The Effect of Decreases in Vehicle Weight on Injury Crash Rates

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EXECUTIVE SUMMARY

This study was conducted as a part of the effort by the National Highway Traffic Safety Administration (NHTSA) to study the effect of changes in vehicle size on the crashes, injuries, and fatalities of passenger car and light truck occupants. This study focuses on the effect on fatal and incapacitating injuries resulting from a reduction of one hundred pounds in vehicle weight.

NHTSA's earlier work in this area, *A Collection of Recent Analyses of Vehicle Weight and Safety* (DOT HS-807 677, May 1991), examined the effect of a 1,000 pound reduction in the average weight of new passenger cars on occupant fatalities and injuries. The 1991 study estimated that the reduction of the average weight of passenger cars from 3,700 pounds (in 1970) to 2,700 pounds (in 1982) resulted in increases of approximately 2,000 fatalities and 20,000 serious injuries each year. The large increase in rollover crashes contributed the most to these increases.

This analysis estimates the effect of a one hundred (100) pound reduction in average vehicle weight on the per crash rates of incapacitating injury to drivers. In the analysis, three "scenarios" were considered: (1) the effect of the 100 pound reduction on light trucks and vans (LTVs), with the weight of passenger cars (PCs) unchanged; (2) the effect of the 100 pound reduction on PCs, with the weight of LTVs unchanged; and (3) the effect of the 100 pound reduction on all passenger vehicles.

Data from Illinois (1990-1992) and Florida (1991-1993) were used. Using the KABCO injury scale, data from these states on fatal injuries (K) plus incapacitating injuries (A) for crash involved drivers were analyzed. K+A injuries, while including the most severe of all injuries, typically include many injuries that could be considered minor. The analysis focused on the crash experience of model year 1985-93 passenger vehicles. The effect of the three scenarios on K+A injuries to drivers in crashes of passenger vehicles with fixed objects, with heavy trucks, and with other passenger vehicles were examined. For two-vehicle crashes, drivers of both vehicles were included in the analysis. The analysis controlled for driver age and a surrogate measure of travel speed.

The estimated increases in the driver incapacitating injury rates resulting from the 100 pound reduction ranged from 1.5 percent for LTVs in crashes involving fixed objects to 5.9 percent for LTVs in crashes with PCs with the weight unchanged. For crashes involving PCs with LTVs, the analysis indicated the weight reduction to one type of passenger vehicle (either the PCs or the LTVs, scenarios 1 and 2) had a small beneficial effect for the vehicles that were not reduced. In other words, occupants of PCs fared better in crashes with LTVs when the LTVs were reduced by 100 pounds; and conversely, occupants of LTVs fared better in crashes with PCs when the PCs were reduced by 100 pounds.

For the three scenarios, the following findings were noted using the estimated percent increases in driver incapacitating injury rates and extrapolated to all occupants:

- A 100-pound reduction in the average weight of LTVs (with PCs unchanged) would result in an estimated increase of 1,795 incapacitating injuries.

- A 100-pound reduction in the average weight of PCs (with LTVs unchanged) would result in an estimated increase of 8,804 incapacitating injuries.

- A 100-pound reduction in the average weight of all passenger vehicles (both PCs and LTVs) would result in an estimated increase of 10,543 incapacitating injuries.

These results are considered consistent with the results from the 1991 NHTSA study.

INTRODUCTION

In 1991, NHTSA published the results of several studies of this issue in *A Collection of Recent Analyses of Vehicle Weight and Safety* (Klein, et al; DOT-HS-807 677; May 1991). The 1991 NHTSA study examined the effect of a reduction in the average weight of passenger cars by 1,000 pounds, i.e., from 3,700 pounds in 1970 to 2,700 pounds in 1982, on the frequency and severity of crash risk. Klein, et al. found that the reduction of the average weight of passenger cars (PCs) by 1,000 pounds was associated with an estimated increase of approximately 2,000 fatalities and 20,000 serious injuries each year. The 1991 study contained the findings from an analysis of the impact of the weight reduction for PCs involved in four crash types: rollovers, collisions with fixed objects, collisions with heavy trucks, and two-car collisions. A relatively large increase in rollover fatalities was found associated with the PC weight reduction. Smaller increases in serious injuries were found for the collisions with fixed objects and with heavy trucks. Finally, for two-car collisions, a significant increase in serious injuries was found.

It was considered timely to reexamine this issue for several reasons. The 1991 NHTSA study focused on the safety impact of weight reductions for PCs. With the increasing numbers of light trucks and vans (LTVs) already in and continuing to enter the passenger vehicle fleet, an assessment of the safety impact of a weight reduction for LTVs is of great interest. The earlier study found the largest increases in rollover crashes occurred with the reduction in the average passenger car weight. The use of safety belts is known to be particularly effective in preventing fatalities in rollover crashes. With belt use continuing to increase, it is important to determine if the large increases in fatal rollover crashes will continue to occur as the average weight of passenger vehicles is reduced.

This study examines the safety impact of a weight reduction on incapacitating injuries for the new PC fleet using the latest available State data and extends the analysis to include estimates for the safety impact associated with a weight reduction for the new LTV fleet. The analysis and findings described in this study are one portion of NHTSA's analytical efforts to assess the safety impact of a weight reduction. In addition to the findings reported in this study, NHTSA plans to publish the results of similar studies of the safety impact of a weight reduction on fatalities and AIS $\geq$ 2 injuries.

DATA

Data from NHTSA's State Data Program[1] for selected States were used to analyze the changes in the rate of driver incapacitating injury that would be associated with a reduction in vehicle weight. The states used in the analysis were Illinois (data for the calendar years 1990-1992) and Florida (data for the calendar years 1991-1993). The three most recent years of data available for each of the two states were used. Florida and Illinois were selected for use in the analysis, based on two "criteria": both states experience a considerable number of crashes each year, thereby yielding large sample sizes and both states collect and record vehicle identification numbers (VINs) for crash involved vehicles. This second criterion was particularly important, as the VINs were essential to obtaining the weight of each vehicle used in the analysis.[2] Finally, the crash data used was restricted to those crashes involving vehicles of model years 1985-93.

The measure of safety that was used for this analysis was the per crash rate of driver incapacitating (K+A) injury using the KABCO injury coding scheme in which K=fatal injury, A=incapacitating injury,
B=non-incapacitating injury and C=possible injury. K+A injuries, while including the most severe of all injuries, typically include many injuries that could be considered minor.

Three analytical "scenarios" for crashes with driver incapacitating injury were considered: (1) the effect of the 100 pound reduction on LTVs, with the weight of PCs unchanged; (2) the effect of the 100 pound reduction on PCs, with the weight of the LTVs unchanged; and (3) the effect of the 100 pound reduction on all passenger vehicles, i. e., both PCs and LTVs.

For each of the analytical scenarios described above, changes in the rate of driver incapacitating injury were analyzed for four crash types. The crash types studied were:

- crashes between the vehicle and a fixed object;
- crashes between the vehicle and a heavy truck;
- crashes between the vehicle and a PC; and
- crashes between the vehicle and an LTV.

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[1] For more information, refer to NHTSA's brochure titled *State Data Program*, National Center for Statistics and Analysis, NRD-31, 400 7th Street, S. W., Washington DC 20590.

[2] Determining vehicle weights and accurately classifying vehicles as PC or LTV is not a trivial exercise. Dr. Charles J. Kahane of NHTSA's Plans and Policy developed programming code to accomplish this task using VINs.

The analysis focused on these four crash types as these crashes are those for which changes in the vehicle's weight could be expected to be related to changes in the risk of driver incapacitating injury.

This analytical effort focused on vehicle crashworthiness, i.e., injury rates conditioned on the occurrence of a crash. Vehicle crash avoidance was not addressed in this study due to the greater inherent difficulty of the problem but also because reducing the average weight of the passenger vehicle fleet might well result in a change in driving patterns that may be associated with smaller cars. Also, no attempt was made to address possible environmental, economic, or other questions and issues that may be part of the picture involving a reduction in average vehicle weight. Standard errors are calculated for these estimates of per crash driver injury rates and, in general, they suggest that the estimates are very close.

Driver incapacitating injury, rather than injury to any occupant, was used as the measure of safety impact as state police accident reports (PARs) often do not list uninjured occupants. If one assumes that the effect of change in vehicle weight is similar on all occupants, estimates based on analyzing the safety impact of reductions in vehicle weight on driver injury can be extended to estimating the safety impact for all occupant injuries.

METHODOLOGY

Logistic regression was chosen as the analytical method for measuring the effect of changes in vehicle weight on the odds of driver incapacitating injury. Logistic regression has been used successfully in other NHTSA studies, including NHTSA's 1991 study on vehicle weight and safety .[3], [4] Logistic regression is a statistical methodology that is used in analytical situations in which the outcome is dichotomous.[5]

Using data from Florida and Illinois, a logistic regression model was estimated for each of the four crash types and three scenarios. Each model was estimated using observations corresponding to a crash-involved vehicle with a K or A injury to the driver as the positive

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[3] Hertz, Ellen, Ph. D., J. Hilton, and D. M. Johnson. *An Analysis of the Crash Experience of Light Trucks Equipped with Antilock Braking Systems* (DOT HS-808 278, May 1995), and *An Analysis of the Crash Experience of Passenger Cars Equipped with Antilock Braking Systems* (DOT HS-808 279, May 1995), U. S. Department of Transportation.

[4] Klein, Terry M. *A Statistical Analysis of Vehicle Rollover Propensity and Vehicle Stability*, SAE Technical Paper Series 920584, The Society for Automotive Engineers, [1992].

[5] Hosmer, David W. and S. Lemeshow. *Applied Logistic Regression*. John Wiley & Sons. [1989]

response. For the crashes involving a PC and a fixed object, an LTV and a fixed object, a PC and a heavy truck and an LTV and a heavy truck , a logistic regression was modeled of the form:

$$\text{Logit (p)} = \text{CURBWT RURAL DRVAGE;} \tag{1}$$

where p is the probability of a positive response, CURBWT is the vehicle weight, RURAL is an indicator of whether the crash occurred in a rural vs. an urban area, and DRVAGE is an indicator variable representing the age of the crash-involved driver.

For the crashes involving a PC or an LTV with another PC or an LTV, two logistic regression models were estimated so that all possibilities would be accounted for. These models were of the form:

$$\text{Logit (p)} = \text{CURBWT OTHERWT RURAL DRVAGE} \tag{2a}$$

and

$$\text{Logit (p)} = \text{CURBWT DIFFWT RURAL DRVAGE} \tag{2b}$$

where

$$\text{DIFFWT} = \text{CURBWT} - \text{OTHERWT}.$$

In these logistic regression models, the coefficient of an independent variable represents the effect of a unit change in that variable on the log odds of a positive response, when the other independent variables in the model are held constant. As such, the coefficient of CURBWT in (2a) measures the effect on the PC (or LTV) driver who hits an LTV (or PC) when only PCs (or LTVs) are reduced but not the other vehicle. CURBWT in (2a), therefore, measures the safety impact on driver injury rates for the drivers of the vehicles with reduced weight when involved in a crash with a vehicle without the weight reduction. The coefficient of CURBWT in (2b) measures the effect on either the PC or LTV involved in a crash with a PC or LTV and the weight of both vehicles are reduced.   The coefficient of OTHERWT in (2a) measures the effect on the case vehicle when only the other vehicle is reduced, that is, the effect on the injury rates of PC (or LTV) drivers who hit LTVs (or PCs) under the scenario that only LTVs (or PCs) are reduced. OTHERWT, therefore, measures the safety impact on driver injury rates for the drivers of the vehicle with the weight unchanged when in a crash with a vehicle with the weight reduction.

The variables RURAL, a surrogate for the travel speed at the time of the crash, and DRVAGE were included in the models to account for the possibility that each may have an effect on injury probabilities and also could be associated with vehicle size, and therefore the vehicle's weight. Initially, the models were also estimated including a variable representing the sex of the driver. The final models were reestimated without including the sex of the driver, as the coefficient was not found to be significant in any of the models.

Ideally, it would have been desirable to include a variable representing seat belt use in the final models. The percentage of surviving crash victims reporting belt use in crashes, however, is typically greater than the percentage belt use observed for the general public (Hunter et al, 1988). As a result, a variable reflecting reported belt use in a crash would not be considered reliable. To minimize injuries resulting from lack of restraint use, ejected drivers were eliminated from the Florida data. Unfortunately, it was not possible to identify ejected persons in the Illinois data.

While data from two states were used in this analysis, it would be reasonable to expect that the effects of a weight reduction for PCs or LTVs should not differ dramatically from state to state. The results for the various models did not appear to contradict this expectation. Therefore, the coefficients of the variables of interest, CURBWT, OTHERWT and DIFFWT, were combined over the two states, using the method described in Fleiss (1981)[6]. This method also produces standard errors of the coefficients as well as their point estimates. The results are displayed in Table 1. WEIGHT1 is CURBWT from Models (1) and (2a). WEIGHT2 is CURBWT from Model (2b).

The values shown in Table 1 represent the change in the log of the odds of a positive response that would be caused by a unit gain in the specific independent variable, while holding all other independent variables constant. Vehicle weights were expressed in one hundred pound units. That means, for example, that the coefficient of CURBWT in Models 1 and 2 represents $\ln\{[p_1/(1-p_1)]/[p_0/(1-p_0)]\}$ where p_0 was the previous probability of incapacitating injury to the driver and p_1 is the new probability after the crash vehicle gains 100 pounds and nothing else is changed. If both values of p are small, then the ratio of the two values of 1-p is near 1 so that the relative odds is approximately equal to the relative risk, that is, p_1/p_0.

[6] For a thorough treatment on combining log odds ratios, consult Fleiss, Joseph L. *Statistical Methods for Rates and Proportions*, John Wiley & Sons, [1981].

TABLE 1
The Effects of Vehicle Weight * per Hundred Pounds
On the Log Odds of Driver K+A Injury
[Coefficients and Standard Errors]

Crash Type	WEIGHT1	Std. Error	WEIGHT2	Std. Error	OTHERWT	Std. Error
PCs & FOs	-0.037550	0.0031536	N/A		N/A	
PCs & HvyTrks	-0.034556	0.0041539	N/A		N/A	
LTVs & FOs	-0.015463	0.0045746	N/A		N/A	
LTVs & HvyTrks	-0.035766	0.010052	N/A		N/A	
PCs & PCs	-0.046725	0.0025908	-0.030389	0.0034553	0.016346	0.0023191
PCs & LTVs	-0.046926	0.0041734	-0.032713	0.0052250	0.014209	0.0031120
LTVs & PCs	-0.057388	0.0052408	-0.044581	0.0075698	0.012684	0.0054412
LTVs & LTVs	-0.052550	0.0076503	-0.031879	0.0099916	0.020946	0.0066007

FOs = Fixed Objects
HvyTrks = Heavy Trucks
* WEIGHT1 is CURBWT from Models (1) and (2a); WEIGHT2 is CURBWT from Model (2b).

The coefficients in Table 1 can be used to develop estimates of the impact on the annual numbers of occupant K+A injuries that would result from each scenario; since a small minority of crashes in each state data base involves K+A injuries, the relative risk for a 100 pound reduction is approximately exp(-coefficient) and the percentage change is 100{exp(-coefficient)-1}. The target populations of K+A injuries to which these estimated changes were applied are from the NHTSA General Estimates System (GES), 1993. In these calculations, the estimated change in injury probability for the driver is assumed to be the same for all occupants of the passenger vehicle.

Approximate confidence bounds for the expected injury changes can be derived using linear approximation: As stated, the expected change, Eprop, in the probability of getting injured in a given scenario is very nearly exp(-c)-1, where c is the relevant coefficient. Then Var(Eprop) is approximately exp(-2c)*std(c)*std(c). Also, if Noinjs is the target population, then the expected change in the number of injuries is Eprop*Noinjs. The linear approximation for its variance is

$$\text{Var(Expected Change)} =\sim \text{Var(Eprop)}*\text{Noinjs}^2 + \text{Var(Noinjs)}*\text{Eprop}^2$$

The standard error of c is obtained from the logistic regression. The variance of Noinjs is obtained from the formula described in the GES. The variances for the estimates under each scenario are summed to obtain variances for the total changes.

These results are displayed in Tables 2a-2c.

TABLE 2a
Impact of Reducing LTVs by 100 Pounds [With PCs Unchanged]
On the Incidence of Occupant Incapacitating (K+A) Injury

	K+A Injuries (GES, 1993).	Percent Increase	Net Change
LTV Occupants in FO Crashes	26,544	1.6	414
LTV Occupants in HvyTrk Crashes	3,966	3.6	144
LTV Occupants in Crashes w/ PCs	25,642	5.9	1,515
PC Occupants in Crashes w/LTVs	48,546	-1.4	-685
LTV Occupants in Crashes w/LTVs	12,550	3.2	407
Total	117,248	1.5	1,795 Confidence bounds based on $\pm 2\sigma$ 1,131 - 2,459

TABLE 2b
Impact of Reducing the PCs by 100 Pounds [With LTVs Unchanged]
On the Incidence of Occupant K+A Injury

	K+A Injuries (GES, 1993).	Percent Increase	Net Change
PC Occupants in Crashes w/FOs	68,703	3.8	2,629
PC Occupants in Crashes w/HvyTrks	14,009	3.5	493
PC Occupants in Crashes w/LTVs	48,546	4.8	2,332
LTV Occupants in Crashes w/PCs	25,642	-1.3	- 323
PC Occupants in Crashes w/PCs	119,039	3.1	3,673
Total	275,939	3.2	8,804 Confidence bounds based on ± 2σ 7,438 - 10,170

TABLE 2c
Impact of Reducing All Passenger Vehicles [Both PCs and LTVs] by 100 Pounds
On the Incidence of Occupant K+A Injury

	K+A Injuries (GES, 1993).	Percent Increase	Net Change
PC Occupants in Crashes w/ FOs	68,703	3.8	2,629
PC Occupants in Crashes w/HvyTrks	14,009	3.5	493
LTV Occupants in Crashes w/FOs	26,544	1.6	414
LTV Occupants in Crashes w/HvyTrks	3,966	3.6	144
LTV Occupants in Crashes w/LTVs	12,550	3.2	407
PC Occupants in Crashes w/PCs	119,039	3.1	3,673
PC Occupants in Crashes w/LTVs	48,546	3.3	1,614
LTV Occupants in Crashes w/PCs	25,642	4.6	1,169
Total	318,999	3.3	10,543 Confidence bounds based on $\pm 2\sigma$ 9,071 - 12,015

DISCUSSION

The above tables present estimates of the safety impact on driver incapacitating injury rates, and, by extension, occupant incapacitating injury rates, for each of the three scenarios involving the reduction of average vehicle weight. Comparing the point estimates of the coefficients with their standard errors in Table 1 indicates that, within the assumptions of the model, the estimates of the percent changes in injury rates are very accurate. The “target” populations, that is, the class of injured occupants that could be affected under each scenario, are from NHTSA’s General Estimates System. The estimates of net change in Tables 2a-2c are, therefore, reliable, subject to the assumptions under which they were derived.

Two caveats are worth noting. Interestingly, they appear to point in opposite directions in terms of estimating the injuries that could occur. First, the most obvious limitation is that the vehicles considered were, necessarily, vehicles that have already been designed and manufactured. The implicit assumption becomes that a typical 2,500 pound vehicle becomes similar to a typical 2,400 pound vehicle in the same data base. However, engineering advances might very well develop lighter vehicles with some of the advantages of present heavy vehicles. Second, in this analysis, primary rollovers were excluded. Obviously, when a rollover takes place it is always very dangerous. Any discussion of the relative chances of being injured in a rollover as a function of vehicle weight would be remiss if the discussion did not include any treatment of the chances of becoming involved in a rollover crash, as a function of vehicle weight. This issue was not addressed.

These two caveats aside, the results from this analysis corroborates earlier NHTSA research, while illuminating the potential crashworthiness impact of reductions in vehicle weight.

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