A MODEL FOR CONSIDERING THE 'TOTAL SAFETY' OF THE LIGHT PASSENGER VEHICLE FLEET

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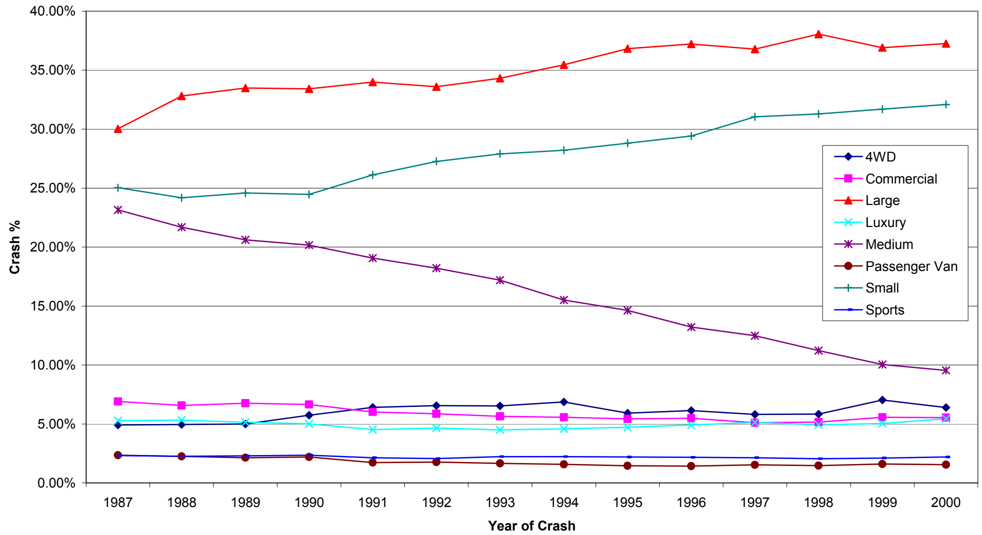
ABSTRACT

This paper describes the results of research to develop and apply a comprehensive model to consider the influence of the mix of vehicle types in the fleet on the total safety of the light passenger vehicle fleet in Australia. Key inputs to the model are estimates of the crashworthiness and aggressivity of light passenger vehicles in the key crash types representing the majority of crashes in which these vehicles are involved. They include crashes between two light vehicles, single vehicle crashes, crashes with heavy vehicles and crashes with unprotected road users such as pedestrians and bicyclists. The model combines these key crashworthiness inputs with measures of crash exposure of each vehicle class in the fleet mix to estimate the average injury outcome in all crashes involving the light vehicle fleet. By varying the key parameters of the model, it is possible to examine the effects on the average safety of the light vehicle fleet resulting from changes to the mix of types of vehicles in the fleet. Application of the model is demonstrated through a number of scenarios varying the mix of vehicles in the fleet by broad market group classification. Scenarios considered include natural changes in market group mix of the fleet in recent times and projected over the next 10 years, elimination of various market groups from the fleet, homogeneous fleets composed of a single market group, and fleets composed of only vehicles with the best possible safety performance in each market group. Results of applying the model to the various scenarios considered point to how the vehicle fleet mix might best be manipulated in the future to optimise average safety outcomes. They are also able to quantify the safety outcomes resulting from recent current and projected future trends in vehicle fleet mix.

BACKGROUND AND AIMS

Sales trends in new vehicles in Australia over the past ten years have seen a polarisation of the vehicle fleet into large and small vehicles, with sales in the medium segment showing a rapid decline. Over the same period, sales of four-wheel drive (4WD) vehicles have increased greatly. These sales trends are generally reflected in the population of crashed vehicles by year of crash shown in Figure 1, although crashes involving 4WD vehicles have not increased proportionately to sales.

Figure 1: *Crashed vehicle population by year of crash and market group*



One of the key questions resulting from the observed changes in the distribution of new vehicle sales between market groups concerns the impact these changes may have had on safety. For example, much attention has been given to the likely effects of the growth in the 4WD sector given the high risk of injury these vehicle pose to other road users with which they collide (Hollowell and Gabler, 1996; Attwell and Glase, 2000; Cameron, Newstead and Le, 1998). Newstead and Cameron (2001) also express concern over the polarisation of the fleet into large and small cars contributing to the observed trend towards poorer small car occupant protection performance during the 1990s.

The aim of this study was to build a model to estimate the influence of cross sectional changes in the composition of the light passenger vehicle fleet in terms of its mix by market segment on injury outcome in crashes involving the light vehicle fleet. The model built had to reflect not only injury outcomes within the light passenger vehicle but also amongst other road users involved in the crash. It also had to be proportionately representative of the major crash types involving light passenger vehicles. Newstead et al (2004) has identified these major crash types as crashes between light passenger vehicles, single light passenger vehicle crashes, crashes between a light passenger vehicle and an unprotected road user such as a pedestrian or bicyclist and crashes between a light passenger vehicle and a heavy vehicle including trucks and buses.

Upon development of the model, a further aim of the research was to apply the model to consider the safety implications of various changes in the composition of the light passenger vehicle fleet in terms of mix of vehicles by market group.

INPUT DATA

Analysis has focused on vehicles classified into 8 market groups representing the light passenger vehicle fleet. They are large (L), medium (M) and small (S) passenger cars, sports cars (SP), luxury vehicles (LX), 4 Wheel Drives (4WD), passenger vans (PV) and light commercial vehicles (C).

There are two key data inputs required for the model of total safety of the light passenger vehicle fleet. First, the crashworthiness or aggressivity of each vehicle market group in each of the four major collision types given above was required. Real crash data sources from four Australian states from the years 1987 to 2000 assembled by Newstead et al (2003) have been used to estimate these measures across the eight market groups defined. The method and results of the estimation are described in detail in Newstead et al (2004). The input crashworthiness and aggressivity measures estimated by Newstead et al (2004) are summarised as follows.

- The crashworthiness of light passenger vehicles in collisions with other light passenger vehicles by market group as a function of the colliding passenger vehicle market group.
- The crashworthiness of light passenger vehicles in crashes with heavy vehicles by market group as a function of the class of heavy vehicle in the crash (bus, rigid truck or articulated truck).
- The crashworthiness of light passenger vehicles in single vehicle crashes by market group.
- The aggressivity of light passenger vehicles towards unprotected road users (pedestrians, bicyclists, motorcyclists) by market group.

In the above, crashworthiness is defined as the probability of death or serious injury to the driver of the light passenger vehicle given involvement in a crash where at least one vehicle is towed from the scene or someone is injured. Aggressivity towards unprotected users is the probability of death or serious injury to the unprotected road given the unprotected road user is injured. Drivers of heavy vehicles in crashes with light vehicles and drivers of light vehicles in collisions with unprotected road users are typically uninjured so their injury outcome was not considered.

The second data input required is the proportionate involvement of each crash configuration within a given crash type and the proportionate contribution of each crash type to the total crash population. The first of these data requirements was met from the data used to estimate the crashworthiness and aggressivity ratings by market group of Newstead et al (2004) that were used in the model. The relative proportion of the total crash population represented by each of the four major crash types was derived from NSW crash data which was considered to be generally representative of the national situation. The estimated proportions are shown in Table 1.

METHODOLOGY

The Total Safety Model

The total safety model used to calculate total fleet safety for a given vehicle fleet mix was defined as a two-step process. The first step estimates the average injury outcome in each of the four crash types considered for a given mix of vehicles in the fleet by market group. Equations 1 to 4 give the average crashworthiness or aggressivity for light vehicle to light vehicle (pp), light vehicle to heavy vehicle (ph), single vehicle (sv) and unprotected road user (ur) crashes respectively

$$CWR_{PP} = \sum_i \sum_j \left(w(pp)_{ij} \times cwr(pp)_{ij} \right) \ldots \text{Equation 1}$$

$$CWR_{PH} = \sum_i \sum_k \left(w(ph)_{ik} \times cwr(ph)_{ik} \right) \ldots \text{Equation 2}$$

$$CWR_{SV} = \sum_i \left(w(sv)_i \times cwr(sv)_i \right) \ldots \text{Equation 3}$$

$$CWR_{UR} = \sum_i \left(w(ur)_i \times agg(ur)_i \right) \ldots \text{Equation 4}$$

In the above

i	is the index of the focus passenger vehicle market group (4WD, L, M, etc)
j	is the index of the colliding vehicle market group (4WD, L, M, etc)
k	is the index of the colliding heavy vehicle class (Artic, Rigid, Bus)
$w(xx)_{ij}$	is the proportion of crashes of type xx involving market group *i* colliding with market group *j* (or heavy vehicle class *k*) where relevant.
$cwr(xx)_{ij}$	is the crashworthiness of a vehicle from market group *i* in crash type xx when colliding with vehicle market group *j* (or heavy vehicle class *k*) where relevant.
$agg(ur)_i$	is the aggressivity of vehicle from market group *i* towards unprotected road users
CWR_{xx}	is the average crashworthiness or aggressivity in crash type xx

The final total safety index is simply a weighted average of the estimates of average crashworthiness or aggressivity for each crash type weighted by the proportionate occurrence of each crash. Equation 5 gives the formal definition of the final index.

$$TSI = \sum_c \left(w(tsi)_c \times CWR_c \right) \ldots \text{Equation 5}$$

where

c	is the crash type index (pp, ph, sv, ur)
$w(tsi)$	is the proportion of crashes of type *c* from Table 1
CWR_C	is the weighted average crashworthiness or aggressivity for crash type *c*.

The Baseline Scenario

For the purposes of comparing the effect on the total safety index (TSI) from making changes in the fleet composition, it was necessary to calculate a baseline level of the TSI from a baseline set of input conditions. The conditions for the baseline scenario represented the average crashworthiness and aggressivity by market group and crash proportions during the year 2000 derived from all police reported crashes in Victoria, New South Wales, Queensland and Western Australia in that year. The baseline TSI computed for these conditions is given in Table 1 and equals 8.29%. This TSI is a measure of the average probability of death or serious injury to drivers of light passenger vehicle or unprotected road users involved in crashes with light passenger vehicles given involvement in a crash where at least one vehicle is towed from the scene or someone is injured.

Table 1: *Baseline Total Safety Index and its Components*

Crash Type (c)	Crash Weight $w(tsi)_c$	Component Index CWR_c
Vehicle to Vehicle (pp)	45.33%	2.24%
Vehicle to Heavy Vehicle (ph)	16.00%	4.71%
Single Vehicle (sv)	28.93%	11.22%
Unprotected Road Users (ur)	9.74%	33.62%
Baseline TSI		**8.29%**

Change Scenario Consideration

After defining the total safety of the fleet, the aim of the study was to identify how changes in the mix of vehicles in the fleet by market group affect the TSI. This is readily achieved using the defined model through altering the weights associated with each market group in the component index measures of average crashworthiness or aggressivity given by Equations 1 to 4 ($w(pp)_{ij}$, $w(ph)_{ik}$, $w(sv)_i$, and $w(ur)_i$). The only restriction on altering the weights is that they add to unity for each component index. The effects of crashworthiness changes on the TSI can be investigated in a similar way by altering the crashworthiness estimates by vehicle market group and collision partner, where appropriate, in each of the component index measures.

APPICATION OF THE MODEL

Historical Effects and Effects of Likely Future Trends

The first scenario considers the impact on the total safety index of historical changes in the vehicle fleet mix since 1990 and the impact of the most likely projected changes in the vehicle fleet mix until 2010. The models used to project vehicle fleet mix beyond existing data are described in detail in Oxley et al, (2003). Changes in the proportion of vehicles in each market group both historically and predicted by Oxley et al (2003) have been translated into changes in the weighting factors in the crash type component index measures ($w(pp)_{ij}$, $w(ph)_{ik}$, $w(sv)_i$, and $w(ur)_i$). The resulting estimates of the total safety index are shown in Table 2 below along with the crash type component index measures from which each is derived.

Table 2: *Total Safety Index Based On Past and Predicted Future Fleet Mix.*

Crash Type	1990 Fleet Safety	1995 Fleet Safety	2000 Fleet Safety	2010 Fleet Safety
Vehicle to Vehicle	2.23	2.21	2.22	2.21
Vehicle to Heavy Vehicle	4.48	4.54	4.67	5.00
Single Vehicle	11.32	11.12	11.05	11.04
Unprotected Road Users	35.33	35.29	35.00	34.65
TSI	**8.44**	**8.38**	**8.36**	**8.37**

The above estimates represent changes in total vehicle fleet safety that has been influenced only by changes in vehicle fleet mix by market group. They do not reflect general improvements in vehicle safety over time, such as those brought about by general safety improvement in cars. Further, they do not reflect changes in buyer selection of more or less safe cars over time, a factor that has been argued by Newstead and Cameron (2001) to have lead to reduced levels of safety in Australian small cars over the 1990s.

Despite what appear to have been major shifts in the composition of the Australian vehicle fleet over the last 10 years, Table 2 shows that this has had little impact on the total safety of the vehicle fleet. The estimates of the total safety index for each of the years under examination indicate that average fleet safety has actually improved slightly in the last 10 years due to market group composition changes. It also indicates that the total safety index will remain fairly steady due to this influence based on the most likely scenario of change until 2010.

Extreme Scenarios

<u>Homogeneous Fleet</u>

The scenarios presented below consider the case in which the passenger vehicle fleet is homogenised to only one vehicle market group. For example, passenger cars are restricted to being medium sized vehicles only. These fleet scenarios are the most extreme to be considered and are not likely to ever become a reality given the need for people to purchase different vehicle types to serve specific purposes. However, these scenarios define the boundaries of safety change that could be achieved through modification of the fleet composition in terms of market groups.

Under this scenario, all crash types involve only one market group. This is reflected in the calculation of the total safety index by setting the weights in the component crash indexes to zero for all but the single market group of focus. The remaining non-zero weights are scaled to sum to unity for each crash type. The resulting TSI estimates are detailed in Table 3 for a homogeneous vehicle fleet of each market group in turn.

Table 3: *Total Safety Index Values base on Various Homogeneous Fleet Scenarios.*

Crash Type	Baseline	4WD Vehicles Only	Commercial Vehicles Only	Large Vehicles Only	Luxury Vehicles Only	Medium Vehicles Only	Pass. Vans Only	Small Vehicles Only	Sports Vehicles Only
Vehicle-to-Vehicle	2.24	2.31	3.01	2.16	1.66	1.96	4.96[a]	2.06	1.82
Vehicle-to-Heavy Vehicle	4.70	3.25	4.50	4.55	3.30	5.50	5.20	5.75	4.60
Single Vehicle	11.22	14.19	12.44	10.06	10.17	11.42	13.21	11.65	10.95
Unprotected Road Users	33.62	38.67	36.94	32.25	34.96	33.21	36.43	34.48	34.15
TSI	**8.29**	**9.44**	**9.28**	**7.76**	**7.63**	**8.31**	**10.45**	**8.58**	**8.06**

The results in Table 3 indicate that, if the fleet comprised only luxury vehicles, the TSI would fall to 7.63, an improvement of around 9% on the baseline standard. A vehicle fleet comprising of large vehicles only also improves the TSI to 7.76 or about 7% in comparison to the baseline estimate. In contrast, a vehicle fleet comprised solely of passenger vans, 4WDs or commercial vehicles would see the overall TSI become worse by 25%, 13% and 11% respectively in comparison to the baseline standard.

Removal of Single Market Group

In order to examine the relative effect of each market group on the total safety of the current vehicle fleet, the scenarios presented below remove a single market group from the analysis. The crashes that would be expected to involve this market group are then transferred to other market groups in a proportionately representative mix of vehicles from the remaining market groups replaced crashes involving the eliminated market group. In terms of the market group weights in Equations 1 to 4, this corresponds to setting the weights for the eliminated market group to zero and then rescaling the remaining weights to sum to unity. Table 4 shows the TSI values calculated for these scenarios along with the crash component indices.

Table 4 demonstrates that the removal of small vehicles from the vehicle fleet would result in the largest expected improvement (reduction) in the TSI compared to the base scenario. The estimated improvement is about 8%. This suggests that the presence of small cars in the vehicle fleet reduces the overall safety of the fleet. In contrast, the removal of sports cars from the vehicle fleet increases the TSI by the greatest amount, although the increase (representing a decrease in overall safety) is only 6%. Examination of the component crash indices shows this is a result of poorer average injury outcomes in crashes with heavy vehicles and in single vehicle crashes. The complete removal of passenger vans from the vehicle fleet also worsens the TSI, again through worsening single vehicle and heavy vehicle crash outcomes. The maximum variation in the TSI from the baseline standard is a 9% improvement through the removal of small cars. Results relating to the sports car and passenger van market groups should be interpreted with care given the relatively small number of distinct vehicle models in Newstead et al (2004) contributing to their estimated average crashworthiness.

Table 4: *Total Safety Index Resulting From Removal of a Single Market Group and Replacement with a Proportionate Mix of the Remaining Market Groups.*

Crash Type	Baseline	4WD Vehicles Removed	Commercial Vehicles Removed	Large Vehicles Removed	Luxury Vehicles Removed	Medium Vehicles Removed	PV Vehicles Removed	Small Vehicles Removed	Sports Vehicles Removed
Vehicle to Vehicle	2.24	2.23	2.22	2.21	2.27	2.24	2.23	2.22	2.22
Vehicle to Heavy Vehicle	4.70	4.98	4.79	3.46	4.76	4.59	5.05	3.85	5.24
Single Vehicle	11.22	10.92	11.13	12.03	11.25	11.19	12.56	9.49	12.71
Unprotected Road Users	33.62	33.44	33.50	34.51	33.57	33.74	33.54	33.34	33.62
TSI	**8.29**	**8.22**	**8.26**	**8.40**	**8.32**	**8.27**	**8.72**	**7.62**	**8.80**

Safest Vehicle in Market Group

The extreme scenarios involving either a homogeneous fleet or the complete removal of market groups is unlikely to ever occur in reality. They are also based on keeping the mix of vehicles with respect to safety performance constant within each market. The following scenarios consider perhaps more realistic goals for fleet composition in which drivers use only the safest vehicle in the market group of their choice. Scenarios for defining the safest vehicle within each market group are examined in two ways.

Using the first method, the hypothetical best vehicle in each market group is defined by identifying individually the best crashworthiness and aggressivity ratings amongst all vehicles in a market group rated by Newstead et al (2003). These ratings need not be associated with the same vehicle. Indeed, it is likely that the vehicle selected in each market group with the best crashworthiness rating will not be the same as that selected with best aggressivity rating. The crashworthiness and aggressivity estimates by market group for each of the four crash types making up the TSI, given by Equations 1 to 4, are adjusted by the proportional difference between the average crashworthiness or aggressivity of the market group and the best performing vehicle in that market group. This scenario does not represent what is possible given vehicles necessarily currently available on the market. Rather it represents, hypothetically, what could be achieved if the design aspects to produce best possible crashworthiness and aggressivity within a market group were included in all vehicles in the market group.

The second method is similar to the first in execution except it identifies the best vehicle in each market group based on the best combination of crashworthiness and aggressivity exhibited in the one vehicle. In contrast to the hypothetical scenario considered above, this scenario is based on vehicles that already exist in the fleet and it is certain the safety benefit of this scenario could be achieved in practice.

The resulting TSIs from the two best in market group scenarios are presented in Table 5 along with the component crash indices.

Table 5: *TSI Resulting From the Use of the Hypothetical and Existing Safest Vehicle in Each Market Group Only.*

Crash type	**Baseline**	**Hypothetical Safest Vehicle**	**Existing Safest Vehicle**
Vehicle to Vehicle	2.24	0.91	1.38
Vehicle to Heavy Vehicle	4.70	2.72	3.36
Single Vehicle	11.22	6.62	7.98
Unprotected Road Users	33.62	23.67	28.20
TSI	**8.29**	**5.07**	**6.22**

It is clear that significant improvements in total fleet safety could be achieved were all drivers to drive the safest (as measured by combined crashworthiness and aggressivity) currently available vehicle in the market group in which their current vehicle is classified. Further improvements would be generated if all vehicles incorporated within a single design aspects that produce the best currently available crashworthiness and aggressivity in the market group. If all vehicles in each market group performed as well as the current existing benchmark vehicle in the market group (Existing Safest Vehicle), an improvement of around 26% in the total fleet safety index would result. If each vehicle in each market group met the individual benchmarks for crashworthiness and aggressivity (Hypothetical Safety Vehicle), an improvement of 40% in the total fleet safety index would result.

DISCUSSION

This study has demonstrated the development of a model to estimate the effects of fleet mix changes on the total average safety of the light passenger vehicle fleet. The output of the model is the Total Safety Index (TSI) which measures the average probability of death or serious injury amongst drivers or unprotected road users in crashes involving light passenger vehicles.

Of particular interest was using the model to examine the effect of actual changes in the vehicle fleet over the decade leading up to 2000 and changes in the vehicle fleet expected to occur over the following ten years. These scenarios demonstrate that there has been and is unlikely to be significant improvements or deterioration in the TSI as a result of fleet mix changes. During the period from 1990 to 2000 the TSI fell by around 1% as a result of changes in the mix of the vehicle fleet, a marginal improvement in average injury outcome. However, it is estimated that over the following ten-year period the TSI will remain largely uninfluenced by vehicle fleet mix change. This result suggests that any goals for improvements in the safety of the passenger fleet aimed for in the future will have to come entirely from general improvements in crashworthiness and aggressivity of new vehicles entering the Australian fleet unless the mix can be changed from that predicted.

Because of the relative static nature of fleet mix safety effects in historical and likely future Australian fleet mix trends, it was also of interest to consider other scenarios that might lead to dramatic improvements or worsening of the TSI. The extreme fleet mix change scenarios considered were useful for determining boundaries on safety changes as measured by the TSI resulting from fleet mix changes. Whilst a number of the scenarios considered were not realistic and are unlikely to ever occur in practice, they provide the parameters within which more realistic changes can be examined.

Of interest in this context are the scenarios considering homogeneous fleets. The largest increase in the TSI, indicating worsening injury outcome, occurred when passenger vans were the only passenger vehicle in use (a TSI of 10.45 compared to the baseline TSI of 8.29). In contrast, the situation in which only luxury vehicles were available would generate the greatest improvement in overall fleet safety use, with a TSI of 7.63. The TSI for a fleet comprised only of large cars was close to the figure for luxury vehicles at 7.76. This result suggests that large vehicles provide the optimum balance of safety between crashworthiness and aggressivity in the mix of the four major crash types represented in the Australian crash population. The result shows that the maximum gain that could be achieved through fleet mix changes is around a 10% improvement in the TSI whilst the potential loss could be up to 25%.

The scenarios considered in which a single vehicle market group is removed and replaced by either a proportionate mix of the remaining market groups or one particular market group provide information on the relative contribution of individual market groups to current safety levels. The contribution of both small and 4WD vehicles is of particular interest given the increasing trend towards the purchase of vehicles from these two market groups. The removal of either of these groups from the vehicle fleet and their replacement by a proportionate mix of the remaining market groups is estimated to improve overall fleet safety in comparison to the current situation. However, removal of small cars was estimated to produce much greater gains than removal of 4WD vehicles.

Scenarios where single market groups were replaced with other market groups similar in functionality generally related in smaller safety losses or gains as measured by the TSI. For example a particularly relevant scenario is replacing all large cars with 4WDs. This takes the current trend to increased purchase of 4WDs in preference to large cars to the extreme. If this were to happen in practice, there would be an increase in the TSI from 8.29 (base scenario) to 9.01, an increase of about 9%. It is unlikely all large cars would ever be replaced by 4WDs, however, movements in that direction would result in reductions in overall fleet safety to a degree proportionate to the movement but overall fleet safety would not fall further than estimated in the extreme case of complete replacement. It is interesting to note, however, that the large increase in 4WD sales in the late 1990s is not reflected in the same increase in their representation in the crash population (see Figure 1). This suggests that whilst sales have grown, either these types of vehicles are being driven particularly safely or their exposure has not increased proportionately. The latter is considered more likely although further research would be necessary to establish this. The lack of increase in 4WD crash representation also explains why this vehicle class has not had the expected effects on historical or predicted future trends.

The increases and decreases in overall fleet safety discussed above generally affect total fleet safety by less than one death or serious injury per 100 crash involvements. In reality any potential improvement in total fleet safety due to the changes identified are likely to be less profound as the changes in the fleet mix will not be as extreme or complete as in the scenarios considered. Of the scenarios considered, analysis demonstrates that adopting a best in market group approach would lead to the greatest improvement in the TSI. Currently, great variability exists in the crashworthiness and aggressivity estimates of vehicles within each of the market groups. If each vehicle had a crashworthiness and aggressivity ratings equivalent to the currently available best vehicle in its market group, total safety could be improved by up to 26% from the current level. This improvement in TSI from 8.29 to 6.22 is in excess of two driver deaths or serious injuries per 100 crash involvements and suggests that the promotion of safety as a key determinant of vehicle choice and subsequent changes in buyer behaviour could lead to the most significant improvements in total fleet safety. The TSI could be further improved to 5.07, or 40% from the current situation, all vehicles incorporate design aspects that produce the best currently available crashworthiness and aggressivity within a market group. These improvements are based on currently available designs and safety features. Further gains in vehicle design and safety specification will further increase the estimated improvement in the TSI. Further regulation of vehicle safety standards and increased emphasis on safe choices in vehicle purchase through mechanisms like consumer information programs can help the vehicle fleet move towards these targets.

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