RESTRAINT SYSTEM OPTIMISATION FOR MINIMUM SOCIETAL HARM

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ABSTRACT

The focus of road safety in the past has been on reducing the road toll. This resulted in the introduction of legislation making the wearing of seat belts compulsory in Victoria in 1970. This was a world leading approach that has been of great benefit to the Australian community. More recently, it is being recognised that serious injury, particularly long term and irrecoverable injury to the head and neck are a major concern and cost for the individual and the community. Detailed crash analysis in Australia has identified the wide range and frequency of crash types and severities that occur on Australian roads. Varying occupant protection needs have also been identified, in terms of age, sex, size and seating position. An optimising technique has been developed and applied to the design of the restraint system of a new model Holden Commodore passenger vehicle. Various seat belt retention and webbing characteristics, airbag and inflator characteristics, seat stiffness and anti-submarining structures have been considered during the optimising process. A Societal Harm measure of the cost of injury was used to evaluate the effectiveness of the restraint system in providing protection to the community in the range of real-world crashes which occur. This technique is proposed as a more appropriate approach to restraint system design than designing for government regulations or consumer information tests.

INTRODUCTION

Motor vehicle accidents are causing increasing concern in the community, as evidenced by the high profile media coverage given to motor vehicle crashes. Accidents have been identified as a major cause of injury and death, and thus the cause of major social and economic costs to the community.

Head injury is appropriately called the silent epidemic. There has been a dramatic increase in head injury over the last decade, not as a result of increased accidents, but because of increased survival. This has resulted from the use of ambulances with life support systems, helicopter ambulances and the use of CAT scans to identify haemorrhaging and location of blood clots. There is a growing awareness of the incidence of non-fatal head injury and its impact on the individual, the family unit and the community. Similarly, the long term and debilitating effects of relatively low severity neck injury are not adequately recognised in a strategy to simply reduce road fatalities. Consequently, there is growing concern for developing strategies for reduction of injury frequency and severity.

The objective in vehicle safety development at Holden is to protect car occupants by minimising their injury risk. Media focus is usually on safety devices, such as new seat belts or airbags, or on consumer information test results. This focus does not recognise that the injuries that occur on Australian roads are the result of a spectrum of crash types and severities, of vehicle crash performance and of occupant vulnerabilities. In developing vehicle safety to provide the maximum benefit to the community, a broader consideration of injury risk reduction must be given. The complete vehicle, with its structure, its restraint system and its occupants, must be developed as a total system. The front structure must be designed to absorb crash energy efficiently at the lowest loads possible. The passenger compartment must support the crash loads generated. On this foundation, the restraint system can be optimised for the broadest spectrum of passenger protection.

Protection Requirements

The crash parameters which determine the injury risk to vehicle occupants are the severity of the crash, the behaviour of the vehicle structure and restraint system, and the vulnerability of the passengers. The crash severity is basically determined by the collision speed, and the stiffness and mass of the car or obstacle struck. The behaviour of the vehicle system is determined by the way energy is absorbed, by the strength of the passenger compartment, and the characteristics of the restraint system. The vulnerability of car occupants is determined by their seating position, health, size, sex and age.

Legislative regulations in all industrialized countries set requirements for the performance of vehicles in crash tests. Consumer information organisations conduct tests at higher speeds with the objective of evaluating relative safety performance, on the assumption that measurements made during a higher speed barrier test would indicate improved field performance. Vehicle design must satisfy the government regulation for performance at 48 km/h frontal collision with 50th percentile male dummies in the mid-seating position.

It must also provide protection for all vehicle occupants, many of whom are small females, or large males, or older people with more fragile bones, and who will become involved in a range of collisions at various speeds, at various angles and overlaps, and with obstacles and other vehicles of various sizes and stiffness. Vehicle system performance must result in minimum injury risk to all vehicle occupants in all accident situations.

Developing a restraint system with the single focus of minimizing injury risk in a single laboratory test, as measured by the response of the test dummy representing the mid-sized male in the mid-seating position, does not recognise the additional, and possibly conflicting protection needs of females, the young and the elderly, nor the risks associated with the full spectrum of real world crash types and severities. Current occupant protection technology cannot provide a single design solution that gives optimum protection for every size and fragility of passenger, in each seating position, and for all of the types and severities of crashes that occur in the community.

Crash Pulse Optimisation

Passenger car structures are being developed which will substantially improve the safety of car occupants. The behaviour of the vehicle structure during a collision, so-called vehicle crashworthiness, has the major influence on the occupant injury risk. During a collision, the part of the structure which is deforming due to contact with the impacting object collapses, decelerating the remaining, still undeformed part of the vehicle, including the passenger cell. The deceleration-time signature of the passenger compartment is referred to as the crash pulse. It is ultimately the shape of this crash pulse which determines the severity of the injury risk, as it determines the loading applied to the restraint system.

The severity of a crash is determined by the direction of impact, the collision speed and the shape, stiffness and mass of the car or object struck. Most collisions occur at low speed. The crash pulse must be optimised to balance three conflicting requirements:

1. Minimum vehicle damage in low speed crashes.
2. Minimum deceleration and hence occupant loading for the most frequent injury causing crashes.
3. High energy capacity for high speed collisions.

Accident Investigation

Road accident research is conducted in order to obtain an understanding of the accident injury risks in the Australian environment. This research is contracted to Monash University's Accident Research Centre (MUARC). The MUARC team investigates the majority of crashes in Australia involving a Commodore airbag deployment, plus a large number of non-airbag Commodore collisions, both front and side impact crashes. The data they collect is progressively analysed to measure the effectiveness of changes made to the Commodore safety system. These analyses involve measuring the injury risk for each injury level and the evaluation of the statistical significance of the differences between data. As a result of this research, an understanding of the risks and the value of safety improvements in the Australian environment is being developed.

Societal Harm

Societal Harm is a metric for quantifying injury costs from road trauma, involving both a frequency and a unit cost component [2]. In its most general form, it is a measure of the total cost to the community of road trauma, and includes hospital costs, rehabilitation costs, lost income and some value on lost ability and quality of life. It can also be used to evaluate the contribution made by vehicle design for occupant protection.

The concept of Societal Harm was introduced in the 1980's in the USA to evaluate the benefits of road safety countermeasures [8]. It provides a broader vehicle design perspective than design for fatality reduction alone. This type of analysis helps focus attention on the relative importance of injury as a leading health risk in the community, and allows a systematic priority setting for safety development. It allows the development of more sophisticated restraint systems including airbag systems.

The Societal Harm technique is similar to the WIC technique introduced by Viano and Arepally [14], but is based on a cost factored analysis. Based on the costing of motor vehicle injuries done by Miller, for the US Federal Highway Administration [10], the initial steps to a biomechanical injury cost model were taken by Newman [11] using a model with dummy-based injury assessment functions, to predict the probability of occurrence and the probable cost of specific AIS injuries, despite the model being tentative in some areas of the Injury Assessment Functions used.

The Abbreviated Injury Scale (AIS) does not measure impairment or disability. An injury of the same AIS to different body regions can have a significantly different rate of recovery, and functional loss can occur in one region but not in another. In addition, females, children and older people have different fragilities to young males, and an injury with the same AIS rating may have a significantly different effect on each of these groups.

A national data based is used to evaluate the potential benefits of any proposed vehicle design change. The database contains information from the Federal Office of Road Safety's National Fatality File, the *hospitalised sample of crashes from the MUARC Crashed* Vehicle File and medically treated cases from the Transport Accident Commission in Victoria. Injury severity was evaluated using the Association for the Advancement of Automotive Medicine's Abbreviated Injury Scale (AIS 85). Using this information, a Cost of Societal Harm in Australia Matrix by AIS and body region has been developed by MUARC, for use in this restraint optimisation process.

RESTRAINT SYSTEM OPTIMISATION

An optimising technique based on a Multiple Step Taguchi Method was used to drive a MADYMO evaluation of restraint system parameters to arrive at a design providing a Minimum Societal Harm solution. It incorporates a numerical optimisation procedure utilising a orthogonal grid method [13], a form of direct search method modified to increase the rate of convergence. Objective function values are used for constructing the solution algorithm. The objective function to be optimised is defined as:

$$\mathbf{G} = \sum_{i=1}^{3} W_i \ f_i$$

where -

G is the objective function, Societal Harm,
f_i is the i-th sub-objective function (I=1,3), and $\boldsymbol{W}_i$ is the weighting factor for f_i (I=1-3)

The f_i represents the percentage of the i-th injury with respect to its limit, and W_i is the statistically significant factor of the i-th injury type which ranks the priority of the i-th injury type.

Based on the results of a sensitivity analysis, parameters from the restraint system were selected as design variables, denoted by X_j (j=1,8). The upper and lower boundaries for the j-th variable are defined as $X_{max,j}$ and $X_{min,j}$, and the mathematical model for the optimisation process is expressed as -

$$\text{Min. } \mathbf{G} = \sum_{i=1}^{3} f_i \ \mathbf{W}_i$$

with constraints $\mathbf{X}_{min,j} \le \mathbf{X}_j \le \mathbf{X}_{max,j}.(j=1,...,8)$

The optimisation procedure is illustrated in Figure 1. MADYMO software was used as a solver to calculate the injury values for various design configurations. The modified orthogonal grid method was implemented as an optimising module of the program. The data exchange between the optimiser, and MADYMO input and output is conducted by the main controller in the program.

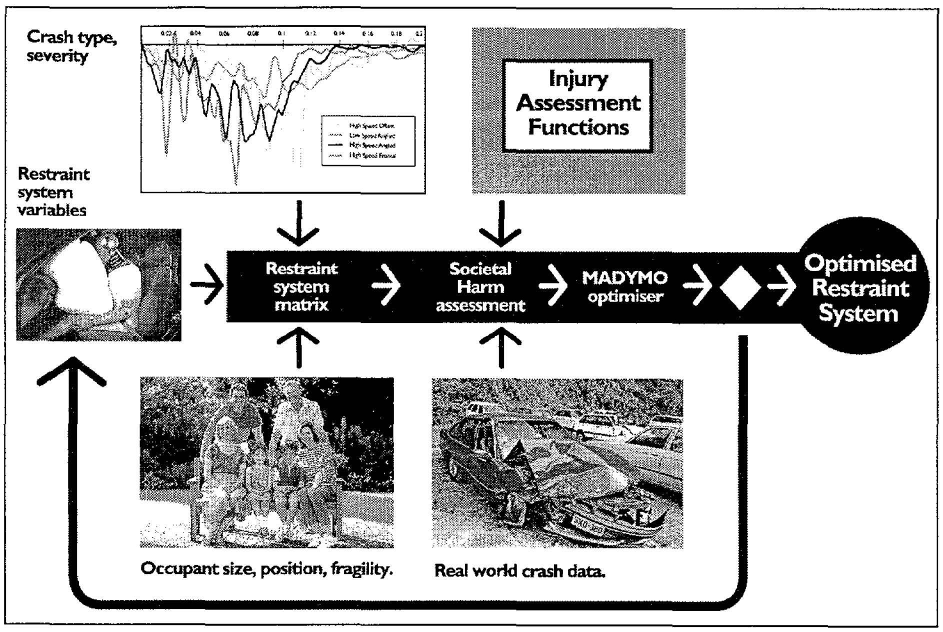

Figure 1. Schematic Illustration of Restraint System Optimisation Process

FUTURE APPLICATIONS

An important future application of this technique will be in the development of side impact protection. There are specific injury risks associated with side impact crashes. The strategies currently being used to achieve the performance levels required by government regulation and consumer information body testing will not achieve appropriate occupant protection. There is a risk that these measures may even be counter productive, by encouraging vehicle design to achieve the desired dummy response which increases the risk to vehicle occupants. This technique of optimising for minimum Societal Harm could be applied to side impact design, in order to optimise occupant protection. A biomechanical injury cost model would ensure that the design characteristics chosen result in benefit to the community, in terms of reduced risk of fatality, brain injury and other societal harm

Before this technique can be applied to side impact protection optimisation, further research and development is required in a number of areas, including the development of validated mathematical models of BioSID and SID IIs test dummies, and improved Injury Assessment Functions to assess the risk of injury from lateral impacts, particularly for brain, neck and lower limb injury. A research project funded by the Australian government and supported by MUARC, GM Holden and others is currrently working at addressing this need.

CONCLUSIONS

An optimising technique has been developed and applied to the design of the restraint system of a new model Holden Commodore passenger vehicle. Seat belt retention and webbing characteristics, airbag and inflator characteristics, seat stiffness and anti-submarining structures have been considered in an optimising process to select the restraint system characteristics which provide the best community protection in the range of real-world crashes in which they will be involved. A Societal Harm measure of the cost of injury was used to evaluate the effectiveness of the restraint system. This technique is proposed as a more appropriate approach to restraint system design than designing for government regulations or consumer information tests.

An important future application of this technique will be in side impact protection optimisation, however further work is required in a number of areas to obtain the information required to support the development of a suitable technique.

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