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"THE HEAVY VEHICLE LIMITS PROJECT" GEOMETRICS AND SAFETY

The Geometrics Evaluation for the Heavy Vehicle Limits Project

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Abstract

The Heavy Vehicle Limits Project for Transit New Zealand considered 2 scenarios for increases in weights and/or dimensions limits for Heavy Vehicles in New Zealand. Scenario A proposed an increase in gross combination mass limits while maintaining current length limits for heavy vehicles on all public roads in New Zealand. Scenario B considered increases in length and gross combination mass limits for a specific network of routes comprised mostly of major state highways.

This paper outlines the Geometrics Investigation which constitutes part of the benefit/cost assessment for Scenario B of the Heavy Vehicle Limits Project. The Geometrics Investigation sought to estimate the cost of widening roads to accommodate two trial vehicles, longer and heavier than currently allowed on New Zealand roads. The amount of road widening required to accommodate longer vehicles is strongly dependent on the assumptions used to determine whether widening is necessary. Five different assumption sets were considered such that estimates of the cost of road widening for the network of routes ranged between 18 million dollars and 292 million dollars.

1 Introduction

The Heavy Vehicle Limits Project was separated into two parts; Scenario A proposes an increase in gross combination mass limits for heavy vehicles on all roads in New Zealand and Scenario B considers changes in mass and length limits on a specific network of routes comprised mostly of main roads. The benefit/cost assessment entailed

1. The Geometrics Investigation considered the cost of widening curves and modifying roundabouts on the specific network of routes to accommodate the proposed longer vehicles (Scenario B only).

2. The Safety Investigation sought to estimate the safety implications of a change in weights and dimensions for Scenario A and Scenario B.

3. Costs for additional wear to bridges and pavements under a change in weights and dimensions regulations were estimated.

4. An economic analysis estimated the benefits of improved efficiency due to a change in weights and dimensions regulations.

This paper outlines only the Geometrics Investigation of the Heavy Vehicle Limits Project [Milliken, 1999].

The vehicles proposed in Scenario B are 2.5 metres wide, the same width as is currently allowed. However, the trial vehicles proposed in Scenario B may occupy more road width than current vehicles in certain situations. This is because of an effect known as *offtracking*. Offtracking is where the trailing axles of a vehicle follow a different path to the front axle and is defined as follows.

Definition 1 *Offtracking is the maximum, over all axles, of the distance between the path of the steer axle and the path of each other axle. An illustration is shown in Figure 1.*

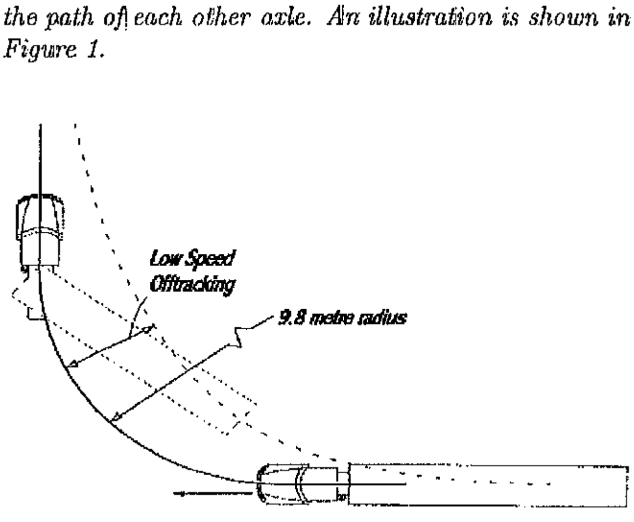

Figure 1: Offtracking Illustration.

Offtracking can be calculated at crawl speed, where dynamic effects are negligible, or at highway speed where dynamic effects cannot be ignored. To determine suggested modifications to roundabouts, crawl speed simulations were used and to determine modifications to curves on the network of routes, highway speed simulations were used. Note that offtracking can also occur on straights due to cross-slope of the road, cross-winds and transient dynamics. Offtracking due to these effects is known as *trailing infidelity*. For this study, trailing infidelity has been ignored because the effects are small compared to the offtracking due to cornering.

Prior to the Heavy Vehicle Limits project, two previous studies were done to assess weights and dimensions regulations in New Zealand [Sleath and Wanty, 1998]. Both these studies concluded that the costs of upgrading bridges and geometric modifications of the roads would outweigh the benefits.

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These prior studies differ from the Heavy Vehicle Limits Project in two ways

- Prior studies considered the modification of the entire State Highway network whereas the Heavy Vehicle Limits Project considered longer vehicles only on a specific network of routes.

- Prior studies used only low speed offtracking for vehicle simulations so that dynamic effects were ignored. The Heavy Vehicle Limits Project used simulations that permitted non-zero lateral accelerations which reduce inboard offtracking.

2 Preliminaries

The Geometrics investigation required the specification of a network of routes for Scenario B, where an increase in mass and length limits were proposed. Only highly trafficked roads were considered for Scenario B to attempt to keep the benefit/cost ratio high.

The resulting network of routes is shown in Figure 2

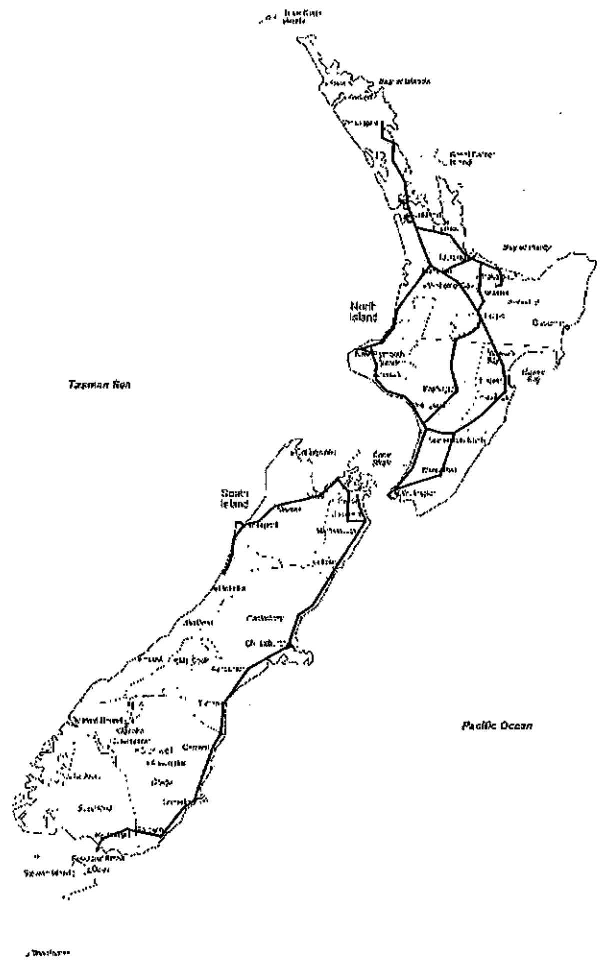

Figure 2: The Network of Routes for Scenario B.

Two trial vehicles, longer and heavier than those currently permitted on New Zealand roads, were considered for use on the Scenario B network of routes. The two trial vehicles were a 25 metre long, 62 tonne B-train and a 21 metre long, 62 tonne B-train. A benchmark tractor-semi-trailer that meets current weights and dimensions requirements was used for comparison.

The reason for considering widening on the network of routes is safety. Therefore, the Safety Investigation [Milliken et al, 1999] and the Geometrics investigation are interrelated. Thus, a range of possible road widening scenarios was considered in the Geometrics Investigation. The amount of road widening specified for a curve on the network of routes depended on the assumptions that were made to ascertain whether widening was necessary. Five sets of assumptions were considered:

Original Assumption 1

While the current network of roads is generally satisfactory, only for existing vehicles, in practice it is unlikely that corner widening would be undertaken where the calculated required widening is less than α metres (equivalent to $\frac{\alpha}{2}$ metres on each side of the road) where $\alpha = 0.25$.

From Assumption 1, if a curve was found to require widening by an amount less than 0.25 metres then it was assumed that widening would not be carried out. However, if the offtracking of a trial vehicle was found to be significantly greater than the offtracking of the worst of the benchmark vehicles then Assumption 2 specified the required seal width for such a curve.

Original Assumption 2

If a corner is such that a trial vehicle takes up significantly more road width than the benchmark vehicle representing the existing fleet (Assumption 1 specifies α metres as significant) then the amount of road width is unsatisfactory unless two trial vehicles, travelling in opposite directions, can pass with β metres clearance between their swept paths while each vehicle remains at least γ metres from the edge of the road, where $\beta = 1$ and $\gamma = 0.5$.

The half metre provided at the edge of the road was chosen to allow for two effects; firstly, driver variation and, secondly, avoidance of excessive edgebreak problems for unkerbed roads. The 1 metre clearance allowed between swept paths of opposing vehicles was provided to allow for driver variation. Note that, if there was to be provision for cyclists, at least 1.5 metres clearance between the path of a truck and the edge of the road would be required. Since a negligible proportion of the routes will have provision for cyclists, the cost of this widening has been ignored.

Original Assumptions 1 and 2 were such that the 'spare' space between vehicles and to the edge of the road was minimal, therefore, four alternative sets of assumptions were also considered:

- Alternative Assumption set 1 was the same as the Original assumption set except that $\alpha = 0.15$, $\beta = 2$ and $\gamma = 1$.
- Alternative Assumption set 2 was

  Alternative 2 - Assumption 1

  While the current network of roads is generally satisfactory only for existing vehicles, in practice, it is unlikely that corner widening would be undertaken where the calculated widening is less than α metres (equivalent to $\frac{\alpha}{2}$ metres on each side of the road).

  Alternative 2 - Assumption 2

  The current network of roads is only just wide enough to accommodate the current fleet. Therefore, any increase in vehicle offtracking would require an increase in road width.

- Alternative Assumption set 3 was of the same format as the Original Assumption set but with $\alpha = 0.05$, $\beta = 2$ and $\gamma = 1$.
- Alternative Assumption set 4 was of the same format as Alternative Assumption set 2 but with $\alpha = 0.05$.

Under the Original Assumption set and Alternative Assumption sets 1 and 3, widening is not necessary if

- the increase in swept path for the new vehicles is less than some threshold value α *or*
- the amount of spare road space when two of the trial vehicles pass, while travelling in opposite directions, is greater than a threshold value $\beta + 2\gamma$.

Conversely, Alternative Assumption sets 2 and 4 specify that widening is not necessary if and only if the increase in swept path for the trial vehicle is less than a threshold value α.

For roundabout modification, it was assumed that any increase in offtracking will require a corresponding modification to each roundabout on the network of routes.

3 Method

Assessing the cost of modifying the network of routes for Scenario B to accommodate each of the two trial vehicles required determining the amount of curve widening required and calculating the cost of roundabout modifications.

First, we consider the modification of curves on the network of routes. It was assumed that, for the purposes of determining appropriate geometric modifications, a curve could be characterised by three parameters; length of the curve, minimum radius of curvature of the curve and seal width. Widening was then specified in accordance with one of the Assumption sets presented in the Preliminaries.

It was necessary to develop a relationship between radius of curvature and offtracking for the trial vehicles and for the benchmark tractor-semi-trailer. High speed simulations were done for 90 degree curves with a range of minimum radii of curvature. The 90 degree curves were constructed from a Cornu spiral which is the recommended shape for a curve [Austroads, 1997]. A sequence of 90 degree curves based on Cornu spirals are shown in Figure 3

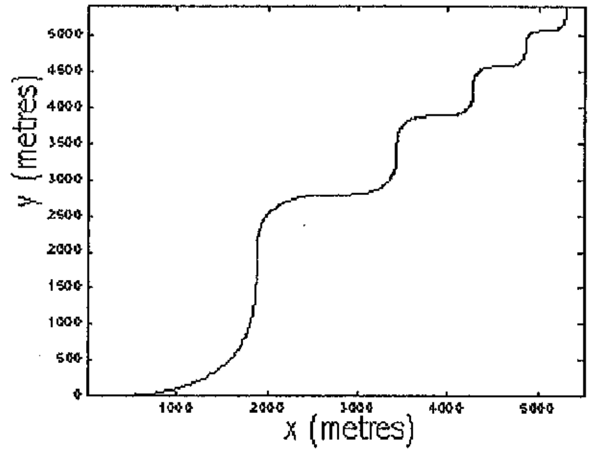

Figure 3: Sequence of 90 degree curves constructed from Cornu spirals.

Simulations were done for each of the trial vehicles and the benchmark tractor-semi-trailer at a range of speeds between the advisory speed for the curve and half the advisory speed for the curve[1]. It turned out that, in each case, the maximum offtracking was inboard and, therefore, occurred at half the advisory speed.

Remark 1 For a given vehicle, offtracking is a function of plan geometry of the curve and the history of lateral acceleration. Since the maximum offtracking occurred at half the advisory speed (where the lateral acceleration is $0.055g$) and superelevation does not change the plan geometry of a curve then maximum offtracking is roughly independent of superelevation. However, the speed required to achieve a lateral acceleration of $0.055g$ does depend on the superelevation angle θ

$$v_s = \sqrt{v_f^2 + gR\theta} \qquad (1)$$

where v_s and v_f are the speeds for the superelevated road and the flat road, respectively.

The simulations resulted in offtracking versus curvature relationships for the two trial vehicles and the benchmark tractor-semi-trailer. The amount of curve widening required depends on the offtracking of the appropriate trial vehicle and the difference in offtracking between the trial vehicle and the benchmark vehicle.

[1] The advisory speed for a curve is such that the maximum lateral acceleration experienced is $0.22g$

This information is shown in Figures 4 and 5, respectively.

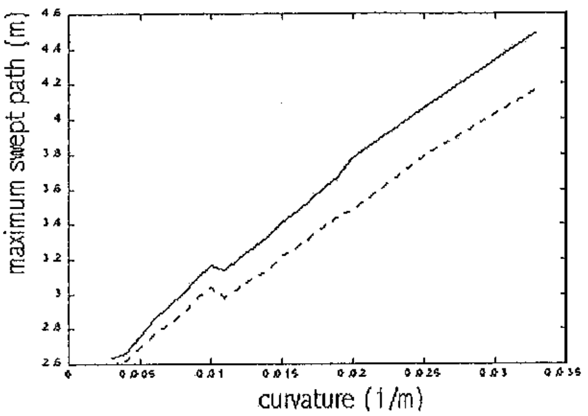

Figure 4: Maximum swept path versus curvature for 25 metre (solid line) and 21 metre (dashed line) trial vehicles.

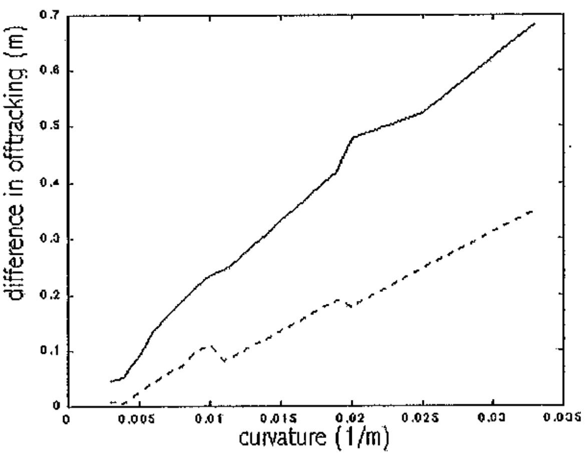

Figure 5: Difference in Offtracking between trial vehicles and benchmark vehicle versus curvature. Solid line: 25 metre trial vehicle, dashed line: 21 metre vehicle.

Straight lines were fitted to Figures 4 and 5 giving (2) and (3) for the 25 metre B train and (4) and (5) for the 21 metre B train.

$$D = 62.8R^{-1} + 2.47 \quad (2)$$

$$\delta = 43.2R^{-1} \quad (3)$$

$$D = 52.2R^{-1} + 2.45 \quad (4)$$

$$\delta = 22.0R^{-1} \quad (5)$$

where D is the swept path of a vehicle and δ is the difference between the swept path of the trial vehicle and the swept path of the benchmark tractor-semi-trailer.

The cost of widening a curve of arbitrary length by 0.5 metres, 1 metre or 1.5 metres was estimated for mountainous, rolling and flat terrain. This information was then used with (2), (3), (4), (5), each of the Assumption sets outlined in the Preliminaries and the RAMM database to determine the cost of modifying curves on the network of routes to accommodate each of the trial vehicles.

Now, consider roundabout modifications. Three representative roundabouts were chosen and the costs for modifying these roundabouts were determined. It was then assumed that the modifications required for an arbitrary roundabout were a function of central island diameter only. While this assumption will probably not give an accurate estimate of the cost of modification for each roundabout, it should provide a good estimate for the total cost of modifying roundabouts on the network of routes.

To determine the modifications to three representative roundabouts, we first simulated the benchmark tractor-semi-trailer turning right and then turning left at the roundabout. The two trial vehicles were also simulated turning right and turning left at the roundabout. The simulations were such that the front axle of each vehicle followed the same path. An example plot of one of the simulations is shown in Figure 6.

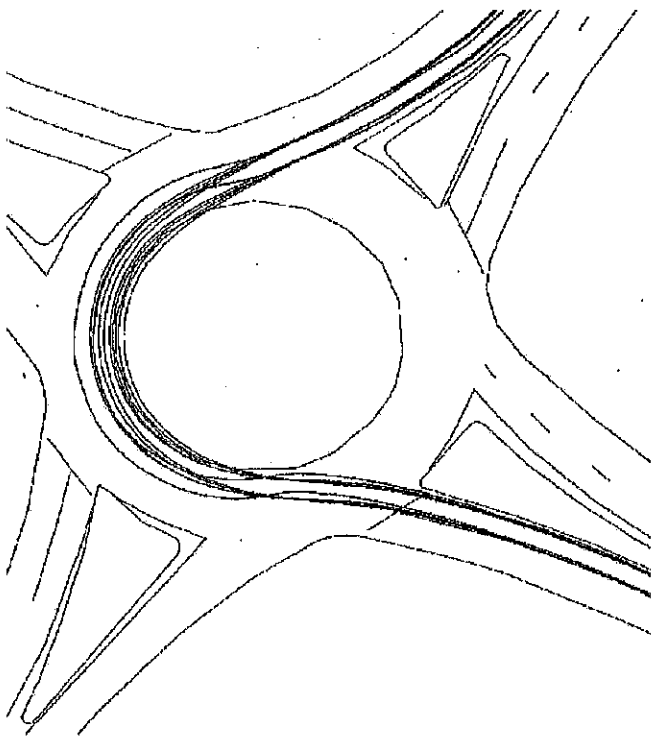

Figure 6: Example low speed simulation.

Suppose the difference in offtracking between the trial vehicle and the benchmark vehicle on the right turn manoeuvre is denoted δ_r. Similarly, the difference in offtracking between the trial vehicle and the benchmark vehicle for the left turn manoeuvre is denoted δ_l. Modifications to the roundabout are as follows

- the radius of the non-mountable part of the central island of the roundabout should be reduced by δ_r and a mountable kerb should be constructed in place of the existing kerb.

- the non-mountable part of the outside kerb should be moved out by δ_l and a mountable kerb built to replace the existing non-mountable kerb.

These modifications are shown in Figure 7.

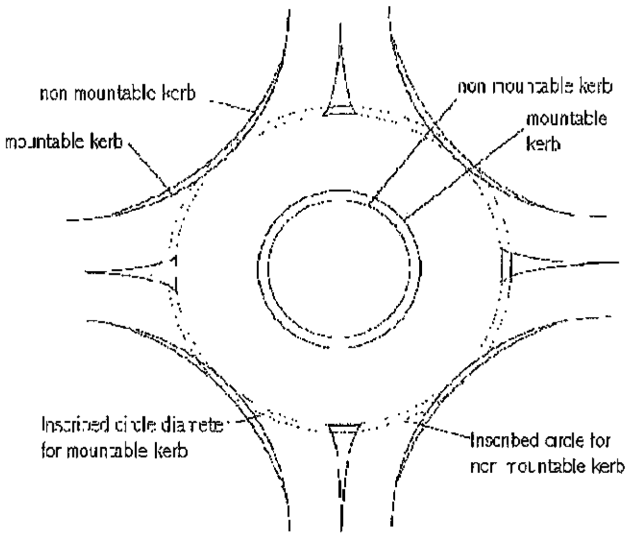

Figure 7: Modifications to Roundabouts.

Estimates of the costs of modifying each of the three representative roundabouts were determined. To estimate the cost of modifying a roundabout of arbitrary central island diameter we interpolated between the costs for modifying each of the three representative roundabouts. The costs for modifying the three representative roundabouts are shown in Figure 8

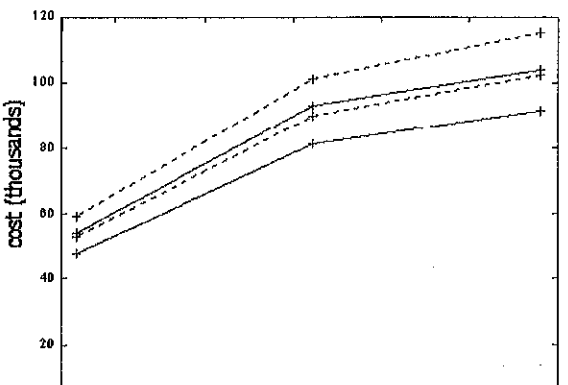

Figure 8: Costs for modifying representative roundabouts for the two trial vehicles in urban/industrial zones and rural zones. Solid line: 21 metre vehicle, dashed line: 25 metre vehicle.

Remark 2 Both the low speed and highway speed models used here have been validated. Validation of the highway speed model involved experimental data from a road trial done using a 26.5 metre 62 tonne B-train. The road trial was also used to get an impression of what a longer vehicle looks and feels like on New Zealand roads.

4 Results

The estimated cost of modifying all roundabouts on the network of routes to accommodate the 25 metre trial B-train was 1.3 million dollars. Similarly, the estimated cost was 1.2 million dollars for the 21 metre B train.

Estimated costs of modifying curves on the network of routes to accommodate each of the trial vehicles under the five assumption sets are shown in Table 1.

Trial vehicle length	25 m	21 m
Original Assumption set	44	19
Alternative Assumption set 1	132	45
Alternative Assumption set 2	214	63
Alternative Assumption set 3	162	114
Alternative Assumption set 4	292	191

Table 1: Cost of modifications to curves on the network of routes (millions of dollars).

Remark 3 Curve widening on State Highway 6 between Blenheim and Greymouth and State Highway 67A to Cape Foulwind constituted a disproportionately large cost; over half the cost of modifying curves on the network of routes in accordance with the original assumptions to accommodate the 25 metre B-train was for these roads. This is because these roads already have narrow seal width.

Remark 4 The Geometrics Investigation outlined here has been completed and the Heavy Vehicle Limits Project is nearing completion.

References

[Austroads, 1997] Austroads (1997). *Rural Road Design - Guide to the Geometric Design of Rural Roads*, Austroads, Sydney.

[Milliken, 1999] P. Milliken (1999). *Heavy Vehicle Limits Project, Geometrics Evaluation Summary Report.* TERNZ report for Transit New Zealand.

[Milliken et al, 1999] P. Milliken, T. Mueller, D. Latto, P. Baas, J. dePont and D. Wanty (Traffic Design Group) (1999). *Heavy Vehicle Limits Project, Safety Evaluation Summary Report.* TERNZ report for Transit New Zealand.

[Sleath and Wanty, 1998] L. Sleath and D. Wanty (1998). *Further Investigations into the feasibility of heavy transport routes in New Zealand.* Proceedings of the 5th Heavy Vehicle Weights and Dimensions Conference, Maroochydore, AARB.

Safety Investigation for the Heavy Vehicle Limits Project

Paul Milliken *

Abstract

This paper outlines part of the Transit New Zealand Heavy Vehicle Limits Project, the Safety Investigation [Milliken et al, 1999]. The objective of the Safety Investigation was to assess the safety implications, for heavy vehicles, of the changes in weights and dimensions regulations proposed in Scenarios A and B which are described in the Geometrics Investigation [Milliken, 1999]. The results of the safety investigation were presented as estimated numbers of fatal, injury and non-injury heavy vehicle crashes.

For the safety investigation, it was specified that transportation of goods, measured in tonne kilometres of payload transported by heavy vehicles, would be independent of the changes in weights and dimensions regulations. This means that an increase in weight and/or dimension limits would cause a reduction in the number of kilometres travelled that is inversely proportional to the increase in average payload. Also, a change in weights and dimensions regulations may affect heavy vehicle crash rates, largely because increasing the payload and centre of gravity height of a vehicle reduces its resistance to rollover. The effect of the estimated reduction in kilometres travelled combined with heavier but less safe vehicles was to predict that there would be little effect on the total number of truck crashes. The uncertainty associated with estimating numbers of truck crashes is high and difficult to determine, so, the results for the Safety Investigation are inconclusive.

1 Introduction

This paper outlines the Safety Investigation of the Heavy Vehicle Limits Project [Milliken et al, 1999] which seeks to assess the safety implications, for trucks, of the changes in heavy vehicle weights and dimensions regulations proposed in Scenarios A and B. A number of similar studies of Heavy Vehicle Safety have been done in New Zealand and abroad, for example, [Mueller et al, 1999], [Ervin and Guy, 1986] and [Saccomanno and Shortreed, 1996].

The breakdown, by crash type, of fatal heavy vehicle crashes in New Zealand for 1996 are shown in Figures 1 and 2.

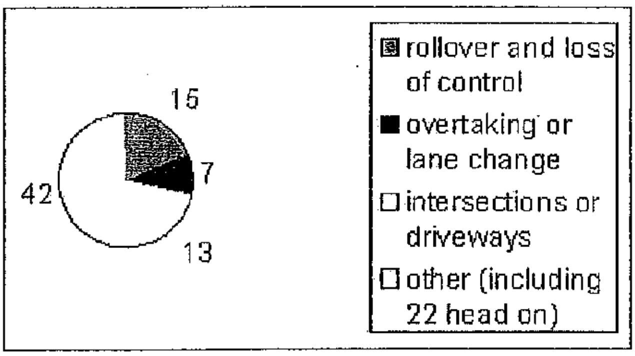

Figure 1: Fatal Heavy Vehicle Crashes in New Zealand in 1996, separated by crash type.

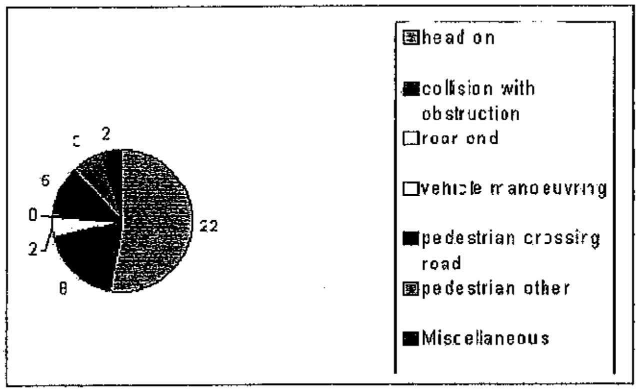

Figure 2: Breakdown of the 'other' category of fatal heavy vehicle crashes for 1996.

To estimate numbers of heavy vehicle crashes under a change in weights and dimensions regulations, vehicle performance parameters were used. Two of these performance measures are Static Rollover Threshold (SRT) and Dynamic Load Transfer Ratio (DLTR), defined as follows

Definition 1 *The Static Rollover Threshold (SRT) is the maximum level of steady state lateral acceleration a vehicle can tolerate without overturning. It is usually expressed in g, where g is the acceleration due to gravity.*

SRT is typically found by a quasi steady-state simulation; the vehicle's steer angle is increased slowly (at 2 degrees per second) until the vehicle rolls over. The SRT is the lateral acceleration at the time when all wheels on one side of the vehicle (apart from the steering wheels) have lifted off the ground.

For combination units, which are entirely roll-coupled, the SRT is calculated over the entire combination. For truck-trailers the SRT is determined separately for the

*TERNZ, email: p.milliken@ternz.co.nz, the Safety investigation [Milliken et al, 1999] also involved Tim Mueller, Doug Latto, Peter Baas, John dePont and Dave Wanty (TDC)

trailer and the truck. This is because they are not roll-coupled so one portion of the combination can overturn without the other, the unit with the worst (lowest) SRT is the SRT value recorded for the combination. Figure 3 shows a typical path for a simulation used to determine SRT.

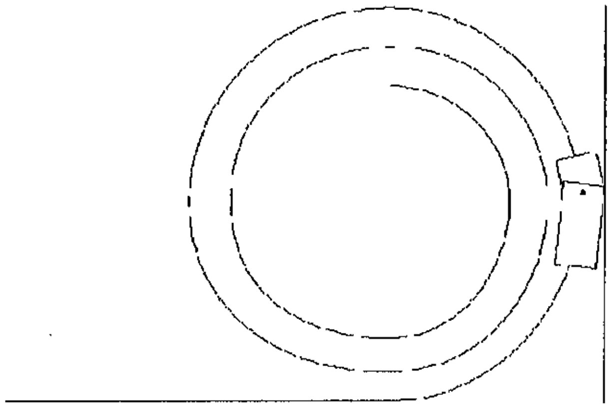

Figure 3: Manoeuvre to determine SRT.

The DLTR is determined by simulating the vehicle combination in a lane change manoeuvre. The vehicle path, if followed precisely, results in a lateral acceleration time history of the form of a single-cycle sine wave with peak accelerations of 0.15 g at the prime mover's centre of gravity. The time between left and right acceleration peaks is 3 seconds. Figure 4 shows the DLTR manoeuvre.

Definition 2 *Dynamic Load Transfer Ratio (DLTR) is a measure of dynamic roll stability, and is given by*

$$DLTR = \frac{F_{zl} - F_{zr}}{F_{zl} + F_{zr}}, \qquad (1)$$

where F_{zl} is the sum of all vertical tyre forces along the left hand side of the vehicle (except the steer axle), and F_{zr} is the corresponding sum for the right hand side.

Travelling along a flat, straight road, a vehicle will have a DLTR of zero. At the limit when all wheels except the steer axle on one side of the vehicle lift, the DLTR is 1[1].

For combination units, which are entirely roll-coupled, the DLTR is calculated over the entire combination. For truck-trailers, the DLTR is determined separately for the trailer and the truck. This is because they are not roll-coupled, that is, one portion of the combination can overturn without the other. The worst (highest) value is recorded as the DLTR for the combination.

[1]Steering axles on trucks tend to have lower roll stiffness than other axles and, therefore, steering wheels lift off after the rollover limit of a vehicle is reached

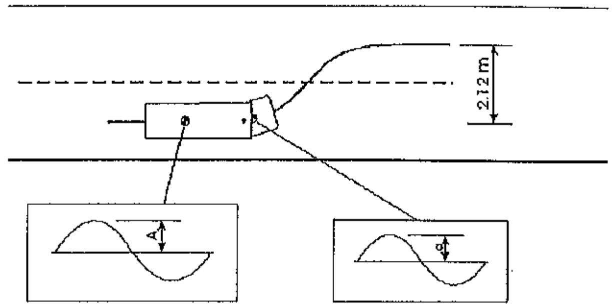

Figure 4: Path of vehicle for lane change manoeuvre to determine DLTR.

2 Preliminaries

The Safety Investigation separated heavy vehicle crashes by crash type. Crash types included rollover and loss of control crashes, crashes at intersections and overtaking or lane change crashes. A previous study [Mueller et al, 1999] found relationships between the performance measures SRT and DLTR and the relative rollover and loss of control crash rate. These relationships are shown graphically in Figures 5 and 6.

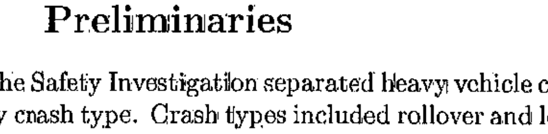

Figure 5: SRT versus relative crash rate.

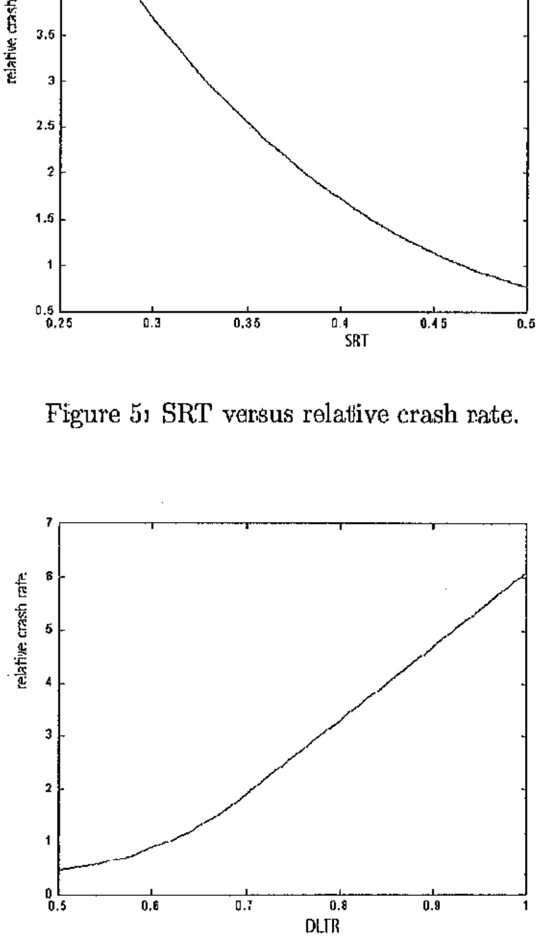

Figure 6: DLTR versus relative crash rate.

The curve shown in Figure 6 has been extrapolated for DLTR values above about 0.8, so, in this region, the relationship is even more uncertain than for other DLTR values.

Other types of heavy vehicle crashes were believed to be less strongly related to vehicle performance than rollover and loss of control crashes, however, we attempted to find relationships between vehicle performance measures and crash rates for other crash types as well. The treatment of the different types of crash are outlined in the method.

3 Method

120 vehicles were simulated for the Safety Investigation of the Heavy Vehicle Limits Project. These simulations gave performance measures including Static Rollover Threshold (SRT), Dynamic Load Transfer Ratio and Low Speed Offtracking (LSO). Vehicles considered were B-trains, tractor-semi-trailers and truck-trailers. A range of lengths and axle loads were considered, and load densities were either such that the vehicles were simultaneously 'grossed out' and 'cubed out' or the load was of constant density. The suspensions were either multi-leaf steel springs or air springs. The simulation results and vehicle weights and dimensions were used to estimate crash rates for the 120 vehicles that were simulated. For the estimation of numbers of truck crashes, four categories of crash type were considered:

- rollover and loss of control crashes
- overtaking crashes
- crashes at intersections
- 'other' crashes.

Rollover and loss of control crash rate was estimated for each of the simulated vehicles using the relationships shown in Figures 5 and 6. This was done by taking the maximum of the estimates of relative crash rate from these two curves and multiplying by the average rollover and loss of control crash rate per kilometre for heavy vehicles in 1996 [LTSA, 1997]. In 1996, there were 15 fatal rollover and loss of control crashes and 144 injury rollover and loss of control crashes.

To estimate the number of overtaking crashes per kilometre for each of the simulated vehicles, we attempted to find a relationship between crash rate per kilometre for overtaking crashes and the distance required to overtake a vehicle. The distance required to overtake a vehicle is the *overtaking distance* and is the total distance covered from the time when the following vehicle decides to overtake until the time at which the overtaking vehicle pulls back into the left lane. Typical speeds and accelerations were assumed for the overtaking and overtaken vehicles. LTSA crash statistics [LTSA, 1997] were used to find the overtaking crash rate per kilometre for heavy vehicles and for light vehicles: there were 67 overtaking crashes involving trucks and a total 379 overtaking crashes in 1996.

Next, it was assumed that exactly two vehicles (call them vehicle 1 and vehicle 2) are involved in each overtaking crash. This gives four possible permutations:

1. Vehicle 1 and vehicle 2 are trucks
2. Vehicle 1 is a truck and vehicle 2 is a light vehicle
3. Vehicle 1 is a light vehicle and vehicle 2 is a truck
4. Vehicle 1 and vehicle 2 are light vehicles.

Situations 1, 2 and 3 are overtaking crashes involving a truck. The total number of vehicles involved in overtaking crashes will be denoted n and the number of trucks involved in overtaking crashes n_t. Also, the probability of vehicle 1 being a truck is $p = \frac{n_t}{n}$. Thus, the number of overtaking crashes involving a truck, C_T is

$$C_T = C\left(p^2 + 2p(1-p)\right) \tag{2}$$

where C was the total number of overtaking crashes for 1996. C also satisfies

$$C = 2n \tag{3}$$

since it was assumed that 2 vehicles are involved in each overtaking crash. Therefore, it was estimated that the total number of vehicles crashed in injury overtaking crashes was $n = 758$ and the proportion of these vehicles that were trucks was $p = 0.0927$ so the estimated number of trucks crashed was $n_t = 70.3$. Since trucks travel a distance of $D_T = 1.85$ billion kilometres per year [Baas, 1999] the injury overtaking crash rate per million kilometres for trucks was 0.038. Similarly, the total distance travelled on the roads each year is $D = 30$ billion kilometres, so the injury overtaking crash rate per million kilometres was 0.027. A straight line was fitted to these two points using typical overtaking distances for light vehicles and heavy vehicles. This function was used to estimate the overtaking crash rate for each of the simulated vehicles based only on vehicle length.

Remark 1 *Heavy vehicles and light vehicles are different in numerous ways. Therefore, finding a relationship between crash rate for overtaking and lane change crashes and vehicle length by interpolating between light vehicle crash rate and heavy vehicle crash rate is unreliable. However, this method was used because it was believed it gave a better estimate than the alternative of simply assuming that overtaking and lane change crash rate is independent of vehicle weights and dimensions.*

Crash rate for crashes at intersections was assumed to be independent of the weights and dimensions of a heavy vehicle. 1996 crash rates [LTSA, 1997] were used to represent crash rates at intersections for the simulated vehicles. Just as with overtaking and lane change crashes, crashes at intersections also involve more than one vehicle. The numbers of fatal and injury crashes involving trucks at intersections in 1996 were 13 and 55 respectively. For all vehicles, the numbers of fatal and injury crashes at intersections were 248 and 3302, respectively. It was assumed that exactly 2 vehicles are involved in each intersection crash and a method similar to that used for overtaking and lane change crashes was used to estimate the fatal and injury crash rates at intersections as 7.5×10^{-9} crashes per kilometre and 137×10^{-9} crashes per kilometre.

Remark 2 *Initially, we tried to relate crashes at intersections to vehicle length, However, it was suspected the relationship would be adversely affected by the fact that light vehicles have a greater exposure to intersections, per kilometre than heavy vehicles. So, it was assumed that crashes at intersections are independent of vehicle weights and dimensions.*

The 'other' category of crashes (crashes other than rollover and loss of control crashes, overtaking and lane change crashes and crashes at intersections) were, largely, assumed to be independent of vehicle weights and dimensions.

Heavier vehicles cause more splash and spray in wet weather [Ashton and Baas, 1998] so adjustments were made to the crash rates depending on the gross combination mass of each vehicle. These adjustments made very little difference to the estimates of crash rates.

The Geometrics Investigation [Milliken et al, 1999] considered a range of road widening scenarios. A corresponding range of multipliers were calculated to adjust the crash rates of the simulated vehicles for each of the road widening scenarios in the Geometrics Investigation. Two previous studies were used as a basis for this adjustment: an Australian study suggested "a 1 metre increase in seal width (either as additional lane width or shoulder seal) produced a 20 percent reduction in accident rates" [McLean, 1999]. Also, a New Zealand study, currently in progress at TERNZ, shows some evidence to suggest that roads with a 6 metre wide sealed carriageway may be as much as 3 times as dangerous as roads that are 7 metres wide. Therefore, it was assumed that narrowing the road by one metre (or increasing vehicle offtracking by half a metre) would cause a threefold increase in heavy vehicle crash rate. Interpolating between those two points and the status quo, a multiplicative adjustment was made to the estimated crash rates for the simulated vehicles based on the average widening for curves of radius of curvature less than 250 metres on the Scenario B network of routes. The multipliers ranged between 0.944 and 0.993, for the three sets of widening assumptions outlined in the previous paper and for the two trial vehicles used for the Geometrics Investigation. The multipliers also have a high level of associated uncertainty due to large uncertainties associated with the data used for the interpolation.

4 Results

The estimated numbers of fatal, injury and non-injury heavy vehicle crashes per annum for Scenario A were fairly insensitive to the proposed changes in weight limits. This was the result of two counter-effects; heavier and more dangerous vehicles, but fewer of them. Similarly, for Scenario B, the estimated numbers of heavy vehicle crashes were largely unaffected by the proposed changes in weights and dimensions.

Remark 3 *Estimating the safety implications, for heavy vehicles, of the proposed change in weights and dimensions regulations is difficult. Therefore, the uncertainties associated with the estimates of crash rates in this study are high. However, these estimates were required for the benefit/cost assessment for the Heavy Vehicle Limits Project so the results are a 'best attempt' at estimating the safety implications, for heavy vehicles, of the changes in weights and dimensions regulations proposed in Scenarios A and B.*

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