

Train crashworthiness and its impact on society

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SUMMARY: *In an environment where resources are scarce, decisions to spend more on safety or risk reduction need to be made on a rational basis. The assessment of such a situation must reflect the impact on society as a whole. When death and injury are involved this assessment becomes very complicated. This paper discusses how societal cost models can assist in making these difficult decisions. The example chosen in this paper is concerned with train crashworthiness but can easily be adapted to other mass transportation incidents.*

1 INTRODUCTION

Virtually any engineering project has an effect on the welfare, health and safety of society. Engineers therefore have an obligation to consider the consequences of their actions and designs, direct or indirect, immediate or long term. In general, engineering projects are very safe and have a beneficial effect, but errors and accidents do occur. Consequently, the possibility of a catastrophic event has to be considered. The assessment of such a situation must reflect the impact on society as a whole. When death and injury are involved this assessment becomes very complicated. It is difficult to quantify death and injury with its entire trauma, pain and suffering without inadvertently trivializing such suffering and reducing human life to a commodity value. However, in an environment where resources are scarce, decisions to spend more on safety or risk reduction need to be made on a rational basis.

In recent years societal cost models,^{1,2,3,4} have been developed to assist engineers and authorities in making these difficult decisions. The purpose of this paper is to demonstrate the use of these cost models to the wider engineering community. The example chosen is concerned with train crashworthiness with emphasis on societal cost.

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Whilst the cost of carriage repairs receives some consideration in this paper, the issue of repair crashworthiness is a significant study in its own right and is part of continuing studies by the first author. The methodology has application not only in justifying the expense of outfitting new trains but also of modernizing the older fleet with modern crashworthiness devices.

2 BACKGROUND

A severe train crash has implications and ramifications far beyond the trauma and drama of the immediate event. At one end is the cost of disruption to commuter traffic resulting in lost production and wages. At the other end are the Inquiries and Royal Commissions staged at massive cost to the community. Throughout, are the costs of the pain and suffering of the victims and the bereaved.

Effects are also felt by those in need of emergency and hospital services which as a result of a major train crash will be stretched to capacity. Emergency service delivery to "routine" motor vehicle and industrial accidents must endure triaging (battle front prioritising) to a level not normally experienced. Immediacy of delivery of emergency treatment is a significant factor in fatality rates.⁵ Accordingly, such delays in treatment may be responsible for a far higher rate of fatalities in cases not directly associated with the train crash.

Rail authorities have a responsibility to consider the possibility of a catastrophic event involving a high-energy device such as a speeding train. Increasing the crashworthiness of the carriages is one way to reduce passenger injuries in the case of a crash. However, this comes at a cost and the decision how much to spend on crashworthiness needs to be made on a rational basis. This assessment should include the impact on society as a whole as an essential part of the return-on-investment decision. Only when all the costs are known can benefit-maximization decisions be made. This is where societal cost models can help.

3 GENERAL APPROACH

The risk of a rail accident occurring in the life of the train is an important parameter in the overall cost analysis. In order to obtain a Risk Adjusted Savings (RAS) on the crash costs, the potential cost saving is multiplied by the accident frequency of the crash.⁶ This relation is shown in the following equation:

$$\text{Risk Adjusted Savings on Crash Cost} = \text{Potential Savings on Crash Cost} \times \text{Frequency (of Crash)}$$

In terms of a crashworthiness device, it can be said that if the rail authority spends more than the RAS on providing the device, the community is "in front". On the other hand, if the authority spends less, it is not carrying its full social responsibility. At the point of indifference, the rail authority spends all of the RAS on providing the crashworthiness device. This relation can be shown in the form of an equation as:

$$\text{Indifference Value of Crashworthiness Device} = \text{Potential Savings on Crash Cost} \times \text{Frequency (of Crash)}$$

In this paper, this equation will be used as a basis to determine how much rail authorities can be expected to spend on the installation of a particular crashworthiness device.

4 SOCIETAL COST MODEL

4.1 General

The costs associated with a major train crash can be divided into the following categories:

- Cost of death or injury of occupants;
- Cost of carriage repair or replacement;
- Remote costs.

In this paper, remote costs such as infrastructure damage and injuries beyond arm's length are excluded to limit the scope to manageable proportions. The general approach taken is one of conservatism, if the item of cost under consideration is largely inappropriate or appears remote, it is excluded altogether to ensure that the conclusion is understated in terms of the device's value.

4.2 Cost of death or injury

Crashworthiness devices generally result in reduced deceleration of passengers during a crash. The smaller the deceleration, the smaller the chance of injuries. To determine the potential savings in societal cost, this change in deceleration has to be converted into savings on injury cost. This conversion is quite involved, deceleration is an engineering parameter whilst injury cost is determined by medical parameters. The present section describes this conversion in detail. It starts with discussing common medical injury scales, which are subsequently related to cost. It then continues with discussing how biomechanical engineers measure injury and how these injury criteria are related to medical injury levels. Finally a statistically based relationship is presented that can be used to calculate the so-called probability injury costs of a specific crash scenario.

4.2.1 Medical injury scales

Medical practitioners use a number of methods for rating injuries. The score allocated has prognostic and triaging use as well as other purposes. An overview of the most common injury severity scores is shown in table 1.

Table1
Injury scoring systems

Scoring system	Example	Source
Anatomical Scores	AIS: Abbreviated Injury Scale ISS: Injury Severity Score NISS: New Injury Severity Score	Peden ⁷
Physiological Scores	GCS: Glasgow Coma Score RTS: Revised Trauma Score PTS: Paediatric Trauma Score	
Combination Scores	TRISS: Trauma Score-Injury Severity Score ASCOT: A Severity Characterization of Trauma	
Other	LOS: Length of Hospital Stay	Rosman ⁸

Most researchers in crashworthiness employ the Abbreviated Injury Scale (AIS).⁹ This paper follows convention in this regard.

4.2.2 Abbreviated Injury Scale (AIS)

Injury to the human body during energy exchange occurs at several concentrated points owing to the structure and contour of the human body. To reflect this the American Association for Automotive Medicine published a scale for injury severity known as the Abbreviated Injury Scale (AIS). The AIS was initially devised to standardize the terminology used to describe injuries. Its relative simplicity is its virtue.⁷ The scale ranges in severity from AIS 0 (no injury) to AIS 6 (death). The scale is ordinal in the sense that scale 4 (AIS 4) is not twice as severe as scale 2 (AIS 2). The scale is body region specific and reflects a risk of death resulting from the injury.

The AIS can be represented in the form of a table of actual injuries⁹ as shown in table 2.

4.2.3 Relation between injury scale and injury cost

Quantifying death and injury with its entire trauma, pain and suffering is extremely difficult. Notwithstanding, most people would have no difficulty in choosing between a thumb and a little finger if confronted with the choice of loss of one or the other, emphasizing that intrinsic value and relative value do exist. Courts of law are regularly asked to decide on the value of loss of life or limb and do so but seldom to the satisfaction of all parties, highlighting the lack of community consensus rather than criticising the legal systems.

Similarly, the approach discussed here is not without difficulty, some of which is raised below:

- Discrimination as to what is an immediate ramification from the crash and what is remote.
- Determining cost or value of life between say, a lifer in jail, a liability to the community and another Albert Einstein, arguably an asset.

Table 2
Correlation of AIS and typical body region injury

AIS Code	Body Region				
	Head	Thorax	Abdomen & pelvic components	Spine	Extremities & bony pelvis
1	Headache or dizziness	Single rib fracture	Abdominal wall; superficial lacerations	Acute strain (no fracture or dislocation)	Toe fracture
2	Unconscious less than 1 hr; linear fracture	2 – 3 rib fracture; sternum fracture	Spleen, kidney or liver laceration or contusion	Minor fracture without cord involvement	Tibia or pelvis or patella: simple fracture
3	Unconscious 1 – 6 hours; depressed fracture	4 or more rib fracture	Spleen or kidney; major laceration	Ruptured disc nerve root damage	Knee dislocation; femur fracture
4	Unconscious 6 - 24 hours; open fracture	4 or more rib fracture + complications	Liver; major laceration	Incomplete cord syndrome	Amputation or crush above knee; pelvis crush (closed)
5	Unconscious more than 24 hours; large haematoma	Aorta laceration	Kidney, liver or colon rupture	Quadriplegia	Pelvis crush (open)
6	Death				

- Determining cost of injury to account for the differences in loss of earnings for different professions.
- Cultural variations reflected in legal, medical and insurance costs. (eg. suing propensity).
- Cost of pain and suffering of victims.
- Cost of grief of relatives and friends of victims.

For a discussion of these and other associated matters the reader is referred to “The Economic Cost of Motor Vehicle Crashes 1994”.¹⁰ The societal cost of injuries used in this paper is taken from the NHSTA (National Highway Safety and Traffic Authority) Technical Report encompassing only the following:

Medical costs

The cost of all medical treatment associated with the injuries at the particular injury level.

Emergency services

The cost of ambulance or helicopter as well as police and fire department response cost.

Vocational rehabilitation

The cost of job or career retraining.

Market productivity

Lost wages and fringe benefits over the victims remaining life span.

Household productivity

Lost productive household activity valued at the market price to hire someone else to accomplish the tasks.

Insurance administration

The administrative costs associated with processing insurance claims.

Workplace cost

The cost of workplace disruption due the absence of the victim as an employee.

Legal/court cost

The legal fees and court costs associated with civil litigation. (Pay-outs are deemed capital reimbursements of the relevant costs above)

Premature funeral cost

Present discounted value of paying for a funeral in the present instead of at the normally expected end of the victim’s life.

A typical victim has injuries of varying severity to several body parts. However, the overall injury cost for a victim is largely determined by the most severe injury level. For example, the injury cost for a victim with an AIS5 injury is not likely to be significantly affected by some additional injuries ranking AIS2. Choosing the most severe injury from the field of AIS severity codes for all injuries sustained by a victim derives the Maximum Abbreviated Injury Score (MAIS) for that victim. Whilst the AIS is body region specific, injury cost from the MAIS becomes anatomically independent once a cost has been assigned.

The cost values shown in table 3 are derived from US motor vehicle crashes. Since the costs are tabulated against injury level and since injury cost stands independent of causal mechanism, the table is therefore useful for train crashes as well. (eg. a

Table 3
Total Societal Costs of Injuries By Severity Per Person
(1994 US Dollars)¹⁰

Cost item	Maximum Abbreviated Injury Scale (MAIS)						
	MAIS 0	MAIS 1	MAIS 2	MAIS 3	MAIS 4	MAIS 5	MAIS 6
Medical Costs	\$1	\$956	\$8144	\$28064	\$100820	\$354819	\$12089
Emergency Services	\$19	\$152	\$337	\$506	\$1150	\$1171	\$1055
Vocational Rehab	\$0	\$15	\$99	\$217	\$410	\$620	\$0
Market Productivity	\$0	\$1315	\$11645	\$35776	\$58073	\$184260	\$576266
Household Productivity	\$28	\$413	\$3598	\$10903	\$18746	\$54119	\$132630
Insurance Admin.	\$69	\$573	\$3481	\$11219	\$21165	\$49576	\$28646
Workplace Cost	\$29	\$217	\$1681	\$3671	\$4043	\$7049	\$7489
Legal/Court Costs	\$0	\$136	\$2179	\$7655	\$17087	\$45919	\$60766
Premature.Funeral	\$0	\$0	\$0	\$0	\$0	\$0	\$3389
TOTALS	\$146	\$3777	\$31164	\$98011	\$221494	\$697533	\$822328

Example: The total societal cost of a maximum injury sustained to the level of MAIS 1 is \$3777.

broken leg costs the same to fix whether it is sustained in an automobile accident or on a train). No allowance for pain and suffering was included. Injury cost estimates are thus understated but still considered to be a useful measure. The transportability of the table to and from countries that have different suing propensities, large court awards and expensive insurance rates is not claimed absolutely. Even a relative comparison may require some caution in its use. The caution applies also to the difficulties in applying the MAIS value. Since MAIS is estimated soon after the incident, even small injuries may develop complications later. Other items such as whiplash may not be discerned at material time but later account for significant cost.

An Australian conversion of injury costs from US costs is offered in Fildes et al³ based on earlier work by Miller.¹¹ Since Blincoe¹⁰ is a later study than Miller, this paper will retain the US dollar as the currency without attempting to convert.

4.2.4 Biomechanical indices

The system used by biomechanical engineers to measure injury is completely different from that used by the medical profession. Biomechanical engineers measure injury with a different index system for each anatomical part under consideration. Such systems are not only limited to the anatomical part but also to the direction of application of force, owing to the unique response characteristic of each part of the human body. Biomechanical indices in common use are listed in table 4.

The human body consists of many different body parts. Having to determine possible injury levels for all these parts, for all possible crash scenarios is extremely time consuming. However, head injury

dominates the general injury cost.¹⁶ Therefore, rather than considering injuries to all possible body parts, this paper considers head injury as the barometer of injury cost.

4.2.5 Head injury criterion (HIC)

HIC's genesis was the Wayne State University Concussion Tolerance Curve, representative of brain injury rather than head injury. In Society of Automotive Engineers Paper 660793, Gadd¹⁷ proposed a severity index based on raising the head deceleration dose to the power of 2.5 and integrating over the deceleration time period. The exponent of 2.5 was the log-log slope of the Wayne State Curve. The Severity Index (SI) was replaced by the HIC with US Federal Motor Vehicle Legislation (FMVSS 208) specifying a limit of HIC=1000 as the concussion tolerance level. (SAE 1986). As can be seen in the equation below for HIC determination, the exponent of 2.5 was retained.

$$HIC = \left\{ t_2 - t_1 \right\} \cdot \left[\frac{1}{\left\{ t_2 - t_1 \right\}} \int_{t_1}^{t_2} a dt \right]^{2.5}$$

where a = acceleration in multiples of g, and t₁ and t₂ are any two points in time during the impact which are separated by not more than a 36 milliseconds time interval.

4.2.6 Relation between medical and biomedical injury models

The link that connects factual observations of injury by a medical practitioner with prediction of injury by an engineer is a probability function based on statistical data gathered over many events.

Table 4
Some biomechanical indices in common use

Index	Inputs
HIC: Head Injury Criterion	Deceleration + Exposure Time
GAMBIT: Generalized Acceleration Model for Brain Injury Threshold	Linear & Rotational Deceleration (Newman ¹²)
Nij: Neck Injury Criterion	Deceleration
VC: Thoracic Viscous Criterion	Velocity + Deflection (Pipcorn 1996)
TEC: Translational Energy Criterion	Energy (Stalnaker et al ¹⁴)
DV: Delta V	Secondary Impact Velocity (Roberts ¹⁵)

Irrespective of the injury index used, the format is the same. In its most basic form, the probability function separates death from life in a cumulative distribution curve. Such a curve was put forward as the position of the US delegation to the International Standards Organization. This much reported curve, shown below, has HIC as the basic index and has superimposed on it the abbreviated injury scale domains.¹⁸

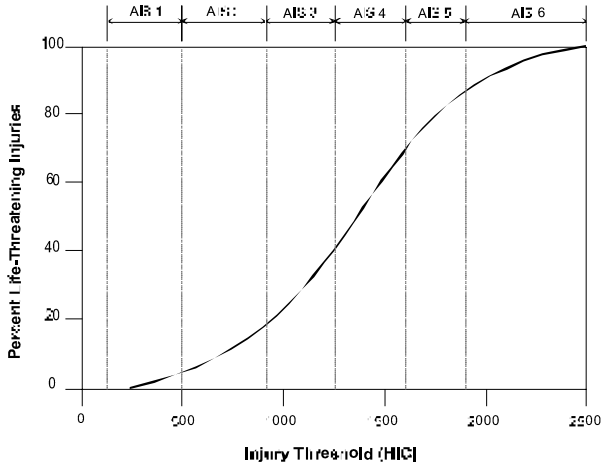


Figure 1: Probability of fatality vs. head injury criterion
Example: A victim with head injury caused by exposure to acceleration to a level of HIC =1000 has approximately an 80% chance of survival and falls in the Abbreviated Injury Scale Domain of AIS 3.

A single line dividing life from death such as shown in figure 1 is of limited value since it does not address the risk of injury at each injury level according to the AIS. Also, the same exposure to decelerating forces affects people in different ways.

Weight, height, age etc were shown to influence injury severity level significantly.¹⁹

To address these variations, statistics have been accumulated and frequency distributions developed for the head injury criterion. Figure 2 shows the relation between HIC and the MAIS. The bold lines separate injury/no injury and death/life. The dotted lines separate the zones of injury and must be read differentially.

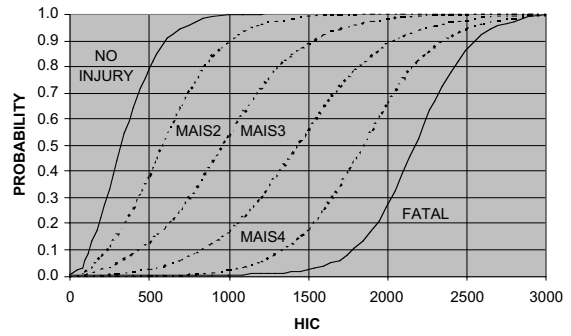


Figure 2: Injury risk curves & protection reference values

For example, for a HIC of 1500 the probability of injury severity is as follows:

- where HIC = 1500,
- MAIS 1 = 1%
- MAIS 2 = 10.5%
- MAIS 3 = 32.8%
- MAIS 4 = 37.5%
- MAIS 5 = 16.2%
- MAIS 6 (fatal) = 2.1%
- No injury = 0.0%
- Total = 100%

A mathematical representation of the curves in figure 2 is given in table 5 below.

Table 5
 Expanded Prasad/Mertz Formulae (NHTSA¹⁹)

Maximum Abbreviated Injury Scale	Probability @ MAIS n =
MAIS 1 =	$[1 + \exp ((1.54 + 200/HIC)-0.0065 \times HIC)]^{-1}$
MAIS 2 =	$[1 + \exp ((2.49 + 200/HIC)-0.00483 \times HIC)]^{-1}$
MAIS 3 =	$[1 + \exp ((3.39 + 200/HIC)-0.00372 \times HIC)]^{-1}$
MAIS 4 =	$[1 + \exp ((4.9 + 200/HIC)-0.00351 \times HIC)]^{-1}$
MAIS 5 =	$[1 + \exp ((7.82 + 200/HIC)-0.00429 \times HIC)]^{-1}$
MAIS 6 =	$[1 + \exp ((12.24 + 200/HIC)-0.00565 \times HIC)]^{-1}$

The information given in table 3 and table 5 can now be used to calculate the so-called probability injury costs of a specific crash scenario. The probability injury costs are defined mathematically below:

Probability Injury Costs⁴ =

$$\begin{aligned}
 & [\text{Probability (MAIS1)} \times \text{Cost (MAIS1)} \\
 & + \text{Probability (MAIS2)} \times \text{Cost (MAIS2)} \\
 & + \dots\dots\dots \\
 & + \text{Probability (MAIS6)} \times \text{Cost (MAIS6)}]
 \end{aligned}$$

This approach will be further explained in the example at the end of this paper.

5 PROPERTY DAMAGE

The typical carriage considered here has a crumple zone at the front and rear, separated by a significantly more robust central section called the survival zone. A minimum repair cost threshold would include recovery from the crash site, cutting affected parts, rewiring, replumbing, repainting and replacement of draft gear. This threshold and a price per metre of crush have been estimated using a fabrication cost manual.²⁰

A severe impact will use up the entire crush zone and extend to deforming the survival zone. A deformed survival zone is deemed to have rendered the carriage unrepairable. The upper limit of property damage is thus established. The indicative overall cost profile is shown in figure 3.

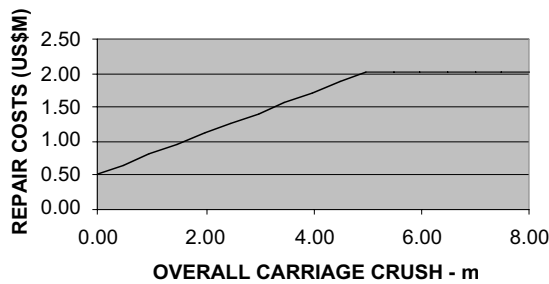


Figure 3: Indicative carriage repair costs

The amount of crush includes both ends, reflecting overall shortening of carriage. Repair prices are indicative and will vary depending on the type of carriage and many other factors, consideration of which are beyond the scope of this paper. The US dollar has been retained to be consistent with other costs considered.

Older style carriages with stiff underframes do not have crumple zones. End impact gives rise to a compressive stress in the underframe. This stress

is superimposed over bending stresses in the underframe that service the normal functioning of the carriage. The likely failure will occur midway between the bogies where the bending stress is likely to be highest. This has the effect of distorting survival space over the long central section, making repair extremely expensive. Under such conditions, even a low speed collision can render a carriage uneconomical to repair. Accordingly, figure 3 is inappropriate for carriages with stiff underframes.

6 INCIDENT LIKELIHOOD

As mentioned earlier, the risk of a rail accident occurring in the life of the train is an important parameter in the overall cost analysis. Figure 4 shows the risk expressed in events per 10⁹ passenger kilometres.

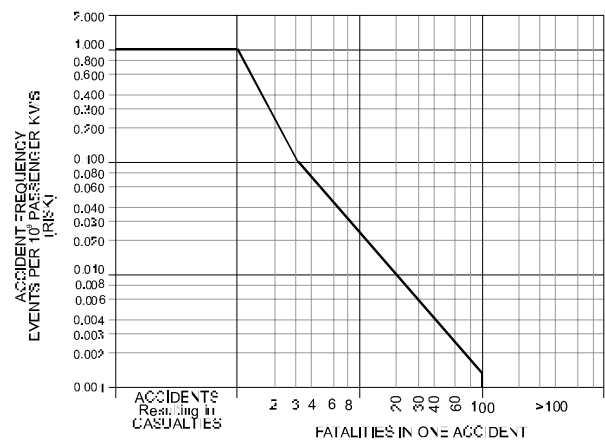


Figure 4: Risk profiles for US passenger railroads

Accident frequency is expressed in events per 10⁹ passenger kilometers travelled. The passenger distance (PD) is calculated for a passenger train travelling 500,000 km per year as follows:

$$\begin{aligned}
 \text{PD} &= \text{Annual mileage of train (in km)} \\
 &\quad \times \text{Life expectancy of train (in years)} \\
 &\quad \times \text{Passenger Density (Average No/train)} \\
 &= 500,000 \times 25 \times 100 \\
 &= 0.125 \times 10^9 \text{ Passenger km}
 \end{aligned}$$

Reading figure 4, the risk of a serious rail accident which results in casualties is once every 10⁹ passenger kilometers travelled. For the example train considered above this risk is therefore 0.125.

The risk of a rail accident occurring in the life of a train with a severity of 100 casualties is read from figure 4 as 0.0014 for every 10⁹ passenger kilometres. Hence this risk for the example train is 0.125 x 0.0014 = 0.000175.

7 WORKED EXAMPLE

7.1 Problem description

1. Determine the risk-adjusted societal cost saving of a device that improves Head Injury Criterion from HIC=1450 to HIC=750
2. Assume 100 passengers, 125,000,000 passenger km in the life of the train of 25 years.
3. Ignore property damage and present value calculations to maintain problem simplicity.

7.2 Solution

The probability injury cost can be determined on a whole person basis, the end result varies only in rounding errors. This approach is preferred since it is nonsensical to consider injury of a portion of a person.

The probabilities are read directly from figure 2 (or calculated from table 5 formulae) for all injury severity levels for both HIC=750 and HIC=1450 and recorded in tables 6 and 7 below.

The saving on societal cost of death and injury for a crash difference of HIC=1450 and HIC=750 is calculated as follows:

$$= \$23,192,312 - \$5,776,986$$

$$= \$17,415,326$$

Table 6 above shows 2 fatalities (AIS 6 vs HIC=1450). Figure 4 shows the risk of such an accident to occur as 0.25 times per 10⁹ passenger kilometers travelled. Since the typical train as defined travels only 0.125 x 10⁹ passenger km, the risk is computed as follows:

$$\text{Frequency (of Crash)} = 0.25 \times 0.125$$

$$= 0.03125$$

Table 6
Number of persons injured vs. injury level

Maximum Abbreviated Injury Scale	HIC=750		HIC=1450	
	Probability of injury at MAIS level	Converted to WholePersons	Probability of Injury at MAIS level	Converted to WholePersons
MAIS 0	0.044	4	0	0
MAIS 1	0.252	25	0.012	1
MAIS 2	0.408	41	0.122	12
MAIS 3	0.222	22	0.353	35
MAIS 4	0.066	7	0.363	36
MAIS 5	0.007	1	0.135	14
MAIS 6	0	0	0.015	2
TOTAL	1.000	100	1.000	100

The cost of each accident can now be computed as shown in table 7 below:

Table 7
Probability Injury Cost Comparison

Injury level	HIC=750			HIC=1450		
	No Persons	Table 3 Costs	Injury Cost	No Persons	Table 3 Costs	Injury Cost
AIS 0	4	146	4 x 146= 584	0	146	0 x 146 =0
AIS 1	25	3777	94425	1	3777	3777
AIS 2	41	31164	1277724	12	31164	373968
AIS 3	22	98011	2156242	35	98011	3430385
AIS 4	7	221494	1550458	36	221494	7973784
AIS 5	1	697553	697553	14	697553	9765742
AIS 6	0	822328	0	2	822328	1644656
TOTAL	100		\$5,776,986	100		\$23,192,312
SAVING						\$17,415,326

Taking into account the number of times that the saving occurs in the life of the train gives the budget for the crashworthiness device:

Indifference Value of
Crashworthiness

Device = Potential Savings on Societal Cost
of Crash

$$= \$17,415,326 \times 0.03125$$

$$= \$544,229$$

7.3 Outcome

By improving the crashworthiness of the train where head injury is reduced from HIC=1450 to HIC= 750 a total societal cost saving of \$M17.4 would be realized in the event of a crash. However, taking into account the low likelihood that an event of the particular magnitude would occur, spending only \$544,000 is justified on the particular crashworthiness device responsible for the improvement.

8 CONCLUSION

A model has been presented that links input engineering parameters such as velocity change with cost to the community of medical, legal and funeral costs as well as loss of productivity of the victim on the basis of injury and death. By the use of the HIC as the critical cost parameter, the need to cost out every type of injury is obviated. Published probability statistics relating to the levels of injury are combined with injury costs to provide a probability injury cost which when adjusted for the crash likelihood becomes the risk-adjusted societal cost.

The model has immediate application in optimising the comparative passive safety values of crashworthiness devices. Indeed, any incident where blunt injury is caused by the application of force can be assessed by the model presented. The model validity is confined to comparative use since the US dollar value is retained as published. However, with a suitable conversion rate that takes account of social differences as well as dollar value, there is scope to extend the model to absolute use.

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Edward's love of trains has its genesis in his early years as an apprentice. There he gained the Commissioner for Railways Prize for Best Apprentice. The Amalgamated Engineering Union also awarded him their Best Apprentice Prize in his final apprenticeship year.

His practical career start gave him a solid foundation, on which to build and pursue an academic path as well, earning him a Bachelor of Science Degree majoring in Mechanical Engineering. As a Practising Engineer he was awarded an Excellence Award from the Society of Automotive Engineers for his design of an elevating work platform insert for truck-mounted cranes.

Eager to contribute to safety in trains he researched crashworthiness of trains at the University of Southern Queensland who conferred the degree of Master of Engineering. The research work complemented his consultancy to Queensland Rail on the Heritage Train renamed the Great South Pacific Express. There he performed the task of checking that the GSPE was crashworthy according to the Australian Railways Code.

He is first Author in a number of peer-reviewed papers:

Having spent two years full-time researching general crashworthiness at the University of Queensland, he recently transferred to Queensland University of Technology where the facilities are more appropriate to his present focus, being injury during short duration crash pulses. The present research work is expected to lead to the award of a PHD degree.

The Co-authors Professors Gerard Van Erp and Chris Snook were Edward's Supervisors during his Master's studies. Both Professors made a significant contribution to the paper.