Road Safety Enhancement : An Evaluation Overview

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Abstract:

The single vehicle run-off road toll on New Zealand highways is about equivalent to a 737 commercial aircraft crashing each year killing all on board. However, road systems and vehicles that we know are unsafe at any speed are just accepted when a crash occurs, because liability is often shed through blaming one of the victims. Roads and vehicles must be designed to be tolerant of human error so that they are benign in terms of injury and fatalities when an error does occur.

This paper discusses the paradigm shift in road-safety and crashworthiness thinking that must now be applied to our road system. Examples are presented to demonstrate a fundamental understanding of safety subsystem within the road system. The author argues that a robust understanding of the accident process, the injury process and structural crashworthiness must be acquired in order to reduce severity of these crashes.

Some economic evaluations of road safety enhancement through retrofit programs on state highways in New Zealand demonstrate an acceptable approach. The author further argues the funding for mass actions of seal widening and providing 9 meters of recoverable clear zone on existing state highways than a project traditionally tied to a physical location may enhance road safety.

This paper is based on a review of the benefits and costs of retrofit programs considered for Transit's safety certification program. This was part of an overall economic evaluation of the 2010 Road Safety Strategy. The views and comments expressed in this paper are those of the author and do not necessarily be construed as being those of Transit New Zealand.

Introduction

When we fly in an aircraft or travel by train we do not expect to be injured or killed. Yet when we drive or travel as a passenger in a car, we know the risk of a crash is high. We regularly see crashes on the roads we travel. We know that if we have a crash, possibly not of our fault, it may result in an injury or fatality. Society and in particular engineers tolerate this outcome as if it is inevitable result of the technology we are using and the resources we have available.

In the five-year period between 1995 and 1999, the reported single vehicle injury crashes on New Zealand highways were 7539. Of these 6185 collided with a fixed object and 450 crashes resulted in fatality. The single vehicle run-off road toll on our highways is equivalent to about a 737 commercial aircraft crashing each year killing all on board. If this occurred the aircraft would be grounded until a government inquiry revealed the causes and industry and government provided an assurance that such regular crashes were eliminated.

This paper discusses the road-safety enhancement through crashworthy appurtenances thinking that has to be applied to further reduce injuries and fatalities within our road system. The author argues that a robust understanding of both the accident process and injury process must be acquired and further that prevention is not just a statistical and policy issue but one of application. Examples of where a lack of fundamental understanding in crashworthiness as a total road system is resulting in fatalities are discussed. Some methods of analyses for assessing the crashworthiness of the system also presented. The examples discussed demonstrate that the road infrastructure, vehicle and user/driver industries and regulators such as road authorities can no longer continue developing products and services in separation of each other.

A crashworthiness perspective

A clear distinction needs to be made here between the cause of a crash and the cause of the injury arising from a crash. Serious injuries arise from impacts where forces in excess of human tolerance values are transferred. Injury prevention measures must reduce (filter) the energy and forces down to tolerable levels. Recognition of this principle is at the heart of Sweden's Vision Zero [Tingvall (1998)] road safety philosophy, that

*'no foreseeable accident should be more severe than the tolerance of the human in order not to receive an injury that causes long term health los*s".

The Swedish Parliament adopted this philosophy in 1997. It clearly has far reaching ramifications in terms of system design requirements. It moves totally away from the 'blame the victim' viewpoint and explicitly recognise that the system designers and the road users share responsibility for safety. A key principle from Vision zero is that:

'The designers of the system are ultimately responsible for the design, operation and use of the road transport system and thereby responsible for the level of safety within the entire system'.

Systems performance effectiveness for injury prevention will also demand increased scrutiny and accountability of system designers for safety performance. Hence, the need for increased system effectiveness for injury prevention leads to the notion of the recognition of the need of *crashworthy system*s, rather than simply crashworthy vehicles.

A crashworthy system approach requires a paradigm shift in road-safety and crashworthiness thinking [Rechnitzer and Grzebieta (1999)]. It calls on the different industries (road-safety, vehicle and infrastructure) to collaborate, exchange information and seeks a compatible state for the benefit of the users of their particular subsystem. It suggests a systems approach should be used to design vehicles and infrastructure for the environment they have to operate in.

Associated with this view of the need for crashworthy systems and design integrity, is the need to recognise and apply first principles relating to injury prevention in impacts. Whereas adherence to such principles will help ensure design effectiveness, it is also axiomatic that violation of these fundamental principles will inevitably result in systems failures leading to serious injury or death.

Examples where violation of first principles occur are common place, and include the roadside furniture such as guardrail. Examples of crash types that have yet to be dealt with effectively for occupant protection include rollovers, and various fixed objects, which inherently disregard the laws of physics as regards to force, acceleration or other performance criteria.

Systems Interaction

The following example demonstrates failure of the interface compatibility between two subsystems, namely a car and the road environment. Figure 1 shows an example where an obvious miss-match between the crashworthiness system of a car and the end terminal of a barrier. Yet another example of a bad interface between roadside objects and vehicle systems are pole and tree crashes. They account for a large number of fatalities.

One of the main problems identified by researchers is that the vehicle fleet is continuously changing to accommodate design variations in respect to aesthetics, aerodynamics, fuel economy and crashworthiness. Vehicles are now softer and more slender (wedge shaped). This can present under ride problems making the roadside safety hardware obsolete. Tests and evaluation of crashworthiness are becoming increasingly complex.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials (AASHTO) initiated National Cooperative Highway Research Program (NCHRP) employing modern scientific techniques.

The following example demonstrates success of the interface compatibility between two subsystems. Figure 2 shows an example where an obvious match between the crashworthiness system of a car and the truck-mounted attenuator.

Figure 1 Result of impact with guardrail terminal,

Figure 2 Result of impact of car with truck-mounted attenuator

In considering countermeasure options for reducing the harm potential in impacts and the development of crashworthy systems, certain design concepts and principles need to be kept in mind to ensure the effectiveness of any measure. These are primarily:

i) Reduce the possibility of a collision with roadside object – Geometry and Clear Zone.

ii) Ensure compatible interfaces (stiffness and geometric) between interacting systems, be they structures or roadside objects.

Roadside Hazards & Hazard Protection

Roadside hazard protection involves either;

- removing,
- relocating or
- protecting the hazard.

Clear zone provides unobstructed area facilitating recovery and therefore minimizing single vehicle crashes.

Guardrails protect motorist from a serious roadside hazard.

Single vehicle crashes

The reported injury accident statistics for the five-year period between 1995 and 1999 lists the single vehicle crashes on State Highways as in Table1.

Objects collided with	Number of crashes	% of the single vehicle crashes
Upright cliff or bank	1474	19.55
Over edge of bank	550	7.30
Fence	1291	17.12
Guardrail	344	4.56
Pole	764	10.13
Tree	713	9.46
Ditch	1049	13.91

Table 1: Single Vehicle Crashes on State Highways (1995-99)

Seal width

State Highway Performance Indicator and Targets, December 2000 has identified a seal width deficiency of 2296 km within the state highway network that requires upgrading (less than target standards). It also suggests that 2912 km of the highway network meet the current cross- section standards. The rest of the network does not meet today's standard but not required to be upgraded now.

Considering the reported non-intersection injury accident statistics for the five year period between 1995 and 1999, both inclusive, the average accident rate on the portion of network that meet the cross-section standard is 58 numbers per 100 million vehicle kilometres.

Although only 2296 km of the network need to be upgraded, the links that includes these sections would be 7294 km in length. Appendix A shows the detail calculation and the results are summarised in Table 2; Crash per 100 million vehicle kilometres shows the crash rates for under-width sections.

Category	Crash per 100 million vehicle kilometers
Sections identified for seal widening	64
Links that include the sections identified for seal widening	61
Routes that complies with the current standard	58

Table 2: Crash per 100 million vehicle kilometres

Accident rate for narrower seal sections would be marginally higher than wider seal sections.

i.e accident rate where the width is deficient = $x * r$

where r = accident rate where width is not deficient

If P is the proportion of deficient section length to the total length of highways; then

The expected number of accident on a link is;

$$= x\ r P V + r(1-P) V$$

Where V= AADT * Length (vehicle km)

The best estimate for $N \sim x\ r P V + r(1-P) V$

Considering the links that has some deficiency

$$\sum N \sim x\ r \sum(P V) + r \sum (1-P) V$$

$$x \sim \frac{\sum N \ - \ r\sum (1-P)V}{r\sum PV}$$

$$x \sim \frac{7657 \ - \ 58*10^{-8}*[68885203-1702712]*5*365}{58*10^{-8}*1702712*5*365} = 1.2$$

Therefore; the expected accident rate where width is deficient = 1.2 * 58 = 69.6 / 10^8 vkm

The portion of the network that needs to be upgraded amounts to 620.5 million vehicle kilometres in a year. Therefore widening of seal is expected to have a reduction of 11.6 accidents per 100 million vehicle kilometres, which is savings of 71.98 accidents per year.

The Author considers a reduction of 71.98 crashes in a year due to seal widening as a part of network upgrade. The adjusted crash rates per year are shown in Table 3; Single vehicle crash per year for standard cross section.

Objects collided with	**Fatal**	**Serious**	**Minor**	**Total**	**Percent**
Upright cliff or bank	15.24	200.36	65.13	280.73	23.83
Over edge of bank	13.14	66.85	24.76	104.75	8.89
Fence	14.47	167.60	63.80	245.87	20.87
Guardrail	3.81	46.47	15.24	65.52	5.56
Pole	13.33	93.32	38.85	145.51	12.35
Tree	13.90	83.42	38.47	135.79	11.53
Ditch	11.81	140.36	47.61	199.78	16.96
Total				1177.95	99.99

Table 3: Single vehicle crash per year for standard cross section

The expected benefit types are:

- Overall reduction in crashes due to the provision of clear zone, and
- Reduction in severity due to the installation of guardrails.

The next step in the process is to select the safety treatments based on the description of the object collided with.

Description	**Safety treatment**
Upright cliff or bank	Guardrail
Over edge of bank	Guardrail
Fence	Beyond road reserve
Guardrail	Existing
Pole	Clear zone
Tree	Clear zone
Ditch	Clear zone

Table 4: Safety treatments

Clear zone

Provision of clear zone will reduce the probability of a crash. Considering the percentage of the single vehicle crashes collided with guardrail, the author has assumed a residual crash rate of 5.56%.

The expected crash reductions for various hazards are given Table 5; Expected crash reduction rates.

Crash type	**Expected reduction (Total)**	**Reduction per year**
Pole	55 % (6.79 %)	79.98
Tree	51.8 % (5.97 %)	70.32
Ditch	67.2 % (11.4 %)	134.29
Total		***278.38***

Table 5: Expected crash reduction rates

Given that high proportion of the benefits are expected in near rural or in remote rural environment the cost is assumed to be in the range of $460,000 and $700,000. Therefore, the expected safety benefits due to the provision of clear zone would be in between $128 and 194.8 millions.

Guardrail: Provision of guardrail will reduce the severity. The author has also assumed that this reduction in line with the crash rate for existing installations.

Upright cliff or bank: Considering the crash statistics, no change in severity is expected.

Over edge of bank: Seven percent change from fatal to serious crash is expected, which would be equal to a benefit of $2.36-2.26 millions per year.

Benefit

The total expected benefit would be in the range of $130.26 – 197.16 millions per year.

Cost

The total cost to eliminate and protect roadside hazard has been identified as being in the range of $330 - 630 millions with a best estimate of $480 millions.

Benefit cost ratio

Based on the available data the benefit cost ratio to eliminate and protect roadside hazards would be between 1.9 and 2.8, throughout the cost range. This assumes that the average project mix remains constant.

The benefit/cost analysis considered a total cost of $630 millions (PV of $425 M) to ensure delivery of the benefits.

PILOT STUDY

A typical section of a highway (SH3 Hawera - Bulls) was selected. Single vehicle crashes for a period of five years (1995-1999) from Accident Investigation System (AIS) were used to determine the base crash rate and crash cost for this particular section of road.

The mix of treatments for providing the roadside hazard protection were then identified and the cost per unit length was estimated.

Assuming a design life of 25 years and a discount rate of 10% the B/C of providing roadside hazard protection was calculated.

The AIS listed 123 reported injury crashes for the five-year period between 1995 and 1999. Of these crashes eight fatal and 25 were serious. The balances of ninety were minor injury crashes.

Various studies have shown that single vehicle accidents have a different trend when compared to multi vehicle accidents. Therefore, the average accident cost was derived from the Transfund's estimate for cost per accident by speed limit, severity, movement and vehicle involvement.

The average estimated crash cost is $231,800 per injury crash (original estimate is $460,000 – 700,000).

Cost of clear zone

The cost of physical work excluding the purchase of land for this particular section was estimated as $87,000 per kilometer. This estimate was based on combination of relocating power poles, cutting trees, reshaping water-tables, tidying-up banks, extending culverts, earth works cut and fill, relocating some land drains, fencing and installing guardrail for some 16.1 kilometers.

A large proportion of SH3 has a 20-meter road reserve and requires additional land purchase to provide a 9-meter clear zone. A detailed analysis of this particular section shows 27% of the single vehicle crashes had an impact with a fence. The cost of additional land purchase is estimated to be $35,000 per kilometer, although only 56 of the 102 kilometers of this section required land purchase. Hence the average cost over the full length of this section for land purchase is estimated at $19,500 per kilometer.

The total cost of providing the clear zone is therefore estimated as $106,500 per kilometre. It should be noted that the cost estimate is derived from traditionally small projects previously carried out in the region. The extent of corridor level retrofits may achieve economy of scale, due to the larger project sizes, which could result in higher benefit cost ratios than estimated.

Economic Evaluation

AASHTO suggests that a 9-meter clear zone on a straight alignment with a 100 km/h speed environment will provide 85% recovery of vehicles run-off the road. Considering the mix of proposed physical works and history of single vehicle accidents on State Highways, the expected crash savings will be in the order of 50-85%.

The B/C ratios for the levels of accident saving performance are summarised in Table 6; Crash savings and Economics. For example, the worse case scenario where only 50% of benefits accounted was resulted in a B/C of 2.5

Acc Saving per year per km		**25 year Benefit**	**B/C**
85%	$47,188.20	$449,420.41	4.2
80%	$44,412.42	$422,983.92	4.0
75%	$41,636.65	$396,547.42	3.7
70%	$38,860.87	$370,110.93	3.5
65%	$36,085.09	$343,674.43	3.2
60%	$33,309.32	$317,237.94	3.0
55%	$30,533.54	$290,801.44	2.7
50%	$27,757.76	$264,364.95	2.5

Table 6; Crash savings and Economics

Conclusion

Roadside hazard protection involves either removing, relocating or protecting the hazard. Overall, there may be a substantial net benefit from the roadside hazard protection. The pilot study showed that providing roadside hazard protection could provide considerable safety benefits. Based on this study, the author believes that roadside hazard protection will have a safety B/C ratio in the range of 2.5 to 4.2. It should be noted that the cost was based on smaller projects and that corridor level retrofits may achieve economies of scale, due to the larger projects. The effect would be the achievement of higher B/C than these intended estimates.

In order to overcome the uncertainty in the benefit/cost estimations the performance of the retrofit program needs to be monitored and reviewed routinely to enable a refocusing of the efforts for maximum returns, throughout the implementation period.

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Appendix A

Sector	SH	Sect_Id	Length m	Target Width	Injury Accidents	AADT	Seal Width Length Deficient %	Length of Deficiency	Accident Contribution	Defficient Length X AADT	Length with some Deficiency	Accident on deficient links	Length X AADT	Length of 100% Compliance	Length of 100% Compliance X AADT	Accident on 100% Compliance
001	1F	01F-0000	33953	7	0	148								33953	5025	0
002	1F	01F-0054	49923	8.5	0	514	73	36444	0	18732	49923	0	25660.42			
003	1N	01N-0000	10433	8.5	18	1802								10433	18800	18
004	1N	01N-0010	76143	8.5	60	464	17	12944	10.2	6006	76143	60	35330.35			
005	1N	01N-0088	21003	8.5	44	1644								21003	34529	44
006	1N	01N-0109	47397	10	123	2046	17	8057	20.91	16486	47397	123	96974.26			
007	1N	01N-0158	9695	10	104	5720										
008	1N	01N-0168	50065	10	152	2686	4	2003	6.08	5379	50065	152	134474.6			
009	1N	01N-0220	27526	10	92	2652	27	7432	24.84	19710	27526	92	72998.95			
010	1N	01N-0248	19257	10	61	3169	31	5970	18.91	18918	19257	61	61025.43			
011	1N	01N-0267	17508	10	63	4644	14	2451	8.82	11383	17508	63	81307.15			
012	1N	01N-0284	14783	10	139	7473	26	3844	36.14	28723	14783	139	110473.4			
013	1N	01N-0296	31327	0	207	24648										
014	1N	01N-0335	26106	0	883	40074										
015	1N	01N-0360	24582	0	137	13492										

FULL DATA SET IS NOT SHOWN

Sector	SH	Sect_Id	Length m	Target Width	Injury Accidents	AADT	Seal Width Length Deficient %	Length of Deficiency	Accident Contribution	Defficient Length X AADT	Length with some Deficiency	Accident on deficient links	Length X AADT	Length of 100% Compliance	Length of 100% Compliance X AADT	Accident on 100% Compliance
Total			10775704					2296411	1986	1702712	7293541	7657	6885203	2911751	3632303	3873
Rate								64			61			58		

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