ORIGINAL ARTICLE

Prevention of motor-vehicle deaths by changing vehicle factors

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Objective: To estimate the effect of changing vehicle factors to reduce mortality in a comprehensive study.
Design/methods: Odds of death in the United States during 2000–2005 were analyzed, involving specific makes and models of 1999–2005 model year cars, minivans, and sport utility vehicles using logistic regression after selection of factors to be included by examination of least-squares correlations of vehicle factors to maximize independence of predictors. Based on the regression coefficients, percentages of deaths preventable by changes in selected factors were calculated. Correlations of vehicle characteristics to environmental and behavioral risk factors were also examined to assess any potential confounding.
Results: Deaths in the studied vehicles would have been 42% lower had all had electronic stability control (ESC) systems. Improved crashworthiness as measured by offset frontal and side crash tests would have produced an additional 28% reduction, and static stability improvement would have reduced the deaths 11%. Although weight–power that reduces fuel economy is associated with lower risk to drivers, it increases risk of deaths to pedestrians and bicyclists but has an overall minor effect compared to the other factors.
Conclusion: A large majority of motor-vehicle-related fatalities could be avoided by universal adoption of the most effective technologies.

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Recent research suggests that a few currently available motor-vehicle features would prevent the majority of mortalities associated with motor vehicles, if adopted for all vehicles. Electronic stability control (ESC) automatically adjusts braking, throttle, or suspension to reduce the likelihood of loss of control of the vehicle. It is estimated to reduce fatalities by about 42% in the US[1] but less in Sweden.[2] Failure to obtain the highest ratings on 40-mph offset crash tests is associated with a 25% excess deaths, and unnecessary weight contributes as much as 28%.[3] Since changing one or more of the vehicle attributes would likely prevent some of the deaths attributed to others, the percentages cited cannot be added to obtain a total estimate.

The purpose of this study is to estimate the effect of these and other vehicle factors (side-impact crashworthiness, static stability, braking distance from 60 mph to 0, and 0–60 mph acceleration time), each adjusted for the effect of the others, in a comprehensive analysis of preventable motor-vehicle mortality. Static stability is the distance between the centers of the tires divided by twice the height of the center of gravity (T/2H), a factor that increases the risk of rollover when below 1.2.[4] I also analyzed the potential for confounding of results by environmental and behavioral factors.

METHODS

I selected passenger cars, minivans, and ''sport utility vehicles'' (SUVs) sold from the beginning of the new 1999 model year (beginning in October 1998) through September 2005, for which data were available on the mentioned vehicle characteristics. I excluded pickup trucks because their weights and other characteristics vary considerably within make-model designations. If a vehicle was redesigned during the study period, it was treated separately as a new model. In those cases where ESC was added in a given model year without other changes, the vehicle was designated as a new model.

I counted deaths during the years 2000–2005 for each vehicle make-model designation and obtained data on environmental and behavioral factors from the Fatality Analysis Reporting System that contains data on virtually every fatal crash in the US. To account for differential exposure, I estimated years of vehicle use by multiplying the monthly sales of a given make and model by years remaining during 2000–2005, discounted by subtracting the estimated percentage scrapped as the vehicles aged.[5] One hundred fourteen make-models with more than 100 000 years of use each were selected for analysis. These vehicles were involved in 25,367 crash-related deaths to their occupants or bicyclists and pedestrians.

Data on ESC availability and crash test results by make and model were obtained from the website of the Insurance Institute for Highway Safety.[6] Vehicle specifications and the results of the government's front and side crash tests were obtained from a vehicle information website.[7] Because real-world crashes seldom involve the full front of the vehicle, the Insurance Institute for Highway Safety conducts frontal offset crash tests at 40 mph into a fixed barrier with a 40% overlap of the barrier and the driver side of the vehicle. It assigns qualitative ratings of ''good'', ''acceptable'', ''marginal'', and ''poor'' to various aspects of performance on its offset frontal crash tests. I assigned weights of 1 (good) through 4 (poor) to the ratings of four life-threatening elements of the tests—structural integrity, forces on the heads, and, separately, the chests of test dummies, and engineers' assessment of the performance of seat belts and air bags in the tests. These were averaged as an index of frontal offset crashworthiness.

The US government tests vehicles in full-frontal barrier crash tests at 35 mph and collects data on head and chest injury criteria as well as other body sites. Since head and chest injuries are the most threatening to life, the injury criteria relevant to these injuries were considered in the analysis. The government also tests side crashworthiness by impacting the sides of vehicles with a 3015-pound barrier at 38.5 mph, with ''give'' in the barrier to simulate the front of a vehicle. Injury criteria measured on driver and passenger test dummies were included in the analysis. Because about 70% of occupant deaths occur to

Abbreviations: ESC, electronic stability control; SUV, sport utility vehicle drivers, I weighted the injury criteria as 0.7 times driver side plus 0.3 times passenger side when assessing all deaths. When assessing driver deaths, I used the driver-side injury criteria. I obtained static stability data from US government measurements[8] as well as the vehicle information website. I classified a vehicle as stable if T/2H was 1.2 or higher.

I obtained data on braking distance from 60 to 0 mph and acceleration time from 0 to 60 mph from the Consumer's Union road-test data.[9] I analyzed the data using least-squares correlation and logistic regression.

RESULTS

Logistic regression estimates the odds of an event, in this case death, as a function of specific factors that are assumed to be independent, that is, not significantly correlated.

Neither the presence of electronic stability control nor crash test results were correlated significantly to the other factors. Correlations that could bias the assessment of vehicle weight, engine power, size, static stability, and braking are displayed in table 1.

Although excess weight and horsepower are adverse to other road users, size is related to a lower risk because it gives occupants more room to decelerate in a crash.[10] The weight, horsepower, and size variables (wheelbase and turn distance) are correlated to a degree that using more than one could bias the estimates. Because poor fuel economy is highly correlated with these variables, particularly weight and horsepower, and is an important consideration in vehicle purchases, it was chosen as an inverse proxy of weight–power. Braking distance, acceleration distance, and static stability are sufficiently independent of one another and the other factors to be used in the regression analysis. The analysis also controlled for types of vehicle (minivan, SUV) because of their differential use compared to cars.

Preliminary analysis indicated that the head and chest injury criteria in the government's full-frontal crash tests and braking distance are not significant factors in relation to odds of mortality, controlling for the other factors. These variables were dropped from the analysis. The logistic regression coefficients of the remaining factors and their 95% confidence intervals are presented in table 2, separately for deaths to all road users, driver deaths, and deaths to pedestrians and bicyclists. Lower risk of all deaths is associated with the presence of ESC, particularly as standard equipment, good performance on the offset frontal and side crash tests, static stability of 1.2 or higher, and faster acceleration from 0 to 60 mph. Drivers have a lower risk of death when fuel economy is lower, but the correlation reverses for all deaths—particularly pedestrian and bicyclist deaths. Vans and SUVs have lower overall death rates when the other factors are controlled.

I calculated the reduction in deaths achievable by changing a given vehicle characteristic as other characteristics remained the same by substituting the value of a given variable in the regression equation for total deaths, applying the rate to the number of vehicles in use for each vehicle, subtracting the result from the actual total deaths, and summing the result across the vehicles. If all vehicles were equipped with ESC, the estimated death reduction would be 11 098, about 42% of the total. If all of the vehicles averaged one on the offset frontal crash test index, there would have been approximately 2211 fewer deaths, 8.6% of the total. If the vehicles that had injury criteria above average on the side crash tests were improved to the average, 4950 (19.4%) deaths would have been prevented. A static stability of 1.2 or higher among vehicles with lower stability would have prevented 2737 deaths, 10.7% of the total deaths.

The effects of weight–power, reflected by fuel economy, and acceleration time were much less. If the weight and horsepower of all vehicles that had less-than-average fuel economy (28.4 mpg) were changed to the average, the death reduction would be 492, 1.9% of the total. Achieving average acceleration time (9.4 s) for those with more would result in 495 fewer deaths, 1.9% of the total. The percentages add to an 85% potential reduction in deaths if all vehicles had the best of the mentioned characteristics.

For environmental or behavioral factors to confound these results, they would have to be correlated substantially with the vehicle factors. Since there are no data on the exposure to environmental and behavioral factors by make/model of vehicles, the potential for confounding must be assessed indirectly. If there were potential confounders among major known risk factors, they would be revealed by the correlation of ratios of lower to higher risk in the fatal crashes. Formally, C(L/H) = RL/RH = b(vehicle factor), where L = low exposure to a risk factor; H = high exposure to a risk factor; C = constant ratio of risk from lower to higher; RL = fatalities in lower-risk factor situations; RH = fatalities in high-risk factor situations; b = the slope of the correlation.[11]

Table 3 contains the correlations of the ratios of lower- to higher-risk environmental and behavioral factors relative to the vehicle characteristics and equipment. Almost all of the correlations are low and are not consistently in the direction of confounding. The two large correlations are opposite from what one would expect if there were confounding. Vehicles with poor scores in side crash tests are more involved in urban areas where the risk of fatalities is lower than in rural areas, but the specific risk of a side crash at an intersection is higher than in rural areas. The correlation does not suggest confounding but increases confidence in the specification of the effect of side crashworthiness. Drivers of vehicles equipped with ESC are somewhat less likely to have a valid drivers license, the opposite expected from confounding.

DISCUSSION

When the effect of each factor is corrected for the effect of the others, the estimated effect of electronic stability control is

Table 1 Least-squares correlation of selected vehicle factors

	Weight	Wheelbase	Turn distance	Braking distance	Horsepower	Acceleration distance	Static stability
Weight	1.00						
Wheelbase	0.64	1.00					
Turn distance	0.60	0.65	1.00				
Brake distance	0.20	0.17	0.06	1.00			
Horsepower	0.70	0.59	0.50	0.04	1.00		
Acceleration distance	−0.22	−0.19	−0.25	0.24	−0.50	1.00	
T/2H	−0.34	0.02	0.15	−0.18	−0.06	−0.14	1.00
Fuel economy	−0.76	−0.44	−0.39	−0.21	−0.65	0.10	0.47

Table 2 Logistic regression estimates of the preventive effects of vehicle factors

	All road users	Drivers	Pedestrians and bicyclists
	Coefficient (95% CI)	Coefficient (95% CI)	Coefficient (95% CI)
Intercept	0.2468	−1.7855	−2.9905
ESC standard	−0.5764 (−0.669 to −0.484)	−0.7806 (−0.943 to −0.618)	−0.4813 (−0.617 to −0.345)
ESC optional	−0.2551 (−0.297 to −0.213)	−0.3304 (−0.397 to −0.264)	−0.2014 (−0.270 to −0.133)
Front crash test	0.1329 (0.105 to 0.161)	0.3758 (0.339 to 0.413)	0.0928 (0.045 to 0.141)
Side crash test	0.0111 (0.010 to 0.012)	0.0090 (0.007 to 0.011)	0.0030 (0.001 to 0.005)
T/2H<1.2, else 1.2	−8.7614 (−9.559 to −7.964)	−8.258 (−9.532 to −6.985)	−6.0460 (−7.313 to −4.779)
Acceleration	0.0477 (0.034 to 0.062)	0.0687 (0.048 to 0.089)	0.0483 (0.024 to 0.073)
Fuel economy	−0.1100 (−0.114 to −0.106)	0.0036 (−0.002 to 0.009)	−0.0260 (−0.032 to −0.020)
Van	−0.3266 (−0.394 to −0.259)	−0.9167 (−1.034 to −0.799)	−0.3283 (−0.435 to −0.221)
SUV	−0.2994 (−0.369 to −0.230)	−0.5262 (−0.633 to −0.419)	−0.3548 (−0.465 to −0.244)

similar to the estimate from the cited research comparing vehicles of the same make-model before and after adoption of the technology. The effects of "good" scores on offset crash tests and power–weight reflected by fuel economy are less than expected from previous research. Apparently, ESC would prevent some of the deaths formerly attributed to the other factors.

Electronic stability control is the most important innovation in reduction of vehicle-related mortality in decades, perhaps the single most effective innovation since the invention of seat belts. If all vehicle purchasers bought only vehicles with ESC and good offset frontal and side crash test ratings, deaths would be reduced by more than half after the older vehicles were scrapped. A list of 2007 and subsequent model vehicles that have the ESC system, as well as the top scores on crash tests and good static stability, will be updated on the internet as new models are tested.[12] Although pickup trucks were not included for technical reasons, the results should apply to them as well. Pickups as a class have higher deaths rates than passenger cars, vans, and SUVs. Few pickups on the market in the US have ESC or do well on crash tests.

The effect of low static stability is substantial despite the effect of ESC. Apparently, the installation of ESC does not negate the need to achieve a minimum static stability of 1.2 or higher.

A surprise in the results is the lack of effect of braking distance. Since ESC selectively applies brakes to wheels, which could account for some of the same variance, a regression of the other factors and braking distance was done excluding vehicles with standard or optional ESC. No effect of braking distance was found among these vehicles either. Although actual braking distance is measured accurately, braking distance is somewhat subjective, dependent on the ability and willingness of the test driver to apply brakes fully while controlling the vehicle. It may not be possible to obtain an objective measure of braking distance that is applicable to drivers in panic situations.

Despite the evidence that vehicles with higher weight–power and lower fuel economy contribute to excess total deaths, the Insurance Institute for Highway Safety continues to promote such vehicles based solely on driver death rates with no consideration of the net losses related to weight-power. The Institute calculates only driver death rates to obtain a rate with known exposure because every vehicle in motion has a driver, but the number of passengers may vary among vehicle make-models.[13] While driver death rates are lower in vehicles with more weight–power, their excess involvement in bicyclist and pedestrian deaths more than offsets the advantage to drivers and occupants in such vehicles. This is not to suggest that the weight of the vehicle, per se, causes fatal injury. A lightweight car has more than enough weight to kill. More likely the

Table 3 Correlation of vehicle characteristics, environmental and behavioral variables

	Front crash test	Static stability	ESC optional	ESC standard	Side crash test	Acceleration time	Fuel economy
Environment							
Urban/rural	0.035	0.292	0.081	−0.200	0.602	−0.180	0.206
Interstate/other	−0.159	0.178	0.285	0.300	−0.036	−0.291	−0.086
Onroad/off	−0.194	0.013	0.005	−0.030	−0.268	0.050	−0.227
3+ lanes/2 lanes	−0.160	0.189	0.033	0.386	−0.102	−0.121	−0.204
Speed limit<55/55+	−0.136	0.126	0.086	0.324	−0.092	−0.193	−0.128
Straight/curve	−0.174	0.240	0.159	0.319	−0.025	−0.254	−0.123
Level/grade	−0.160	0.044	−0.112	0.168	−0.064	−0.016	−0.232
Concrete/blacktop	−0.220	0.152	0.122	−0.032	0.101	−0.027	−0.141
Dry/wet	−0.141	0.062	0.193	−0.081	0.069	−0.003	−0.051
Daylight/other	−0.132	0.001	0.073	0.228	0.001	−0.112	−0.193
behavior							
Valid license/other	0.202	0.349	−0.371	−0.572	−0.209	−0.148	−0.206
No prior crash/1+	−0.046	0.050	0.133	0.199	0.100	0.149	−0.048
No prior suspension/1+	0.115	−0.034	−0.087	−0.007	−0.056	−0.074	−0.189
No prior driving while intoxicated/1+	0.002	0.040	0.089	0.150	0.102	0.103	−0.170
No prior speeding/1+	0.145	−0.020	−0.044	0.045	0.133	0.073	−0.248
No other conviction/1+	0.017	0.017	0.063	0.167	0.170	0.152	−0.215
No blood alcohol/.01+	0.046	−0.015	−0.042	0.147	0.126	0.097	−0.211
No illegal blood alcohol/1+	0.028	0.037	−0.024	0.101	0.133	0.115	−0.239
Age 25+/<25	0.028	0.029	0.051	0.171	0.198	0.110	−0.173
Women/men	−0.043	0.056	0.181	0.294	0.296	0.234	−0.127

problem is the difficulty a driver has in regaining control of a heavier vehicle out of control. Heavy vehicles are over-involved in deaths to children backed over in home driveways, deaths that are not reported in the Fatality Analysis Reporting System because they do not happen on public roads, probably because their size more often obscures vision.[14] They dump more carcinogenic polycylic aeromatic hydrocarbons and greenhouse gases in the environment and deplete oil supplies. If vehicles have ESC and perform well on crash tests, there is little advantage in risk reduction to drivers who select a vehicle based on heavier weight and far more harm to others. Vehicles that are too small to protect occupants do poorly on crash tests and can be avoided on that basis.

While the percentage reduction in fatalities applies only to the vehicles and period studied in the US, the vehicle features studied should have substantial consequences anywhere they are applied. The mix of vehicles in other countries and the ratios of pedestrians and bicyclists to motor vehicles would undoubtedly alter the percentages but it is unlikely that vehicle characteristics would have a different effect in different countries.

The major threat to the validity of the conclusions of this study is the potential selectivity by risk-conscious vehicle buyers who select vehicles based on crashworthiness tests and ESC. The lack of correlation of the major known behavioral risk factors with vehicle characteristics suggest that such selectivity did not occur to the extent that selectivity is manifested in well-known indicators of relative risks among drivers. Seat belt use is not included in the study because police and occupant reports of belt use in crashes have proved unreliable when crash-recorder data are compared to reported belt use.[15] Nonuse of belts is highly correlated to illegal alcohol concentrations among drivers.[16] The lack of correlation of alcohol and the vehicle characteristics studied here suggest that there is no systematic choice of less safe vehicles by higher-risk drivers.

The significant correlation of reductions in pedestrian and bicyclist deaths with crash test results suggests the possibility of some degree of selectivity in buying vehicles that do well on crash tests by drivers less likely to hit other road users. They may also drive in environments where there is less exposure to pedestrians and bicyclists. There is no reason to expect that front and side crashworthiness would reduce pedestrian and bicyclist deaths. Yet, when the regression results on other road users are used to estimate death reductions, pedestrian and bicyclists are 22.5% of the reduction in deaths attributed to good offset frontal crash tests and 9.4% attributed to better-than-average side protection. Even if 25% of the effects of each of the vehicle factors are attributable to selectivity, however, total deaths would have been 64% lower if each of the vehicles met the criteria mentioned on each factor.

In Europe, evaluation of crashworthiness includes ratings of potential harm to pedestrians of front ends.[17] Research on the relation of these test results to actual injuries to pedestrians by make and model would be useful.

Implications for prevention

This is a study of the effects of preventive measures, not causation. When such research is reported, vehicle manufacturers and others often comment that the main cause of vehicle crashes is behavior. The inference in such comments is that preventive efforts should be directed at the major causes. In fact, changing only necessary conditions for harmful results substantially prevents a variety of diseases and injuries. For example, the lack of barriers on windows in high-rise buildings does not cause children to crawl out of windows, but the presence of barriers prevents them from doing so.[18] A simple barrier negates the effect of the diverse causes of parental inattention that results in lack of supervision of the child. Similarly, numerous factors contribute to drivers losing control of their vehicles. ESC detects when the vehicle is nearing loss of control and adjusts throttle, braking, and suspension accordingly. While changing vehicles does not preclude efforts to change behavior, the results of this study indicate that a substantial majority of vehicle-related deaths can be prevented by full adoption of changes in vehicle characteristics that are preventive, whatever the complex mix of factors that lead to serious crashes.

Key points

- A substantial majority of motor-vehicle fatalities are preventable by modification of vehicle factors.
- Electronic stability control installed in all vehicles would reduce mortality 42%.
- Improved crashworthiness as measured by offset frontal and side crash tests would have produced an additional 28% reduction.
- Static stability improvement would have reduced the deaths 11%.

Competing Interest: The author has no investments or benefits in no other way from motor-vehicle manufacturers or equipment suppliers.

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