An Application of System Dynamics and Risk Management Techniques to School Bus Safety Policy

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New Zealand's Land Transport Safety Authority (LTSA) has a dilemma in that it is charged with setting safety standards in a politically sensitive environment. However, the standard benefit/cost justification process for safety initiatives cannot adequately cater for catastrophic risk events of low probability, uncertain probabilistic distribution and high political impact.

The school bus sector is one area where this dilemma is highlighted; a base level of risk exists from daily operation, in addition to a catastrophic risk of a major school bus accident. The LTSA's ability to manage these risks is limited by the interaction of the stakeholders, namely the Ministry of Education, students, parents, schools, communities, bus operators, and central government.

This paper approaches this situation from the perspective of a comprehensive risk management analysis, based upon the New Zealand Standards and the State Services Commission guidelines. The system dynamics approach provides an analytical framework to develop an understanding of the interaction of policies with the school bus environment, and their subsequent impact on the risk factors to be managed by the LTSA.

A Powersim model has been developed to investigate the validity of this approach, and to demonstrate the relationships between the four aspects of modern risk management, namely financial, behavioural, reputation and hazard. The model is used to provide insight into five proposed policy initiatives and four realistic future scenarios facing the LTSA. The model suggests that the most volatile risk that the LTSA faces is reputation-based, a clear example of which is a school bus catastrophe.

The Land Transport Safety Authority (LTSA) is the New Zealand statutory body charged with developing and ensuring the enforcement of safety policy, regulations and standards for all forms of land-based transport, and the users of such transport (both operators and passengers) within New Zealand. As a regulatory body, the LTSA develops rules and regulations for safe operation of vehicles and services.

Policy and rule development requires a consultative process offering all significant stakeholders the opportunity to have input in the process. The LTSA has the responsibility of receiving and assessing the relative merits of submissions and, along with its own specialist research, skills and knowledge, translating them into potential policies. Potential policies are then assessed against set benefit/cost criteria[i] to determine which will be pursued into rules, regulation or statute as appropriate.

Safety issues for school buses are a significant policy concern. This is a politically sensitive issue. As the service users (i.e. children) are voiceless, advocacy on their behalf has been passionate, particularly as their advocates perceive a safety contradiction in existing regulations, which require all children to be secured by seatbelts when travelling in cars, but not when travelling in buses, and which allow bus loading factors with up to 33% of children standing. Significant pressure has been brought upon the LTSA to review these regulations, as approximately 67,000 children travel daily to and from school on buses, in addition to incidental bus travel involving a further 50,000 children. In addition to the daily risks faced by children travelling in school buses, the possibility of a major catastrophe involving a school bus, with consequent serious injury and loss of life has been cited by advocates as a justification for increasing safety standards.

However, counter-advocacy cites the significant costs of increasing safety standards, and the fact that bus travel is approximately 10 times safer than travel by car as reasons to maintain the status quo.

Using traditional benefit/cost tradeoffs, the LTSA has been unable to justify additional mandatory safety policies (e.g. fitting seatbelts). In addition, the difficulty in quantifying the probability of a major catastrophe involving a fully laden school bus has not enabled this component to be adequately factored into any meaningful benefit/cost or policy analysis. Furthermore, the benefit/cost framework does not readily facilitate analysis of multivariate policy options, or an evaluation of the effect of multiple policies interacting with each other over an extended period of time.

A new approach is needed to satisfactorily address these issues. The application of a risk management approach combined with a system dynamics model of the school bus sector enables the LTSA to explore the impact of a variety of policy options both singly and in combination, as an additional tool to the existing benefit/cost analysis in assessing which policies it will pursue into regulation. A prototype system dynamics model was created using the Powersim modelling package to demonstrate the potential of this approach, to gain a fuller understanding of the interrelationships between the multiple variables in the system, and to enhance justifications for policies to be developed into rules, regulations and statutory legislation.

Risk Management Approach

The current LTSA methodology of benefit/cost analysis relies upon historical data. The justification for new initiatives, for example, mandatory wearing of seatbelts, is based upon the number of deaths and injuries that occurred to non-seatbelt wearers that would have been prevented had the policy been in effect. The 'value of statistical life' is used to calculate the social costs of fatal and serious injuries so that a benefit/cost ratio - which must be greater than one to one - can be obtained.

However, in order to measure the average cost to society in a single year, to evaluate the benefit/cost ratio, there needs to be a statistically significant number of accidents that fit the description. The risks associated with any type of infrequent accident that has catastrophic consequences are difficult to measure. This is a traditional problem with low probability disasters, such as earthquakes and aircraft crashes.

Traditional "risk management is the process of making and carrying out decisions that will minimise the adverse effects of accidental losses." (Head and Horn 1985)

The role of state agencies such as the LTSA is to minimise political risk to the Government while carrying out their primary objectives. In the LTSA's case, their primary objective is targeted upon reducing the social cost of the loss of life and injury upon New Zealand's roads. They achieve their objectives by setting standards for vehicles and drivers, sponsoring training and liaising with other agencies, such as the Police and the Ministry of Health.

McNamee (1997) has identified four strategic areas of risk, covering soft risks in addition to the traditional hard risks:

Hard Assets		**Soft Assets**	
Financial	Physical	Human	Intangible
Financial Risk Management	Hazard Risk Management	Behavioural Risk Management	Reputation Risk Management

The LTSA needs to manage all four of these types of risk.

Financial Risk
The LTSA has the role of reducing the costs of risk to society. While the LTSA does not itself meet any costs directly, the New Zealand Government is liable for the emergency services, medical and rehabilitation costs involved with any accident. In addition, each person killed or injured reduces the Government's income via a reduced economic base. The Government has instructed the LTSA to use the calculated average economic value of each death and injury as the justification for any risk management measures.

Hazard Risk
Hazard is the main type of risk that the LTSA has traditionally focused upon. The objective of the LTSA is to reduce the number of deaths and injuries through improvements in vehicle standards, driver education and improved maintenance measures.

Behavioural Risk
Behavioural risk is an area that is only partially managed by the LTSA. The objective is to reduce risky behaviour by road users, with the effect of reducing the deaths and injuries on the road.

Reputation Risk
The LTSA is a politically accountable organisation. An increased hazard on the roads is politically undesirable and a Government can suffer consequential political damage

in a subsequent election. Conversely, any widespread action by the LTSA that appears to have beneficial effects can improve the Government's reputation.

Risk Management Applied to School Bus Policy

The LTSA is responsible for minimising the social costs from the school bus fleet, by setting standards to which all school buses must adhere. This is an issue where the LTSA feels intuitively that new policies need to be introduced, but it cannot find the justification using their standard benefit/cost formula.

A risk management framework offers the LTSA a new method of justifying policy changes. Using Head and Horn's (1985) five point framework[ii] for creating a risk management strategy, the LTSA's key strategic risk factors, exposures and alternative risk management policies have been identified.
Four potential risk scenarios that have been identified are:

- bus over the edge
- forestry industry growth
- distance education through internet-based services
- reduction in average bus age required by the Ministry of Education,

while the policies that seem to offer the most opportunity for improvement, in order of cost effectiveness, are:

- Removal of side-facing seats
- Adding padding to the existing seats.
- Reducing the maximum bus passenger capacity by 25% to ensure that all passengers have seats.
- Replacing the existing seats with padded high-back seats fitted with 3 point seat belts, preferably rearward facing.
- Improved warden surveillance.

However, selecting the best combination of policies, and justifying it within the existing benefit/cost framework, is compromised by the inability to quantify the risks of a school bus catastrophe, and the complexities of interaction between the policies when applied in combination.

System Dynamics Approach

System Dynamics, as developed by Forrester (1961) and enhanced by Coyle (1977), ffers the LTSA the opportunity to model the complex interrelationships of the school bus environment and to observe their dynamic behaviour over time, with particular respect to how these interrelationships impact upon the main risk factors facing the Authority - hazard, financial, reputation and behaviour. In particular, it will allow a series of scenarios to be developed which include both expected future behaviours (e.g. population growth) and statistically low risk events (e.g. a significant bus accident involving high loss of life and injury).

Furthermore, such a model will enable the LTSA to observe the impact of suggested safety policies, either singly or in conjunction, upon these risk factors. Results of simulations using these policies will provide an alternative set of measures to the traditional cost focus, of the benefits and trade-offs of risk as well as financial cost, likely to occur as a result of these policies. As Morecroft (1984) states, such modelling will provide "support to strategy support, in which the man/machine combination is used to provide more effective assessment of strategic proposals".

The school bus sector is a complex environment involving many stakeholders and interrelationships, both explicit and implicit, some clearly defined, but others relying more upon intuition than fact. Developing a complete and robust model is an extensive exercise, which must involve the combined knowledge of the stakeholders, in setting the scope and parameters of the model, in building and testing the model, and in developing scenarios to be explored through the model.

This paper records the commencement of this process, in developing:

- a qualitative analysis of the environment (as per Wolstenholme and Coyle, 1983) via cause and effect relationships as they impact on the key risk factors, and
- a pilot system dynamics model using the Powersim modelling package.

The model demonstrated here is a significant simplification of the real situation. Additional development is required to produce a comprehensive model that accurately reflects the complexity of the real situation. This model is principally to demonstrate the possibilities that exist to utilise a combination of system dynamics methodology and modelling to improve the policy formulation process in a risk management environment for the school bus sector.

Causal Relationships

For this project, the key problems facing the LTSA were defined to be:

- what are the main risk factors relating to school bus safety that the LTSA must manage?
- what effects do specific safety policies have upon these risks? and
- how are these risks impacted by an isolated catastrophic event such as a major school bus crash?

The process of defining, developing and documenting key variables and relationships consisted of a series of structured meetings between the project team, who acted as facilitators, and key LTSA personnel representing various stakeholder interests within the Authority. These relationships formed the basis for the causal loop diagrams.

This process resulted in the development of four influence diagrams. Three depicted the current impacts on the four risk factors from:

(a) the passenger and roading sector,
(b) the bus fleet sector; and
(c) the human behaviour sector,

while the fourth documented the impacts on the risk factors from the implementation of suggested policy changes.

Figure 1 shows the diagram derived for the passenger and roading sector:

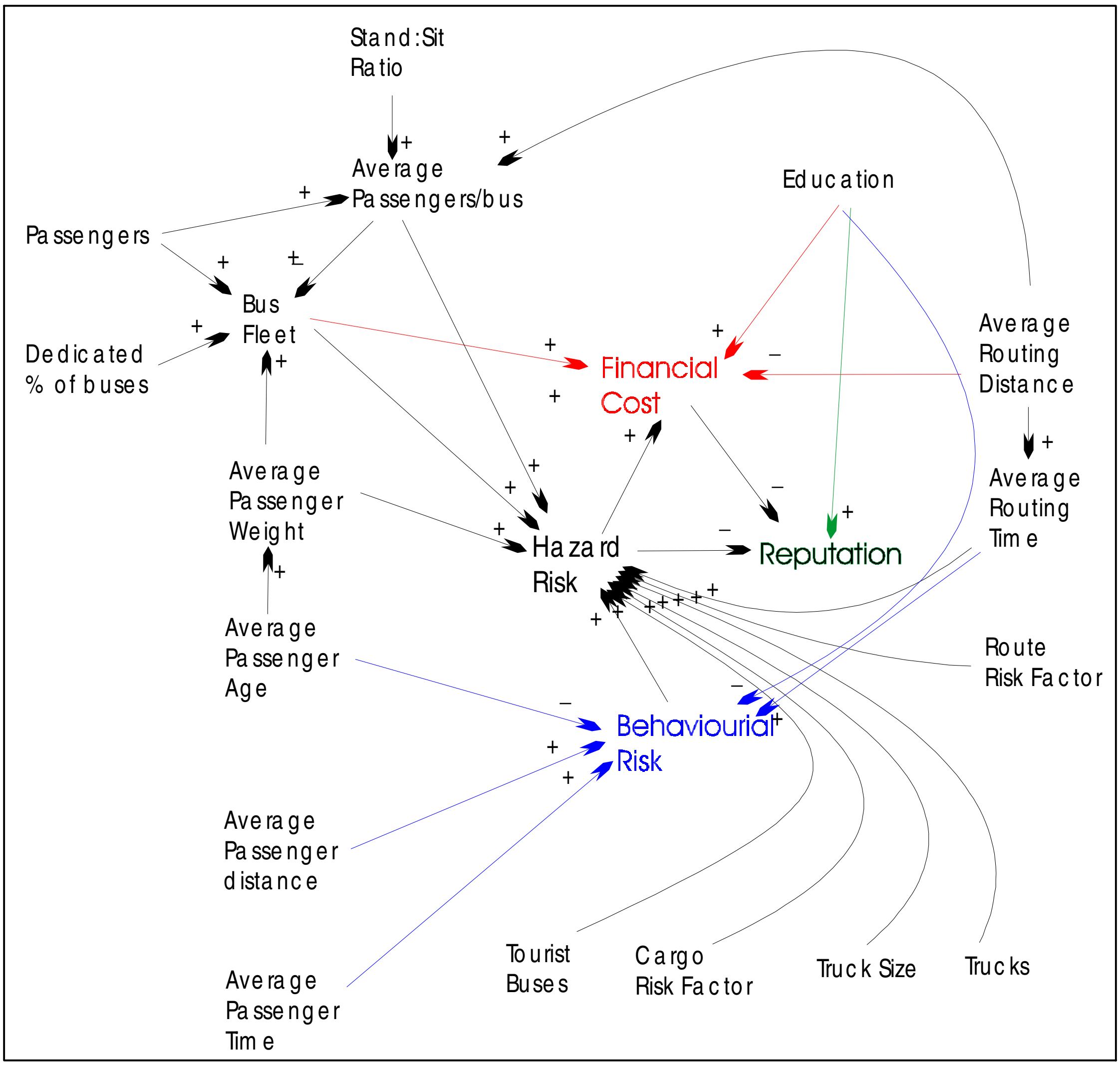

Figure 1. Simplified Influence Diagram for the Bus and Passenger Sector

Base Case Model Development

Using the relationships and data identified and provided by the LTSA, a Powersim model was constructed to represent the current interactions as depicted in the first three causal loop diagrams. The resulting base case scenario reflected the status quo, without any policy changes.

The core of the base case is the risk management issue at the central portion of the causal loop diagram. The interplay between these risks determines the flow of risk from one area to another (Figure 2). The risk management core is then extended to include all of the other factors of the status quo, namely the bus fleet and behavioural issues. These factors allow the model to demonstrate the interplay of factors within the status quo and provides a platform for testing new policies and different scenarios (Figure 3).

The simulation model was run using a 50 year period to allow for the long term impact of a low risk catastrophe, conservatively estimating the chance of a school bus incident with at least a two percent chance per annum.

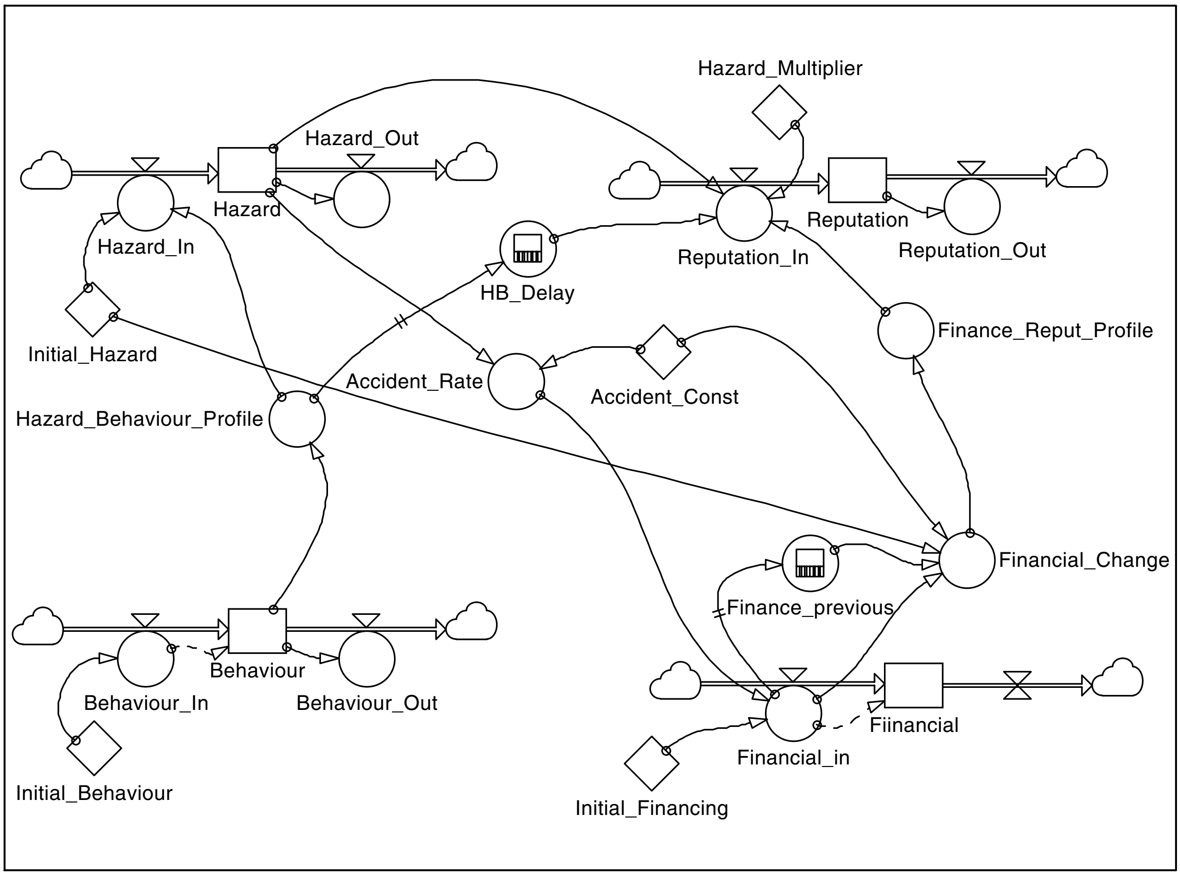

Figure 2. Risk Management Sector

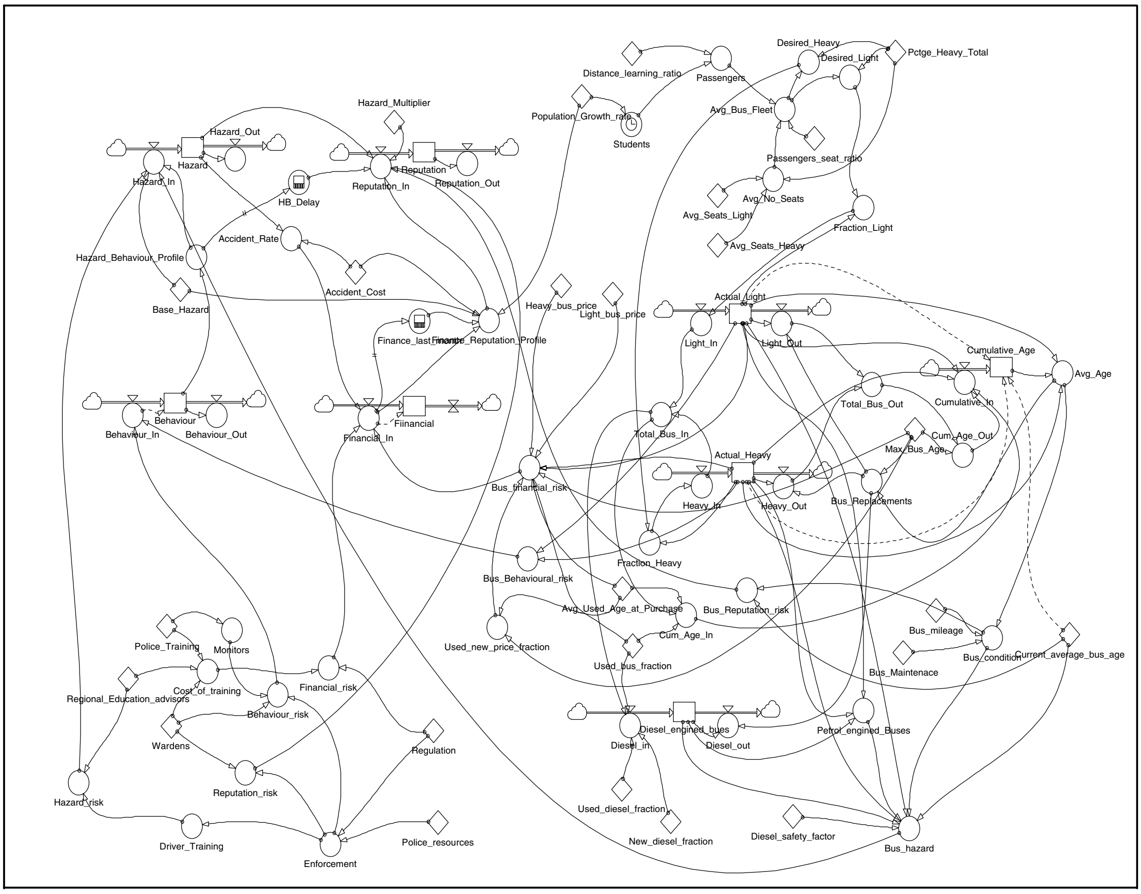

Figure 3. Merged Base Case.

Policy Changes

The model was then extended to include each of the five policy changes identified. This allowed both qualitative and quantitative assessment upon the impact of each risk factor as a result of the policy. While financial risk figures provided supporting and supplementary evidence for the benefit/cost analysis, reputation, behaviour and hazard information changes provided additional insight into both the direction and quantity of the other dimensions of risk to be managed.

For example, the results of introducing 3 point lap and seatbelts over a 36 month horizon is shown below:

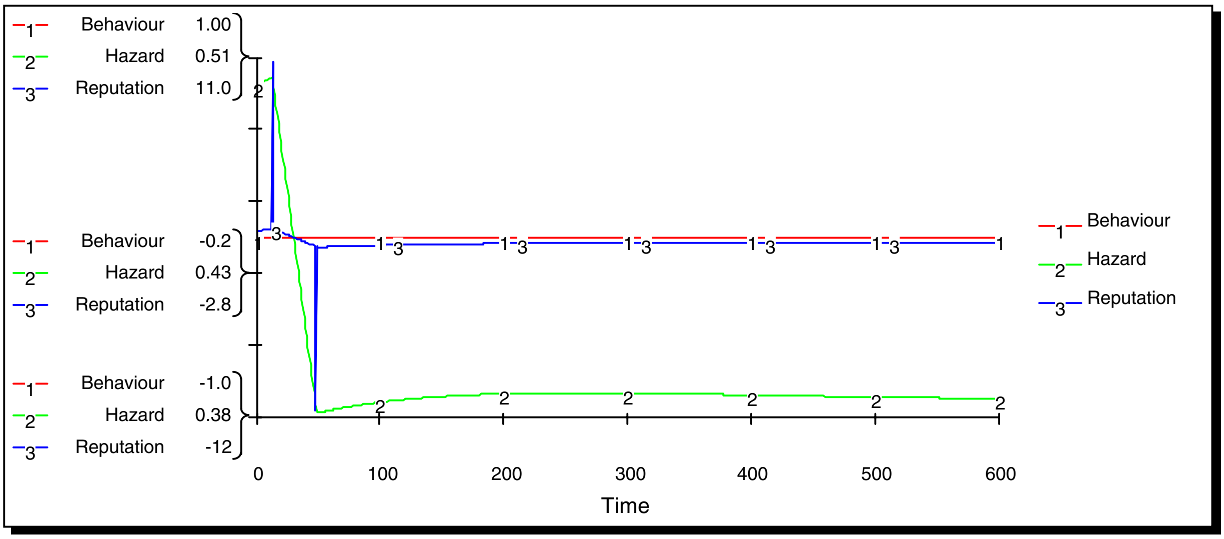

Figure 4. 3 Point Lap and Sash Belts – Behaviour, Hazard and Reputation

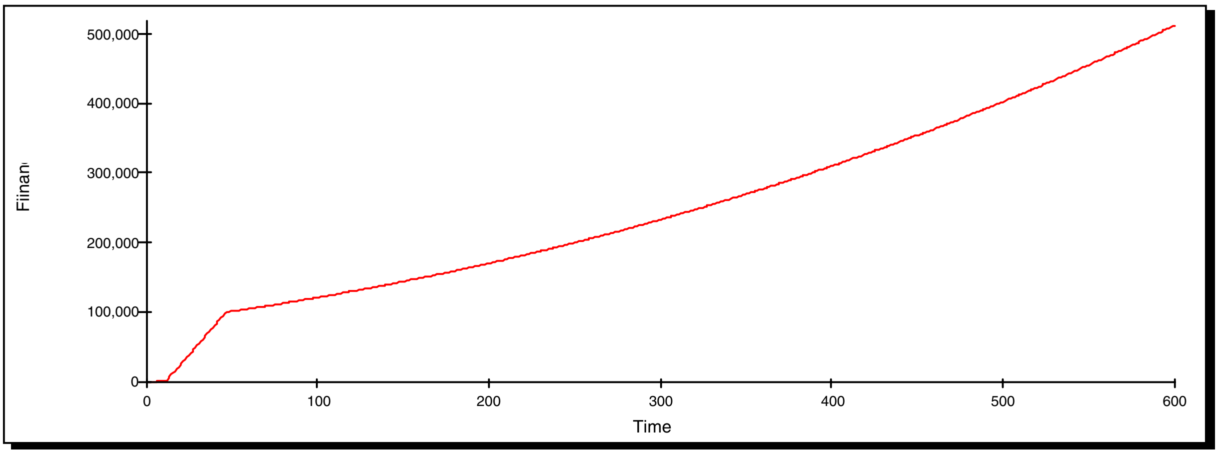

Figure 5. 3 Point Lap and Sash Belts – Financial

Introducing seatbelts gradually reduces hazard by 24%, but initially increases reputation risk for the government as resistance to increased cost and new regulations is registered. However, as hazard is reduced, the reputation benefit accrues, first sharply, and later settling to a sustainable level lower than that prior to introduction of the policy. Cost increases are identified as increased financial exposure over the base case.

The five policy changes were subsequently included in one model to demonstrate the costs and benefits of combining multiple policies. Furthermore, timing of these changes can be experimented with to examine the potential of spreading risk exposures over different chronological time and implementation periods. This provides a significant additional advantage over the current benefit/cost analysis, which is focused almost exclusively upon financial cost, and is challenged by the dynamics of policies interacting and operating over discrete time periods

Scenario Development

In addition to the value provided by planned policy implementation, the model also provides insight into the impacts on all four aspects of risk as a result of exogenous environmental effects. The four scenarios identified by the LTSA as the most likely occurrences were built into the model, and the consequent effects on the four risk elements were tracked against the base case.

The effects of increased logging truck traffic as a result of projected harvesting growth after 2010 are shown below. Hazard and government reputation risks grow as per the base case up to period 132, due to natural population increase and road usage. However, from 2010, without any other intervention, both increase significantly until peak levels are reached 10 years later, when they flatten out and continue growing at the rate associated solely with population growth. Financial risk (not shown) grows in response to the rise in hazard, to reach a level 14% higher than that of the base case.

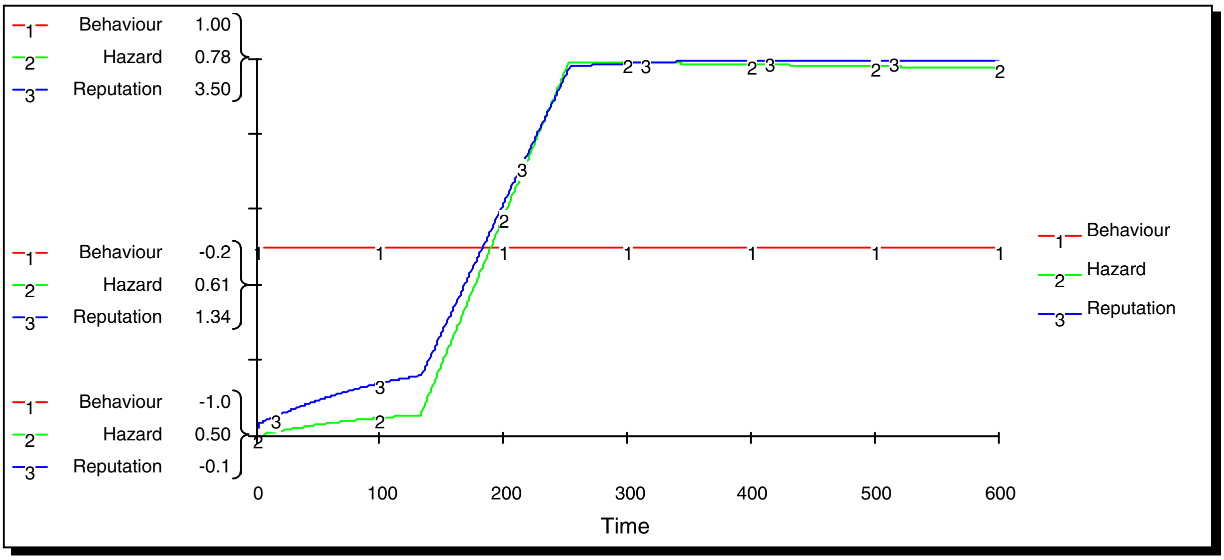

Figure 6. Logging Truck Growth – Behaviour, Hazard and Reputation

The "bus over the edge" scenario provided some interesting insights into the movement of reputation risk. The simulation model shows significant financial cost, but no impact upon underlying hazard and behaviour risks as a result of the catastrophe. These appear consistent, as the catastrophe is a one-off incident and has no impact upon long term risks. The model shows a significant leap in reputation risk, as would be expected, with people blaming the government for insufficient safety measures in buses. However, following the catastrophe, there is a compensatory drop in risk, settling back to the pre-catastrophe level after approximately 10 periods. In terms of the model, this is explained by a "perverse" reduction in the growth of hazard cost, with consequent reduction in reputation risk, following the one-off burst caused by the catastrophe. This appears counterintuitive in real life. However, shortly after the model was developed, a fatality involving a school bus occurred. Tracking this event showed that there was a sharp increase in reputation risk after the event, with parents throughout the country demanding increased safety measures. Interestingly, the drop in reputation risk was very rapid, as the news became "old", and for a time did appear to be below the pre-crash level, although not as much as suggested by the model, before settling back to the pre-crash figure. One commentator suggested this may have been a consequence of public sympathy for the LTSA being prevented from introducing regulations by the benefit/cost criteria, a fact that was given considerable media attention at the time of the catastrophe!

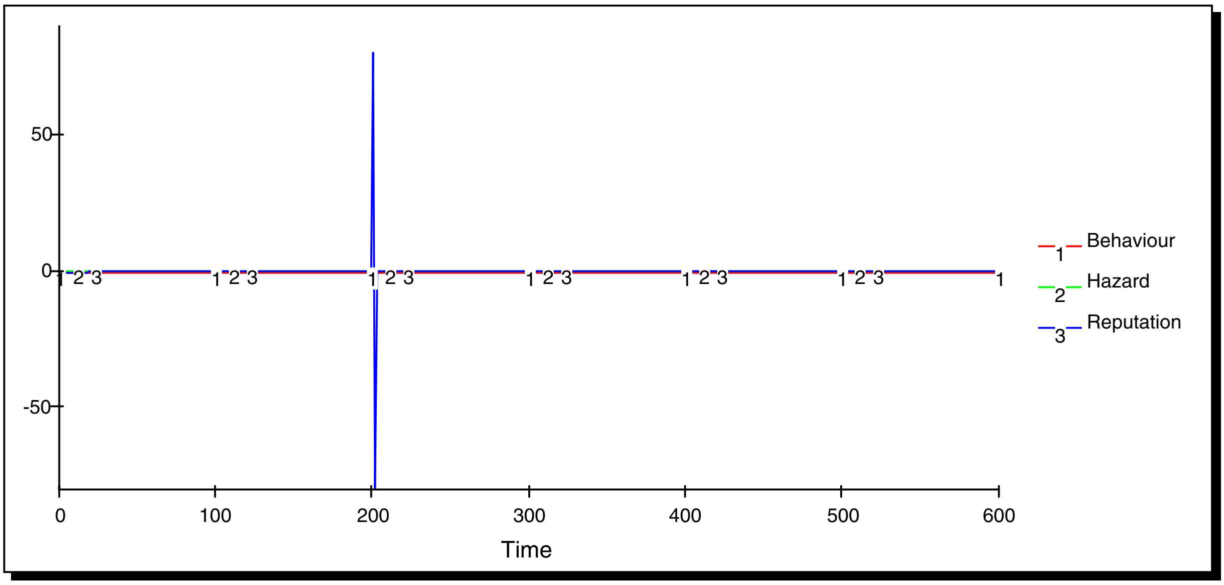

Figure 7. Bus Over the Edge – Behaviour, Hazard and Reputation

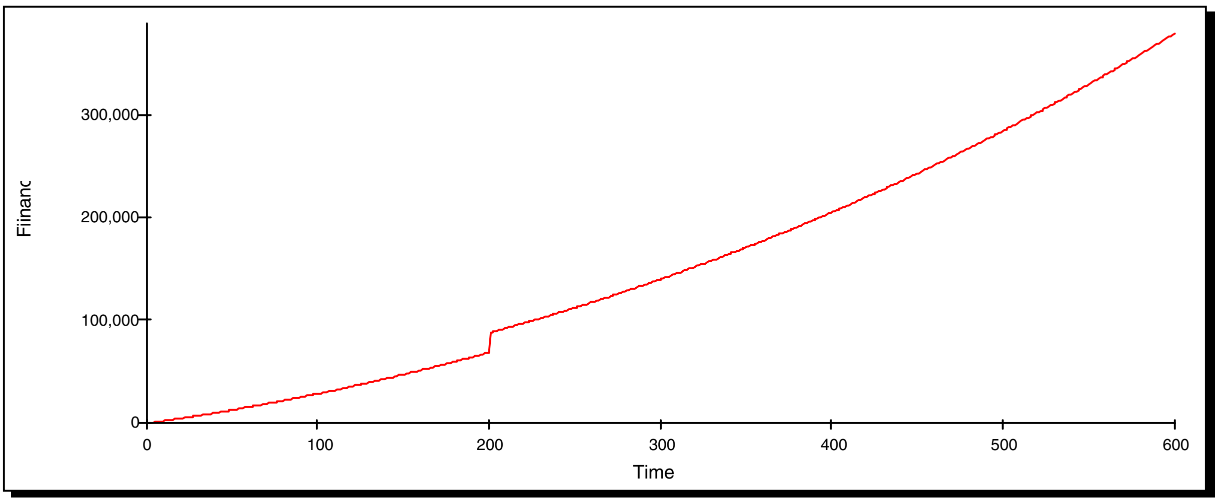

Figure 8. Bus Over the Edge – Financial

Conclusions

The benefits of utilising the system dynamics framework to support a risk management justification of policies has been demonstrated and applied in the LTSA school bus situation. The key advantages have been in assessing the interactions of multiple policies, and in demonstrating the effects of these policies over extended time periods.

The approach has also been beneficial in assessing the effects of scenarios which unfold over several time periods.

In both of these cases, the inclusion of behaviour, hazard and reputation risks provides augmenting data to financial costs, offering a broader range of assessment criteria than the traditional benefit/cost approach. Furthermore, the system dynamics approach, combined with the Powersim package, offers the LTSA a more flexible set of tools for analysing policies under uncertainty than their existing Monte Carlo and Operations Research models.

However, the system dynamics approach, in this model at least, does not appear to yield as much additional information about the effect of single period, high cost but low probability events such as a school bus catastrophe. Nonetheless, it does illustrate the effect of such a catastrophe upon risks other than financial. In particular, the ability to track the impact upon reputational risk provides new insights, which justify further investigation.

Overall, the model developed has enabled insights to be provided into policy development, timing and implementation issues, which can be utilised in both justifying policies and scheduling their deployment.

As the risk management approach is increasingly becoming the preferred method for New Zealand Government departments to use in assessing the potential of proposed policies, we see significant benefit for the use of system dynamics in combination with risk management to conduct such assessments. Our experience with the LTSA model demonstrates the potentials of such an approach.

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[i] The LTSA is required to justify proposed activities and programmes by showing they promote safety at reasonable cost. Specifically, Section 16 of the Land Transport Act 1993 states:

> "Principal objective of Authority
> (1) The principal objective of the Authority shall be to undertake activities that promote safety in land transport at reasonable cost.
> (2) For the purposes of subsection (1) of this section, a cost is a reasonable cost where the value of the cost to the nation is exceeded by the value of the resulting benefit to the nation.

Traditionally, benefit/cost analyses based on historical data yielding a ratio of greater that 1 have been required to justify policies becoming rules or regulations - that is, empirically calculated expected benefits must exceed empirically calculated expected costs.

[ii] 1. Identifying exposures to accidental loss that may interfere with an organisation's basic objectives.
2. Examining feasible alternative risk management techniques for dealing with those exposures.
3. Selecting the apparently best risk management technique(s).
4. Implementing the chosen risk management techniques(s).
5. Monitoring the results of the chosen techniques(s) to ensure that the risk management programme remains effective.