PROJECTING EFFECTS OF IMPROVEMENTS IN PASSIVE SAFETY OF THE NEW ZEALAND LIGHT VEHICLE FLEET TO 2010

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Abstract - In the year 2000, NZ road safety targets were set for a reduction in social cost of 15.5% associated with improvements in crashworthiness, which is a measure of the occupant protection of the light vehicle fleet. Since that document was produced, new estimates of crashworthiness have become available allowing a more accurate projection. This paper describes a methodology for projecting changes in casualty rates associated with passive safety features, including the effects of two potential interventions: restrictions on the importation of cars into New Zealand and restriction of government fleet vehicles to those with superior crashworthiness. Compared to the quite large social cost reduction of about 22% expected to occur largely due to improvements in the crashworthiness of the fleet over time, these additional interventions were predicted to yield fairly modest savings.

BACKGROUND

The New Zealand National Road Safety Committee produced a road safety strategy for 2010 (National Road Safety Committee, 2000) that included a target for casualty reductions associated with improvements to built-in safety features (providing *passive* or *secondary* safety) of light passenger vehicles. The degree of passive safety provided by a vehicle was expressed in terms of its crashworthiness, which is estimated by statistical analyses of police-reported crash data. At that time the only crashworthiness figures available were those for Australia. The target set in 2000 was a reduction in baseline (year 2000) social cost of 15.5%.

Since that document was produced, new estimates have become available via Monash University's study of crashworthiness of the New Zealand light vehicle fleet (Newstead and Watson, 2005) and five years have passed, allowing a more accurate assessment than could have been made in 2000 of projected savings. This paper describes modelling procedures and projected changes in casualty rates, including the predicted effects on social cost of two potential interventions. These are restrictions on the importation of cars and regulation of the fleet of Government-owned vehicles, specifically:

- From the year 2006, no imported used light vehicle to be more than 7 years old.
- From 2006, only light vehicles that are at least 4-star rated to be allowed to enter the NZ Government fleet.

The crashworthiness rating (CWR) used in this report is a measure of the risk of fatal or serious injury to a driver of a car involved in crash with another vehicle whose driver is injured (Newstead and Watson, 2005). Note that this differs from crashworthiness measures used in countries such as Australia where non-injury crashes are available in most states' official databases, meaning that crashworthiness can be the risk of driver serious injury (or death) given that the driver is involved in a *tow-away* crash (e.g., Cameron et al., 1994). Nevertheless, the New Zealand and Australian crashworthiness measures are expected to vary proportionately in the same fashion (Newstead and Watson, 2005). In other words, for any comparison between two vehicles, A and B, an *x*% difference in rating for vehicle A compared to vehicle B is expected to be estimated by both rating methods.

DATA

The crash data analysed in this study consist of police-reported injury crashes. The ages of the vehicles used for the analysis are as recorded in the Traffic Crash Report. In the analysis that follows, it is assumed that the distribution by vehicle age of vehicles involved in all injury crashes is similar to the distribution of vehicles involved in serious and fatal injuries, which is true for 2001-2002 data (see Keall et al., in press). The reason for using vehicles involved in all injury crashes is to make the most of the added statistical power available from dealing with larger numbers of crashed vehicles. A decision needed to be made as to whether to make inferences about the crash effects of changes in the fleet of registered vehicles or to deal directly with the shape of the crashed fleet and then decide what changes amongst registered vehicles would lead to such shapes. Although the distributions of the on-road vehicle fleet and the crashed vehicle fleet are different, they nevertheless have a close to functional relationship that allows us to use the crash fleet distribution in predictive models and then make statements about the underlying on-road fleet along the following general lines: for a given proportion of older vehicles in the crash fleet, there will be a relatively smaller proportion of older registered (on-road) vehicles; for a given proportion of newer vehicles in the crash fleet, there will be a relatively larger proportion of newer registered vehicles (Keall et al., in press). Given these considerations, it was clearly simpler to deal with projections regarding the crash fleet distribution.

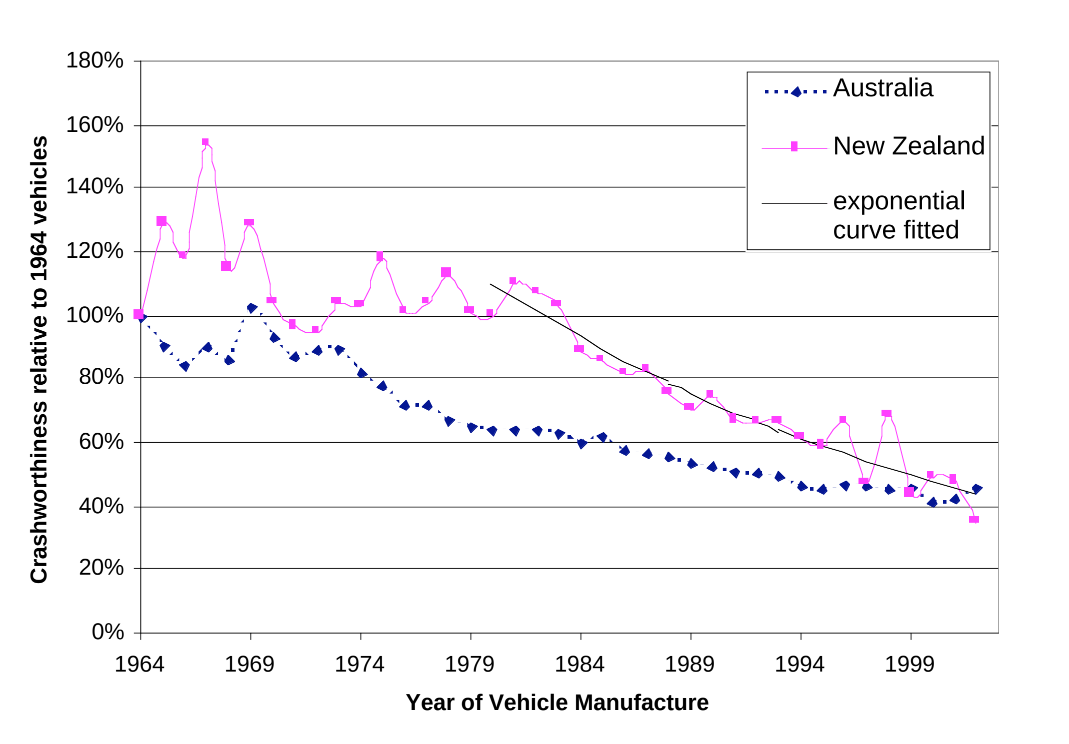

Figure 1: Crashworthiness of the NZ and Australian vehicle fleets relative to 1964 vehicles by year of manufacture, with exponential trend line fitted to NZ data from 1980 to 2002 (estimates from Newstead and Watson, 2005).

The relative crashworthiness rating (CWR) of the NZ and Australian fleets is plotted in Figure 1, with levels indexed to the average 1964 (data from Newstead and Watson, 2005). NZ crashworthiness appears to follows a negative exponential curve against vehicle age from 1980 to 2002 according to the fitted curve shown, which has an R^2 of 0.89. This means that the CWR of the fleet can be projected quite simply into the future using this trend. This projection is used as the most likely scenario for the future, but the possibility that crashworthiness may have plateaued is also considered. The slower improvement in crashworthiness (indicating slower improving outcomes for the crash-involved driver) from a lower 1980 level for Australia is likely to be associated with many safety benefits being introduced to the Australian fleet several years before they influenced the NZ fleet (Newstead and Watson, 2005). In Australia, technical improvements flow into the fleet more rapidly than in New Zealand as their fleet is generally younger. From the early 1980s to the early 2000s years of manufacture, NZ CWR has improved by about 50%, equivalent to the total improvement seen in Australian vehicles from 1964 to 2002 (ibid).

ANALYSIS

Predicting the shape of the crash fleet in 2010

Various methods can be used to predict the shape of the distribution of the crash fleet. The method chosen analysed the changes happening over time in the crash fleet and estimated the shape of the distribution by projecting these patterns of change into the future. Figure 2 shows seven distributions of the crash fleet by vehicle age for pairs of years from 1991 to 2004, simplified by aggregating these distributions across age intervals that appeared to best summarise the changes from year-to-year.

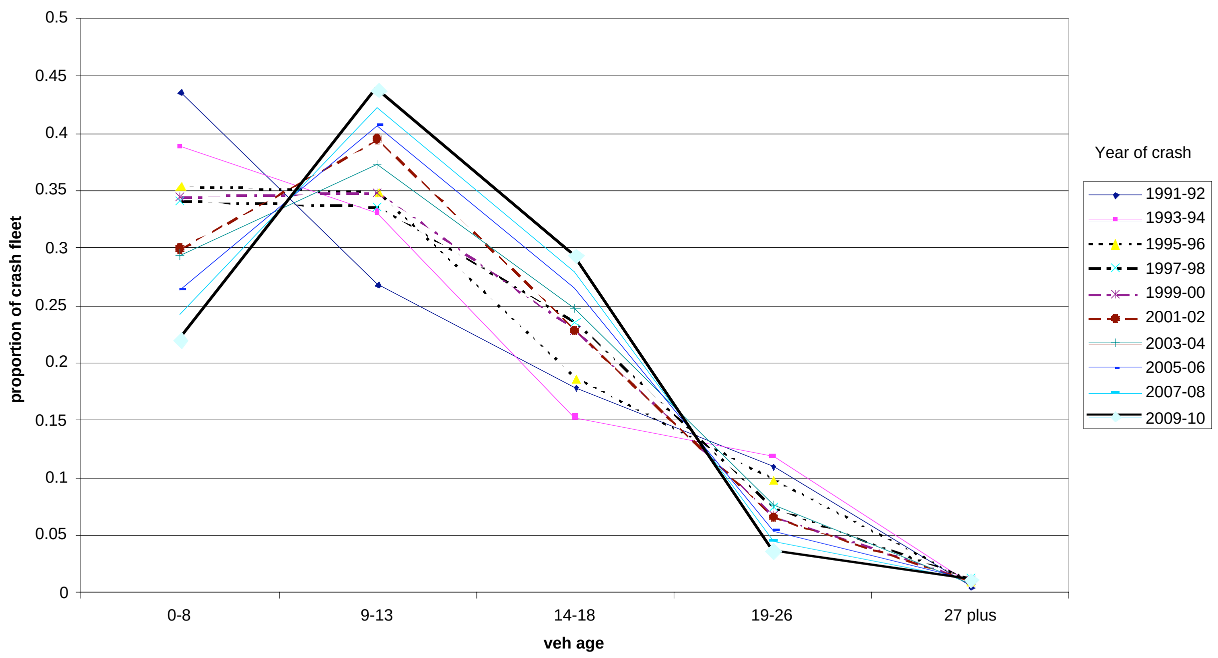

Figure 2: Simplified distribution of crash fleet by vehicle age and years of crash

The distribution appears to be changing over time, becoming older on average with proportionately fewer new vehicles entering the fleet, although many used vehicles are imported into the fleet. Also shown in Figure 2 are projected distributions for 2005/2006, 2007/2008 and 2009/2010, derived by projecting the patterns of change into the future. This was achieved by simple linear regressions of the proportion of crashed vehicles within vehicle age ranges against year of crash, showing a trend with time for fewer new vehicles, more vehicles aged 9-18 years, but proportionately fewer vehicles older than 18 years (see Keall et al., in press). By 2003/2004, only about 29% of the crash fleet were these newer vehicles. This is an unusual way for a population to change over time and is due to the large number of used imported vehicles that enter the fleet, boosting the proportions in the 9-18-year-old age bracket.

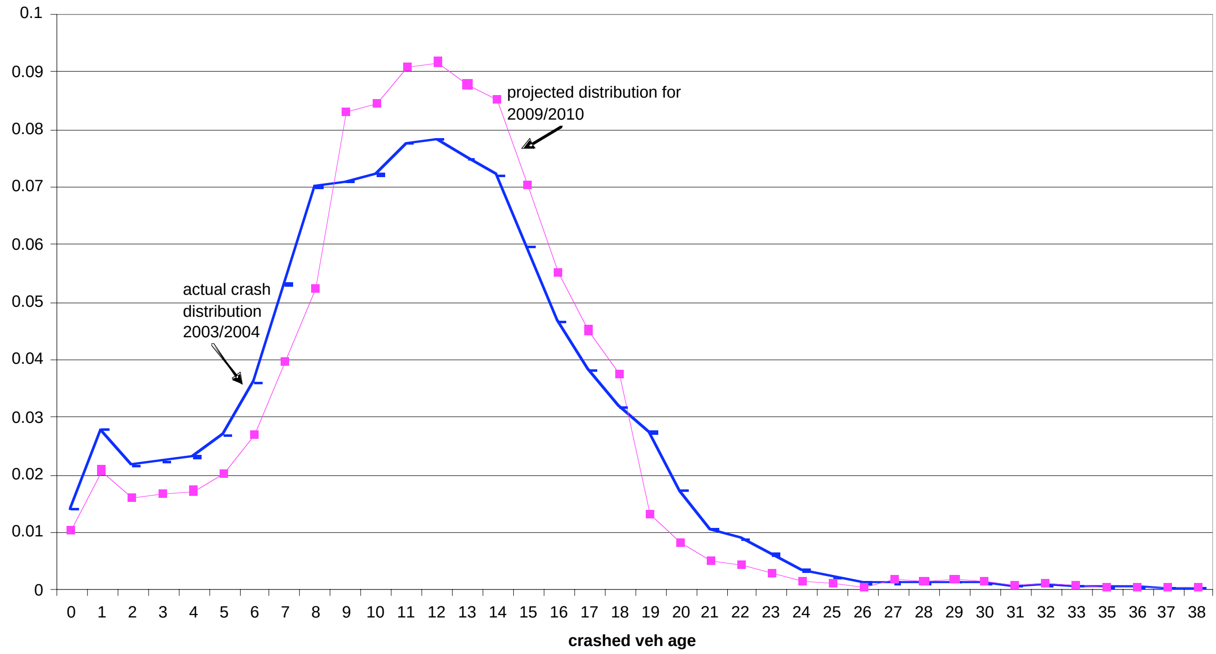

Figure 3: Distribution of crashed vehicles by vehicle age for 2003/2004 and projected distribution for 2009/2010

When these projected changes were applied to the most recent available distribution of the crash fleet (2003/2004), the crash fleet for 2009/2010 could be predicted, as shown in Figure 3. As shown in the Results section, below (Table 1), the shape of the projected crash fleet distribution has a relatively minor effect on projected injuries compared to the influence of diminishing CWR over time. This is really an artefact of the shape of CWR curve against vehicle age, which takes the approximate form of an exponential curve (see Figure 1). A mathematical explanation of the lack of strong distributional effects is given below. It is important to note the reduction in the proportion of older vehicles in the fleet shown in Figures 2 and 3. This shows that the used import programme may be encouraging (or at least supporting) purchasing patterns leading to a reduced lifetime for vehicles in New Zealand.

Combining crashworthiness estimates with crash fleet projections

The following describes how changes in injury rates were estimated. The crashworthiness estimates can be combined with estimated fleet distributions in the following way:

1. Take *NA* drivers of crash-involved vehicles in time period *A* that have crashworthiness *CWR(A)*. Then, by the definition of crashworthiness, the expected number of these drivers who will be killed or seriously injured will be: $CWR(A) \times NA$
2. Suppose that in ten years time, in period *B*, the vehicles of these drivers are replaced by vehicles of the same age (years since manufacture) with better crashworthiness *CWR(B)* (better protection for the driver in the event of a crash).
3. Then a certain proportion of the *NA* crashing drivers who would have been seriously injured or killed will be better protected by their vehicles and will not be injured or will have minor injuries. It is estimated that $CWR(B) \times NA$ will still be killed or seriously injured.

4. There may also be changes in the distribution of the crash fleet by age of vehicle, such that for vehicle age *i* in time period *A*, there are NA_i crashed vehicles in time period *A*, but a different number, NB_i in period *B*, with vehicle age *i* (years since manufacture as at time *B*). Of course, the years of manufacture will differ for these two groups of vehicles. For example, if *B* is the year 2010 and *A* is the year 2000, then for *i*=10, NB_i will refer to vehicles manufactured in the year 2000 and NA_i to vehicles manufactured in 1990.
5. Then the change in the serious and fatal injury rate of drivers due to the combined effect of the change in the crash fleet distribution and the crashworthiness of the fleet can be estimated by $\frac{\sum_i CWR(B)_i \times NB_i}{\sum_i CWR(A)_i \times NA_i}$, which is the ratio of the total expected number of fatal and seriously injured drivers in time *B* relative to the expected number in time *A*.

Although the crashworthiness measures refer to driver risk of injury, it is reasonable to assume that other occupants of a given vehicle will share many of the benefits of the safety features that protect the driver (Evans, 2004). Therefore, it is assumed that improvements in crashworthiness will proportionally affect the number of vehicle occupants who are injured in crashes in a similar way to the number of drivers injured in crashes. Further, it is likely that safety features that reduce the occurrence or severity of serious injuries will have at least the same beneficial effect on the occurrence of less serious injuries[1] (ibid). As minor injuries in light vehicle crashes are a relatively small proportion (about 12%) of total social cost (Jones, 2005), there would be relatively little bias in the estimates presented here if the assumption were not justified. Mathematically, as long as $NA_i \cong NB_i \; \forall i$, the shape of the distribution of the crash fleet has almost no impact on the estimated saving. As mentioned above, this is because the shape of CWR curve against vehicle age takes the approximate form of an exponential curve (see Figure 1). This means that for any vehicle of a given age, there will be a constant improvement in CWR over a set time period (in this study, 10 years). Using the equation of the fitted regression line of Figure 1, the predicted CWR for a vehicle manufactured in year *x* relative to a vehicle manufactured 10 years earlier is (having cancelled out the constants in numerator and denominator):

$$\frac{e^{-0.0418x}}{e^{-0.0418(x-10)}} = e^{-0.418} = 66\%$$

Note that this is constant, not dependent on year of manufacture *x*.

Projected casualties if no action taken ("business as usual")

The evolution of the distribution of the crashed vehicle fleet from year to year consists of the combined impact of new and imported vehicles entering the vehicle fleet and the scrapping of (mainly older) vehicles. If no vehicles were to enter the vehicle fleet and none to exit it (by being scrapped), then the distribution of vehicles by vehicle age (such as shown by the solid line of Figure 4) would shift horizontally along the vehicle age axis. For the distribution to remain the same with respect to vehicle age as time passes, there need to be some vehicles entering and exiting the fleet. Figure 4 shows the distribution of crashed vehicles by vehicle age for the years 2001-2002 combined (solid line). Distributions of inputs (imported new or used cars, represented by the dashed line) to the fleet and subtractions from the fleet (via

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[1] However, Lie and Tingvall (2002) found no relationship between minor injury risk and crashworthiness as measured by NCAP stars.

vehicles being scrapped, represented by the dotted line) for there to be no change two years hence (2003-2004) are also shown. The vehicle ages shown for the vehicles added and scrapped are ages as at 2003/2004 (two years after 2001/2002), so some new vehicles added to the fleet will appear as aged 0 or 1 year old, depending on when in the two year period they appear in the crash fleet.

Figure 4: Example of proportions of crash fleet imported and scrapped over a 2-year period to result in no change to the distribution (2001/2002) of the crash fleet by age.

Rather than modelling two separate distributions, one for additions to the population of crashed vehicles, one for subtractions, as shown in Figure 4, the approach used in this study, to model various scenarios of changes to the fleet, considered a single distribution, showing net vehicles added to or subtracted from the crash fleet. The line with solid squares shown in Figure 5 shows the *net* proportion of vehicles in each age group entering the fleet (positive proportions) or leaving the fleet (negative proportions) under particular policy scenarios. The sort of curves shown by the solid squares of Figure 5, which represents change in the crash fleet, is used to represent the effects of proposed interventions on the shape of the crash fleet distribution, and can then be used to quantify any benefits accompanying the intervention when combined with estimates of crashworthiness of vehicles by vehicle age. The use of two years' crash data is arbitrary and based on the amount of data required to generate reasonably smooth distributions.

Newstead and Watson (2005) found that the crashworthiness of vehicles sold new in NZ was not different from the crashworthiness of used imported vehicles with the same year of manufacture. Thus, the projections used in this report, which are dependent on estimated and projected crashworthiness by year of manufacture, need not discriminate between NZ new vehicles and used imported vehicles.

Scenarios under policy changes

Two scenarios of regulations taking full effect from the end of 2006 are tested in the following analyses, an optimistic outcome, and a pessimistic scenario of a worst outcome of this policy. Another scenario involves regulation of the government fleet.

1) Scenario 1. This is an optimistic result of import restrictions, in which only cars manufactured 7 years ago, or more recently, could be imported. People who would have bought an older import decide instead to purchase a newer car (and presumably a more

expensive car than the one they might have bought in the absence of the restriction). There is no change in the scrapping of older vehicles (aged 14 years plus) already in the fleet. The line in Figure 5, with the solid squares, represents these changes in the fleet.

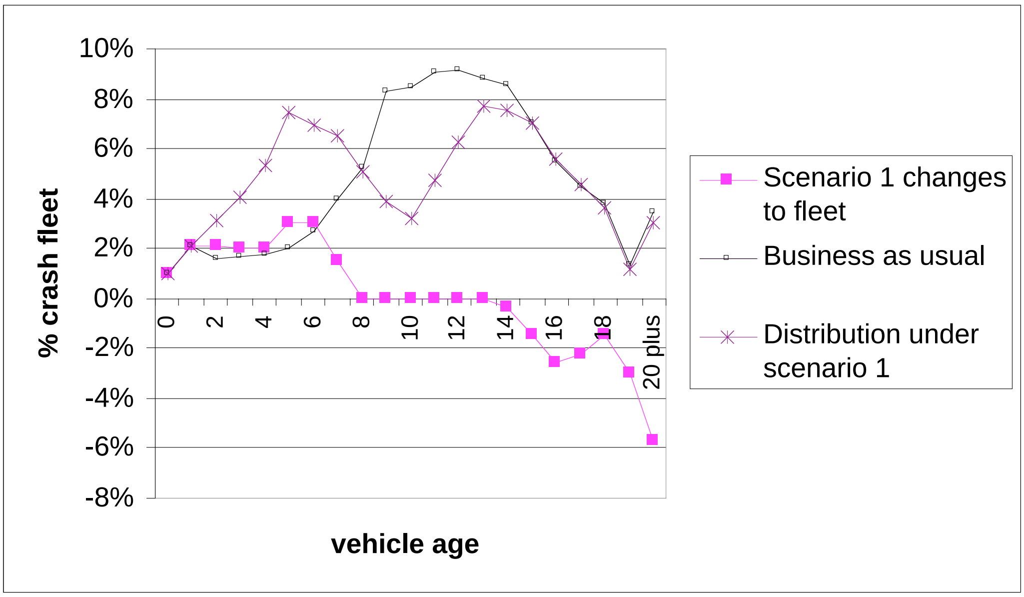

Figure 5: Scenario 1. Optimistic outcome where buyers choose younger imports, no change in scrapping. Introduced 2006 and compounded over four years

2) Scenario 2. This is a pessimistic result. There is increased demand for vehicles close to the age threshold (6 and 7 years old) but many drivers are put off by the higher prices for these imports and choose to retain their older vehicles (repairing them rather than scrapping them). The three curves of Figure 6 show the distribution of vehicles new to the fleet minus scrapped vehicles (large squares), the projected distribution of the crash fleet 2009/2010 under 'business as usual' and the distribution in 2009/2010 projected under scenario 2.

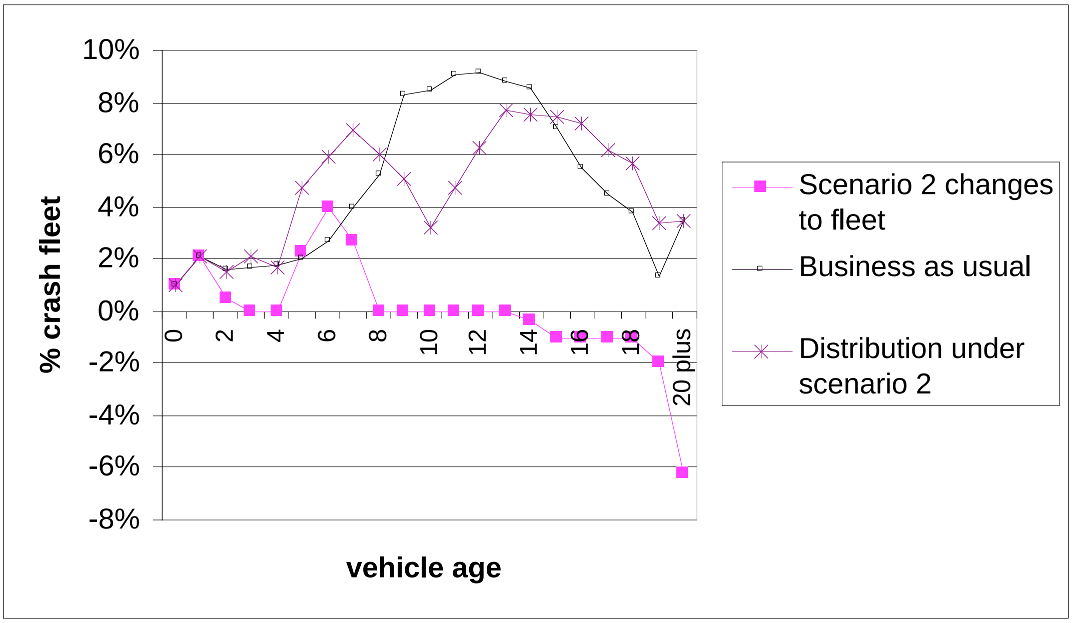

Figure 6: Scenario 2. Pessimistic outcome where buyers are put off by higher prices of imports and retain existing older vehicle introduced 2006 and compounded over four years

3) Scenario 3. From 2006, all new government fleet vehicles must have the best CWR and aggressivity within the given market group. About 0.4% of the light four-wheeled vehicle fleet are government vehicles[2]. We can assume that about 25% of these are sold per year and replaced with new vehicles. From Newstead et al. (2003), the best (15th percentile CWR) performing recent model vehicles within market group have approximately 85% of the CWR of the group average, and similarly for aggressivity. CWR is projected to improve at the rate predicted by the fitted line of Figure 1. The safety effects of the superior safety vehicles sold as second-hand vehicles in the crash fleet were included in the projection. Although the estimates are therefore somewhat optimistic, it was assumed that superior CWR and aggressivity could be found within the same vehicle. The estimate is also optimistic in that 0.4% of the on-road fleet are government vehicles, but proportionally fewer are likely to be in the crash fleet (as newer vehicles are under-represented in the crash fleet relative to the on-road fleet: Keall et al., in press). The improvements in aggressivity were modelled by estimating the effect on the outcome of two-vehicle crashes involving vehicles affected by this policy.

RESULTS

Table 1: Projected savings in injuries and as a proportion of overall (all road trauma) social cost associated with various scenarios 2010 compared to 2000 or to 'business as usual' (as specified) due to improvements in secondary safety (injury risk given crash occurrence) of fleet

Scenario	Description	Light Vehicle injury rate	Overall social cost
Compared to year 2000			
No action 1	Same trends in purchasing as recent years; crashworthiness with constant proportional improvement	-30%	-22%
No action 2	Same trends in purchasing as recent years; crashworthiness *no change* from 2000-2002	-28%	-21%
No action 3	2010 crash fleet *distribution as 2003/4*; crashworthiness with constant proportional improvement	-31%	-23%
Compared to business as usual (no action)			
Scenario 1	No imports >7 years old, optimistic result	-5%	-4%
Scenario 2	No imports >7 years old, pessimistic result	+0.3%	+0.2%
Scenario 3	From 2006, govt fleet new vehicles have best available CWR and aggressivity	-0.1%	-0.1%

Table 1 shows that the projected safety of the light vehicle crash fleet under conditions of "business as usual", where there is no regulatory or public information change, is quite robust to changes in the assumptions. "No action 1" shows the estimate expected to be the most accurate, where (a) crashworthiness is predicted to continue to improve with a year-to-year change similar to that experienced in the past and (b) the vehicle crash fleet is predicted to continue its year-to-year trends. "No action 2" gives predicted safety given assumption (b),

[2] This was estimated by classifying as government vehicles all those on the motor vehicle register (of licensed vehicles) with government or government agency ownership.

but assuming crashworthiness has plateaued, and remains at the level of the average crashworthiness of 2000-2002 vehicles. “No action 3” assumes improvements in crashworthiness but replaces assumption (b) with the assumption that the crash fleet distribution remains unchanged from 2003/2004. Of course, this last scenario (“No action 3”) is unlikely, but the results in Table 1 show that the modelled projections are robust to variations in the shape of the crash fleet distribution by vehicle age. Scenario 2, which presents a pessimistic outcome from age restrictions on imported vehicles, shows a very small *increase* in social cost. Given that this scenario is an unlikely extreme result, it can be concluded that a seven-year age restrictions on imported vehicles will almost certainly improve light vehicle[3] injury rates, although such improvement may be modest (at best, a 5% improvement in injury rate and a 4% decrease in social cost, as shown in Table 1).

Note that the predicted social cost changes listed in Table 1 for Scenarios 1 to 3 are in relation to social cost predicted for 2010 under business as usual. Therefore, for the combined effect of “No action 1” and “Scenario 1” it is not valid just to add the -30% estimate for the “No action 1” scenario estimates to the -4% for Scenario 1 to get -34%. The combined effect for this example is estimated by (1-0.3)x(1-0.04)-1=-32.8%. So the effectiveness projected for Scenario 1 is in terms of 2010 social cost, which is predicted under the conditions of “No action 1” to be only 70% of 2000 social cost. The same considerations apply to Scenarios 2 and 3.

DISCUSSION

When considering the estimates shown in Table 1, it is important to remember that the savings in casualties and social cost are those associated only with secondary safety improvements to the fleet (due to improvements in crashworthiness and changes in the age distribution of the fleet). Other improvements in casualty rates are likely to occur due to improvements in primary safety, or avoidance of collisions in the first place, which are likely to accompany improvements in the road network, road use behaviour (speed, alcohol use, etc) and possibly improvements in vehicle technology (improved stability, braking, etc). This last factor has often proved disappointing in the past, probably due to drivers’ absorption of the safety benefits by driving faster under the conditions favoured by the improved technology. Consideration of primary safety effects is outside the scope of this report. Nevertheless, there will be some apparent improvement in primary safety associated with secondary safety improvements. Some crashes that would have caused injury in the past will not cause injury in the future due to improving crashworthiness. As non-injury crashes are not consistently recorded in NZ, this will result in an apparent improvement in primary safety. Consequently, the estimates of this study should be regarded as being slight underestimates as these effects are difficult to quantify. However, as the sorts of crashes affected by this mechanism will be of minor severity, it is not thought that this bias will be large in terms of social cost. Also excluded from the projections are secondary exposure effects of policy changes. If light vehicles become more expensive to buy as a result of policy restricting the age of imported used vehicles, for example, then some current car drivers and passengers may transfer their travel to other modes, such as motorbikes (an adverse effect on safety, discussed below) or elect to travel less (an adverse effect on mobility, but with safety benefits through reduced

[3] This study restricts its scope to light vehicle safety effects. However, there are likely to be adverse effects on overall safety if some current car drivers lose access to cheap cars and elect to buy and ride motorbikes instead.

exposure to risk). These effects are difficult to predict and were outside the scope of this study.

As mentioned above, a seven-year age restriction on imported vehicles will almost certainly improve light vehicle injury rates slightly. Not considered here was the availability of used vehicles in the age range required. For example, if there were insufficient used vehicles available from Japan to fulfil the increased demand following the imposition of age restrictions on imports, then car owners may choose to retain their existing older vehicle, leading to increased ageing of the fleet. Although it is tempting to consider an even more restrictive regime, it is likely that some of the gains resulting from the used import availability in New Zealand could thereby be lost. Such gains may have included increased mobility through the availability of more affordable vehicles, a reduction in motorcycle[4] use and possibly improvements in the age profile of the fleet (see above). For example, throughout the 1980s, there were at least 100 motorcyclist deaths annually. By 2003, there were only 28 (LTSA, 2004). The extent to which such changes can be attributed to used vehicle importation is potentially the topic of further research.

The final scenario considered, in which all new government fleet vehicles must have the best CWR and aggressivity within the given market group, is limited in its effect because of the relatively small NZ government vehicle fleet, even though these fleet vehicles then enter the general vehicle fleet through being sold second hand. Such a policy does present a consistency in governmental attitude favouring crashworthy and non-aggressive vehicles, which in itself may be sufficient justification for the application of this policy despite its modest safety effects.

CONCLUSIONS

If trends in fleet constitution and crashworthiness continue, there is predicted to be an improvement (compared to the year 2000) of about 30% in light vehicle casualties and 22% in total social cost. Compared to this large social cost reduction, the potential interventions evaluated are predicted to yield fairly modest savings. If age restrictions were imposed on imported vehicles, allowing only those manufactured seven years or less prior to their sale in NZ, it was predicted that, at best, there may be as much as a 4% saving in overall social cost in the year 2010 compared to the "business as usual" approach. Not considered in this report was the potential for motorcycle ownership to increase in response to restrictions on the availability of used vehicles in the lower price ranges. Such an eventuality could have a serious impact on road trauma. Also not considered was the availability of used vehicles in the age range of seven years or less since manufacture. If imported used vehicles are not sufficient to fulfil demand, there may be an adverse impact on fleet crashworthiness as drivers retain older vehicles that would otherwise have been scrapped. The final scenario considered, in which all new government fleet vehicles have the best crashworthiness and aggressivity within the given market group, was limited in its effect because of the relatively small NZ government vehicle fleet. Only a 0.1% saving in social cost was predicted as the most optimistic result of this scenario.

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[4] Per distance travelled, a motorcycle ridden under New Zealand road conditions is estimated to be about 18 times as risky as a car (LTSA, 2000).

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