though, it was difficult to specify the protective performance of the facebag given the general lack of published information of its potential for injury mitigation. [The fullsize US airbag has accumulated more than 15 years experience of injury testing and real world crash experience, hence it was easier to specify its likely benefits].

Various injury reduction scenarios were employed to use as a basis for this analysis. The *maximum* scenario assumed that facebags would be 75% as effective as fullsize airbags and would provide a reduced restraining benefit for unrestrained drivers. Using this scenario, the facebag BCR would be close to unity [BCR = 0.89], would result in close to a break-even NPW but would yield an 11.5% reduction in vehicle occupant trauma.

The *minimum* scenario assumed **that** the facebag would only provide injury mitigations from contacts with the steering wheel and could not offer a restraint benefit for unrestrained occupants. Using these criteria, the facebag would not be cost-beneficial [BCR = .58], would therefore produce a negative NPW [-$91 million] although it would reduce vehicle occupant trauma by a sizable 6.8%.

Given the lack of performance information available at the time of this analysis, the expert panel were forced to conclude that only *minimum* benefits would accrue for these units. Clearly, facebags should be subject to further review when more information becomes available on their likely effectiveness and cost. Moreover, there might still be some worth in considering facebags as part of a package of measures aimed at improving occupant protection for drivers. It should be stressed, though, that facebags do not appear to offer the same level of protection [especially to unrestrained drivers] that the fullsize US airbag does and their costs do not appear to be substantially lower for single sensor electro-mechanical supplementary restraining units.

8.2.2 Padded Upper Areas

The US Congress has just passed a law requiring NHTSA to publish a rule on head protective padding for US passenger cars. The fact that this measure failed to be cost-beneficial in this analysis [BCR=.30 to .40, NPW = -$19 to 31m] is interesting and needs further clarification. It might be because of differences in the injury patterns between the two countries or possibly because of the higher wearing rate of seatbelts observed in Australia, or merely the difference in estimated costs for the treatment. Additional research is warranted to help clarify this discrepancy and hence the worthiness of the measure.

8.2.3 Passenger Airbags

Passenger side airbags failed to be cost-beneficial because of less frequent use of the front passenger seat relative to the driving position and the relatively high costs associated with these units currently [BCR=.18, NPW = -$192million]. There is no doubt, though, that these units would lead to substantial injury benefits for both restrained and unrestrained front seat passengers and potentially would lead to a further 2.4% reduction in vehicle occupant trauma. It would be worth monitoring experience with these units in the USA as they become more readily available and, hence, cheaper to produce.

8.2.4 Shoulder Pretensioners

As noted earlier, these units tend to be relatively more expensive than webbing clamps and offer mainly chest injury reductions to restrained front seat occupants [current evidence suggests that they are less able to offer abdominal protection than seat pretensioners]. As a result, they were not cost-beneficial [BCR=.46], would yield a negative NPW of -$33 million, and would produce a 1.2% reduction in vehicle occupant trauma.

8.3 MEASURES OF UNKNOWN ECONOMIC WORTH

It was not possible to obtain (or estimate) costs for reduced vertical and lateral column intrusions and for reduced floor intrusions as it was less clear what structural changes were necessary and it would be very much dependent on the design and type of vehicle involved. However, it is worth noting that these two measures have the potential for a reduction in Harm of approximately $200million each year which would lead to a 6% saving in vehicle occupant trauma. They should not be overlooked, therefore, in efforts aimed at improving occupant protection.

TABLE 8.2
COUNTERMEASURE PACKAGE BCR'S, NPW'S and % TRAUMA SAVED

COUNTERMEASURE PACKAGES	ECONOMIC COST	UNIT HARM BENEFITS	LIKELY BCR	LIKELY NPW	VEHICLE TRAUMA SAVED
PACKAGE 1 - FULLSIZE AIRBAG FULLSIZE DRIVER AIRBAG (electro-mechanical) ENERGY ABSORBING STEERING WHEEL SEAT PRETENSIONER (front passenger only) WEBBING CLAMP (front passenger only) SEATBELT GEOMETRY & SEATS KNEE BOLSTERS	$543 - $608	$858	1.4 - 1.6	$133 - 168 million	25%
PACKAGE 2 - DRIVER FACEBAG DRIVER FACEBAG (Minimum & Maximum Benefits) ENERGY ABSORBING STEERING WHEEL SEAT PRETENSIONER (front passenger only) WEBBING CLAMP (front passenger only) SEATBELT GEOMETRY & SEATS KNEE BOLSTERS SEATBELT WARNING DEVICE	$519 - $596	$695 MIN $792 MAX	1.2 - 1.3 MIN 1.3 - 1.5 MAX	$53 - 94 million $105 - 146 million	20% MIN 23% MAX
PACKAGE 3 - NO AIRBAG ENERGY ABSORBING STEERING WHEEL SEAT PRETENSIONER (front seat occupants) WEBBING CLAMP (front seat occupants) SEATBELT GEOMETRY & SEATS KNEE BOLSTERS SEATBELT WARNING DEVICE	$167 - $275	$568	2.1 - 3.4	$156 - 214 million	17%

8.4 COUNTERMEASURE PACKAGES AND THEIR BENEFITS

Chapter 2 listed the various vehicle safety measures for detailed consideration in this report and initial consideration of what might constitute suitable countermeasure packages for inclusion in modern vehicles. This is extended further here by describing *three* countermeasure package options to enhance vehicle occupant safety. These are summarised in Table 8.2.

8.4.1 Package 1 - Driver Airbag Option

The first countermeasure package to be considered is based around provision of a fullsize airbag for the driver offering supplementary restraint benefits for restrained and passive restraint benefits for unrestrained drivers. In addition, a knee bolster for increased leg protection and an energy-absorbing (E-A) steering wheel to reduce head injuries in low speed impacts [when the airbag does not deploy] should also be included.

It should be noted that the basic TRRL energy-absorbing steering wheel has substantial padding around the hub which cannot be maintained if an airbag is fitted to this region. Thus, some mitigation benefits will be foregone as a package, although this is unlikely to degrade its performance much for low speed contacts.

To improve occupant protection for front seat passengers, a seat pretensioner and a webbing clamp on the inertia reel unit are also envisaged as is a better design seat and improved seatbelt geometry by attachment of the out-board seatbelt anchorages on the seat.

Costs for the installation of only a single set of webbing clamps and seat pretensioner were assumed to be half the cost for a pair (summarised in Table 7.3). It is unlikely that a manufacturer would only fit a single set of units in a normal production run. Nevertheless, it was not appropriate here to include a cost per pair for only a single benefit as manufacturing decisions should not enter this benefit cost analysis.

This package of measures would provide a moderate cost-benefit ratio [BCR=1.4 to 1.6], a high Net Present Worth [NPW = $133 to $168 million], and importantly, would result in a 25% reduction in vehicle occupant trauma.

8.4.2 Package 2 - Driver Facebag (Minimum) Option

The second package of measures is founded on the provision of a driver facebag as an alternative to the fullsize airbag in Option 1. It was noted earlier that this seems to be the preferred approach currently by some European manufacturers and government agencies where they also experience high seatbelt wearing levels similar to Australia. While both minimum and maximum facebag injury reductions have been included in this analysis, it is assumed that the package will essentially provide *minimum* benefits for reasons previously elaborated.

This package also includes knee bolsters, a seat pretensioner and webbing clamp for the front seat passenger, and better designed seats and seatbelt geometry for both front seat occupants as in the previous package. However, given the lack of benefit provided by the facebag for unrestrained drivers, a seatbelt warning device would also be necessary to maximise occupant protection for this package.

This second minimum facebag package of measures would also be cost-beneficial [BCR=1.2 to 1.3], would return a High to Nominal Net Present Worth [NPW =$53 to $94 million], and lead to a 20% reduction in vehicle occupant trauma.

8.4.3 Package 3 - No-Airbag Option

A third option for countermeasure packages includes an energy-absorbing steering wheel, seat pretensioners and inertia reel webbing clamps for both front seat occupants, better seat and seatbelt geometry, as well as a knee bolster and seatbelt warning device. This package looks at vehicle occupant protection without the use of airbags, taking up other known cost-beneficial measures.

Recent testing by the Federal Office of Road Safety (Seyer 1992) suggested that the energy-absorbing steering wheel, in conjunction with webbing clamps and seat pretensioners, was likely to produce a marked reduction in head injuries for occupants in frontal crashes (approximately 40% reduction in Head Injury Criteria was observed in a driver dummy during a 48km/h frontal barrier crash test). On this basis, a 2 AIS injury reduction seems appropriate for head injury mitigation with this combination of measures.

The improvement noted was based on tuning the restraint system for one type of crash condition. While it is acknowledged that a full restraint optimisation program would normally consider other crash conditions likely to occur in the real world, the actual injury mitigation potential for the full range of real world crashes may be different and will vary for individual occupant sizes, seat adjustment positions and vehicle models.

This package of measures was the cheapest option considered here [$164 to $242 total per car] yet still returned a moderate BCR [2.1 to 3.4] and a high NPW [$156 to $214million]. Importantly, though, Package 3 would only produce a 17% reduction in vehicle occupant trauma [some $314million less Harm reduction annually than Option 1].

8.4.4 Package Comments

From the preceding discussion, it is evident that varying degrees of improved occupant protection were associated with varying community costs and returns. Option 1 [fullsize airbag option] offered the greatest potential for reducing trauma where 25% of vehicle occupant injuries could be reduced if this package of measures were to be introduced. Indeed, this would be a significant reduction [about a 14% drop in road trauma overall] and like seatbelt wearing was, would be seen in the years ahead as a major milestone in road safety improvement.

Options 2 and 3 would also lead to substantial reductions in road trauma too, albeit not as marked as the first option. Importantly, though, two of the three option packages were clearly cost-beneficial [the third was only around break-even] and selection of a preferred package, therefore, needs to take other factors into account. Naturally, adopting any one of the three options listed above as a vehicle safety [and indeed road safety] priority should not preclude the inclusion of other measures such as improved lower panel materials and/or structure, vertical column intrusions, and structural improvement to the floor and toe pan area being also considered.

8.5 STRENGTHS & LIMITATIONS OF THESE FINDINGS

Clearly, the strength of the findings reported here lie in their objectivity and are enhanced by adoption of traditional economic analysis in arriving at these findings. As noted earlier, the Harm assessment procedure used for calculating injury mitigation benefits was something of a first and proved to be an extremely powerful and valuable tool for this analysis. There were, however, a number of questions raised in this report [predominantly involving the conservative nature of the assessment] and other relevant issues that need to be reviewed.

8.5.1 Injury Savings Using HC and WTP

The project specification noted the desirability of making injury assessments using both the Human Capital and Willingness To Pay approaches. As noted earlier, while there is some debate about the suitability of willingness to pay as a legitimate economic approach for assessing community benefits, it is, nevertheless, being used in other countries for this purpose and its acceptance seems to be slowly gaining momentum world-wide.

As the willingness to pay method gives much higher values to human life than does the human capital approach, the resultant BCR and NPW values listed in this report would be larger [and other measures would have produced BCR's greater than 1] if the willingness to pay approach had been adopted.

8.5.2 Discount Rate

The Federal Treasury typically use a figure of 7% for the discounting rate when computing proposal benefits using the Discounted Present Value method which is approximately equivalent to the long term bond rate minus inflation. This is consistent with the figures used by Steadman and Bryan (1988) in establishing the injury costs used in this report. However, the Victorian Government have traditionally used a 4% value for their estimates which gives greater weight to the benefits received in the distant future relative to benefits received in the near future.

It should be noted that a reduction in the discount rate has a double-edged effect in these calculations. First, it increases the cost of injury by 17% (Steadman and Bryan 1988), and second, it increases the amount of Harm reduction applicable for each measure by reducing the denominator in the formula described in Chapter 7. In short, using a 4% in lieu of a 7% discount rate increases the Harm benefits by 46%.

Table 8.3 shows the consequence of both a 7% and a 4% discount rate in BCR rankings including where the BCR = 1 break even line is situated. What these comparisons show is when a 4% discount rate is used, seat pretensioners, fullsize driver airbag with electronic sensors, and driver facebags become cost-beneficial.

8.5.3 Discounted Present Value Versus Equilibrium

There was debate throughout the course of this research about the most appropriate means of computing benefits from total Harm calculations. In essence, it came down to a choice between the Discounted Present Value (DPV) and the Equilibrium methods.

The difference between the two methods was discussed fully in Chapter 7 and will not be restated here, except to say that the DPV method is normally used for these calculations in this country and was adopted for this study. The equilibrium method, however, is used by the NHTSA to assess the annual cost of a safety regulation in the USA. They do not require BCR calculations. It is understood that they feel this is inappropriate as an absolute measure of the "cost" of injuries or the "value" of preventing them, and that the Discounted Present Value method further compounds deficiencies in the injury cost calculations.

The discounted present value computations are between 58% (7% discount rate) and 72% (4% discount rate) the value of the equilibrium equivalents. Thus, the benefits to society calculated here are considerably less than the values calculated by NHTSA (differences in the dollar rates aside).

TABLE 8.3
BCR RANKINGS OF SAFETY MEASURES USING BOTH A 7% AND A 4% DISCOUNT RATE

7% Discount	*4% Discount*
E-A padded wheel	*E-A padded wheel*
seatbelt geometry & seats	*seatbelt geometry & seats*
improved lower panels	*improved lower panels*
seatbelt warning device	*seatbelt warning device*
knee bolsters	*knee bolsters*
fullsize airbag (E/M)	*fullsize airbag (E/M)*
webbing clamps	*webbing clamps*
- - - - - break even - - - - - -	*seat pretensioner*
seat pretensioner	*fullsize driver airbag (E)*
fullsize driver airbag (E)	*driver facebag*
driver facebag	*- - - - - break even - - - - - -*
padded upper areas	*padded upper areas*
shoulder pretensioner	*shoulder pretensioner*
passenger airbag	*passenger airbag*

8.5.4 Countermeasure Costs

It was a relatively more difficult task (with a higher degree of uncertainty) to determine costs than benefits for some of the countermeasures. Vehicle manufacturers were somewhat reticent in providing these figures. Thus, many of the costs listed here were either derived from part suppliers costings or overseas costs, adjusted for testing and fitting to Australian vehicles, or were estimated from first principles.

This means, therefore, that some of the Benefit-Cost-Ratios may need to be revised in the light of additional costing information becoming available. The large differential between electronic and electro-mechanical full size airbags is an example of a measure that would benefit from additional details. However, an accurate cost assessment for these measures is only ever likely to be possible (or available) in retrospect, hence, the costs listed here were considered the best available for this purpose.

8.5.5 Evidence of Injury Mitigation

While there was reported injury mitigation for many of these countermeasures based on overseas crash experience or local or overseas testing, it was not possible to obtain data on some of the measures not currently in production or where there is limited field experience. In particular, facebags, webbing clamps and pretensioners, seatbelt warning device, and to a lesser degree, Energy-Absorbing steering wheels, were subject to a degree of expert panel assessment of likely injury mitigation.

Moreover, the harm reduction benefits of limiting vertical column and floor intrusions were not clear and it was difficult to cost these measures as well. Thus, there is a need for reviewing many of these figures in the light of additional information becoming available. The discrepancy in the benefit of head padding between the US and Australia also needs further research.

Furthermore, no injury reductions were assumed for airbags and facebags over 64km/h (40mph), even though there is a general acceptance that these units will continue to offer benefits above this modest figure. This is yet another instance of the conservative nature of the figures published here.

8.6 CONCLUSION AND RECOMMENDATION

The study was undertaken to determine Benefit-Cost-Ratios for a range of occupant protection countermeasures as further evidence of the economic worth of these vehicle features to the community. An attempt was also made to obtain information from local automobile manufacturers as to their plans for the voluntary introduction of these measures. Various options were explored regarding desirable countermeasure packages and there was some discussion about the conservative nature of many of the assumptions and assessments involved in the study.

8.6.1 Recommendation

Four recommendations are made from the findings of this study.

1. *That due consideration be given to the introduction of the measures outlined above in Table 2 as packages of vehicle safety improvements. [Trauma reduction would be greatest with the introduction of Package 1 which will eventually lead to a 25% reduction in vehicle occupant trauma].*

2. *That consideration also be given to ways of reducing vertical and lateral steering column intrusions and floor and toe pan intrusions as a matter of priority.*

3. *That further consideration be given on how to encourage vehicle manufacturers to improve the crashworthiness of lower instrument panels.*

4. *That further research be undertaken to examine why the estimated BCR of padding the header rail, A-pillar, side rails, and B-pillar is considerably less in this country than in the USA.*

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APPENDIX 1

RESPONSE BY THE

FEDERAL CHAMBER OF AUTOMOTIVE INDUSTRIES

THE INDUSTRY'S PLANS FOR THE FUTURE

FEDERAL CHAMBER OF AUTOMOTIVE INDUSTRIES (FCAI)

Consolidated response to list of safety features in feasibility of occupant protection project for Federal Office of Road Safety (FORS).

INTRODUCTION

Input from FCAI member companies for this consolidated response is based on several fundamental considerations.

1. Total support for an injury criteria based occupant protection performance as specified for frontal impact test in FMVSS 208.

2. The means by which satisfactory injury criteria performance is achieved is at the discretion of the vehicle manufacturer, who may need to use any or more of the "alternative occupant protection counter measures" listed in the Ernst and Young Consultancy briefing papers provided to FCAI.

3. Leadtime requirements for "alternative" means of improved occupant protection where injury reduction is expected may be no less than those necessary for full compliance with FMVSS 208. Under this assumption the rationale for introduction of "alternative counter measures" before an injury criteria based design requirement or without a performance basis can only be viewed as a marketing exercise, with unclear benefits to safety of vehicle occupants.

4. In all cases, safety features are not "add-on" accessories suitable for instant adoption to existing vehicle package designs. In most cases, substantial redesign of vehicle features would be required.

   Although not quantified, manufacturer costs for design, development, testing and tooling are of such magnitude as to be prohibitive at other than substantive redesign opportunities, that is at model changes.

   Manufacturer resources of manpower, budgets and facilities capacity also do not provide scope for major running redesign projects on multiple vehicle models.

   Imposed demands to the contrary if possible at all, will significantly impact vehicle retail cost increases due to the additive amortisation effects on limited model life volumes.

   For these reasons minimum lead times and vehicle retail cost increases are generally based on new model introductions only.

FEDERAL CHAMBER OF AUTOMOTIVE INDUSTRIES (FCAI)

Consolidated response to list of safety features in feasibility of occupant protection project for Federal Office of Road Safety (FORS)

1. SEAT BELT PRE-TENSIONING DEVICES

Mechanically activated front seat belt pre-tensioning devices (belt tighteners) are in production in Europe. There is also a pyrotechnic device for seat belt pre-tensioning which is activated by a sensor similar to the supplemental restraint (air bag) system.

The European mechanically activated device tensions the webbing in both the pelvic and torso sections of the seat belt by movement downwards of the buckle assembly.

The webbing tensioning device and buckle assembly must be mounted to the seat frame on the inboard side of the occupant seating position.

The seat frames and seat assembly must then be designed to be capable of withstanding loads for seat anchorage strength and seat belt anchorage strength.

Provision for clearance for the tensioning device on the inboard side of the seat assembly must be provided in the design of front floor pan tunnel shape and floor mounted centre console.

Due to the number of components affected by the installation of seat belt pre-tensioning devices, it is not feasible to provide industry wide cost estimates.

Lead Time : 3 years minimum

2. SEAT BELT WEBBING CLAMPS

A European source front seat belt assembly including a webbing clamp is in production.

The webbing clamp is incorporated in the retractor. In a frontal collision, above a pre-set threshold deceleration level, a mechanical leverage system clamps the belt webbing at the retractor and prevents spool out from the retractor reel.

The use of these devices may require belt webbing with different elongation characteristics to Australian Design Rules.

New design seat belt buckle and tongue components may be necessary to withstand increased belt loads under impact.

Due to the increased dimensions of a retractor incorporating a webbing clamp device, the body side structure must be designed to accommodate the retractor assembly inside the centre pillar or quarter panel.

Moulded interior trim panels for centre pillars or quarter panels and dust sealing components over the retractors must also be designed to suit.

Due to the number of components affected by the installation of front seat belt webbing clamp devices, it is not feasible to provide industry wide cost estimates.

Lead Time : 3 years minimum

3. IMPROVED SEAT BELT GEOMETRY

European regulations currently require improved pelvic restraint seat belt angles throughout the front seat range of adjustment forward and rearward.

These requirements may necessitate the mounting of the inboard seat belt buckle on the seat frame. There are several models in Australia already with seat mounted inboard buckles.

This feature requires design of the seat frame to enable the mounting of seat belt buckle and to withstand seat anchorage and seat belt anchorage loads.

Front floor pan transmission tunnel and floor mounted console must be designed to provide clearance between the seat frame for the added bulk of the seat belt buckle assembly to move forward and rearward with the seat adjustment.

The requirements for a seat mounted inboard buckle interact with similar requirements for a seat belt pre-tensioning buckle device which is also seat mounted (refer item 1).

Due to the number of components affected by the installation of seat mounted seat belt buckles, it is not feasible to provide industry wide cost estimates.

Lead Time : 3 years minimum

4. ADJUSTABLE UPPER SASH GUIDES

An adjustable upper sash guide is fitted to some front and rear outboard seating positions depending on the make and model. This device allows outboard seating occupants to adjust the height of the upper shoulder belt anchorage, within a specific range, to provide a more comfortable belt routing.

The use of an adjustable upper sash guide is seen, primarily as an occupant improved feature, and cannot be considered to be a mandatory device for improved occupant protection.

Provision for front seat adjustable upper sash guides requires design, development and tooling of body side structure to provide for mounting of the adjustable sash guides plus moulded interior trim panels.

Due to the number of components affected by the installation of front seat belt adjustable upper sash guides it is not feasible to provide industry wide cost estimates.

Lead Time : 3 years minimum

5. ANTI-SUBMARINING SEAT CUSHION

The use of an anti-submarining front seat cushion to reduce occupant's forward excursion of the lower torso is only desirable if it reduces injury.

Seat mounted seat belt buckles, seat belt pre-tensioning devices or seat belt webbing clamps all have potential to reduce front seat occupant submarining, but this does not equate to injury reduction.

An anti-submarining seat cushion cannot be considered a necessary feature to reduce submarining and is not mandated anywhere in the world.

Lead Time : 3 years minimum

6. SEAT BELT INTERLOCKS

Seat belt interlocks are not mandated anywhere in the world and FCAI is opposed to any such unique proposal for Australia.

The fitment of seat belt "buckle up" advisory lights in some cars is only seen as a customer convenience item.

Simple seat belt interlocks are ineffective as the occupant only has to latch the belt buckle and sit on it. Seat sensors used in seat belt interlocks can only be regarded as a "customer annoyance" feature.

The experience of the mandated seat belt interlocks in U.S.A. proved their ineffectiveness and the Government had to repeal what was a bad law.

To suggest seat sensors activated at 10kg would be effective, shows a lack of thought for the real world situation. For example, a child restraint which is normally left in the rear seat of a car and which may weigh up to 10kg when unoccupied, would have to be removed every time the vehicle was to be operated without a child buckled up in the restraint. Other examples would be the carrying of groceries and family pets in the car. You cannot "buckle-up" your pet to ensure the seat sensor is de-activated.

The suggestion that four way hazard warning flashers be activated by non-use of seat belt interlocks may contravene international practice which is to use hazard flashers only in emergency conditions. To be used for any other action is not desirable for vehicle safety and the well being of all road users.

7. SUPPLEMENTAL RESTRAINT SYSTEM

7.1 U.S. Type Driver's Side

U.S. type supplemental restraint system (SRS) for driver's side were initially developed for left hand drive cars sold in U.S.A. where mandatory wearing of seat belts is not widely enacted or practised. The systems must be designed and packaged for each individual make and model and also must be specifically developed for L.H.D. and R.H.D.

Systems must be developed specifically for front wheel or rear wheel drive cars and for various engine/transmission combinations, as vehicle crush characteristics in frontal impacts are totally different.

There are many major components affected in the installation of a driver's side SRS. These include basic body structures, steering column assemblies, steering wheels, crash sensors, wiring harnesses, front seats, front seat belt assemblies and possibly combinations of seat belt pre-tensioning devices and seat belt webbing clamps.

Due to the number of components so affected it is not feasible to provide industry wide cost estimates.

Lead Time : 4 years minimum

7.2. U.S. Type Passenger's Side

U.S. type SRS for passenger's side is currently only available in a very few makes and models. The systems have only been developed for L.H.D. cars, and systems for R.H.D. cars must be developed specifically for every make and model of passenger cars according to the package constraints of each individual instrument panel assembly.

There are many major components involved in installing a passenger's side SRS. These include basic body structures, crash sensors, instrument panel sub-assemblies, wiring harnesses, front seats, front seat belt assemblies and possibly combinations of seat belt pre-tensioning devices and seat belt webbing clamps.

There are very significant costs involved for design, development, tooling and testing of a passenger's side SRS.

Vehicle manufacturers do not have the resources to develop a passenger's side SRS concurrently with the development of a driver's side SRS and therefore a longer lead time is required.

Due to the number of components affected by the installation of a passenger's side SRS, it is not feasible to provide industry wide cost estimates.

Lead Time : 5 years minimum

7.3 European Type Driver's Side

There is one European Supplier who has just developed a driver's side SRS. Many of the comments related to item 7.1 for U.S. type driver's side SRS apply to this European system.

Lead Time : 4 years minimum

7.4 European Type Passenger's Side

There are no European passenger's side SRS developed at this time. Many of the comments related to item 7.2 for U.S. passenger's side SRS apply. Costs cannot be given as there are no European systems available.

8. PADDED STEERING WHEELS

The term "padded steering wheel" is not known within the automotive industry. FCAI companies are familiar with the term "soft feel" energy absorbing steering wheels.

Many passenger cars currently marketed in Australia are equipped with energy absorbing steering wheels.

There is no design standard or performance requirement for "padded steering wheels". Without a clearly defined design standard and performance requirement FCAI cannot provide any meaningful costs or lead times.

9. STEERING ASSEMBLY VERTICAL AND LATERAL MOVEMENTS

FCAI members are unaware of any current worldwide requirements for this item, however a European proposal is under review for a limitation on vertical movement.

Without a clearly defined design standard and performance requirement FCAI cannot provide any meaningful costs or lead times. If Australia adopts the injury criteria of FMVSS208, such measures may well become redundant.

10. IMPROVED PADDING OF UPPER AREAS

Additional interior padding on upper body structure could only be considered as cosmetic without a clearly defined performance standard.

FCAI members are not aware of any worldwide regulations for this item.

There are many passenger cars marketed in Australia today which may well meet a performance standard without any additional padding. As well, there may be counter-productive effects. For example, the addition of padding on front windscreen pillars would be such that it may potentially incur significant vision obstructions, which would more than negate any subsequent impact benefit.

If Australia moves to adopt the injury criteria of FMVSS208, the need for supplementary protection measures will be determined by the criteria specified for front seat belted occupants.

As the application of changes in energy absorption in these areas could vary so widely from car to car, and only be realistically determined after clearly defined performance related criteria are tested, we are unable to provide any cost data on this item.

11. **REDUCED INSTRUMENT PANEL PROTRUSIONS**

If Australia moves to adopt the injury criteria of FMVSS208, then the criteria specified for front seat belted occupants would be covered by appropriate design of instrument panel area.

Another approach to be considered would be to adopt ECE Regulation 21 for Interior Fittings, which clearly specifies design criteria and performance requirements for the instrument panel upper and lower areas. This may require revisions to knobs, controls, etc. and could be achieved most effectively when a vehicle manufacturer changes the design of the instrument panel on a specific car.

Lead Time : 3 years minimum

12. **IMPROVED INSTRUMENT PANEL MATERIALS**

The choice of materials and their effect on occupant injury would also be covered most effectively by adoption of the injury criteria of FMVSS208.

13. **IMPROVED PADDING OF LOWER AREAS**

If Australia adopts the injury criteria of FMVSS208, then the criteria specified for the front seat belted occupants would be covered by the interior design which would be most effectively incorporated when a vehicle manufacturer redesigns instrument panels and driver controls.

Lead Time : 3 years minimum

14. **KNEE BOLSTERS**

Knee bolsters are only used in some cars sold in U.S.A. because they are needed with driver and passenger SRS to meet the injury criteria of FMVSS208 with unbelted occupants by limiting forward excursion and submarining.

In Australia, where mandatory wearing of seat belts applies and very high wearing rates are experienced, there is no justified need for knee bolsters.

15. REDUCED INTRUSIONS

FCAI members are unaware of any worldwide enforced regulations with a design standard or performance requirement for front floor pan intrusion into the passenger compartment in frontal impacts.

Angled or offset frontal barrier tests are developed for passenger compartment integrity.

There is no standard for an offset barrier test in the world and there is conflicting data on its effectiveness. A 30 percent angled barrier test gives better correlation with accident experience.

Without a clearly defined performance standard FCAI members are unable to provide any cost data or lead times on this item.

16. INJURY CRITERIA FOR OCCUPANT CRASH PROTECTION

FCAI members totally agree with the performance philosophy of FMVSS208 in specifying injury criteria to be met for front seat belted occupants in a 48kmh frontal barrier test.

If Australia moves to adopt the injury criteria of FMVSS208 some passenger cars may require extensive redesign of major components.

These would include basic body structure, instrument panel assemblies, steering column assemblies, steering wheels, front seats and front seat belts.

Due to the number of components that may require redesign to comply with the injury criteria specified in FMVSS208, it is not feasible to provide industry wide cost estimates.

Lead Time : 3 years minimum

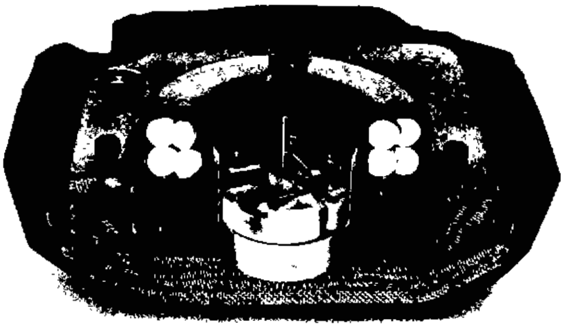
APPENDIX 2

FULLSIZE AIRBAG AND FACEBAG COSTS

SUPPLIED BY

BREED CORPORATION AND AUTOLIV INTERNATIONAL

The Unique Breed All-Mechanical Airbag Systems



The Breed All-Mechanical Airbag Module

The Breed All-Mechanical Airbag System consists of a single compact module, located in the center of the steering wheel for the driver and in the instrument panel for the front passenger. A single module contains all of the components of the system: dual element crash sensor, gas generator and fabric airbag.

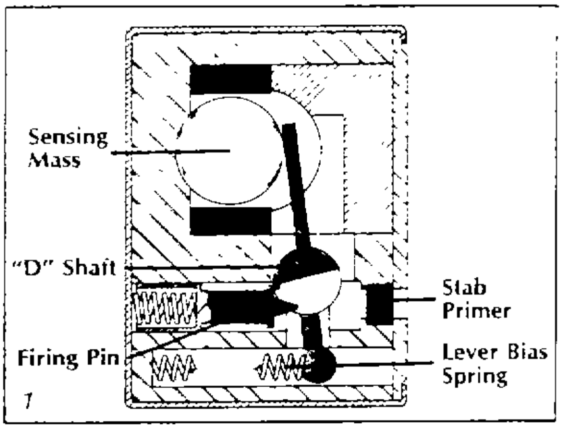
The Breed All-Mechanical Airbag System is simple and reliable. In a crash, the displacement of the ball within each sensor releases a firing pin. This impacts a primer which ignites the gas generating material and inflates the airbag. The system uses mechanical rather than electrical energy for initiation, eliminating the need for wiring or a power supply. The Breed All-Mechanical System does not require a diagnostic package, as ruled by NHTSA. The all-mechanical module shares the same ignition train as electrically triggered systems, once the primary initiation takes place.

Sensor/Initiator

At the heart of the system is the sensor/initiator. The motion of the sensing ball-in-tube is controlled by a spring bias and viscous damping forces. This Breed sensor is a true real time integrator of the acceleration above the bias. Its performance directly correlates with the velocity change of the vehicle.

Breed's viscously damped crash sensor is the mechanical analogue to an electronic integrating sensor. The Breed sensor triggers faster than spring mass sensors of the same calibration resulting in better airbag system performance.

BREED AUTOMOTIVE
C O R P O R A T I O N



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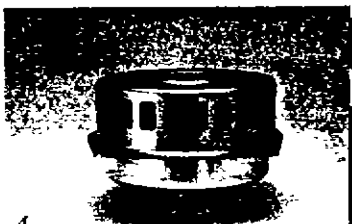
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1. *Breed All-Mechanical Sensor assembly*
2. *Dual sensor/initiators provide system redundancy for added reliability*
3. *State of the art laser welding equipment is used in the assembly of the gas generator*
4. *Breed designed and manufactured gas generator*
5. *Effluent testing — quality audit of inflator performance*

Airbag System Concept

Extensive mathematical sensor modeling by BAC Engineers has demonstrated that crashes in which airbag deployment is desired can be effectively detected with passenger compartment, steering column or instrument panel mounted crash sensors. This pioneering work was demonstrated under a NHTSA program. Many subsequent system development contracts have been completed with automotive companies, worldwide. BAC uses Vehicle Occupant Dynamic Simulation (VODS) to design airbag module and vehicle system components, which together determine successful occupant protection with airbag deployment. These simulations require over 150 data inputs. BAC Engineers work with a library of over 3,000 crashes and scores of different vehicles, to prove the efficacy of single point mechanical sensing.

Where the vehicle has a soft front structure, BAC can usually recommend appropriate modifications to allow the use of single point sensing.

Reliability

The system gains reliability from its simplicity. The absence of wiring and electrical connections eliminates potential failure modes.

Airbags are currently inflated with nitrogen gas produced by the rapid burning of sodium azide propellant. The simplest and most reliable method of initiating this reaction is by using a mechanical firing pin to impact a stab primer. The Breed All-Mechanical Airbag module incorporates this reliable, rugged method of initiation which has been proven over decades of experience in military applications, such as ejection seats in fighter planes. The reliability is increased by providing two separate and independent sensing elements inside the gas generator. Manufacturing and quality procedures ensure the independence of these sensing elements, either of which are capable of initiating airbag deployment. Every Breed mechanical sensor/initiator is subjected to a number of simulated crash pulses during production.

Production

For the 1990 Model Year, facilities are in place with a production/assembly capacity of 15,000 airbag modules. This capacity will be increased for 1991 Model Year programs and beyond.

BAC is a fully integrated airbag system supplier. Breed Engineers originate airbag system concepts and production engineer these to vehicles. Breed's manufacturing group assemble BAC designed inflators, sensors and fabric airbags in our extensive manufacturing facilities.

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BREED'S ALL MECHANICAL AIRBAG SYSTEM OFFERS AUTOMAKERS ADDED RELIABILITY AT LOWER COST

BOONTON TOWNSHIP, NJ -- New vehicle buyers in coming years will benefit from the added reliability and reduced cost of the Breed All-Mechanical Airbag System (AMS), a new generation airbag system that eliminates extensive wiring and electrical connections required in present systems.

Of prime interest to both vehicle makers and buyers, the new system provides substantial cost savings in initial manufacture, and through installation to replacement.

Winning approval of National Highway Traffic Safety Administration officials in 1987, the Breed AMS contains all components -- crash sensor, gas generator and fabric airbag -- in a single compact module. Its design flexibility allows it to fit easily in the center of the steering wheel for driver protection and in the instrument panel to safeguard the front passenger. As ruled by NHTSA, the Breed AMA does not require a diagnostic package.

Already in production since 1989, the driver-side AMS is the choice of Jaguar for the XJS vehicle imported to the U.S. and in the 1990 model year was introduced in Japan by a Breed licensee on three Toyota models. The passenger-side AMS will be installed in the 1993 model year. A new Breed facility in Lakeland, Florida, is being readied as the production site for both types of units.

- more -

While offering comparative simplicity and lower cost, the AMS meets the highest performance standards. In a crash, displacement of the ball in the dual element sensor directly responds to the velocity change of the vehicle to release a firing pin. This impacts a primer which ignites the gas generating materials to instantaneously convert them to nitrogen gas and inflate the airbag.

"This method of initiation has been proven over decades of experience in military applications, such as ejection seats in fighter planes," said Allen Breed, developer of the AMS.

"We went a step further and doubled reliability by providing two separate firing mechanisms inside the gas generator. Either is capable of initiating airbag deployment. Manufacturing and quality procedures ensure the independence of these circuits and every one is subjected to a number of simulated crash pulses during production."

Breed pointed out that other air restraint systems employ a number of sensors in forward positions in the vehicle, while the AMS is reliably served by the sensor contained within the module. This improved concept grew out of extensive mathematical modeling by Breed engineers which proved that crashes warranting airbag deployment can be effectively detected with passenger compartment sensing, with steering column, or instrument panel mounted crash sensors.

"This pioneering work was demonstrated under an NHTSA program," he said. "Many subsequent system development contracts have been completed with automotive companies worldwide."

- more -

This system description covers the following sections:

A) General Description

A1) Application

A2) System Design (Driver- and Passenger Side)

A3) Main Data

A4) General Function

B) Description and Function of Components

B1) Electronics

B2) Inflator

B3) Bag

B4) Cover

B5) Container

C) Performance

C1) System (Driver- and Passenger Side)

C2) Components

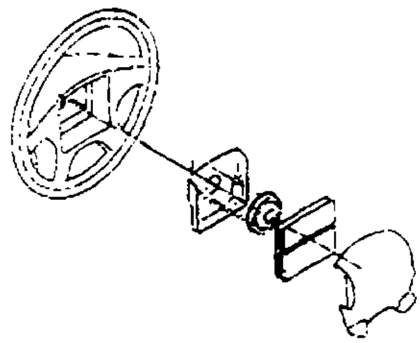
A) General Description

A1) Application

The Eurobag system is a passenger-car-restrain-system for protection of driver and passenger on the front seats. The Eurobag is designed in such a way, that there is optimum protection for car-driver / passenger using a 3-point-safety-belt, i.e. head impact on rigid parts of the car (steering wheel, dashboard) is prevented. But the Eurobag system is activated independently of the use of the safety belts.

A2) System Design

Driver Side



The driver Eurobag module consists of the following components:

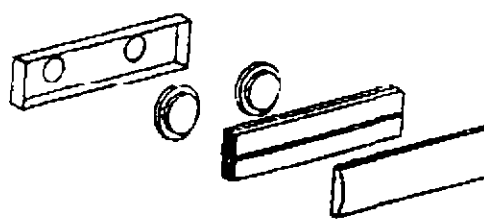
- inflator
- bag
- container
- cover

The inflator is screwed in a cup shaped metal container. On top of the inflator is the bag folded. The subassembled container is closed with a plastic made cover; which is also a protection against damaging of the bag.

The whole assembly is called module. The module can be fixed with some screws on the skeleton of the steering wheel.

The system is activated from a central electronic unit, mounted in a proper place in the car. The electrical connection between this unit, the car side power supply anc the module in the steering wheel is done via a so called coil spring.

Passenger Side



The passenger side Eurobag module consists of the following components:

- container
- 2 inflators bag
- bag
- cover

Both inflators are mounted in a flat,rectangular, cup shaped metal container. Above the two inflators is, analogue to the driver module, the folded bag placed. The cover, protecting the bag, is fixed to the container by rivets.

A3) Main Datas

Driver Side System

- Bag volume is 30 ltr.
- Module weight is ≈ 500 g (without electronics)
- Inflation time is about 28 ms

Passenger Side System

- Bag volume is 60-70 ltr.
- Module weight is ≈ 900 - 1000 g
- Inflation time is about 26 ms

A4) General Function

Sensing

The electronics, which is rigidly fixed to the structure of the car, contains a sensor, detecting the decelerations of the car. The signal from this sensor is checked by the electronics to evaluate, if it is a "real-crash" or if the car is cruising on a rough road.

Activation

If the signal analysis in the electronics is positive, an electrical signal is sent to the ignition unit of the inflator. This ignitor initiates the burning of the propellant inside of the inflator and leads to hot and high pressurized gas. The outcoming hot gas from the inflator streams in the folded bag and increases rapidly the pressure inside the bag.

Inflation

The pressure inside the folded bag stresses the predetermined areas of the cover, the so called split lines, and opens it. So the bag is ejected out of its narrow packaging volume and is inflated within 30 ms.

Protective Effectiveness

The inflation of the bag is just in time to have a smooth submerging of the occupants head into the bag, i.e. an absorption of the kinematic energy on the occupants head in a uniform distribution of the load on facial areas and without causing any injuries.

The protective effectiveness of the Eurobag is checked at low (-35 °C) and high (+85 °C) temperatures, for small and tall persons in forward and far back seat positions.

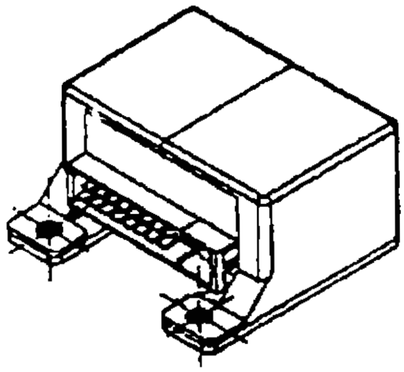
Beside the frontal crash other types of crashes with an angle of plus and minus 30 ° as well as pole- and underride crash are checked.

B) Description and Function of Components

B1) Electronics

The electronics consists of the following major components:

- Crash Sensor
- Safing Sensor
- ASIC
- Microprocessor
- Ignition Cable with connector



Crash Sensor

The crash sensor is a micro machined silicon sensor, which produces a signal at any deceleration / acceleration. The signal is caused by the bending of a bar with a seismic mass on one end. On the bar a Wheatstone's bridge (resistances) is mounted, which is balanced if the bar is in zero position and creates a signal if the bar is bended.

Safing Sensor

The safing sensor is a spring mass (magnet) system. The mass (magnet) works at decelerations against the spring load. If the deceleration is high enough, a Reed Contact is closed.

Safing sensor and crash sensor are in line and if both are closed, the inflator is fired.

ASIC

The ASIC is a part in size of a fingernail, which contains high integrated, especially for the single application developed circuits and was developed by Autoliv. The ASIC is used for signal evaluation like filtering, amplifying ect.

Microprocessor

In the electronics every signal from the crash sensor has to be analysed and evaluated, if it is generated by a real crash situation. This is done by a so called algorithm, which is a methodical calculation procedure to evaluate height and duration of the signal. Depending on the type of the car, different levels have to be passed to initiate an ignition of the Eurobag. The settings of these levels are defined by the results of real crashes performed before with that special car and are then programmed to the microprocessor as car related specific parameters.

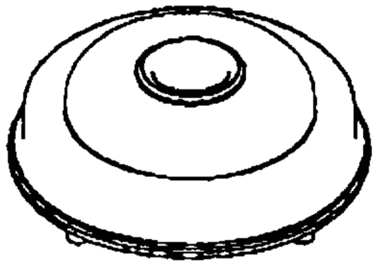
Ignition Cable

The electronic unit has a 26-pin connector which contains the contacts for the signal output to the inflators.

While the cables for the passenger side lead directly to the module, the ignition cable for the driver side unit leads to the end of the column. Here a coil spring enables the connection to the inflator in the steering wheel. The coil spring consists of a fixed part on the column and a turnable part on the steering wheel, which is connected to the squib in the inflator.

B2) Inflator

The inflator consists of the following main parts:



- housing
- ignition unit
- propellant
- catalyst

Housing

The housing is machined out of of high strength steel block and looks like a step wise contracted cup. The housing contains the propellant and the ignition unit; it has sevoral well defined nozzles.

Ignition Unit

The parts of the ignition unit are: a squib holder carrying the squib, the booster charge and a cupped aluminum cap. Booster charge and squib are sealed in the cap.

Propellant

The propellant is an extruded block with a carefully balanced surface in form of an inner and outer gear rim.

- The propellant block is a double base grain, manufactured from nitrocellulose (NC) and nitroglycerin (NGl). Double base propellant is reproducable to manufacture. For the filling of a 30 ltr. bag 8 g of propellant is required.
- For a better aging behaviour small amounts of stabilizer are added to the grain.
- The propellant burns without any residue. There is no slag in the inflator and no solid particles in the gas.
- The gaseous products of the burning propellant consists of CO, CO_2, H_2O, N_2.
- In a scrapping case remaining propellant will be destroyed very slow by microbacteria (about 10 years); there is no pollution of the environment (ground water spoiling).
- If fired prior to scrapping no ash or spoiled filters are to be found in the inflator housing, therefore the remaining steel material is perfect for recycling.
- The inflator fulfill all required tests for BAM-permission with success. BAM-permission exists for Euroflator since 1991.

(BAM: German institute for material testing in Berlin)

For a theoretically thinkable worst case, the inflator has a so called fail safe device: if the pressure inside the inflator exceed a certain max value, which is close to or equal the bursting limit of the housing, the inflator opens on the backside of the module. The gas pass off without danger for the occupants.

Function of the Inflator

In the case of a crash, the electronics close the ignition circuit and the ignition current is sent to the squib of the inflator.

Squib

The squib, activated by the electronics, consists of two pins, connected by a very thin wire (fuse). This wire is surrounded by a pearl of a pyrotechnic mass. This primer mass is inside a metallic cup, filled with another pyrotechnic powder.

If the ignition current melts the thin wire (fuse), the primer mass ignites. The energy of the primer mass is sufficient to ignite the powder inside the cup.

Ignition Unit

The squib is mounted inside a cupped aluminum cup, filled with another pyrotechnic powder, the so called booster or intensifier charge.

The fired squib now ignites the booster charge, which produces hot particles.

Propellant

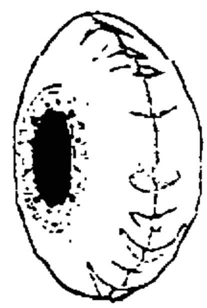
The hot particles of the booster charge are fired on the surface of the propellant bloc. Thus the propellant starts to burn.

In the first beginning, the hot gases from the propellant cannot leave the combustion chamber, because the nozzles are closed with a thin copper made cap. These copper barriers open, when a defined temperature and pressure level is reached after a few milliseconds. Passing the holes, the hot gases are dispensed by a reflection ring and then guided through the catalyst, where a partly reduction of the CO to CO_2 happens. The expansion of the gases beyond the nozzles leads to a cooling down effect before the gases are in contact with the bag.

DO) Dag

Manufacturing

The driver bag (30 ltr) as well as the passenger bag (60 ltr) are manufactured in a new "one-piece-woven" process. Having no joint, the bag has significant advantages in strength, weight, packaging volume, number of parts, quality and cost.



Coating

The bag is internally protected with a silicon layer against hot gases.
Near to the mounted inflator a flame protection is integrated.

Material

The basic tissue is made of polyamide with a thickness of 235 dtex (i.e. about $^1/_4$-bag thickness of the US-version).

Design

The driver side bag is symmetrical and nearly round in shape. The design of the passenger side bag depends on the proportions in the special car.

No straps have to be integrated to reduce the depth of the inflated bag.
To optimize the protective effectiveness the size of the vents varies due to vehicle parameters (10 ... 30 mm diameter).

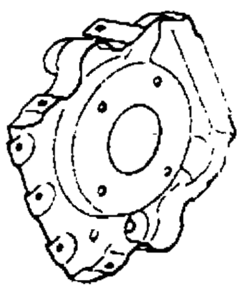
B4) Cover

The cover of the module protects the bag against environmental influences and damaging. The cover is a plastic part which is fixed with rivets or screws to the container. For the opening of the cover, some so called split lines are integrated.

The opening behaviour of the cover is developed and checked at low and high temperatures.

B5) Container

The container is a cup shaped metal part in form of a shell, carrying inflator, bag and cover and is fixed on the steering wheel or behind the dashboard. The strength of this part has to withstand the high load at function. The container is the adapter between steering wheel or dashboard and the airbag module.



C) Performance

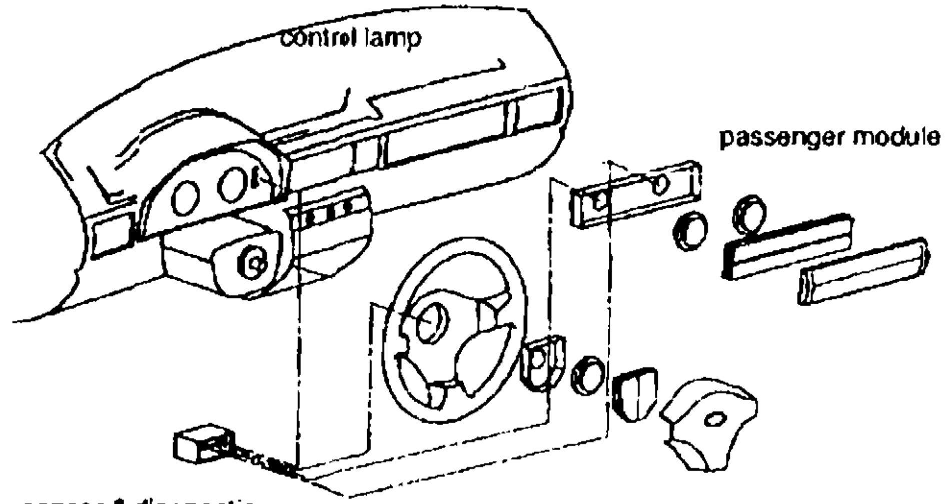
C1) System (Driver, Passenger)

See annex I

C2) Components

See annex II

Eurobag System Performance



Technical Functions

Head protection supplementing the belt system.
Reduces head impact load of belted occupant significantly.

Performance

HIC	< 700
Inflation time	28ms
weight	600-700 grams

self-diagnostic unit with indication lamp, easy recycling

EUROBAG Technical Status

Bag

Driver Side

Volume: 30l

Dimensions: Ø 540 mm

Material: PA 6.6 235 dtex

Weight: 130 g

Coating: Silicon

one piece woven

no neoprencoating

no straps

steering wheel is completely covered by the bag

Passenger Side

Volume: 60l

Material: PA 6.6 235 dtex

Weight: 250 g

Coating: Silicon

one piece woven

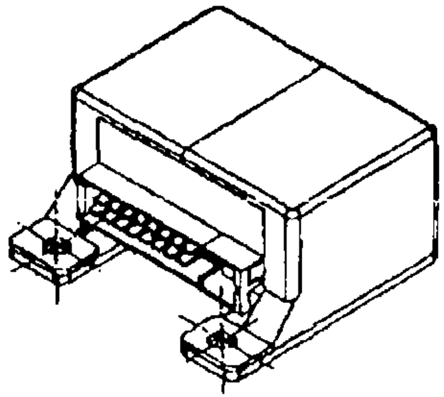
no neoprencoating

no straps

passenger is protected from the dashboard, even in 30° angeled crashes

Electronics

Housing:	90 x 70 x 40
Material:	Aluminium
Weight:	app. 150 g
Accel. Type:	Piezo-resistive
Safing sensor:	Double stage sensor, Reed contact
ASIC:	Anna, 2µ BIMOS-Technologie
Outputs:	3 x squib
Electr. Connections:	Single central 26 pin connector
Features:	Coding on connector for car identification and selection of crash parameters (one unique modul for all car types)



Electrolux Autoliv

Air Bag

EUROBAG Technical Status

Gasgenerator

Technical Data

Dimensions:	
Diameter:	Ø 80 mm
Height:	35 mm
Housing:	Steel
Burst Safety:	> 2,0
Propellant:	NC + Ngl + Stab.
Mass:	7...8 g
Ignition Unit:	c/o US System
Squib:	Davey Bickford
Lifetime:	> 10 years
Gas composition:	acc. to Specs.
Environment:	recycable w/o ignition
Fail save design	

BAM-Approval

BAM - PT_1 - 0414

Availability

serial production line ready in April 1992