Vehicle Roll Over and Logging Trucks
Why, Where and the Outcome

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Heavy Vehicle Rollovers,

The effect of Vehicle and Road factors.

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ABSTRACT

There is a significantly higher chance of a heavy vehicle being involved in a crash in New Zealand than in Australia, the US and Europe. One of the major reasons for this appears to be our lack of an extensive divided highway network compared to these other countries. Overseas experience has found that the two-way roads, which make up almost all of New Zealand's State highway system, have fatal crash rates of between 300 to 400 percent greater than well-constructed divided highways.

Differences in roadway design affect combination vehicles more than single unit vehicles. On US rural arterial roads, which are similar to most NZ State highways, combination vehicles have fatal crash rates that are over 200 percent greater than single unit trucks and passenger vehicles.

A recent analysis of the NZ logging truck fleet has found that a significant number of them are poor in terms of their Static Roll Threshold, Rearward Amplification and Dynamic Load transfer Ratio performance. These performance measures have been found to be key indicators of crash risk. The forestry industry along with LTSA have introduced short term measures to improve the performance of logging trucks and the industry is now developing long term solutuons that do not adversely affect productivity.

Research aimed at developing a better understanding the interactions between driver behaviour, vehicle performance and road design is now underway. The research being undertaken by TERNZ will look at issues such as: how aware drivers are of their vehicle's performance, road design features that may mislead drivers and hence are dangerous, truck speed advisory signs for problem curves, and how weights and dimensions may be improved to increase productivity while not compromising safety.

INTRODUCTION

A rollover occurred in 29 percent of the 650 heavy vehicle (HV) crashes the NZ Police Commercial Vehicle Inspection Unit (CVIU) attended from July 1996 to March 1998. The actual number of rollover crashes will have been much higher than this as CVIU are only able to attend a limited number of crashes. Top priority is given to attending fatal crashes, yet they only went to 50 percent of the recorded fatal crashes. Of the crashes CVIU did attend, 44 percent involved a single vehicle that had lost control.

In the USA in 1995, rollover occurred in 3.4% of the reported large truck crashes. In the Netherlands there is concern about the 100 rollover crashes that occur there every year. While a direct comparison cannot be made with rollover rates in other countries, it would appear that there is a much higher incidence of rollover crashes in New Zealand than in other developed countries.

The high level of rollover crashes reflects the relatively high proportion of fatal and injury crashes that involve a heavy vehicle in New Zealand. Using 1997 data, trucks were involved in 18 percent of all fatal road crashes and 8 percent of injury crashes. This year, up to the end of May 1998, trucks have been involved in 21 percent of all fatal crashes. Trucks accumulate 6.2 percent of the total distance travelled on the road (LTSA, 1996). The distance travelled by HVs has increased by approximately 3.2 percent per year, while freight carried has been increasing at 3.6 percent per year.

By comparison, in the USA (Clarke, 1998) HVs accumulate 7 percent of the distance travelled, are involved in 8 percent of the fatal crashes and 3 percent of all crashes (fatal, injury and property damage only). The relative proportional involvement of HVs in fatal crashes in the US has decreased over the past 8 to 10 years when they typically accounted for 10 to 12 percent of the total.

Undoubtedly the biggest difference between the US and New Zealand is in the roading environment. Sleath (1998) reported that in New Zealand:

- 48% of the roads are on flat terrain
- 30% are on rolling terrain
- 22% are on mountainous terrain.

There is also one horizontal curve of 750 m or less for every 2 km of state highway. Half of these are 250 m or less in radius. Road cross slope and shoulder treatment are also regularly cited as being of concern. There are very few divided highways, the main ones being within the Auckland and Wellington metropolitan areas. Travel on divided highways is in the order of 2 to 5 percent of the total for all state highways.

By comparison in the USA 62 percent of the distance travelled by multi-trailer combination vehicles, 53 percent of the single-trailer combinations and 29 percent of the single unit trucks are on divided interstate highways, freeways and expressways.

Overall fatal crash rates per distance travelled is 300 to 400 percent lower on US interstate highways compared to other roadways. This is similar to the Australian experience where they have found that divided highways have 73 percent fewer crashes than standard two-lane roads (Representatives. 1996).

The above suggests that a significant factor in the relatively high crash rate of HVs in NZ is the lack of high quality divided highways compared to the US and Australia.

DIFFERENCES IN VEHICLE CONFIGURATION ON CRASH RATES.

An analysis of the US situation undertaken by Clarke (1998) found a significant difference in fatal crash rates for different HV types on two way rural roads as opposed to interstate highways. The analysis is based on fatality numbers in the order of 5000 per year (in 1995, 4,903 people were killed in the US in crashes involving HVs).

On interstate highways, rural arterial (equivalent to our main state highways) and other rural roads the relative crash rates per distance travelled are shown in figure 1:

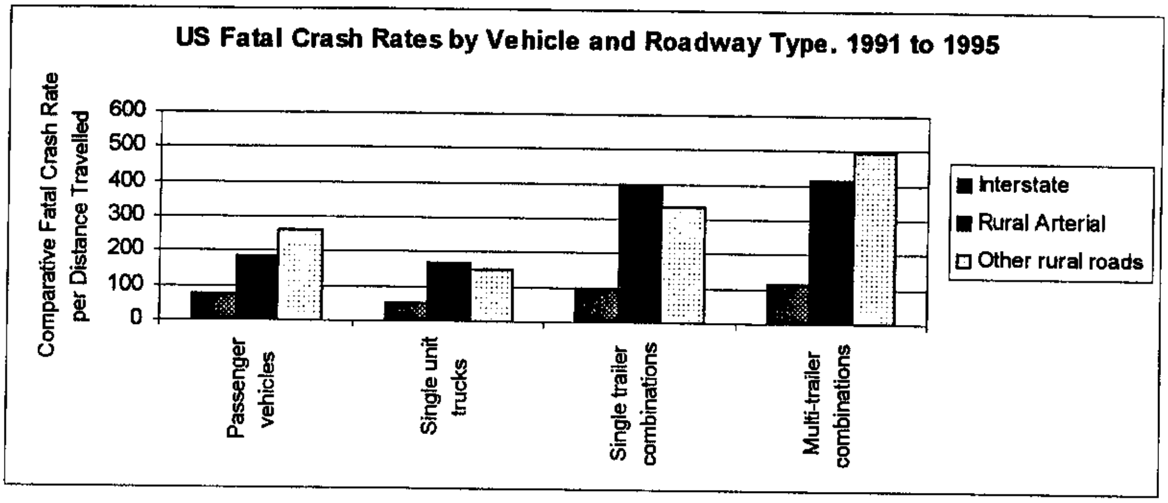


Figure 1. US 1991 to 1995 comparative fatal crash rates per distance travelled for different vehicle and road types.

The analysis shows that combinations have greater fatal crash rates on all road types compared to single unit vehicles. Of note is the relatively low number of fatal crashes for single unit trucks, suggesting that their larger weight and lack of crumple zone compared to passenger vehicles is compensated for by factors such as the experience of truck drivers and their better visibility. Once the weight of a truck is significantly greater than the weight of the vehicle it collides with, any extra weight makes little extra difference in the deceleration experienced by the lighter vehicle during a collision.

To look at the effect highway type may have on crash rates; the rate for each vehicle type has been normalised to their interstate fatal crash rate in figure 2.

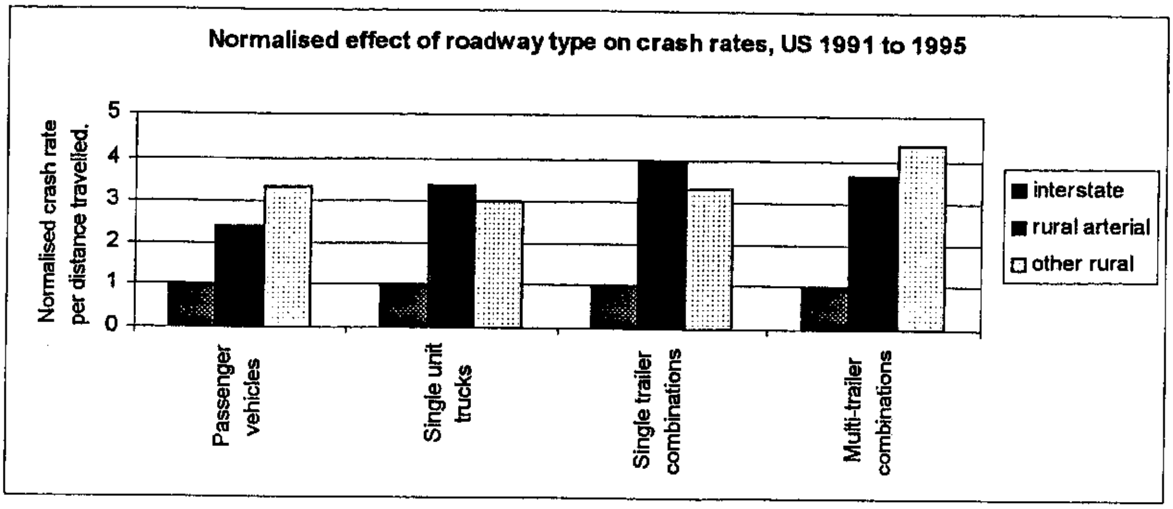


Figure 2. Effect of highway type on vehicle crash rates with the crash rate for each vehicle type set to one for the Interstate.

Clearly crash rates are affected by roadway type by a factor of 300 to 430 percent. The greatest differences were with combination vehicles, especially when driving on rural arterial roads, the equivalent to our state highways. Figure 3 shows the crash risk (by distance travelled) differences for rural arterial roads normalised to the passenger car rate.

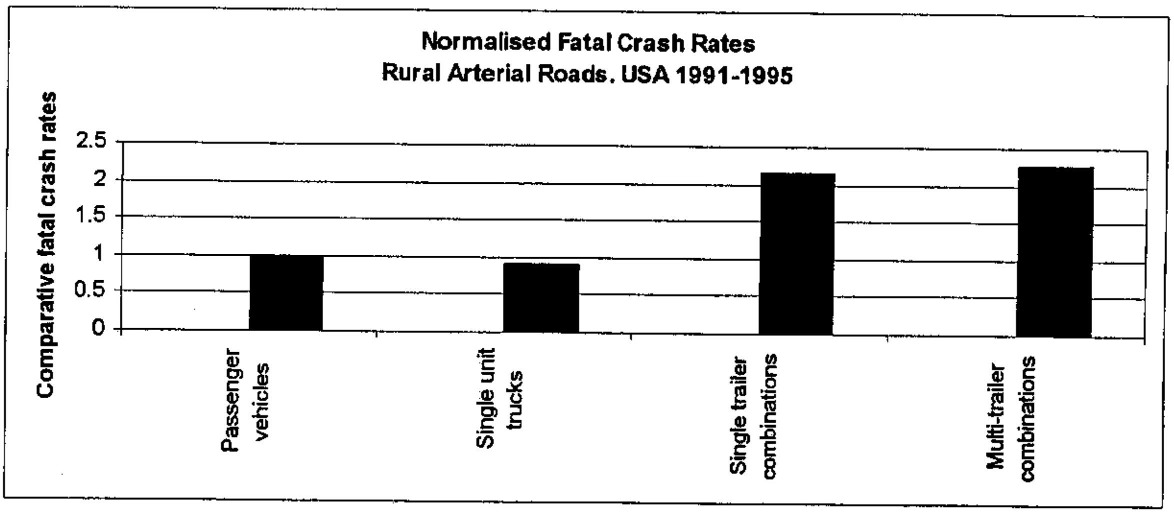


Figure 3. Differences in vehicle crash rates on rural arterial roads (equivalent to most NZ State highways).

EFFECT OF VEHICLE PERFORMANCE ON CRASH RATES.

A number of vehicle performance measures have been developed to describe the behaviour of heavy vehicles. These measures include, for example, stability, road friendliness and manoeuvrability (El-Gindy, Woodrooffe & White 1991). Three performance measures have been identified as key indicators of crash risk (Clarke 1998). A brief description of these key crash risk indicators is given in table 1.

Table 1. Performance Measures

Performance Measure	Brief Description
Static Roll Threshold (SRT)	Maximum steady turning lateral acceleration without rollover. A target of 0.35g minimum is used in NZ.
Rearward amplification (RA)	Ratio of lateral acceleration of the rearmost trailer of a combination to that of the prime mover during an evasive steer manoeuvre.
Dynamic Load Transfer Ratio (DLTR)	Indication of nearness to rollover in highway-speed evasive steering manoeuvres. This measure is highly correlated to both SRT and RA. At values much above 0.6 HVs are highly susceptible to rollovers.

A direct relationship between fatal crash involvement rate and these performance measures has recently been determined using the extensive crash data available in the US (Clarke 1998). Figures 4 and 5 relate fatal crash rate based in crash involvement per 100 million miles to SRT and RA. In 1995 the average NZ heavy vehicle crash involvement rate was 5.5 fatal crashes per 100 million km (Representatives, 1996).

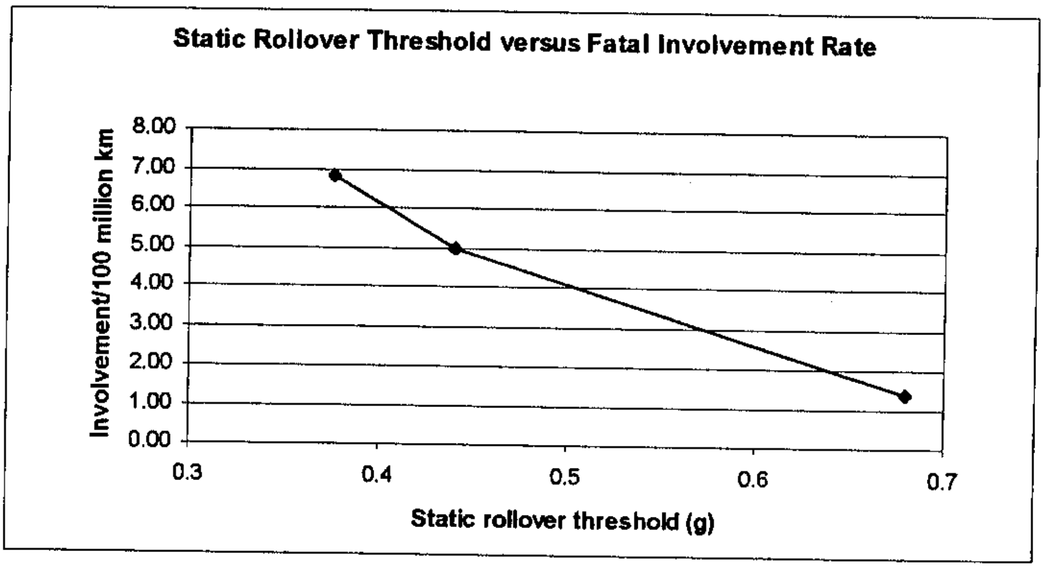


Figure 4. Static Rollover Threshold (SRT) versus fatal crash involvement rate in the USA.

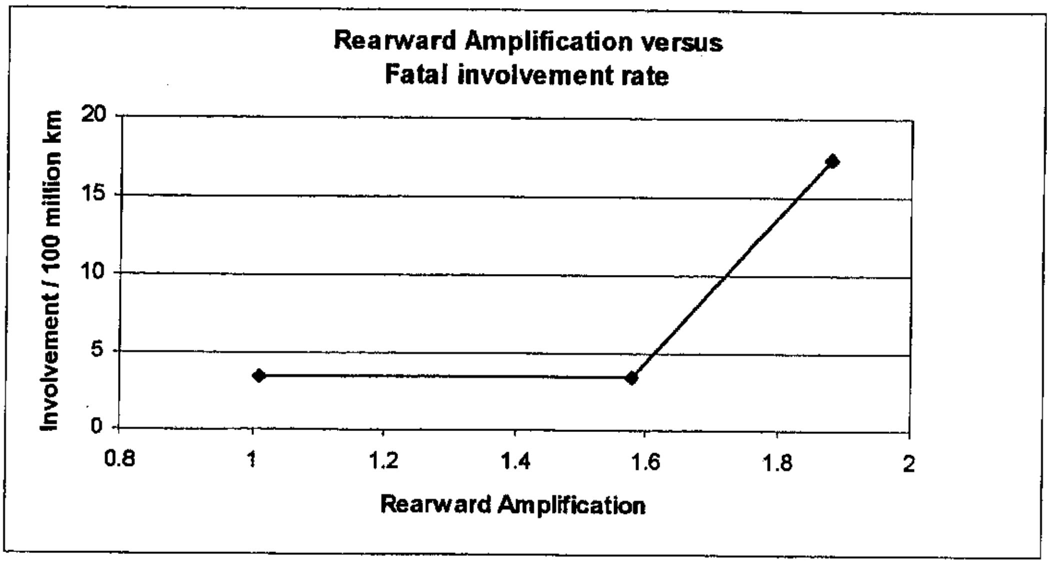


Figure 5. Rearward Amplification (RA) versus fatal crash involvement rate in the USA.

NZ LOGGING TRUCK PERFORMANCE

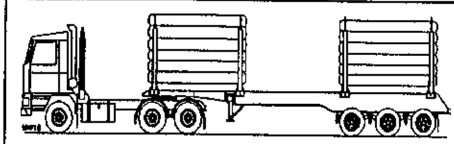
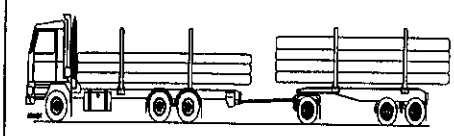
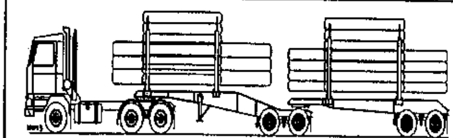
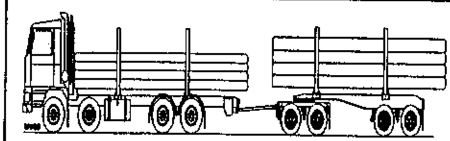
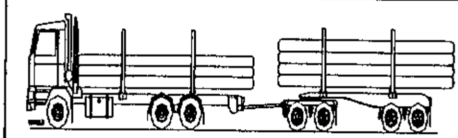
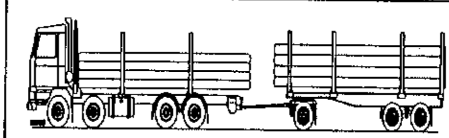
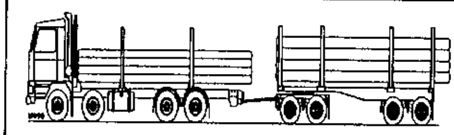
Following earlier concerns about logging truck stability, an analysis of logging truck crashes using NZ Police CVIU crash reports and other data was completed in 1997. This study found that on average one logging truck had been rolling over every week. With approximately 650 logging trucks in the fleet, this equates to one rig in every eleven rolling over each year. This is a conservative estimate; the actual rate may have been twice this amount.

Of the 31 crashes involving logging rigs investigated by the CVIU during the year from July 1996 to June 1997 the major contributing factors included stability 26%, vehicle defects 26%, and speed 32% (a crash may have more than one contributing factor). These compare with stability 9%, vehicle defects 14% and speed 27% for all combination vehicle crashes other than logging rig crashes investigated by CVIU. This suggests that while speed is a significant factor, it is not peculiarly high for logging combinations compared to other combination vehicles. Stability and vehicle defects are however significantly higher.

The stability of many of the combinations used was found to be poor, especially when carrying short logs. The worst of these combinations, 6x4 trucks with 3 axle shorts trailers (type 2 in Table 2) and 8x4 trucks with 3 axle shorts trailers (similar to type 6 in Table 2) account for over 30% of the current logging fleet. Even the B-trains (e.g. type 3) and Bailey Bridge configurations (e.g. type 1) had poor stability, primarily because of their low level of Static Rollover Threshold due to their relatively high Centre of Gravity (5% of the fleet are B-trains).

Figures 6 and 7 show the Static Rollover threshold and Rearward Amplification for some of the main logging truck combinations (Baas & Latto, 1997). A description of the vehicles shown in figures 6 and 7 are given in table 2 below. Log lengths of 3.7m, 4.1m, 5.8m, 7.4m and 8.2m were used in the analysis.

Table 2. Typical logging truck configurations.

Reference number			
1.	6x4 + 3 BB Even	Six wheel tractor, four driving wheels and three axle Bailey Bridge, straight (even) semi-trailer	
2.	6x4 & 3 Shorts	Six wheel truck, four driving wheels and three axle shorts trailer	
3.	6x4 + 4 BT Shorts	Six wheel tractor, four driving wheels and four axle 'B Train' shorts. (tractor/semi/semi)	
4.	8x4 & 4 Shorts	Eight wheel truck, four driving wheels and four axle shorts trailer	
5.	6x4 & 4 Shorts	Six wheel truck, four driving wheels and four axle shorts trailer	
6.	8x4 & 3 Multi	Eight wheel truck, four driving wheels and three axle multi-bolster trailer	
7.	8x4 & 4 Multi	Eight wheel truck, four driving wheels and four axle multi-bolster trailer	

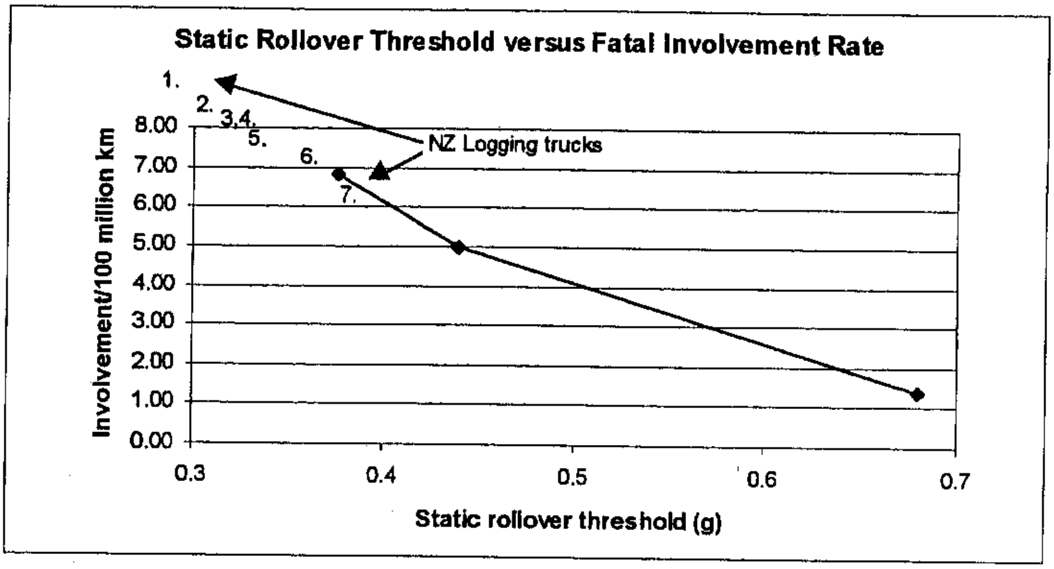


Figure 6. Static Rollover Threshold (SRT) versus fatal crash involvement rate in the US with NZ logging truck values superimposed.

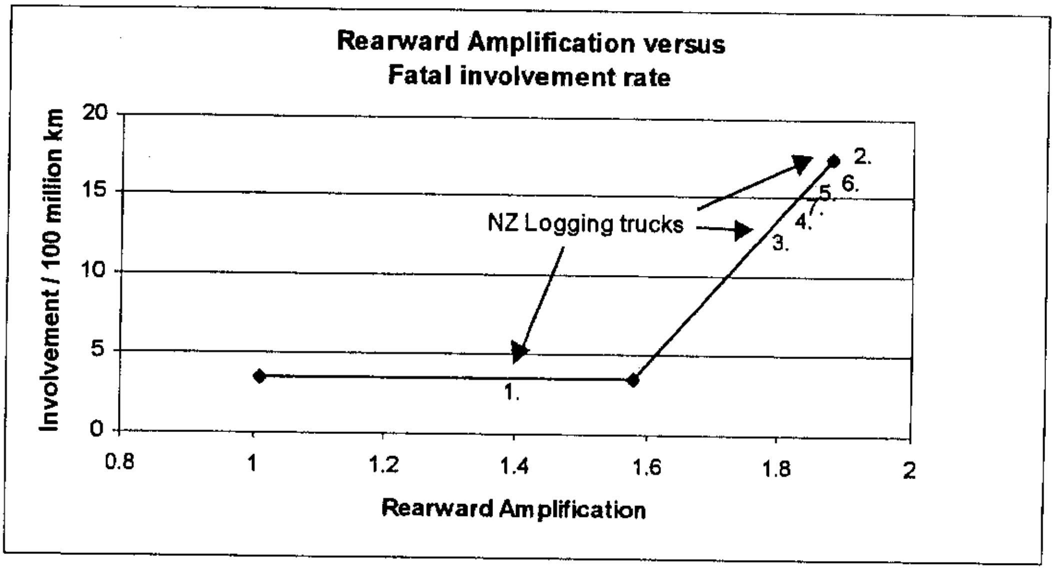


Figure 7. Rearward Amplification (RA) versus fatal crash involvement rate in the USA with NZ logging truck values superimposed.

As a result of these findings LTSA, NZ Police, Forest Owners Association and the Road Transport Forum agreed on urgent short-term measures to improve the stability of trailers short logs. Load heights on two and three axle trailers have been reduced to a maximum height of 3.5metres for all log lengths. On four axle trailers the height has been reduced to 3.8metres. The Forest Owners Association and the Road Transport Forum also arranged for an educational roadshow that has provided training courses for all logging truck drivers throughout New Zealand. The industry and LTSA are now reviewing logging truck and trailer dimensions with the view to developing a long term solution that improves both productivity and safety.

VEHICLE – DRIVER - ROAD INTERACTION

In order to reduce the HV crash rate in New Zealand we need to address vehicle, road and driver related issues together. The above has shown that road type and vehicle performance can have a significant influence on crash risk. Drivers obviously also play an important part. For example, in 30% of all CVIU reported crashes, speed was an issue of major concern. Typically speed related crashes were due to drivers entering curves at speeds in excess of the advisory speed or travelling too fast through intersections, rather than exceeding the legal speed limit for that section of road.

The research we are currently undertaking is looking at how vehicle, road and driver factors affect one another. It will enable us to look at issues such as:

- The extent to which drivers are aware of the behaviour of the trailers they are towing. Opinion varies considerably on this issue. If driver feedback is found to be a problem, it may be possible to develop appropriate warning devices for drivers or address it through weights and dimension changes.
- Whether truck speed advisory signs would be effective in reducing the number of rollovers.
- Road geometry features that cause problems for drivers.
- Improved productivity through the better matching of HV weights and dimensions and road design.

This unique study includes driver simulator studies, computer modelling and on-road testing. The various components will be linked to form an overall model that comprises a series of modules as outlined in figure 8.

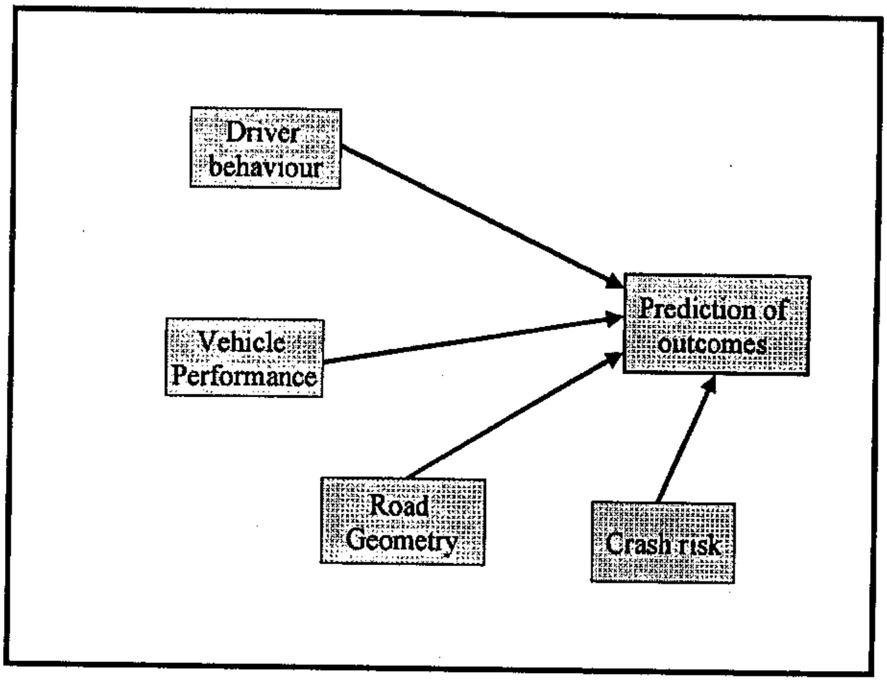


Figure 8. Framework for vehicle-road-driver interaction model

The vehicle performance module uses complex multi-body simulation software. Various vehicle models typical of NZ vehicle configurations are being developed.

These "vehicles" will be able to "drive" over 3 dimensional road surfaces that simulate actual NZ roads.

Measured road geometry data are already available for all of the major highways. These data include the following at 10m intervals: 3 co-ordinates (North, East and elevation), 3 angles (heading, gradient and camber), and horizontal and vertical curvature.

The driver module will consist of driver performance profiles for various driving events and driving situations. Specific driving events such as: braking, reaction to road hazards and the maintenance and adjustment of vehicle speeds will be used to determine driver performance as a function of driver situation awareness, cognitive workload, and perception of driving risk. These factors are being determined through an on-going series of experiments using a driving simulator based at Waikato University.

The simulator is now capable of reproducing realistic road scenes, including measured 3 dimensional road geometry and actual roadside items such as trees and buildings. The roadside images are captured with a digital camera. The response of the simulator will be controlled in real-time using the multi-body dynamics software models.

During the current simulator experiments the participants are seated in the driving simulator and asked to complete a series of three 5-minute driving scenarios. Each scenario contains the features of a typical New Zealand roadway (e.g., left-side drive, road signs, road markings, etc.) as well as other traffic moving through the scenario. Throughout each of the driving scenarios several measures of overall driving performance (vehicle speed, lane deviation, following distance) are collected. In addition, twice during each scenario, a road hazard that requires rapid stopping of the vehicle has been presented to the participants and their brake perception-reaction times were recorded. The mental workload of the drivers has been manipulated by introducing a secondary task into the driving situation. This requires resetting a radio signal that degraded on an average of either every 20 seconds (high workload), every 60 seconds (moderate workload), or once every three minutes (low workload). In addition, twice during each scenario the simulation is halted and the participant presented with six brief questions about various elements of the current driving situation (the situation awareness measure).

To make sure the simulator and the theoretical models are realistic, we recently undertook some on-road trials. For these road trials we used a truck that was set up to measure following distance, vehicle speed, road position, roll rate, lateral acceleration, pitch, brake pedal position, steer angle and engine speed. Ten drivers were tested, with each driver driving around a 7km circuit 4 times. Each driver was required to undertake emergency braking during the trials by having a lead vehicle stop suddenly and without warning. Drivers were also subjected to three different levels of workload that were controlled through the introduction of a secondary task. Part of the circuit included a section of State Highway 3 for which road geometry data is available.

The data collected by the simulator experiments thus far have revealed some interesting driver behaviours. Drivers that have a moderate level of workload tended to have better driving performance (fewer collisions and better vehicle control) and slightly better situation awareness than drivers experiencing either high or low workload levels. The performance of the participants who were driving under conditions of low and high workload was slightly worse in terms of their vehicle control and had many more collisions than the medium workload drivers. Some of these results are shown in figure 9 (Baas & Charlton, 1997).

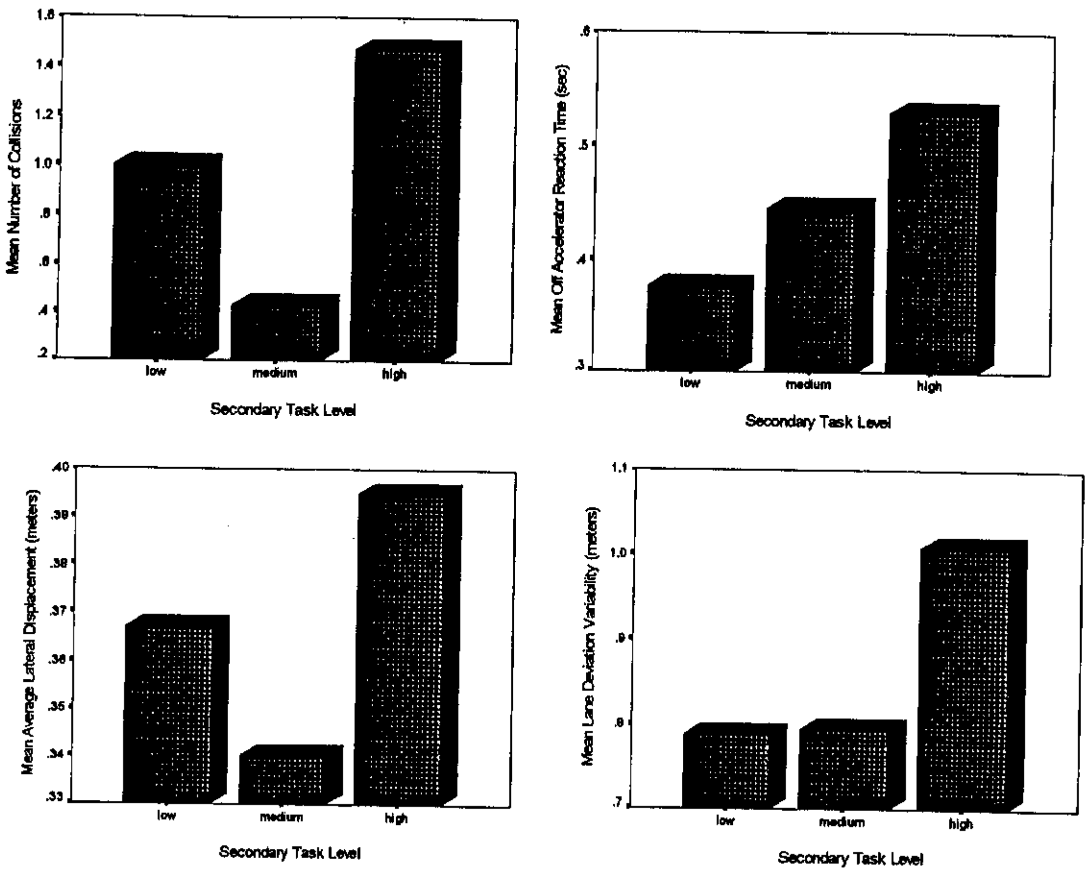


Figure 9. Preliminary driver profile results.

CONCLUSIONS

Crashes are normally due to a combination of highway, vehicle and driver factors.

The predominance of two-way roads is a major contributing factor in NZ's relatively high rate crash rate compared to Australia, USA and Europe where they have extensive divided highway networks. This is true for all vehicle types, including passenger cars and multi-trailer combination vehicles.

The effect of roadway design on the rate of fatal crashes involving combination vehicles is much greater than it is on single unit vehicles (light and heavy) regardless of who caused the crash.

The vehicle performance indicators: Static Rollover Threshold, Rearward Amplification and Dynamic Load Transfer Ratio have been found to be good predictors of crash involvement rate. An analysis of the logging fleet has found that a significant proportion of these vehicles had poor performance levels. This was reflected in their high incidence of rollover crashes. The forestry industry is working with the LTSA in trying to improve the performance of these vehicles while ensuring that overall productivity is not adversely affected.

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