AN ANALYSIS OF IMPROVEMENTS TO VEHICLE SAFETY AND THEIR CONTRIBUTION TO RECENT DECLINES IN FATALITIES AND INJURY RATES

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ABSTRACT

Recent vehicle safety technologies have saved lives, mitigated injuries, and, to some extent, reduced the occurrence of crashes. However there have been few, if any, studies that attempt to quantify how much safer a newer model year vehicle is than an older one, at least in any controlled fashion. This paper attempts such a quantification, and estimates the combined contribution of vehicle improvements to recent declines in fatalities and injury rates. Our analysis assesses the *combined impact* of safety improvements, and not the separate impacts of individual technologies.

INTRODUCTION AND MOTIVATING QUESTIONS

In this analysis, we take a step back, look at the crash data, and ask whether the data indicate improvements in the safety of newer vehicles, and if so, by how much. Rather than looking at the individual effects of particular technologies, we seek to understand the combined effect of vehicle improvements.

Some general questions motivate our study: Do newer vehicles better protect unbelted occupants, or just belted occupants? With Electronic Stability Control a relatively new technology, are we seeing improvements in avoiding rollovers yet? Are we seeing other improvements in crash avoidance? What are your chances of escaping a crash uninjured and by how much has this increased in newer vehicles? What about your chances of surviving a crash?

Our primary interest is in passenger vehicles (passenger cars, light trucks, and vans) and we shall limit the scope of our study to this vehicle type. That is, we do not investigate improvements to motorcycle safety, or large trucks. We shall refer to light trucks and vans collectively as *LTV*s.

DEFINITIONS OF KEY CONCEPTS

Crashworthiness

Given a type *c* of crashes (e.g. frontal crashes), a type *v* of vehicles (e.g. model year 2000 cars with a sober driver), a type *o* of occupants (e.g. belted 25-65 year-old women), and an injury threshold *z* (e.g. non-incapacitating injuries), we define *crashworthiness* to be the probability that an occupant of the given type in a vehicle of the given type in a crash of the given type sustains an injury no worse than the given threshold, i.e.:

P(Injury ≤ z | an occupant of type *o* is in a crash of type *c* in a vehicle of type *v*)

Crash Avoidance

Given a type of crashes *c* and vehicles *v*, we define the *crash avoidance* (*capacity*) to be the probability that a vehicle of the given type driven for 100,000 miles does not get into any crashes of the given type, i.e.:

P(no crashes of type *c* | a vehicle of type *v* travels 100,000 miles)

Assuming the distribution of crashes over miles driven is negative binomial, crash avoidance is related to the crash rate via

$$CA = (1 + 0.00001\ CR)^{-100{,}000} \qquad (1).$$

where *CA* denotes the crash avoidance of some type of vehicle v and crash *c* and *CR* denotes the analogous crash rate, i.e. the number of crashes of type *c* in 100,000 miles of driving a vehicle of type *v*. With crash avoidance defined using such a large number of miles (100,000), *CA* is also approximately equal to the value it would have if we assumed crashes were Poisson-distributed, namely e^{-CR}, where *e* denotes the base of the natural logarithm. (In the vehicle and crash types we consider, the difference will be at most 0.000001. We use a large number of miles in order to put crash avoidance in a range that is easier to interpret.)

DATA SOURCES

We shall use crash data from NHTSA's Fatality Analysis Reporting System (FARS) and General Estimates System (GES), mileage data from the U.S. Department of Transportation's National Household

Travel Survey (NHTS) and the Federal Highway Administration (FHWA), and vehicle registrations from R.L. Polk and Company's National Vehicle Population Profile.

We use FARS and GES files from the 2000-2008 crash years. Although 2009 files are available, we have not incorporated them in our study at this time.

ANALYSIS METHODS

In our study, we impute unknowns and compute raw estimates of crashworthiness and crash avoidance. We then develop statistical models for crash-worthiness and crash avoidance (computed with SAS), incorporating sampling and imputation error. We apply the models to assess safety improvements.

IMPUTATION

FARS provides multiple model-based imputations of driver alcohol. We impute unknown values for other FARS and GES variables with five hotdeck imputations, using the following donor cells.

Table1.
Imputation Donor Cells

Variable to Be Imputed	*Variables Defining the Donor Cells*
Whether a vehicle has a driver	Vehicle type, crash year
Vehicle type	Crash year
Occupant gender	Vehicle type, crash year
Occupant age category	Vehicle type, crash year
Driver alcohol involvement	Gender, age category
Seating position	Vehicle type, crash year
Injury severity (KABCO)	Crash type, restraint use
Vehicle impact area	Vehicle type, crash year
Vehicle model year	Vehicle type, crash year

These cells are admittedly coarse. It is beyond the objective of this paper to develop sophisticated imputation models.

RAW ESTIMATES

Crashworthiness

Computing raw estimates of crashworthiness is straightforward. For instance to compute the estimated likelihood that a belted 25-65 year-old woman in a rollover of a model year 2000 car with a sober driver sustains at worse a non-incapacitating injury, we compute A/B where B denotes the estimated number of belted 25-65 year old women in model year 2000 car rollovers with sober drivers and A denotes the estimated number among them that sustain at most a non-incapacitating injury. We compute A and B as Horvitz-Thompson estimates (i.e. weighted totals) on the dataset formed by combining the crashes in FARS with the non-fatal crashes in GES, using 1 for the sample weight of each FARS case.

The raw estimates indicate steady improvements in crashworthiness as a function of model year. In Figure 1, which presents the overall crashworthiness estimates for cars and LTVs, we recall that the KABCO scale is: O = uninjured, C = possible injury, B = non-incapacitating injury, A = incapacitating injury. Thus the green dots and stars in Figure 1 give the likelihood of escaping a crash uninjured, while the purple symbols plot the chance of experiencing at most a non-incapacitating injury, and the red give the chance of surviving a crash (which is quite high). The blue symbols are a bit more amorphous to interpret as they give the likelihood of escaping with only a "possible injury". This KABCO code is reserved for cases in which the police officer filling out the accident report is not sure whether the occupant was injured or not.

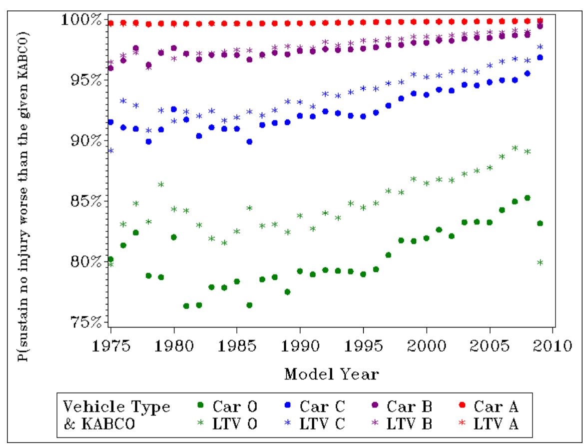

Figure 1. Raw Crashworthiness Estimates

Crash Avoidance

Computing crash avoidance is more complicated. Suppose for instance we wish to compute the estimated probability that a model year 2000 car driven 100,000 miles does not get into any frontal crashes, using data from crashes that occurred in 2008. Using Equation (1), we can estimate this quantity as $(1 + 0.00001\, CR)^{-100{,}000}$, where CR denotes the corresponding crash rate. We can estimate the number of frontal crashes of model year

2000 cars that occurred in calendar year 2008 as a Horvitz-Thompson estimate from our combined FARS-GES database.

We estimate the denominator of the crash rate (i.e. the collective number of miles driven by model year 2000 cars during 2008) using our NHTS, FHWA, and Polk data. Namely, we fit an exponential model, depicted in Figure 2, to the 2001 NHTS estimates of the annual miles driven by a car as a function of its age.

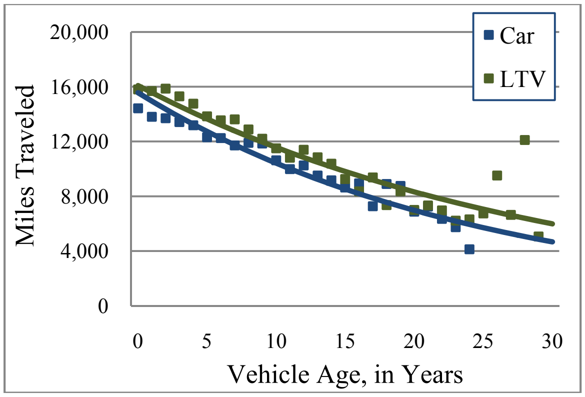

Figure 2. Exponential Models of the Miles a Vehicle Travels in a Year

We apply registration figures from Polk to estimate the collective vehicle miles driven by model year cars during 2008 and benchmark this to the FHWA estimate of car miles traveled in 2008. In total, the collective number of miles driven by model year 2000 cars during 2008 is estimated as

$$V\ M_{2000}R_{2000}/\sum_k M_k R_k \qquad (2).$$

where V denotes the FHWA estimate of car miles traveled in 2008, k ranges over model year, M_k denotes the miles driven by a car during the year in which it is 2008 – k years old as predicted by our NHTS model, and R_k denotes the number of model year k cars registered in 2008 from Polk.

Figure 3 depicts the raw crash avoidance estimates for cars and LTVs based on all crashes in 2000-2008. We don't expect the raw estimates to be tremendously accurate, as we lack mileage data on many of the factors that one would intuitively expect to contribute to crash avoidance, such as miles driven drunk, miles driven by drivers of various age or years of driving experience, and by drivers with a history of moving violations. Consequently we will be somewhat circumspect about interpreting our raw (or model estimates) of crash avoidance.

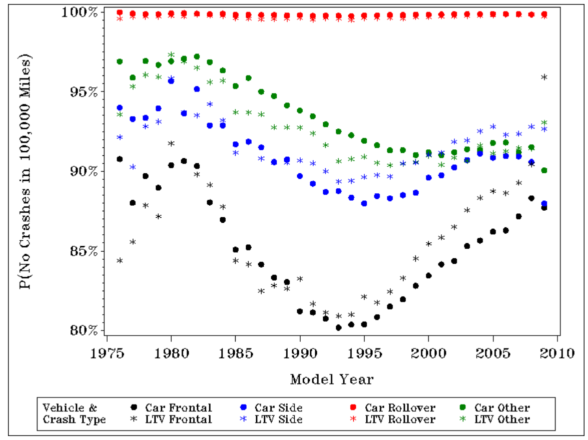

Figure 3. Raw Crash Avoidance Estimates

Indeed, the raw estimates of crash avoidance show a curious picture, with seeming declines in crash avoidance prior to model year 1995 and improvements thereafter. One wonders whether this curious pattern reflects some latent factors for which we do not have mileage data.

THE CRASH AVOIDANCE MODEL

We identified outliers and determined the effects to include in the model through exploratory data analysis (i.e., by examining plots of the raw crash avoidance estimates). Complete details of the model development can be found in (Glassbrenner, to appear), which also explains why our model is in terms of vehicle age instead of model year (which provide equivalent information in the presence of the calendar year in which the driving occurs). The final model has the form:

$$\log(\text{crash rate}) \sim \text{CY, CT, VT, VA, CT*VT, CT*VA, VA}^2\text{, CT*VA}^2\text{, VT*VA}^2 \qquad (3).$$

using the shorthand CY, CT, VT, and VA for the calendar year, crash type, vehicle type, and vehicle age (calendar year minus model year), respectively. Since we have five imputations of the crash data, we fit one negative binomial model of the form (3) to each imputation. (Although there are five models, we can also form a single crash avoidance model by averaging the predicted values from the five imputation-specific models. Thus we alternatively refer to the crash avoidance *model* or *models*, depending on the context.) Our model results reject the hypothesis that crashes are Poisson distributed over miles driven. (See (Glassbrenner, to appear).)

Figure 4 depicts the parameter estimates for the crash avoidance model. Using frontal crashes of model year 2000 cars in the calendar year 2000 as the baseline group, this figure depicts the parameter estimates, expressed as multiplicative effects on the crash rates. The crash rate in our baseline group is 0.15 (frontal) vehicle-crashes per 100,000 miles. The multiplicative effect of LTV is 0.91, meaning that the predicted frontal crash rate for model year 2000 LTVs in the year 2000 is (0.15)(0.91) = 0.14 vehicle-crashes per 100,000 miles. The multiplicative effects for the linear and quadratic vehicle age terms are 1.10 and 0.995, so the predicted crash rate for frontal crashes of model year 1998 LTVs in 2000 is $(0.15)(0.91)(1.10)^2(0.995)^4 = 0.17$. The parameter estimate for interaction between rollovers and LTVs is particularly large, indicating that the crash rate for LTV rollovers is more than twice that for car rollovers.

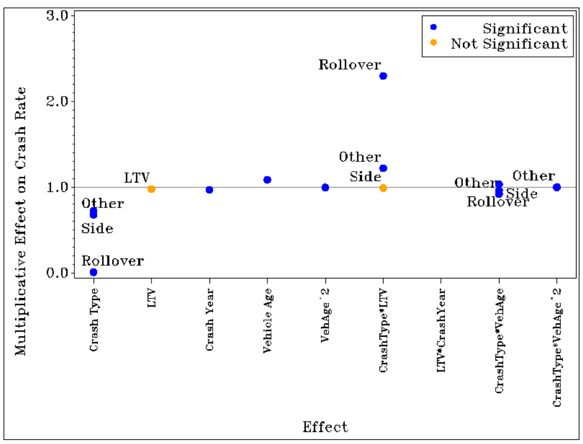

Figure 4. The Crash Avoidance Model Parameter Estimates

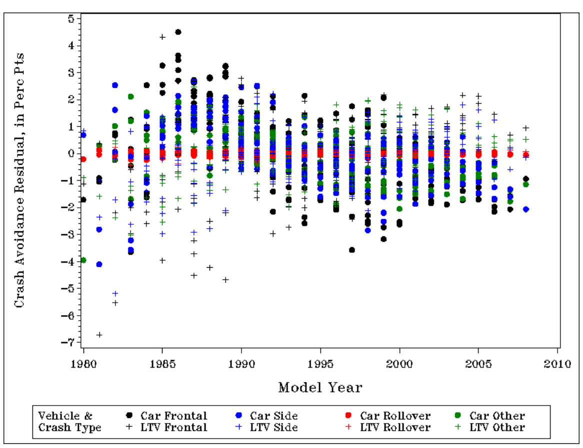

Figure 5. Crash Avoidance Model Residuals

The model's residuals indicate some possible unexplained variation (see Figure 5), perhaps reflecting effects that we could not incorporate in our model.

Plots of raw and fitted values also indicate improvements are possible (Figures 6 and 7), but such is beyond the scope of this paper.

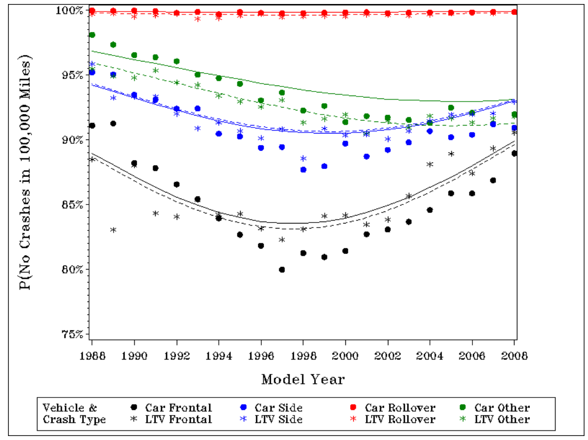

Figure 6. Crash Avoidance in the Calendar Year 2008 (Raw and Model Estimates)

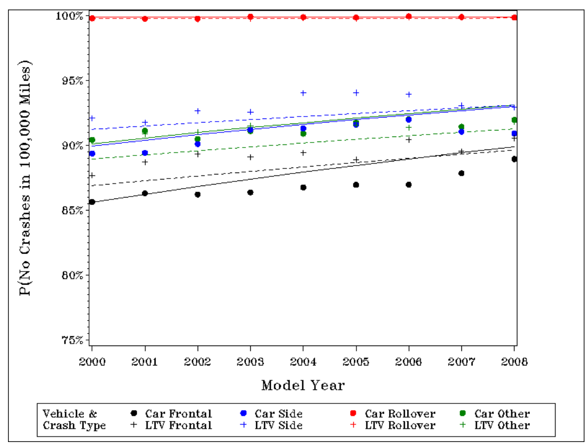

Figure 7. Crash Avoidance for Vehicles at Age 0 (Raw and Model Estimates)

Most of our model's parameter estimates have a relative error less than 20%, with less than 15% of the variance occurring between imputations. The parameters with more than 20% relative error are small (absolute value of the additive effect on the log crash rate being less than 0.1), when a larger relative error is understandable. Thus, our parameter estimates generally have low variability and perturbing the data via imputation yields generally similar parameter estimates, so there do not appear to be relationships among the effects.

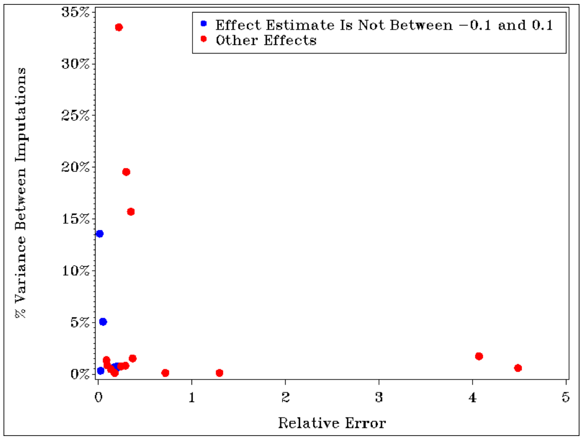

Figure 8. Crash Avoidance Model Variances

Overall our crash avoidance model could be improved somewhat but we proceed with our current model.

THE CRASHWORTHINESS MODEL

Complete details of the model development can be found in (Glassbrenner, to appear). In brief, we identified outliers and determined the model type through exploratory data analysis. We considered both generalized and cumulative logistic models. Our exploratory data analysis rejects both models in favor of one of the form:

$$\text{log-odds } P(\text{Injury} \le k) \sim \text{CT, VT, DA, RU, AC, G, CT*VT, CT*RU, DA*RU, MY, MY*CT, MY*VT, MY*DA, MY*RU, MY*AC, MY*CT*VT, MY*CT*RU} \quad \text{for } k = \text{O, C, B, A} \qquad (4).$$

Here we are using the additional shorthand MY, DA, RU, AC, and G for the model year, driver alcohol use, restraint use, (occupant) age category, and gender factors, respectively.

We note in particular that the change in the car-LTV composition of the vehicle fleet during in the 1990s should be accounted for by the inclusion of the MY*VT term.

Many of the crashworthiness predictions from this model look quite good (Figure 9), although some indicate that improvements are possible (Figure 10).

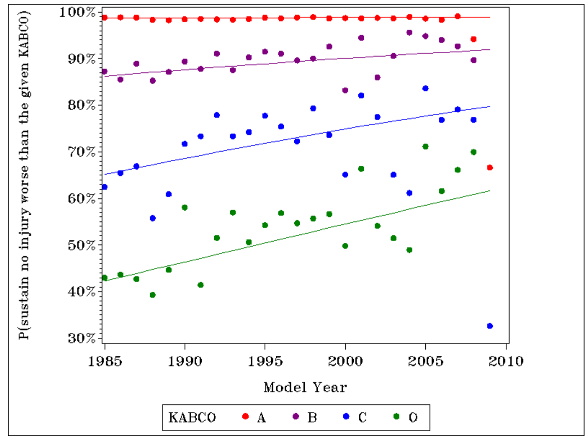

Figure 9. Crashworthiness for Unrestrained 25-65 Year Old Women in Frontal Car Crashes in 2000-2008 with Sober Drivers (Raw and Model Estimates)

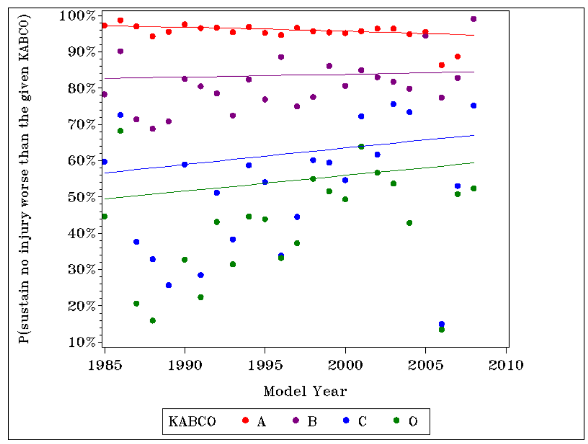

Figure 10. Crashworthiness for Unrestrained 14-24 Year Old Males in Frontal LTV Crashes with Alcohol-Involved Drivers in 2000-2008 (Raw and Model Estimates)

Figures 11 and 12 depict the parameter estimates for the crashworthiness model. Figure 11 depicts the parameter estimates for the effects that do not involve model year. Using unrestrained 25-65 year old women in model year 2000 cars with sober drivers in frontal crashes as the baseline group, Figure 11 plots the multiplicative effects on the odds of sustaining, at worst, a given level of injury. The baseline group's odds of sustaining an injury of at most KABCO *k* are: 1.4 for *k*= no injury (O), 3.2 for possible injury (C), 9.0 for non-incapacitating injury (B), and 89.4 for incapacitating injury (A).

For instance, restraint use improves the odds of a 25-65 year old woman surviving a frontal crash in a model year 2000 car more than eleven-fold (a multiplicative effect of 11.5), and this is statistically significant. Likewise restraint use improves the odds of such a woman escaping with at most a non-incapacitating injury by more than five-fold and her odds of escaping uninjured by more than four-fold. Restraint use is by far the dominant factor in your injury outcome regardless of your age, gender, type of vehicle, and type of crash.

The model indicates that all else being equal, men fare better than women, LTV occupants fare better than car occupants, and rollovers are worse than frontal crashes.

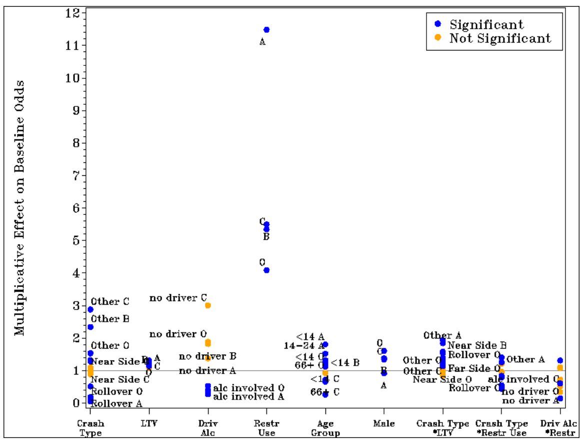

Figure 11. The Crashworthiness Model Parameter Estimates that Do Not Involve Model Year

Figure 12 depicts the parameter estimates for the effects that involve model year. Namely, it plots the multiplicative effect on the injury odds per unit increase in model year. In our baseline group, these multiplicative effects are: 1.039 for KABCO O, 1.036 for C, 1.028 for B, and 1.006 for A. That is, for unrestrained 25-65 year old women in frontal car crashes with sober drivers, being in a model year 2008 car instead of a model year 2000 car increases the odds of escaping uninjured by a factor of 1.039^8, or about 1.4.

Figure 12 indicates that the crashworthiness improvements in LTVs over the modeled period (model years 1985-2008) are not significantly different from those in cars.

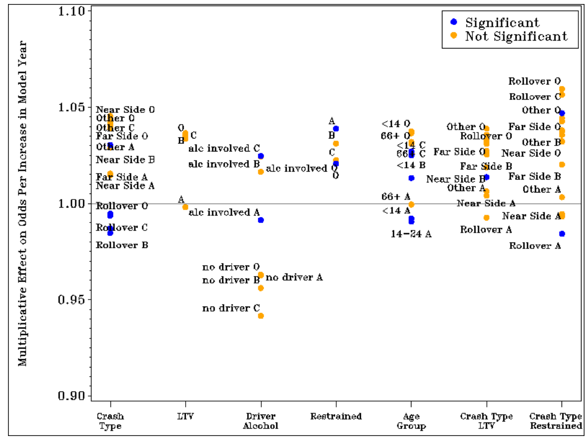

Figure 12. The Crashworthiness Model's Effects per Unit Increase in Model Year from Model Year 2000

The blue dots below the horizontal reference line in Figure 12 (e.g., for rollovers with KABCO level A) may at first appear to give reason for concern. (Although it is not clear from the point labels in Figure 12, the rollover estimates below the reference line are 0.995, 0.994, 0.985, and 0.987 for KABCO O, C, B, and A, respectively, and of these only the KABCO O estimate is not significant.) There are (at least) two reasons why such dots do not necessarily indicate decreased crashworthiness performance.

One possible reason has to do with improvements in crash avoidance. Rollovers might be distinct among crash types in that a rollover that is avoided (whether through Electronic Stability Control or other means) might often result in a crash of a different type (e.g., a frontal crash). In contrast, avoiding a frontal or side impact crash might usually mean avoiding crashing entirely. In improving crash avoidance for rollovers, the remaining rollover crashes may be more severe, leading to an appearance that vehicles may have become less rollover-crashworthy in some scenarios, when they may in fact be protecting us better.

Another reason is that other effects will counteract such an otherwise worrisome blue dot (below the reference line) outside the reference group. For instance, the blue dot with a multiplicative effect of 0.987 for rollovers with KABCO level A applies to the reference group of *unbelted* 25-65 year old women in cars. For belted women of the same age group, cars have *increased* the odds of survival by 1% per model year (i.e. the multiplicative effect per model year is (0.987) (1.039) (0.984) = 1.01).

Additionally, the large residuals for rollovers in the Figure 13 give us reason not to trust the model's predictions for rollovers, and points to potential model refinements. Figure 13 plots the difference between the model and raw estimates of crash-worthiness for the various combinations of crash type, vehicle type, driver alcohol, restraint use, occupant age category, gender, and KABCO level, limiting to those combinations in which there are at least 50 sampled occupants contributing to the numerator and denominator of the raw estimate.

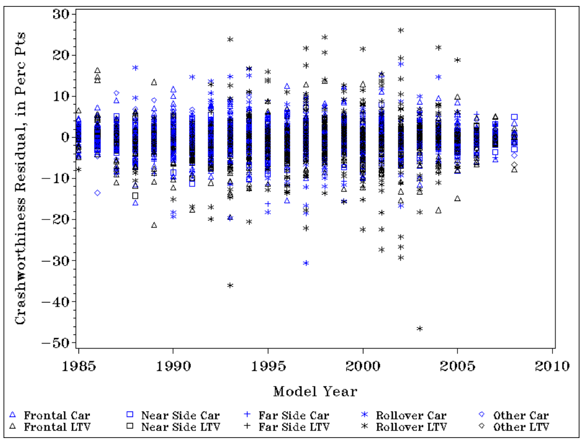

Figure 13. Crashworthiness Model Residuals for Cells in Which At Least 50 Sampled Occupants Contribute to the Numerator and Denominator of the Raw Estimate

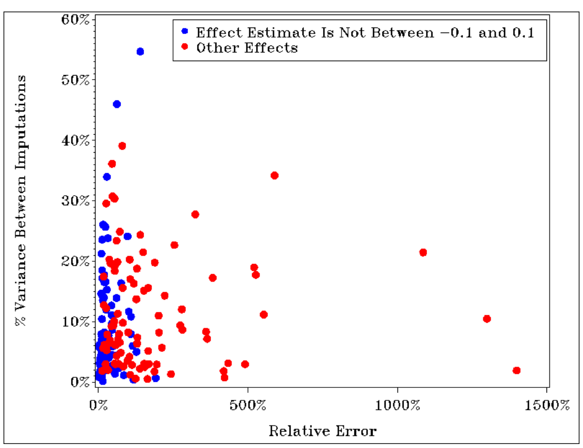

Figure 14. Crashworthiness Model Variances

Assessing the sources of variation for our model's parameter estimates, some of the relative errors are quite large (see Figure 14). However among parameter estimates that, expressed as linear effects on the injury log-odds, are at least 0.1 in absolute value, the relative error is rarely more than 20%. Imputation accounts for a greater share of the parameter estimates' variances than we saw in the crash avoidance model. Most of the effects with more than 20% of the variance occurring between imputations involve Driver Alcohol, which is difficult to impute accurately. All together though, we do not see evidence of multicollinearity. (Not depicted in Figure 14 are Far Side for KABCO B and MY*(Near Side) for KABCO B, whose relative errors are quite large (both over 1,500%), but these parameter estimates are quite small, with additive effects on the log-odds of injury of −0.00051 and −0.00004, respectively.)

ESTIMATED IMPROVEMENTS TO CRASHWORTHINESS AND CRASH AVOIDANCE

In this section we quantify recent improvements in crashworthiness and crash avoidance in light vehicles. That is, we ask: 1) by how much has your chance of crashing decreased? and 2) by how much has your risk of injury decreased?

Crash Avoidance

As noted earlier, we should be cautious in interpreting our raw and model crash avoidance estimates, since the raw estimates show a curious pattern and our mileage data lacks key information on factors that one would naturally expect to contribute to the likelihood of crashing.

That said, crash avoidance depends on who is driving, which appears to have shown up in our data via vehicle age. (See (Glassbrenner, to appear) for more information.) Interpreting our crash avoidance estimates are challenged by the fact that it is rare for a vehicle to be driven more than 100,000 miles in a year. One could interpret these figures by either considering multiple vehicles or by assuming that vehicle age reflects driver cohorts. For instance, the raw estimate of crash avoidance for frontal crashes of model year 2000 cars when they are age 0 (i.e. in calendar year 2000) is 86%. We could interpret this as either: 1) there is a 14% chance of one or more frontal crashes occurring among a group of model year 2000 cars driven a collective 100,000 miles in calendar year 2000, or 2) a person who drives new cars (model year = calendar year) has a 14% chance of getting into (at least one) frontal crash in 100,000 miles of driving a model year 2000 car.

Using the second interpretation (driver cohort), if you are the type of person who drives a new vehicle, your risk of getting in a frontal crash in 100,000 miles of driving dropped from about 14% for model year 2000 car to about 10-11% for model year 2008 (depending on whether one looks at the raw or model estimates). Figure 15 shows improvements of about 1-4 percentage points between the 2000 and 2008 model years for other crash types, with the exception of rollovers. The chance of such a driver experiencing a rollover in 100,000 miles of driving is less than 1%, and so the improvement to be made here is very small. The model indicates slightly larger improvements in side and other crashes than indicated by the raw estimates, and we could not say which indication is more accurate.

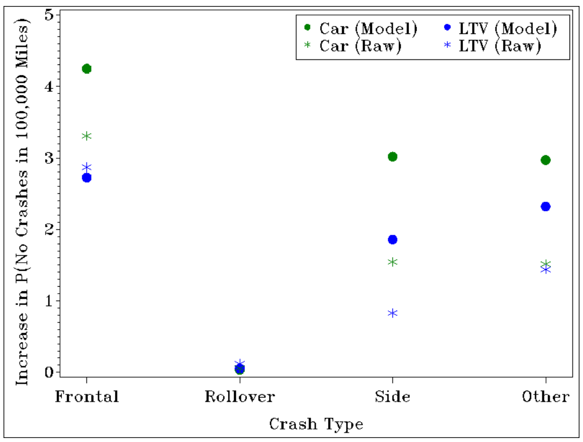

Figure 15. Improvements in Crash Avoidance from Model Year 2000 to Model Year 2008 (Raw and Model Estimates)

The crash avoidance improvements in Figure 15 are based on what we see in crash and mileage data, without regard to which vehicles have which particular technologies. The improvements we see in Figure 15 could be due to increases in the prevalence of technologies such as traction control systems, anti-lock brakes, daytime running lights, and, to some extent, electronic stability control in the model year 2008 fleet, compared to the model year 2000 fleet. It is also possible that the improvements we are seeing reflect improvements in driving, such as graduated licensing programs and a reduction in drunk driving. We do not have mileage data on such features to incorporate them in our raw or model estimates.

Assuming our crash avoidance model reflects a real phenomenon that we are likely to see in at least the near future, they predict the crash likelihoods that are depicted in Figure 16 for vehicles that are 10 years old (or driven by the cohort of persons who tend to drive such vehicles). The calendar years in which the figures in Figure 16 are predicted to be realized are 2010 – 2018. If the future does not look like the past, then the projected improvements in Figure 16 may not be realized.

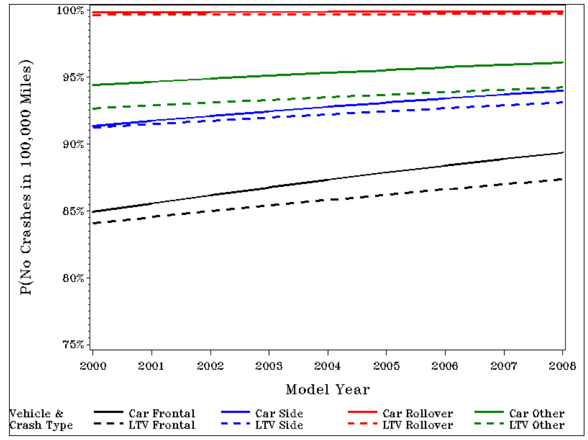

Figure 16. Projected Crash Avoidance When Model Year 2000-2008 Vehicles Are 10 Years Old

Crashworthiness

With crashworthiness dependent on so many factors, we limit the results in this section to 25-65 year-old occupants in crashes with sober drivers. Figures 17-19 depict the likelihood of sustaining an injury at various thresholds in a model year 2008 vehicle using our model estimates.

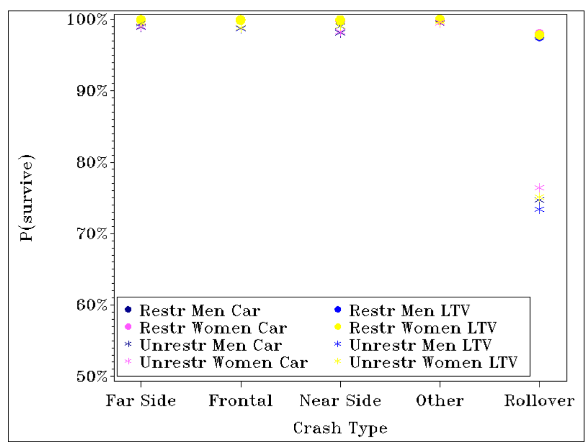

Figure 17. The Likelihood of Surviving a Crash of a Model Year 2008 Vehicle, for 25-65 Year Old Occupants with a Sober Driver

Although we have concerns that our model should perhaps be improved, several items are notable in these figures. Rollovers are more severe than other crashes. In our setting (middle-age occupants of non-alcohol crashes) you have a nearly 100% chance of surviving a crash other than a rollover, even if you are unrestrained. In rollovers, the survival rate is about 98% for belted occupants and 74–76% for unbelted occupants. If you ride unbelted, you have a 40-50% chance of being incapacitated in a rollover and you have only about a 10% chance of escaping uninjured. Belt use improves these chances considerably, to a 10-20% chance of being incapacitated and a 30-50% chance of escaping uninjured. We caution that these estimates are model-based and our model could stand to be improved.

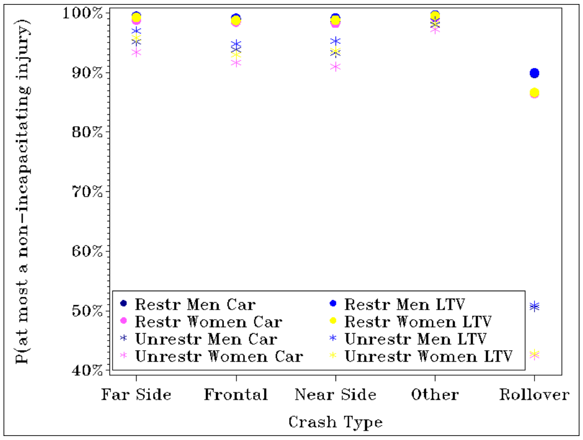

Figure 18. The Likelihood of Sustaining At Most a Non-Incapacitating Injury in a Crash of a Model Year 2008 Vehicle, for 25-65 Year Old Occupants with a Sober Driver

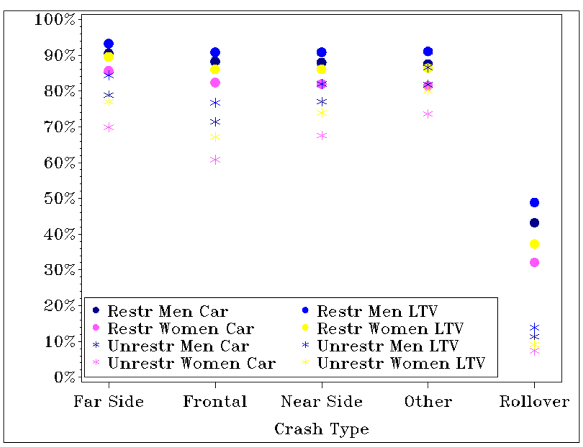

Figure 19. The Likelihood of Escaping Injury in a Crash of a Model Year 2008 Vehicle, for 25-65 Year Old Occupants with a Sober Driver

Our models predict that in each crash type and regardless of belt use, men fare better than women, and model year 2008 LTVs are more crashworthy than cars from the same model year.

We now turn to improvements in crashworthiness from model year 2000 to model year 2008. In Figures 20-21, the green (respectively, blue, purple, red) boxplots show the increase in percentage points to the probability of sustaining an injury of at most KABCO O (respectively, KABCO C, B, A). The boxplots for less severe injury thresholds are generally higher than those for higher injury thresholds, since crashworthiness rises with the injury threshold (and so there is less room for improvement). With the exception of rollovers, your chances of escaping uninjured if you are belted have increased by about 1.5 to 4.5 percentage points from model years 2000 to 2008, depending on the crash type. Our model indicates the corresponding improvements for unbelted occupants to be more than 5 percentage points. (Again we caution that these are model-based estimates.)

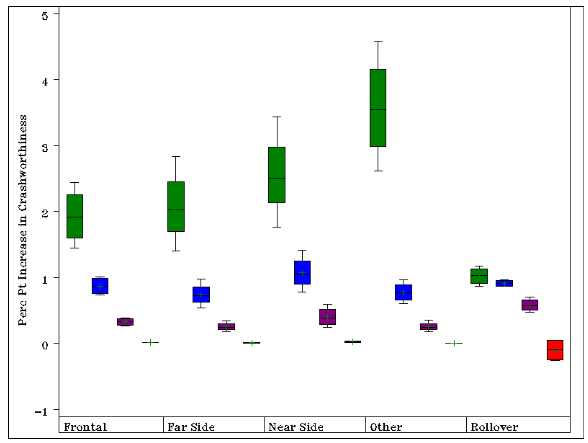

Figure 20. Increase in Crashworthiness from Model Year 2000 to Model Year 2008, in Percentage Points, for Belted 25-65 Year Old Occupants in Crashes with a Sober Driver

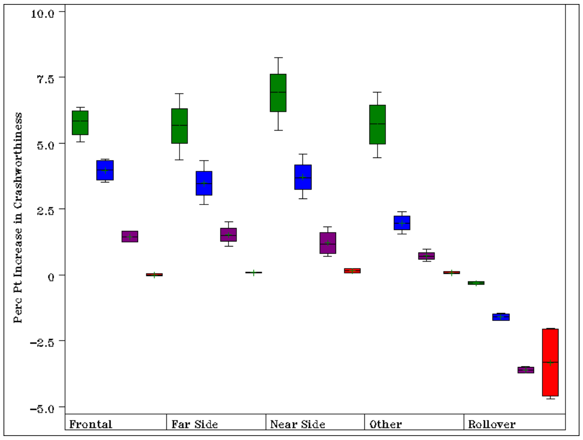

Figure 21. Increase in Crashworthiness from Model Year 2000 to Model Year 2008, in Percentage Points, for Unbelted 25-65 Year Old Occupants in Crashes with a Sober Driver

Our analysis looks at the net improvement to the crashworthiness of vehicles, without investigating the source of the improvements and whether any particular changes to vehicles have impacted crashworthiness negatively. For instance, it is not possible to tell from our analysis whether recent increases in vehicle mass have contributed positively, negatively, or not at all to the overall crashworthiness.

ESTIMATED REDUCTIONS IN CRASHES, FATALITIES, AND INJURIES FROM VEHICLE IMPROVEMENTS

We now use our models to estimate the impacts of model year improvements on crashes, fatalities, and non-fatal injuries. We do so by hypothetically putting crash occupants in newer or older vehicles and estimating the increase or decrease in crashes and injuries from our crashworthiness and crash avoidance models. By using our statistical models and not the raw estimates, we control for factors such as the increased use of restraints during the 2000-2008 time period.

We strongly caution that all estimates in this section are based on our models and we feel that our models should be improved. <u>Our estimated numbers of crashes avoided and injuries mitigated that we present in this section should be taken as indications of the magnitude of the impacts of vehicle improvements, not as solid estimates of crashes avoided and injuries mitigated.</u> Likewise our estimates of crashes that could have been avoided and injuries that could have been mitigated should be taken only as order-of-magnitude indications (at best) and not as point estimates.

Notation

To aid our depictions, we use *Scenario 2000+* to refer to the replacement of model year 2000+ vehicles with model year 2000 vehicles, and likewise define Scenario 2001+ through Scenario 2008+. We define *Scenario 2000−* to refer to replacement of model year 1974 – 2000 vehicles with model year 2000 vehicles. (We will not replace pre-model year 1974 vehicles with newer vehicles, as we do not want to apply our models to very old vehicles.) We likewise define Scenario 2001− through Scenario 2008−.

Impacts on Crashes

As expected, the number of vehicle-crashes of each type decreases in our model as we replace older vehicles with newer vehicles. In Figure 22, the vehicle-crashes that actually occurred in 2008 (about 9.1 million for cars and LTVs combined) appear in the vertical bar marked "Actual". According to our model, if we could have replaced all model year 2001–2008 cars with model year 2000 cars and likewise with LTVs, there would have been 10 million vehicle-crashes in 2008 (the leftmost vertical bar). Replacing model year 1974–2007 vehicles with model year 2008 vehicles of the same type would, according to our model, decrease this number to 7.1 million (the far right vertical bar).

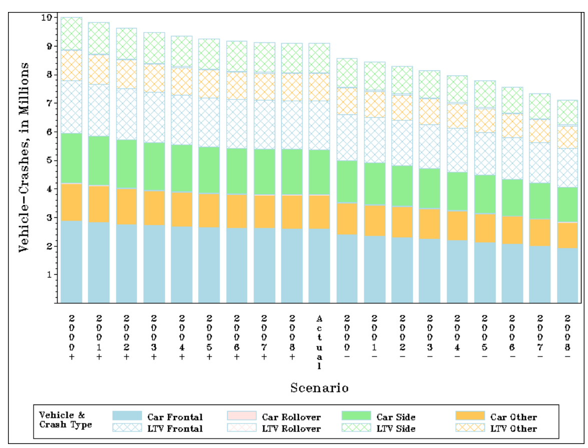

Figure 22. Vehicle-Crashes in 2008 Under the Scenarios

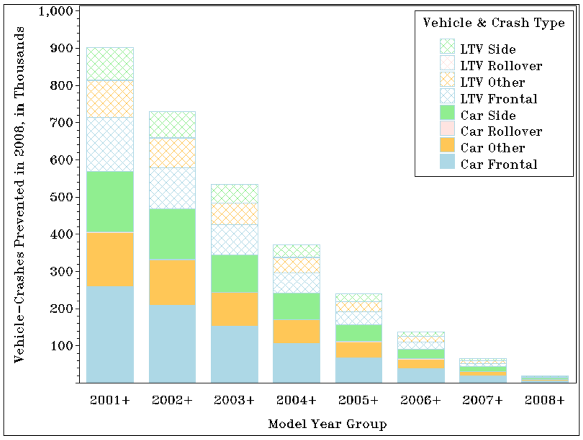

Figure 23. Vehicle-Crashes Prevented in 2008 by Technologies in Model Year Groups

The differences in the bar heights in Figure 22 for Scenarios 2000+ through 2008+ give the model-based estimates of vehicle-crashes prevented, while those for Scenarios 2008− through 2008− give the corresponding estimated numbers of preventable vehicle-crashes. For instance, crash avoidance technologies in model year 2001–2008 vehicles prevented (according to our model) an estimated 900,000 vehicle-crashes in 2008, while if we limit to technologies that appeared in model year 2009 vehicles, there would have been about 900 more. (That is, if we replaced all model year 2001-2008 cars and LTVs with model year 2000 light vehicles, our crash avoidance model predicts that there would have been 900,000 more vehicle-crashes in 2008. Figure 23 omits the vehicle-crashes prevented by model year 2009 technologies, whose value is too small to appear in the chart.)

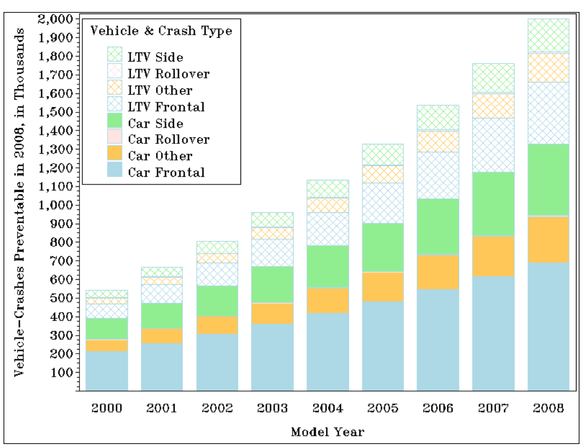

Figure 24. Vehicle-Crashes in 2008 that Could Have Been Prevented by Technologies in Model Year 2000-2008 Vehicles

A similar calculation finds that technologies seen in model year 2000 vehicles could prevented about 500,000 vehicle-crashes, while those in model year 2008 vehicles could have prevented about two million. (That is, if we could have given model year 2008 cars and LTVs to all owners of model year 1974–2007 light vehicles, our model predicts two million fewer vehicle-crashes would result.)

The technologies accounting for these reductions might have been introduced in these model years, or might have been introduced previously but started appearing in greater numbers of vehicles.

As previously mentioned, we would like to be cautious about predictions from our model. That said, we note that the estimates in Figures 23-24 are conservative in the sense that they only account for prevented and preventable crashes among the vehicles being replaced under the scenario. For instance a head-on collision of a model year 2008 car and a model year 1990 car might not have occurred if the 1990 car had been a model year 2000 car, but these two vehicle-crashes are only reduced (at most) by one vehicle-crash in Figure 24.

Impacts on Fatalities and Injuries

Figures 25-27 present the estimated impacts of recent vehicle technologies on fatalities and injuries in 2008. For instance, as indicated in Figures 22-23, our crash avoidance model predicts there would have been about a 10% increase in frontal car crashes in 2008 if all model year 2001-2008 cars were replaced by model year 2000 cars. Assuming that these two model year groups have about the same occupancy (occupants per vehicle), we'd also expect about a 10% increase in the number of occupants in such crashes. Our crashworthiness model predicts greater crashworthiness in frontal crashes of model year 2001-2008 cars than for model year 2000. Applying the difference in crashworthiness (for each model year between 2001 and 2008) to our 10% increase in crash occupants yields an increase of 200 fatalities, 4,000 incapacitating injuries, 7,000 non-incapacitating injuries, and 12,000 "possible" injuries (KABCO level C), and a decrease of 41,000 in the number of uninjured occupants. That is, in frontal car crashes alone, we estimate that model year 2001-2008 technologies saved 200 lives, mitigated or prevented about 4,000 incapacitating injuries and 7,000 non-incapacitating injuries, reduced the number of "possible" injuries by 12,000, and allowed 41,000 occupants to walk away uninjured. A similar computation estimates that about 300 lives could have been saved, and the numbers of KABCO A, B, and C injuries reduced by 7,000, 13,000, and 22,000, respectively, with an additional 42,000 occupants walking away uninjured in frontal car crashes if all model year 1974-2007 cars had been replaced with model year 2008 cars. These estimates reflect improvements to both crash avoidance and crashworthiness, but should only be taken as order of magnitude indications, at best.

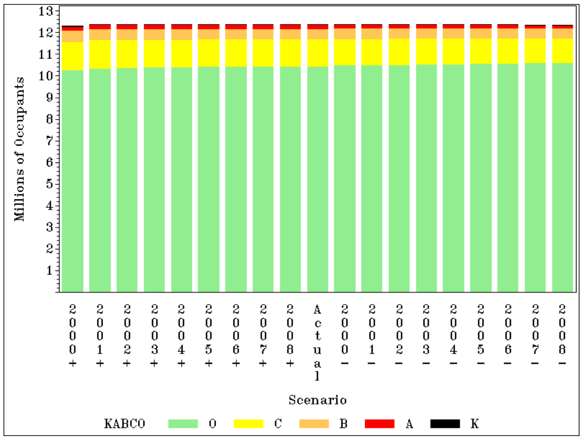

Figure 25. Injuries in 2008 Under the Scenarios

The negative values in Figures 26-27 refer to increases in the numbers of uninjured occupants. For instance, our models estimate that improvements seen in model year 2001-2008 vehicles resulted in about 400 fewer fatalities, 15,000 fewer incapacitating injuries, 27,000 fewer non-incapacitating injuries, 69,000 fewer "possible" injuries (KABCO C), and 177,000 additional uninjured occupants.

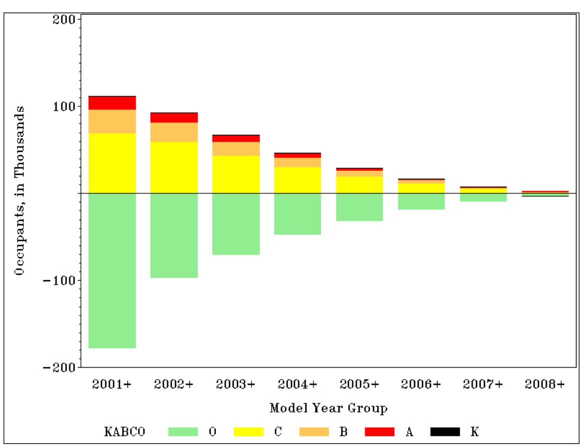

Figure 26. Injuries Mitigated in 2008 by Technologies in Model Year Groups

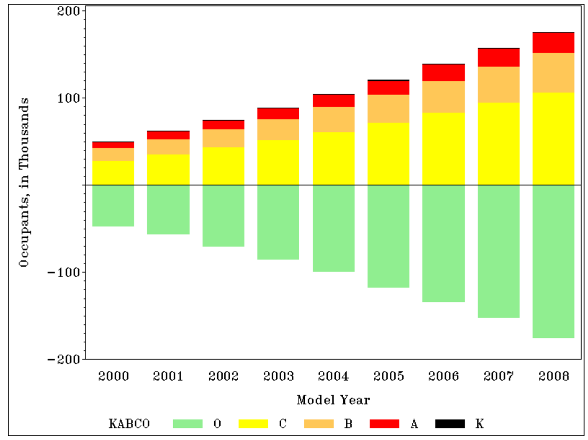

Figure 27. Injuries in 2008 that Could Have Been Mitigated by Technologies in Model Year 2000-2008 Vehicles

CONCLUDING REMARKS

Although our statistical models have limitations, our results indicate that improvements to newer vehicles have contributed substantially to the recent reductions in traffic fatalities. These results are preliminary and some modeling issues, such as with respect to rollovers in the crashworthiness model, suggest future work. We are hopeful that suitable refinements to our methods will lead to a better understanding of the collective contribution of recent safety improvements to crashes, fatalities, and injuries.

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