Injury Epidemiology: Fourth Edition

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Chapter 13. EVALUATION OF AGENT, VEHICLE, AND ENVIRONMENTAL MODIFICATIONS

Product manufacturers and builders of roads, housing, and other infrastructures and products have the opportunity to modify them to reduce the incidence and severity of injurious energy exchanges (Staunton et al., 2007). The sources of the vast majority of serious injuries are the products of industry and builders in everyday or frequent use: among them, drugs, motor vehicles, road characteristics, guns, agricultural and industrial machines, stairs, cigarettes, matches, propane lighters, stoves and space heaters, clothing, bedding, swimming pools, and watercraft.

Many industrially developing countries are repeating the mistakes that occurred during the industrialization of Europe and the U.S. Replacement of human and animal power by engine power exposes people to vastly increased energy, often with no attention to features or alternatives that would minimize harm (Berger and Mohan, 1996; Krishnan, et al., 1990).

Well-designed epidemiological studies can reveal the injuries associated with the characteristics of products and environments that injure. They can also aid in the evaluation of the effectiveness of modifications of products, protective equipment, and environments in injury control.

Decisions that influence the rate of injuries associated with a given product may include design characteristics, quantity per package and type of package, quality control in manufacturing or building the product, and the extent and target of marketing efforts. Most of the efforts by the government to influence these decisions for injury reduction have been focused on standards affecting designs or recalls of products that have design or manufacturing defects. The agreement between the United States Consumer Product Safety Commission and the manufacturers of "all-terrain" vehicles that the vehicles would not be marketed for use by children, and the very occasional banning of a product by the Commission and labeling requirements by various agencies, are exceptions to the general lack of attention to marketing and its targets.

PRODUCT DESIGN. Research that relates the product or environmental designs to injury rates and patterns can inform manufacturers, builders, and governmental regulatory agencies; although there is often resistance to the inference that injury is "caused" by the design. Such research is frequently attacked because every conceivable behavioral factor was not controlled or was inadequately controlled. In contrast, when a behavioral factor is correlated to rates of injury, questions regarding controls for characteristics of products involved are rarely raised by scientists, much less by manufacturers or the government.

Not only is the analysis of causation sometimes a "long cut to prevention" (Chapter 8), but so is the argument about causation regarding injury from product characteristics. If children are being poisoned by aspirin, what are the causes -- the children's natural tendency to put things in their mouths, the parents' or others' failure to store the aspirin inaccessible to children, the attractiveness of the aspirin package, the number of pills per package, or the color of the pills?

If the number of pills per package can be reduced or the cap on the bottle can be changed to make it difficult for the child to open it, why argue about primal causation or launch expensive studies to specify the effects of various risk factors, some of which are much less controllable than a product modification? In the case of child poisonings from aspirin, the aspirin manufacturers were informed by pediatricians and consumer groups that they could make a difference in child poisonings by modifying of quantity per package and type of packaging and did so. Child poisoning from aspirin declined by 80 percent (Done, 1978).

The hazardous characteristics of certain products are obvious but their consequences are often ignored. Examples are points and edges on interior and exterior surfaces of motor vehicles, sharp edges on the ends of roadside guardrails, the height of playground equipment relative to the hardness of the surface under it, the ease of use of handguns, and exposed moving parts of industrial, agricultural, and recreational machines. Product testing can reveal less obvious factors such as vehicle crashworthiness, that is, energy absorption by vehicle parts in crashes before the energy reaches the occupants.

Case studies can be a rich source of hypotheses regarding such characteristics of products, as they were historically in investigations of motor vehicles and aviation (e.g., Woodward, 1948; Gikas, 1972; Snyder, 1975; Champion, et al., 1986; Clark, et al., 1987; Shanahan, 2012). The epidemiologist can draw attention to the extent of a given problem and provide estimates of the effects of modification by correlating the incidence and severity of injuries to variations in relevant characteristics of the products or environments.

Opportunities to study relatively rare phenomena sometimes arise for epidemiologists at the site for other reasons. For example, an area in Guatemala, where nutrition studies were underway, experienced an earthquake. Epidemiologists were able to correlate injury with housing characteristics and other factors (Glass, et al, 1977).

Even products that are sometimes used to injure intentionally may be changed to reduce the severity. As noted in Chapter 2, the physics of bullets and shotgun pellets have been described in detail (Sykes, et al., 1988; Ordog, et al., 1988; Karlson and Hargarten, 1997), but their relative contribution to the severity of injuries in shootings can be subjected to epidemiological investigation. Trends toward higher caliber weapons that remain small enough to be concealed will probably increase the fatalities per shooting (Wintemute, 1996). The companies that aggressively promoted the cheap "Saturday Night Specials" increased their marketing of more powerful, concealable handguns (Wintemute, 1994). The effects of legal approaches to the regulation of guns, including untraceable "Ghost guns" built by home printers (Beyer, 2014), can be investigated by epidemiologists using data on police confiscations (Wintemute, 2021).

Even intended injury to self has been found modifiable by changing characteristics of the weapon used. Suicide by cutting and piercing declined by about 80 percent among males in England in parallel with the replacement of straight razors with safety razors (Farmer, 1992). The removal of carbon monoxide from domestic gas was associated with a reduction of about one-third in the net suicide rate in England and Wales, but not so in Scotland or the Netherlands (Kreitman, 1976; Clarke and Mayhew, 1988). In the United States, suicide by motor vehicle exhaust increased among males as that by domestic gas decreased, but there was a net decrease in suicides among females (Lester, 1990). Various types of deliberate "means restriction" to prevent suicide have been demonstrated but there are not applied generally because of inconvenience to the public and misconceptions about the intent of suicide attempters (Yip, et al., 2012; Barber and Miller, 2014).

Characteristics of products and environments that may not be obvious, but are likely contributors to injury incidence or severity, can be learned by review of elementary physics or chemistry (Chapter 2). Examples are the energy-absorbing capability of vehicle components as well as trees, poles, guardrails, and other roadside objects, stability of vehicles, cigarette burn rates, flammability of clothing, furniture, and bedding, and toxicity of drugs, household chemicals, and chemicals used in farming and industry. Again, the epidemiologist can learn the variations among products and, by observing the patterns of such variations correlated to relevant injury rates, estimate the effect of potential modifications (See Chapter 9, Appendix 9-1). For example, legislation requiring lit cigarettes to self-extinguish when not being smoked was associated with a 19 percent reduction in rates of death from residential fires as states adopted those laws (Yau and Marshall, 2014)

Biomechanical studies in the laboratory also suggest hypotheses for epidemiological investigation. Laboratory studies of simulated pedestrian collisions using bumpers of varying height indicated that bumpers twenty-five or more inches from the road surface produced more severe injuries (Weiss, et al., 1977). Epidemiologic research on the injuries to people struck on the road showed more severe injuries related to higher bumper height (Ashton, 1982).

Collaboration of biomechanical and epidemiological researchers can contribute to the understanding of injury tolerances of subsets of the population. For example, examinations of the severity and circumstances of injuries to children in free falls and biomechanical simulations of the events were used to estimate tolerances of children to head impacts (Mohan, et al., 1979).

EVALUATION OF PRODUCT CHANGES. It is also important to know whether product modifications intended to reduce risk are functioning as intended. For example, of twenty families who had anti-scald devices attached to bathroom faucets, 19 had removed them within 9 months because of sediment buildup in the devices (Fallat and Rengers, 1993). Antilock braking systems on motorcycles are associated with 31 percent lower deaths per vehicle compared to the same makes and models without the system (Teoh, 2013). New crash avoidance technologies on cars, SUVs, and trucks such as automatic brakes, rear cameras, adaptive headlights, lane departure warning, lane departure prevention, and better vision of the side "blind spots" were adopted with limited research as to their effects. The research in Appendix 13-2 suggests that most of these are efficacious but automatic brakes are associated with increased fatal crash risk, possibly because they lead drivers to be less attentive.

Most governmental standards for products are performance standards that do not directly dictate design but set minimum limits for performance in injury reduction or, in the case of worker injuries, set standards and allow for inspections of workplaces. The United States Federal Motor Vehicle Safety Standards, for example, specify criteria for the performance of components, such as the energy absorption of steering assemblies in frontal crashes, but do not indicate how the component is to be designed to meet the standard.

The effectiveness of a regulation depends on the technical effectiveness of the regulation relative to the performance of the regulated product, process, or environment before the regulation, and the degree of compliance to the regulation by manufacturers (or other relevant organizations). There is also the argument, noted in Chapter 12, that persons whose risk is reduced will behave differently, offsetting the effect of laws or regulations. Another test of the hypothesis that increased protection would be offset by behavior was provided by the introduction of airbags in cars. Those drivers protected by airbags could have reduced their belt use to partly offset the reduced risk provided by the airbags but they did not. Belt use by drivers in airbag-equipped cars was not significantly different than in cars without airbags (Williams, et al., 1990).

The research on the effect of motor vehicle safety regulation includes conflicting conclusions, mainly based on inept research methodology by economists (Appendix 13-1). These issues are instructive regarding the misleading results that are often obtained from insufficiently disaggregated data. The research should include the possibility of unintended consequences, including effects on other road users, but should not include built-in biases that falsely infer such consequences.

The evidence of the substantial effect of the initial motor vehicle safety standards does not mean that all regulation is effective or that regulation is always the most effective way to achieve injury reductions. The time necessary for unregulated products to be discarded is also a factor in accomplishing the full effects of regulation, or product changes that are undertaken voluntarily. In the case of passenger cars, the average life of the vehicles is more than 10 years, so it takes that long for the regulations to have full effect as the older vehicles are scrapped. Other products, such as mattresses, may be used longer, and some, such as children's cribs, may be used for generations. Research on trends in child suffocations and strangulations suggests that standards for refrigerator or freezer entrapment and warnings on plastic bags reduced fatalities from those sources, but regulations regarding crib design have had less if any, effect (Kraus, 1985).

EVALUATION OF PROTECTIVE EQUIPMENT AND ENVIRONMENTS.

Irrespective of the means employed to obtain the use of increased protection (persuasion, laws directed at individuals, regulation, or voluntary changes in products and processes), the effect of the protection in use is often worthy of epidemiologic study. Engineers who design and test protective equipment can indicate precisely the energy absorbed, reduction of access to moving parts, stability, and other product characteristics, but other factors cannot always be anticipated -- the range of uses and factors affecting lack of use, the amounts of energy involved in actual injuries, and the possibility of misuse. Epidemiological data on the use and effectiveness of potentially injurious energy sources can be helpful in modifications of design or attempts at changes in how the equipment is used. Unfortunately, failure to consider the plausibility of results misleads some researchers to unwarranted conclusions. In that regard, the decades-long debate on the effectiveness of seat belts is recounted in Appendix 5-1.

When new protective equipment is introduced, it is possible to conduct controlled experiments on effectiveness. Again, the best research design is the experimental-control design where feasible. For modifications of higher-priced products, experimental-control designs are often not considered feasible before sales to the general public, but if large volumes are bought for use by corporations or the government, random assignment to users in those organizations is possible. For example, the effect of the high-mounted brake light on crashes of cars while braking was studied experimentally in corporate and governmental fleets (e.g., Reilly, et al., 1980). A quasi-experimental design was used to study the effect of energy-absorbing floors on the severity of falls in a nursing facility for the elderly. The "quasi" refers to the fact that the new floors were not strictly randomly assigned among parts of the facility. The severity of fall injuries was reduced by almost half in the areas with energy-absorbing floors but the confidence intervals were wide because the numbers on which the estimate was based were too small (Gustavsson, et al. 2015). A review of studies of energy-absorbing flooring concluded that the research methodology was so inadequate that a firm conclusion could not be reached from the results (Drahota et al. 2022).

If the government or other agencies distribute certain products, it can be done experimentally. The New York Health Department undertook an experimental-control study of potential problems with a type of child-resistant cap for medicine containers (the "Palm-'N'-Turn" cap) by randomly distributing them in municipal hospitals and conducting follow-up home visits in experimental and control groups (Lane, et al., 1971). The reduction in injuries to softball players due to the introduction of breakaway bases was demonstrated by randomly rotating teams among fields with and without the breakaway bases (Janda, et al., 1988).

Many studies of protective technology are case-control studies done after the partial adoption of the technology. This always raises the issue of selection bias; risk-averse people may more often be early adopters. One means of estimating potential bias in the selection of cases or controls is the use of more than one control group in a case-control study. For example, in a study of the effect of bicycle helmets in reducing head injuries, persons who were treated at five hospitals for head injuries while bicycling were cases. One comparison group was bicyclists who came to the emergency rooms of the same hospitals for injuries other than to the head. Another comparison group of injured bicyclists was identified from the records of a group health plan. The self-reported helmet use in the two comparison groups was nearly the same but was substantially lower in the head-injured group. Data obtained on several potential confounding factors in the three groups allowed adjustment for these factors in the estimate of helmet effectiveness given an injury while bicycling, which suggested a reduction in risk of head injury of bicyclists using helmets of about 85 percent (Thompson, et al., 1989).

That estimate, like seat belt use, may be too high to the extent that helmet use is misreported. The researchers had no way of verifying that helmets were used in the groups studied. To check on claims of use versus actual use, observed users and nonusers would have to be identified unobtrusively and later questioned regarding use. To control for whether or not bicyclists who are injured are more or less likely to be using helmets, a third control group would be needed -- those bicycling at the same times and places as the injured.

Modifications of environments under the jurisdiction of corporations or governments can usually be studied experimentally, but often are not. Extensive reviews of the literature on road modifications are available (Federal Highway Administration, 1982; Elvik and Vaa, 2009). Much has been learned from cross-sectional studies of road features and before-after studies of modifications. Often the differences in crashes or severity in before-after studies of environmental modifications are so large that the reduction is unlikely due to biased study design, but the lack of control sites and the potential for regression to the mean (Chapter 11), where the modifications were targeted only at high incident sites, raises doubts about the exact magnitude of some effects.

For example, the installation of flashing lights at rural stop signs was associated with an 80 percent reduction in fatal crashes at those sites (Hagenauer, et al., 1982). The lighting of intersections is correlated with a 12 percent reduced night/day crash ratio (Bullough, et al., 2013). Removal of trees from near roadsides or use of impact attenuators at fixed objects was estimated to reduce fatal crashes by 50-75 percent (McFarland, et al., 1979). Pedestrian injuries in areas of New York's Safe Route to Schools initiative were substantially reduced compared to areas without (Dimaggio and Li, 2013).

An analysis of various studies that claimed large reductions in motor-vehicle crashes at high-incidence sites (so-called "black spots") claims that those with controls for regression to the mean show less or no effects (Elvik, 1997). The study did not distinguish between reduced incidence and reduced severity. For example, a guardrail may reduce severity without reducing incidence. While modifications at sites that had temporarily high incidence rates would be expected to return to the average without the modifications, studies that are based on long experience of severe injuries at particular sites show remarkable reductions over similarly long follow-up periods when the modification would be expected to have a long-term effect, such as guardrail installations (Short and Robertson, 1997).

Case-control studies have indicated criteria for selecting high-risk sites for severe crashes where vehicles left the road (Chapter 7). Epidemiologists who become familiar with the literature and gain agreement with highway authorities, park administrators, and others in charge of facilities to aid in study designs could make an enormous contribution to increased precision of estimates of the effects of road and other environmental modifications.

The AAA Foundation for Traffic Safety, in collaboration with state highway departments, developed a system for roadway modifications based on severe crashes on sections of roads in various US states (Harwood, et al., 2010). The studies included maps of roads with relatively high and low risks, ratings of roads as to protective features, and follow-up to see if modifications made a difference in injury risk. Unfortunately, they combined fatal and unreliable A-rated "severe or disabling" injuries. The report is devoid of references to previous research. While such an effort may help to motivate states to do more to improve the safety of roads, it would likely be more effective if more reliable data were used. As noted in Chapter 6, the A-rated injuries recorded by the police are often not serious, and serious internal injuries are sometimes not detected by police.

INSPECTING HAZARDS. Regulation that provides for inspections, such as the workplace inspections of the Mine Safety and Health Administration and the Occupational Safety and Health Administration, could have effects analogous to those discussed for legal controls of individual behavior in Chapter 12 -- general deterrence and specific deterrence. If corporate executives in a position to make changes wish to avoid citations and fines, they could make the changes in the absence of actual inspections (general deterrence). Some may make changes only after citation by inspectors (specific deterrence) and others may not respond even under those conditions.

A substantial increase in the regulation of coal mines followed the enactment of the U.S. Federal Coal Mine Health and Safety Act of 1969. Death rates of miners in the prior ten years showed no trend but declined rapidly in the 1970s (Weeks and Fox, 1983). I have found no attempt to study differential effects in mines inspected versus others to delineate the effects of frequency and quality of inspections. The inspections of coal mines were intense relative to other occupational settings, with about 34,641 inspections of 2,131 active underground mines in 1977 for example. Inspections are more frequent in mines whose workers are organized in labor unions (Morantz, 2011).

The probability of inspection of workplaces regulated by the Occupational Safety and Health Administration (OSHA) was much lower than that of mines in the 1970s and declined substantially in the 1980s. A business could expect to be inspected once per 20 years in 1977 if the inspections were random (Mendeloff, 1979). OSHA targeted industries with higher injury rates for more frequent inspections and some plants were inspected every few years. Several econometric analyses of trends in worker injuries found no effect of OSHA (Mendeloff, 1979; Smith, 1976; Viscusi, 1979). Further analysis of disaggregated data found an effect in one instance but not significantly so in another (Smith, 1979).

One of the economists who found no effect of OSHA inspections claimed that increased protection of workers would be offset by behavior changes (risk compensation again) and that fines for plants cited were too low to provide an incentive for workplace modification in any case (Viscusi, 1979). In a project originally intended to study the epidemiology of worker injuries in three metalworking plants over eight years, I and a colleague serendipitously discovered new data on the issue of the effects on injury rates of workplace inspections (Robertson and Keeve, 1983).

Individual differences in injuries in the plants were mainly correlated to the type of work being done in specific departments with some correlations to worker age, formal education, and the number of previous employers. Using regression estimates of the effects of these factors at the individual level, the expected injury rate in a given year in a given plant was calculated and compared to the actual rate. The actual rates were separated into injuries that could be observed objectively in the plants' clinics (lacerations, burns, amputations), which we called "objective injuries", and those that were discernable as to incidence or severity primarily by patient complaint (mainly back pain), which we called "subjective injuries". Figure 13-1 is a comparison of the actual and expected rates per year in one of the plants. Noting that the actual rates varied from the expected rather sharply in certain years, we asked ourselves what other factors might have affected the rates in a given year. Two obvious external factors were OSHA inspections and Workers' Compensation available to workers who missed work because of injury. When the effects of these factors were examined, "objective" injuries declined relative to those expected in the year following OSHA inspections, and "subjective" injuries increased more than expected when Workers' Compensation increased above inflation (Robertson and Keeve, 1983).

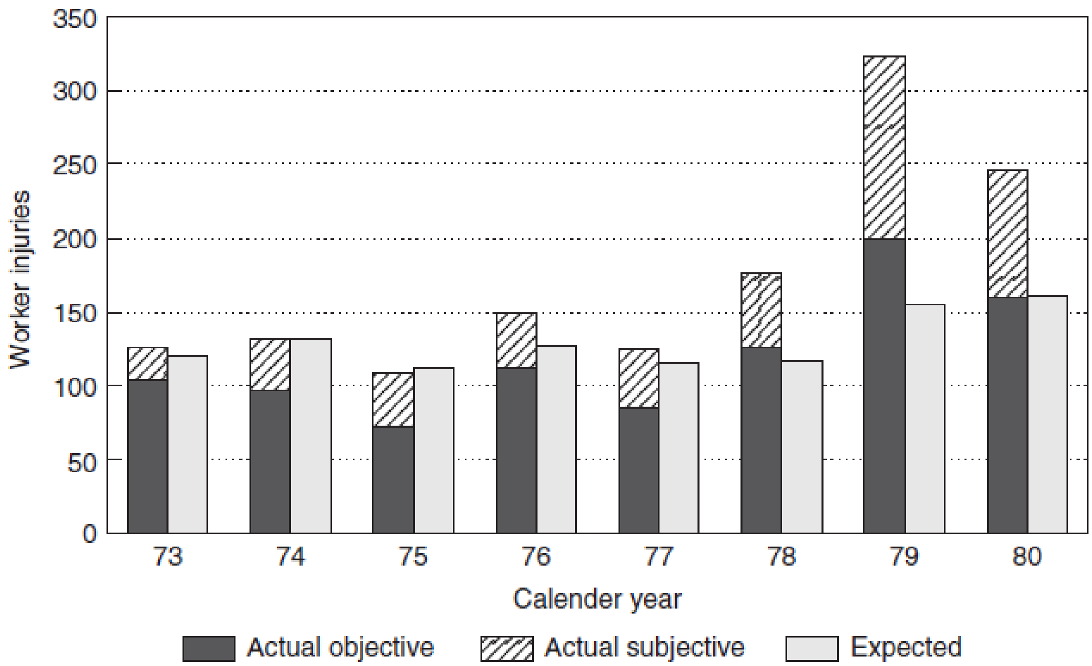

Figure 13-1. Actual Versus Expected Objective and Subjective Worker Injuries in a Metal-Working Plant

The lack of the effect of OSHA in the previous studies of aggregated data was apparently due to the failure to control for workers' compensation effects. We also examined the change in lost workdays from 1975 to 1976 among industries in 20 states, and the injuries decreased in correlation to an increase in OSHA inspections but increased when workers' compensation increased. If "risk compensation" occurred at all, it did not offset the effects of OSHA inspections, but actual compensation that allowed the workers to take time off likely did affect their absence when they could afford to be away from work, particularly for pain and strain, when working and not working is more discretionary.

The economic theory that the fines for OSHA violations were too small for deterrence did not seem a factor in the plants studied. We were given free access to correspondence regarding OSHA citations and it was obvious that management took the citations very seriously, in some cases spending more time and travel to persuade OSHA to reduce a fine than the amount of the fine. The deterrent effect of OSHA inspections did appear to be specific and temporary. Lagged correlations indicated no effect of an OSHA inspection beyond the first year following an inspection.

QUALITY CONTROL. Reducing hazards in products during the production phase may also be important for reducing injuries. In any manufacturing process, variances will occur in the products produced. Prudent manufacturers employ an inspection system to identify and correct safety defects from variances in manufacturing processes, as well as other aspects of the quality of the product. Some manufacturers install internal checks on the operability of safety and other systems even after the product is sold. For example, the airbags and some other systems in motor vehicles are checked electronically each time the vehicle is started.

An important issue in quality control of the manufacturing process, particularly for products or components that can increase injury and death, is how many to inspect and the criteria for rejection of a defective product or inspection of a total batch for defects when one or more is found in a sample. The cost of an inspection is a small proportion of the cost of relatively expensive products, such as cars, but adds proportionately more to the price of inexpensive items, such as matches, propane lighters, and hand tools. In some cases, the inspection of every unit produced may not be feasible and a sample of the products in a batch is inspected.

The probability of finding a percent of defects in a batch is highly sensitive to the size of the sample inspected. Websites are available that allow manufacturers to estimate the probability of defects in a batch of products (e.g., https://reliabilityanalyticstoolkit.appspot.com/acceptance_test_sampling).

The size of samples used in quality control is proprietary to the manufacturers. The author is aware of no federal or state standards for the sample size to detect defects from manufacturing variances. Motor vehicle manufacturers are required to report known design defects or defects due to design or manufacturing variances to the National Highway Traffic Administration, but known defects have not always been reported.

A requirement that sample sizes used for detecting defects be revealed publicly, as well as the numbers found, and the procedure for inspecting the batch, given defects in the sample, would likely result in greater manufacturer attention to the problem. It would also give epidemiologists a tool to correlate the types of quality control and sample sizes to injury incidence and severity related to product variations.

Appendix 13-1 **Evaluation of U.S. Motor Vehicle Safety Standards**

Motor vehicles were essentially unregulated in the United States until the 1960s except for a few consensus standards adopted by the states, such as for headlamps. Installation of lap belts in front outboard seats was required by several states in the early 1960s, and, by 1964, the manufacturers installed them in passenger cars as standard equipment. The federal government required certain standards, such as energy-absorbing steering assemblies and windshields, in 1966 and later models sold to the government, and the manufacturers included these features in public sales of certain models that also were sold to the government in substantial numbers. In 1968 and subsequent model years, the federal government required numerous standards, including several to reduce energy exchanges of occupants and vehicles in crashes and several to reduce the incidence, such as reduced glare in drivers' eyes, redundant brakes, and side running lights.

Since national data disaggregated by type, make and model of vehicles in crashes were not available until FARS (now called the Fatal Analysis Reporting System) began in 1975, it was necessary to assemble state data to obtain such detailed information. I undertook such a study using police reports of fatal crashes in Maryland to evaluate the overall impact of Federal Motor Vehicle Safety Standards. The data indicated that during the calendar years 1972-1975, occupant deaths averaged 44 fatalities per 100,000 cars in pre-1964 model cars, 35/100,000 for 1964-1967 cars, and 27/100,000 for 1968-1975 model cars, a decline of 39 percent from unregulated pre-1964 cars to the federally regulated cars (Figure 13-2). Deaths to pedestrians struck by the cars, compared by model year, were not significantly different -- 8/100,000 for pre-1964 cars, 10/100,000 for 1964-1967 cars, and 9/100,000 for 1968-1975 cars (Robertson, 1977).

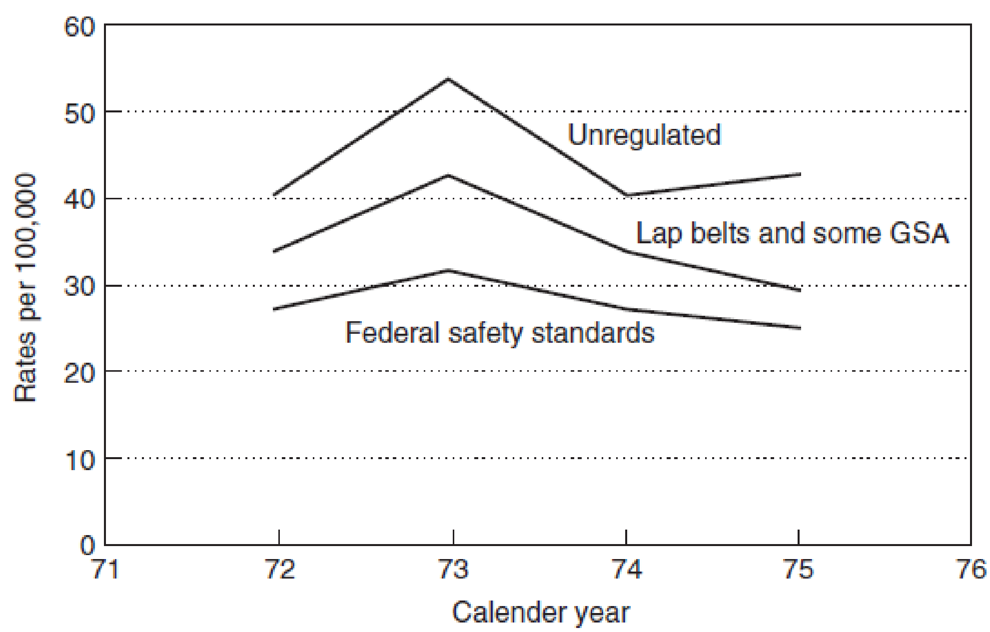

Figure 13-2. Death Rates to Car Occupants in Maryland: 1972–1975.

Factors such as driver age and vehicle age that later came into contention regarding the effect of regulation were not found in the Maryland study. The percentage of youthful drivers (in this case less than 26 years old) was slightly less in the older, unregulated cars -- opposite to subsequent conjectures that older cars had higher rates because they were driven by younger drivers. The death rate of the pre-regulation cars 1960-1963 model cars during 1972-1975 in Maryland was the same as the national death rate for passenger cars in the calendar years 1960-

1963, 44 per 100,000 registered. Therefore, the age of the vehicles did not explain the reductions in deaths of occupants of regulated vehicles.

After completion but before the publication of the Maryland study, an economist published a study using aggregated trends in motor vehicle fatalities and other factors in an attempt to evaluate the effect of motor vehicle safety regulations on fatality rates. He argued that drivers with increased occupant protection would drive more "intensively" -- the "risk compensation" or "risk homeostasis" hypothesis -- and kill more pedestrians.

His study design involved projections of expected death rates based on correlations of death rates and trends in other aggregated data over time. He included separate regressions of the total occupant and "pedestrian" death rates from 1947 to 1965, allegedly using as predictors: alcohol consumption per capita, average speeds on rural roads, linear trend, ratio of younger to older persons in the population, income, and cost of crashes in those years. The regression equations were then used to project the expected death rates from 1966 through 1972 based on year-to-year indicators of the other variables during that time. The actual occupant rates were less than expected but the "pedestrian rates" were greater than expected, the latter offsetting the former. The results, he said, supported risk compensation theory and indicated no net benefit of the regulation (Peltzman, 1975).

Having found no effect of regulation on pedestrian deaths in the Maryland study, perhaps because the numbers were too small for statistical power, I obtained the data used in the econometric analysis in an attempt to account for the difference in results of the two studies. The econometric study was laced with methodological errors. Not only were regulated and non-regulated cars not separated, but occupants of unregulated trucks and "pedestrians" struck by them also were not disaggregated from regulated cars. Motorcyclists were counted as “pedestrians" and single-vehicle motorcycle crashes were not disaggregated from those in collisions with other vehicles. Motorcycle registrations were doubling every five years, guaranteeing a substantial increase in their deaths.

There were also problems with the predictor variables. The alcohol-consumption variable excluded beer. The crash-cost index was based on the Consumer Price Index for auto repair services, which includes such things as oil changes and filters, but not the cost of auto parts damaged in crashes. The "youth" variable was the ratio of 15-24-year-olds to older persons in the population rather than their percentage as licensed drivers or drivers in crashes, which was known for all but three of the earliest years studied.

A regression equation based on 1947 to 1960 data did not predict the rates in 1961-65, a simple check on the validity of the model that would have ruled out its use to evaluate regulation. Some of the predictor variables were virtually substitutes for one another, a condition called multi-collinearity that distorts regression coefficients, and their correlations changed drastically in the pre-and post-regulation periods, guaranteeing invalid projections (Table 13-1). Although just what was considered "intensive" driving was not specified, the most likely candidate, speed, was used as a predictor variable rather than an outcome variable (Robertson, 1977).

Table 13-1. Correlation Matrix of Data Used by Peltzman (1975) to Project Fatality Rates, 1947–1965 (1966–1972 in parentheses)

	1.	2.	3.	4.	5.
1. Crash cost index	—				
2. Income/capita age 15+	–.87 (.88)				
3. Linear trend	–.92 (.80)	.97 (.95)			
4. Alcohol consumption	–.85 (.72)	.90 (.95)	.91 (.91)		
5. Average rural speed	–.89 (.68)	.98 (.88)	.98 (.85)	.89 (.96)	
6. 15- to 24-year-olds/ older population	–.34 (.78)	.29 (.95)	.37 (.99)	.57 (.91)	.32 (.99)

Since the publication of that inept study, it has been cited frequently as gospel in the economic literature, usually without reference to my critique and other research contradicting it, including one study on similar regulations in Sweden published later in the same journal (Lindgren and Stuart, 1980). A recent book on alleged government failures cited the Peltzman (1975) study as fact rather than reviewing the contradictory research (Schuck, 2014).

When the FARS data became available for several years (1975-1981), it was possible to separate data on regulated and unregulated vehicles nationally. Using a survey of mileage per vehicle age, the effect of state and federal regulations on death rates per mile of occupants, pedestrians, motorcyclists, and pedal cyclists in collisions with specific vehicles were estimated in a regression equation, controlling for age of vehicle and type of vehicle (cars versus trucks). The data indicated that significant reductions in car occupant death rates were associated with state regulations, and deaths both to car occupants and non-occupants struck by cars were lower in those subject to federal safety standards. These results were consistent with the fact that state lap-belt requirements and standards for government cars in 1964-67 models were exclusively aimed at occupant protection in crashes while the 1968 and subsequent federal standards included crash avoidance. The occupant death reduction was similar to that found in the Maryland study, 40 percent (Robertson, 1981).

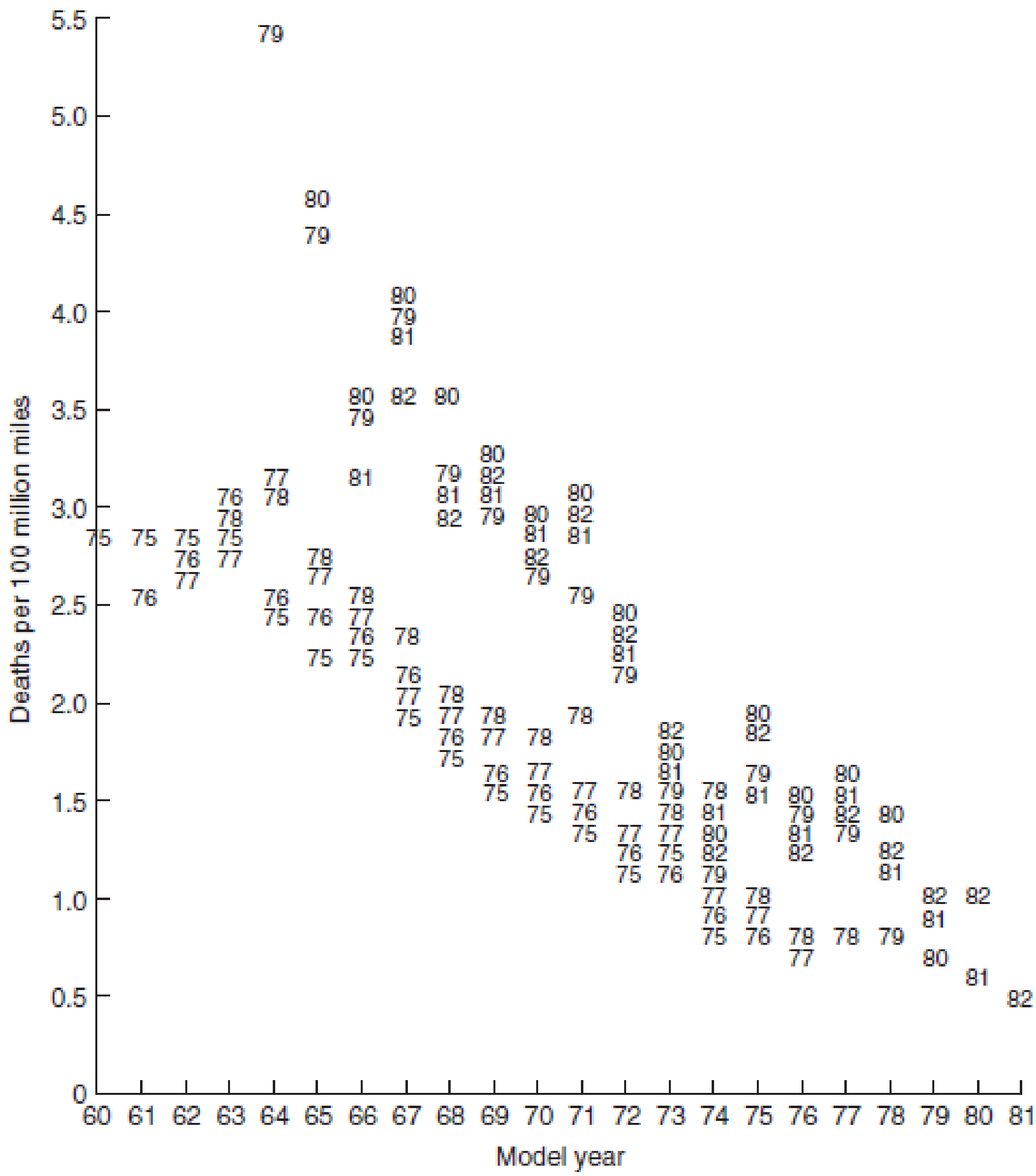

Figure 13-3. Death Rate by Model Year (Calendar Year as Data Points).

The study of the FARS data was attacked by an economist who claimed that it was inappropriate to compare cars to trucks Because the age of the vehicle and model year was correlated, the critic said that the regulatory effect was greatly reduced mainly by his estimate of a vehicle-age effect (Orr, 1984). His estimate of lives preserved, however, was miscalculated by 38 percent using his regression coefficients (Robertson, 1984). A simple graph shows that the primary decline in death rates occurred related to the model year of the vehicles and not vehicle age, as indicated by the calendar year in Figure 13-3.

The most misleading characterization of the alleged vehicle-age effect was presented at a conference at General Motors. Graphs of model-year differences were separated by calendar year, removing rather than demonstrating the vehicle-age effect and totally and mistakenly attributing all model-year differences to vehicle age (Adams, 1985).

Since more data is accumulated each year in the Fatal Analysis Reporting System (FARS), the opportunity to evaluate the effects of safety standards and other factors is available as conditions change. The adoption of safety standards virtually ceased from 1978 to 1987. The Reagan Administration rescinded the federal standard that required seat belts that automatically encircle front-outboard occupants or, in the alternative, airbags. It was restored in the late 1980s only after the courts ruled that the administration had acted illegally. The National Highway Traffic Safety Administration did continue frontal crash tests of a selection of cars annually and published the results. Manufacturers were embarrassed enough by the reported forces on occupant test dummies at 35 miles per hour that on occasion they requested a retest after modifying the vehicles.

The crash tests indicated incremental improvement in crashworthiness during the 1980s, as evidenced by reduced forces on crash-test dummies. Research on fatalities to occupants in frontal crashes indicated reduced deaths in frontal crashes of vehicles that performed well in the crash tests (Zador, et al., 1984b; Kahane, 1994), but the research designs of these studies did not allow for the possibility of offsetting behavior -- the alleged increased risky driving. Seat belt use laws, enacted by the states from 1985 to 1990, largely accounted for more than doubling seat belt use (National Highway Traffic Safety Administration, 1975-1991), and alcohol in fatally injured drivers declined about 20 percentage points during the 1980s (National Highway Traffic Safety Administration, 1995).

By combining FARS data with data from other sources on vehicle use and belt use, I assessed the effects of the various mentioned government policies. Death rates per 100 million miles used in which passenger cars were involved, by the model year of the vehicles and whether the death was to one or more occupants of the cars, were tabulated for model years 1961-1990 in each of the calendar years 1975-1991. The miles per vehicle of a given age in a 1988 mileage survey (Energy Information Administration, 1990) were adjusted to other years by multiplying them by the ratio of average miles driven in other years to the 1988 average (Federal Highway Administration, 1975-1992). The mileage survey included periodic calls to the same households to obtain odometer readings, which is probably more valid than asking people their annual mileage. Rates were available on 254 combinations of vehicle model year and calendar year.

Two sets of rates per 100 million miles were analyzed separately: 1. occupant fatalities, 2. crashes fatal to non-occupants (occupants of the other vehicle in multiple-vehicle crashes, pedestrians, and bicyclists). The first allows an estimate of the effects of safety standards, improved crashworthiness, and other factors on all occupant deaths. The second examines possible effects on other road users. If there is offsetting behavior, non-occupant death rates should increase related to regulation, crash test publicity, or belt use.

Since the General Services Administration imposed some safety standards in 1966 on cars sold to the government and the standards for all cars began to be imposed in 1968, the absence of standards is correlated with vehicle age. Data on the 1975-77 models were available for a full 15 years of vehicle use. The death rates (each of the two sets separately) per mile were calculated for these model years for each year of age and averaged among the three model years. The death rates were neither linear nor monotonic as the vehicles aged (Robertson, 1996). Ten to fifteen-year-old 1975-77 models had substantially lower death rates than the ten to fifteen-year-old pre-regulation vehicles. The 1975-77 rate for a given aged vehicle was used as an expected rate for a vehicle of that age to control for variation attributable to vehicle age.

Other factors considered were the "downsizing" of vehicles and economic conditions during a given calendar year, both of which have been correlated to death rates, observed seat belt use in a given calendar year, and percent of drivers with alcohol greater than 0.10 percent by weight in a given calendar year. Smaller vehicles have higher occupant death rates because of less interior space to decelerate and deaths per mile are marginally higher in years of greater economic prosperity. Wheelbase, the distance from the front to the rear axle, is the best predictor of differences in fatality rates due to vehicle size (Robertson, 1991).

To control for vehicle size, the death rates per mile in the calendar year 1988 were calculated for seven categories in five-inch increments of wheelbase (from <95.1 to 120.1+), using the 1988 mileage survey and decoded vehicle identification numbers for make and model of vehicle in the fatal file and mileage survey file. Expected fatalities were calculated by multiplying the 1988 rate for each size times the number of vehicles of those sizes sold in a given model year, discounted for numbers scrapped as they aged (Ward's Automotive Yearbook, 1960-1992; Flammang, 1992). The expected number was then divided by the mileage previously estimated for each model and calendar year. The index of industrial production was used as an indicator of economic activity (Council of Economic Advisors, 1994). Belt use in a given model calendar year was included in the annual survey of 19 cities and their environs, extrapolating for a few years in which the survey was not done (National Highway Traffic Safety Administration, 1975-1991). Percent of alcohol in fatally injured drivers for each model-calendar year was obtained from FARS in states that test 80 percent or more of such drivers.

Ordinary least-squares regression was used to estimate the effects of the various factors. The variable for minimum safety standards was zero for pre-1966 models, incremented from one to twelve in 1966-1977 models, and assigned a twelve for 1978-1991 models. As noted, the reduction in occupant death rates is incremental in 1966-1977 models, partly because of the imposition of new standards in various years of that period and partly because of delays in meeting the standards in some models. The publication of crash test (NCAP) results began in 1979, so the NCAP variable is zero for 1961-1979 models and incremented by one, from one to eleven consecutively, for 1980 to 1990 models, based on the assumption that crashworthiness was improved incrementally as the crash test results for particular makes and models became known.

The regression coefficients for the predictor variables are presented in Table 13-2. Controlling for the expected effects of vehicle age and size differences, the incremental model years in which minimum standards were imposed and the model years during which NCAP tests were publicized are strong predictors of reduced occupant death rates and are somewhat related to reduced nonoccupant fatal crash rates.

Table 13-2. Regression Estimates and 95% Confidence Intervals of the Effects on Passenger Car Death and Fatal Crash Rates per 100 Million Vehicle Miles, 1961–1990 Cars in 1975–1991

Variable	Occupant Deaths	Nonoccupant Fatal Crashes
Standards	–0.260 ± 0.023	–0.055 ± 0.010
NCAP publicity	–0.077 ± 0.033	–0.029 ± 0.020
% Belt use	–0.007 ± 0.006	–0.006 ± 0.004
% Alcohol > 0.10	0.007 ± 0.006	0.007 ± 0.005
Calendar year	–0.017 ± 0.036	–0.016 ± 0.022
Industrial production	0.029 ± 0.014	0.019 ± 0.009
Expected age of vehicle effect	0.444 ± 0.212	0.289 ± 0.096
Expected wheelbase effect	1.066 ± 0.454	1.252 ± 0.299
Intercept	–0.793	–1.950
R^2	0.92	0.86

In the 1966-1977 model passenger cars, the reduction was an average of 0.26 death per 100 million vehicle miles (mvm) per model year across 12 model years for a total reduction of 3.12 deaths per 100 mvm (.26 x 12). The reduction in 1980-1990 models was 0.077 per model year, a total of 0.847 per 100 mvm in 11 model years (.077 x 11). The effect of belt use increases and alcohol reductions were much less. A 40-percentage point increase in belt use reduced the rate .28 (40 x .007) and a 20 percentage point reduction in alcohol reduced the rate .14 (20 x .007).

The rates increase marginally in more economically prosperous years as indicated by the predictive coefficient on the Index of Industrial Production. There is no significant linear trend in the rates independent of the other predictor variables as indicated by the coefficient on the calendar year.

The results support the conclusion that vehicle-related fatalities were reduced substantially by increased crashworthiness and somewhat by increased seat belt use and reduced alcohol use. Contrary to offsetting behavior theory, the evidence indicates that the reduction of fatalities per mile attributable to increased crashworthiness of passenger cars and increased seat belt use was not attenuated by increased risk to others from more protected drivers. Indeed, more regulated vehicles were in fewer crashes fatal to other road users.

There are reasonable explanations for the latter. The minimum safety standards included crash avoidance standards (redundant brakes, reduced glare in driver's eyes, and side running lights) as well as crashworthiness standards. The period of NCAP tests and increased seat belt use was also the period of increased aerodynamic designs to save fuel, which may, coincidentally, reduce the severity of pedestrian and cyclist impacts. The points and edges on older models were related to increased risk to pedestrians (Robertson, 1990). The "crumple zones" that absorb more energy may help reduce the velocity changes to occupants of other vehicles in crashes with the more crash-worthy vehicles.

Although most of the reductions in occupant deaths are model-year specific during the period of regulation or publicized crash tests, and therefore vehicle rather than the driver or environmentally based, the data do not allow the conclusion that all of the reduction is attributable to regulation or embarrassment. Some aspects of crashworthiness might have been adopted without government standards had there been no regulation, although the failure of most manufacturers to adopt available technology, until required to do so in the 1960s, and the 18-year battle against the airbag in the 1970s and 1980s, suggests otherwise. And concern for sales lost to manufacturers of vehicles that had better crash indices in the NCAP tests may have motivated improvements, irrespective of embarrassment.

Following that study, another econometric study was published that claimed offsetting behavior (Chirinko and Harper, 1993) apparently from failure to separate passenger cars from pickup trucks and utility vehicles in a time-series analysis. This will give false results on the effects of regulation on passenger cars, not because the regulated cars are more often hitting trucks as claimed by recent proponents of the risk compensation hypothesis, but because the government failed to impose standards to reduce rollover of unstable pickup trucks and utility vehicles that have grown substantially in use. (See Chapter 8, Appendix 8-1).

This discussion may seem to be only an academic quarrel over study designs, but it had more ominous results. The anti-regulation administrators of federal agencies in the 1980s until recent years were often advised by neoclassic economists, and those who attempted some feeble extension of safety regulations were blocked by the neoclassic economists and others in the Office of Management and Budget in the White House. The long delay in the adoption of airbags was but one of many delays in regulations influenced by these governmental debates.

Economic determinists have claimed that the reversal in the growth of road deaths among more economically developed countries in the second half of the 20^{th} Century was mainly a function of economic development. They think that such a reversal in developing countries will occur only when those countries reach a level of economic growth similar to the more economically developed countries. But the change in the developed countries occurred when scientists realized that road death could be controlled by focusing on vehicle and road characteristics rather than driver error and politicians implemented laws that included that focus (Bhalla and Mohan, 2016).

Appendix 13-2. Increased automation, vehicle safety ratings, and fatality rates.

Tests of passenger vehicle crashworthiness and certain crash avoidance technology in makes and models of new vehicles are conducted by the Insurance Institute for Highway Safety (IIHS) in the U.S. and scores for each vehicle on four-point scales are posted online (IIHS, no date). The U.S. National Highway Traffic Safety Administration (NHTSA) uses 5 stars to rank crashworthiness based on full frontal and side crash tests and rollover propensity but only lists the availability of some crash avoidance technologies on each make-model (NHTSA, no date). The Euro New Car Assessment Program tests both crashworthiness and crash avoidance technology and assigns percentages to the performance of each (Euro NCAP, no date).

In the past, crash tests and research on vehicle factors related to injury had a major influence on the improved crashworthiness of vehicles. Ratings of the safety features of new vehicles are taken seriously by manufacturers. When their vehicles receive the IIHS "Top Safety Pick" or NHTSA's 5-star rating, they often use the information in their advertising. But the IIHS ratings and top picks are not comparable across all vehicles; they are awarded within size classes. The webpage that discusses the criteria for top picks says. "These awards identify the best vehicle choices for safety within size categories during a given year. Larger, heavier vehicles generally afford more protection than smaller, lighter ones. Thus, a small car that qualifies for an award might not protect its occupants as well as a bigger vehicle that doesn't earn the award" (Insurance Institute for Highway Safety. No date). The Top Safety Pick web pages for new models in 2022 included 92 vehicles that did well on crash tests, headlight ratings and "superior" on automatic emergency braking (AEB) tests. When the vast majority of vehicles are rated highly, the incentive for improvement is removed.

For almost half a century, the role of vehicle size and weight in road safety has been controversial. In 1974, researchers at IIHS analyzed injuries to unbelted occupants in car-to-car crashes based on the physics of size and weight of the colliding vehicles using data from the University of North Carolina Highway Safety Research Center. In those days seat belt use was about 10-15 percent in the U.S. The physics presented in the report predicts that vehicles with interior space for occupants to decelerate in a crash should have lower occupant death rates. Adding weight to a vehicle increases the energy of vehicles moving at the same speed. Kinetic energy is ½ mass multiplied by velocity squared. Therefore, heavier vehicles should result in increased deaths, particularly so to occupants of the lighter-weight vehicle in multi-vehicle collisions but also with other road users to the extent that braking distances are longer for heavier vehicles. The data on fatal crashes available at the time supported the conclusion that weight relative to the size of vehicles should be minimized and that wide variation in the weight of vehicles in use is detrimental to road safety (O'Neill, Joksch, and Haddon, 1974). While there is no doubt that occupants of lighter-weight vehicles in crashes with heavier vehicles suffer more lethally abrupt deceleration, the problem is at least as much the weight of the heavier vehicle as that of the lighter-weight vehicle. The net effect on the total fatal crash rate depends on whether fewer deaths would have occurred if the vehicles in multiple-vehicle crashes were of more similar weights. Vehicle-to-vehicle crashes produce a minority of fatalities in the U.S.; about 35 percent of vehicles in fatal crashes during 2018 were in multiple-vehicle collisions. Deaths also occur when single vehicles strike fixed objects, roll over and collide with road users unprotected by a shell, mainly pedestrians, pedal cyclists, and motorcyclists.

Another IIHS-supported study of 1440 fatal crashes in Maryland during 1971-1972 found that occupant death rates per registered vehicle were higher in vehicles with shorter distances between the front and rear axles (wheelbase) but the reverse was found for vehicles that struck pedestrians. When all fatal crashes were included, passenger cars with wheelbases less than 106 inches were about 10 percent more often involved than those with wheelbases 121 inches or longer but the rate of pickup trucks was 24 percent more than that of the smaller cars. By far the highest fatal crash involvement per registered vehicle involved motorcycles and tractor-trailer trucks. The authors suggested that future studies of vehicle size should include all road users (Robertson and Baker, 1975). Nevertheless, most of the studies of vehicle size and weight in subsequent decades focused on deaths of occupants, usually drivers only, relative to the size and weight of vehicles in two-vehicle crashes. The weight of road vehicles has consequences other than road deaths. Heavier vehicles that are fueled by gasoline or diesel oil deplete more of those resources and emit more carbon dioxide per mile driven, one of the major contributors to global warming.

Statistical research on motor vehicle size and weight as predictors of fatalities in crashes is complicated by the correlation of size and weight. When predictors of an outcome such as road deaths are strongly correlated, the coefficients in regression models may be distorted (Selvin, 1991). General Motors researchers produced a study of deaths to drivers of vehicles in use during 1975-1989 in two-vehicle crashes that attempted to distinguish the effects of size and weight. When wheelbases of the colliding vehicles were near equal, the authors said, there was a substantial vehicle weight effect on fatalities but when the weights were similar, the effects of wheelbases were negligible. They concluded that weight is more important than size and derisively claimed that research finding reducing weight to increase fuel economy would not have a major effect on road deaths is "the triumph of zeal over science, or perhaps even common sense" (Evans and Crick, 1992). Their graphs, however, showed a wide scatter in the death risk among drivers of vehicles of similar wheelbases but different weights. In his retirement, the senior author revealed in a newspaper opinion piece that he is a climate change denier (Evans, 2010).

A subsequent study of 1999-2000 model year passenger cars, vans, and sports utility vehicles involved in all road deaths during the calendar years 2000-2004 found that driver deaths were lower in association with curb weight but all deaths were higher in association with curb weight. Both driver and all deaths were lower in association with turn distance, an indicator of size less correlated to weight than wheelbase, corrected statistically for performance in crash tests and static stability. Better performance in IIHS and NHTSA crash tests as well as higher static stability was also associated with a lower risk of driver and all deaths (Robertson, 2006). A study of changes in the average and dispersion of vehicle weights in association with CAFÉ standards found that the standards likely reduced road deaths by a few hundred annually as of 2005 (Bento, Gillingham, and Roth, 2017).

The mix of vehicles in use is a function of what manufacturers and retail dealers choose to offer and promote for sale and what vehicle buyers are willing to buy. The average vehicle is in the national fleet for substantially more than a decade. Whether buyers are influenced much, if any, by safety ratings or vehicle weight among the myriad characteristics of vehicles in the marketplace is open to question. A 1989 survey of U.S. new vehicle buyers indicated a variety of factors they say influenced the purchase. Weight was not included as a choice in the questions asked but fuel efficiency, a strongly inverse correlate of weight at that time, was deemed desirable. So were size and safety (Tay, 1998). A study of vehicle sales before and after IIHS issued new ratings suggested that the ratings affected sales (Cicchino, 2015).

The most astonishing trend in vehicle mix in the U.S. is the increased market share of sport utility vehicles (SUVs) and pickup trucks, clumped together in national statistics because most of the original SUVs in the 1970s and 1980s were mounted on truck frames. In 1970, only 17 percent of registered vehicles were "light trucks". The registrations, including SUVs, increased to 28.8 percent in 1990, 39.3 percent in 2000, 45.5 percent in 2010, and 58.5 percent in 2020 (U.S. Department of Transportation, annual). In the 21st century, new pickup trucks are larger and heavier than their predecessors for the most part while SUVs vary widely in size and weight. Based on an analysis of vehicle and driver characteristics in severe injury crashes around the turn of the century, one study concluded that if all cars of the same weight as SUVs and pickup trucks had been the latter vehicles, occupant deaths would have been 26 percent and 64 percent more frequent respectively (Wang and Kockleman, 2005). Another characterized the increase in sales of heavier SUVs and pickup trucks as an "arms race" (White, 2004). A study of pedestrian deaths per number of pedestrians struck found that pickup trucks, SUVs, and large vans were more deadly (Lefler and Gabler, 2004).

For the past three decades, IIHS periodically published in its newsletter, Status Report, driver death rates by make and model of recently sold passenger vehicles.

In a commentary accompanying each publication, vehicle size and weight were emphasized as major factors in the differences in driver death rates. The Institute's classification of vehicles as "small", "midsize", "large", and "very large" is based on a combination of weight and length times width that the Institute calls "shadow". There is a large variation in weight within categories. For example, a passenger car classified as "small" can be up to 4000 lbs. in weight but a car classed as "midsized" can be as little as 2500 lbs. in weight (Highway Loss Data Institute, 2020). Since size and weight are highly correlated, the variation of weight within the size classes is not that large in recently manufactured vehicles.

The most recent IIHS publication of variation of driver death rates in these size classes as well as separate ones for SUVs and pickup trucks and "luxury vehicles" included 2014-2017 models in use during 2015-2018. The headline read "Driver death rates remain high among small cars" (Insurance Institute for Highway Safety, 2020). The data in the table, however, showed a huge variation in driver death rates and little relation between the rates and vehicle size. In the "small" passenger car category driver deaths varied from zero to 98 per hundred registered vehicle years with a median of 45. The median for "large" cars was higher, 50, and a little less, 41, for "midsize" passenger cars. A similar pattern occurred among SUVs – the median driver death rates of "small", "mid-sized" and "large" SUVs were 29, 16, and 25.5 respectively. Such a pattern does not support the "small is bad" rhetoric. Only driver deaths are included under the assumption that the inclusion of all occupants could cause variation in rates because some vehicles may systematically carry more occupants than others. The potential effects of size and weight on the deaths of other road users were ignored. Previous research on the association of vehicle safety ratings and injury rates produced mixed results regarding the predictability of injuries from ratings but none included vehicle weight or recent crash avoidance technology (e.g., Harless and Hoffer, 2007; Lidbe, et al, 2020; Phillips, et al. 2021; Segui-Gomez and Lopes-Valdez, 2007).

This study was undertaken to assess vehicle weight, test-based safety ratings, and available crash avoidance technologies as fatal crash risk factors. The results suggest a better means to inform consumers about the relative importance of vehicle factors in road deaths.

Data on fatal crashes in selected calendar years by make and model of vehicles were downloaded from the Fatal Analysis Reporting System (NHTSA File Downloads, 1975-2020). In an attempt to account for the large variation in death rates by make and model, vehicle curb weight, NHTSA ratings of crashworthiness and rollover propensity, and IIHS ratings of crash test results, headlight performance, and automatic emergency brake (AEB) technology as options were examined for their value in predicting road deaths. Since the Fatal Analysis Reporting System codes by vehicle name do not include some of the distinctions that IIHS uses, where IIHS listed two or more versions of the same named vehicle to distinguish 2-wheel vs. 4-wheel drive and other distinctions, the counts of registered years were added together. Where one or more distinctions of the same make/model were excluded from IIHS data, the make/model was excluded from the analysis of 2014-2017 model year vehicles. Seventy make-models were included.

An attempt to use Poisson regression to assess the relative predictability of crashworthiness and crash avoidance technology was unsuccessful as the model failed to converge. Therefore, logistic regression was used to assess the risks of deaths by make and model of 2014-2017 models in 2015-2018 associated with the predictor variables. The form of the equation is:

Road deaths/years used (where a given make/model was involved) =
B1 (curb weight) +
B2 (small overlap frontal crash test) +
B3 (moderate frontal overlap crash test) +
B4 (side crash test) +
B5 (median headlight rating)
B6 (“Superior” AEB standard or optional) +
B7 (“Advanced” AEB standard or optional) +
B8(“Basic” frontal crash warning signal standard or optional)
B9(1 if pickup truck, else 0)
B10(1 if SUV, else 0)

To assess the reliability of the estimates, a second equation was applied to deaths among 2018-2019 models in their first two years of use. The adoption of AEB as standard equipment on 35 vehicles in those model years allowed the assessment of whether a correlation of AEB with increased risk in 2014-2017 models was an artifact of its previous optional status. Front and rollover ratings from NHTSA as well as lane departure warnings and adaptive cruise control as optional or standard equipment were also added to the second equation.

IIHS crash test and headlights are rated on a 4-point scale with the highest (“good”) value indicating safer. Results of roof strength were rated “good” on almost all the vehicles so it was excluded. Side crash tests by NHTSA were excluded for the same reason. When more than one headlight rating was included depending on trim, the median was used in the analysis. The frontal crash prevention technology labels, “superior”, “advanced” and “basic”, are based on IIHS low-speed tests of the initiation and performance of automatic braking or warning. These systems are supposed to detect situations in which braking is needed to avoid or reduce the severity of collisions. Essentially, the “basic” system warns drivers to apply brakes, and the designations “superior” and “advanced” are qualitative categories based on how the systems react as they approach stationary targets at varying low speeds on a test track (Insurance Institute for Highway Safety, no date). When these technologies were optional in most of the 2014-2017 models they were indicated as 1 if available and 0 if not. The few that were standard were also assigned 1. If the option changed from one year to the next, the variable was apportioned in fractions of 1. The percentage of sold vehicles equipped with the technology varied substantially among manufacturers (National Highway Traffic Safety Administration, 2019) but no data on the number sold by make and model were found.

In the analysis of 2018-2019 vehicles in their first two years of use, new vehicle sales by month were copied and pasted from goodcarbadcar.net or manufacturer websites. The number sold in a given month was multiplied by the months they were in use during two years. The sum of the months was divided by 12 to get the total years of use for each model year of each make-model. Since vehicle scrappage is minimal during the first few years of use, this method is likely more accurate than the once-a-year count of registered vehicles. Only vehicles with more than 100,000 years of use were included in the regressions. The presence or absence of lane departure technology and adaptive cruise control on a given make/model was obtained by searching manufacturer and dealer websites. Since it was not always possible to find whether these were standard or optional equipment, they were assigned 1 if available and 0 if not.

Table 13-3. Odds ratios and 95% confidence intervals of predictors of U.S. passenger vehicle fatal crash involvement

Predictor Variable	2014-2017 model vehicles during 2015-2018	2018-2019 model vehicles during their first 2 years of use
Curb Weight (100 lbs.)	0.983 (0.978, 0.988)	0.995 (0.987, 1.002)
IIHS small overlap front crash	0.895 (0.874, 0.916)	0.904 (0.852, 0.960)
IIHS moderate overlap front crash	0.974 (0.950, 0.998)	0.850 (0.755, 0.956)
IIHS side crash	0.951 (0.930, 0.973)	0.970 (0.928, 1.015)
IIHS headlights	0.900 (0.882, 0.918)	1.012 (0.958, 1.069)
NHTSA full front crash		0.995 (0.912, 1.085)
NHTSA rollover		1.021 (0.966, 1.080)
Lane departure warning (mostly standard)		0.858 (0.801, 0.919)
Adaptive cruise control (mostly standard)		0.982 (0.850, 1.135)
IIHS “Basic” Frontal Crash Warning	1.056 (0.998, 1.116)	0.860 (0.729, 1.017)
AEB Standard		1.336 (1.121, 1593)
IIHS “Superior” AEB (mostly optional)	1.153 (1.085, 1.225)	1.338 (1.203, 1.601)
IIHS “Advanced” AEB (mostly optional)	0.816 (0.752, 0.885)	1.785 (1.351, 2.357)
SUVs	0.710 (0.679, 0.743)	0.638 (0.576, 0.707)
Pickup trucks	1.636 (1.494, 1.791)	1.102 (0.935, 1.297)

The odds ratios and 95 percent confidence intervals of curb weight and the other predictor variables are presented in Table 13-3. Corrected statistically for the other predictors, higher weights were slightly correlated to lower fatality risk for the 2014-2017 vehicles but the confidence intervals overlap 1 for the 2018-2019 vehicles. The heaviest vehicles - pickup trucks - have a higher fatal crash involvement risk relative to cars, SUVs, and vans in 2014-2017 but the association was not significant for the 2018-2019 vehicles. SUVs were associated with lower risk in both samples. The IIHS crashworthiness ratings were predictive of lower risk in both samples but the side test was not significant for the 2018-2019 vehicles. NHTSA frontal crash tests and rollover ratings did not add significantly to the predictive value of the equation. Headlight ratings were related to lower risk in 2014-2017 vehicles but not enough to achieve statistical significance in 2018-2019 models. Lane departure warnings were related to lower fatality risk.

The fatal crash risk was higher in vehicles with optional "superior" AEB systems in both samples and AEB as standard equipment was predictive of higher risk in 2018-2019 vehicles. "Advanced" AEB was associated with a lower risk among the 2014-2017 vehicles but a higher risk among 2018-2019 vehicles. Adaptive cruise control and "basic" warning of the need to brake added no predictive value.

Most of the correlations among the predictor variables were very low. The highest R^2 was 0.25 between curb weight and pickup trucks. The regression estimates are not likely affected by collinearity among the predictor variables.

The IIHS inclusion of AEB systems as criteria for increased safety is not supported by these results. The IIHS tests of AEB technology are conducted at 12 and 25 miles per hour. In 2014, The National Highway Traffic Administration (NHTSA) performed AEB tests on four 2014-2015 model vehicles up to an approach speed of about 30 miles per hour. Of eight tests on each vehicle, only one met the criteria for reliable repeated performance (Forkenbrock and Snyder, 2015). Nevertheless, NHTSA and IIHS persuaded some 20 vehicle manufacturers to agree to provide AEB as standard equipment by 2025. Most did so earlier and almost all 2022 models have the system. A 2013 proposal to add AEB testing to NHTSA's New Car Assessment Program was not implemented but remains under consideration (Homedy, 2022). Manufacturers are likely to design their vehicles to get good ratings on NHTSA and IIHS tests. In 2022, the American Automobile Association reported tests of several AEB systems at 30 and 40 miles per hour. At the higher speed, the system failed to prevent a front-to-rear collision with a stationary plastic vehicle mockup in 14 of 20 test runs but reduced the speed of the crash by 62 percent on average. The system failed to prevent collisions at T intersections or when the vehicle was turning left across the path of an oncoming vehicle (AAA, 2022).

If the tests are not predictive of risk in the range of conditions that increase crash severity, they are not likely to reduce deaths, and the potential for harm cannot be ruled out. Interviews with early AEB adopters indicated that most leave the system turned on, believe that it had prevented crashes, and intended to have it when they purchased their next vehicle. The authors of that study noted that too much dependence on AEB by drivers or driver reactions to it should be more thoroughly researched (Cicchino and McCartt, 2015). A joint IIHS-MIT study of driver behavior during four weeks in more automated vehicles found increased use of cell phones and willingness to have hands off the wheel as they became familiar with the systems (Regan et al., 2021).

The lower risk of fatal crashes associated with lane departure warnings and increased risk associated with automated braking suggest the hypothesis that warnings increase driver alertness and attention but that automation reduces them. Based on regression analysis of numerous studies of insurance claims data, the Highway Loss Data Institute (HILDI) concluded the opposite. Several factors were included in the HILDI regression model in addition to crash avoidance technologies but neither curb weight nor IIHS and NHTSA ratings of crashworthiness were listed among them. There are large differences in the association of crash avoidance technology and insurance claims by type of coverage (HILDI, 2020). While the reasons for the differences in results using insurance claims data and the death data are not obvious, making an insurance claim for minor injury or property damage is discretionary while reporting a death is not. Litigation of liability claims can take years and insurance claims can be fraudulent.

Other researchers used a variety of comparisons in statistical studies that found AEB efficacious. Some of the earliest studies used “induced exposure” -- a comparison of crashes in which the technology should reduce crashes relative to other crash involvement of the same vehicles (Rizzi, Kullgren, and Tingvall, 2014; Fildes et al., 2015). If the technology increases the risk of those other crashes, inference of the effectiveness of the technology is compromised at best and misleading at worst. A study of rear-end crashes exclusively found that AEB was less likely to prevent a collision when either vehicle was turning rather than going straight and on roads with 70+ mph speed limits or on roads slickened by ice or snow. The system was less effective when the struck vehicle was not a passenger vehicle. Because most rear-end crashes are on dry roads with lower than 70 mph speed limits when both vehicles are going straight, the overall rear-end crash rate of vehicles with AEB was lower (Cicchino and Zuby, 2019). A study of an AEB system to detect pedestrians and slow or stop the vehicle automatically found that it was not associated with a reduction in nighttime pedestrian injuries (Cicchino, 2022) so IIHS recommends its use only during daytime. IIHS researchers have also suggested the use of driver monitoring technology that warns when inattention or lack of hand on the steering wheel occurs (Mueller, Reagan, and Cicchino, 2021). But what if AEB increases the risk of various types of crashes for reasons other than driver disengagement? An increase in U.S. Road deaths in 2020 was correlated mainly to increased sales of pickup trucks, lower fuel prices, and warming temperatures (Robertson, 2022) but increased numbers of vehicles with AEB systems may have contributed as well. In some of the vehicles with AEB, the driver has the choice of setting the system at warning only or turning it off. In others, the system is reset to "on" each time the vehicle is started so the driver must actively turn it off to prevent its use. A case-control study of vehicles in all fatal crashes compared to those at the same sites, same time of day, and day of the week can better discern the effect of technology as well as behavior such as speeding (Robertson and Maloney, 1997). Such studies of the types and usage of AEB technology are sorely needed.

Current safety ratings of new vehicles on the IIHS website indicate whether AEB is standard equipment, optional or missing but the Institute does not discuss the relative extent of risk reduction provided by these or the crash test and headlight ratings on each page devoted to specific makes and models. Lane departure warning systems related to lower risk are not included in the ratings. A consumer has no way to evaluate which ratings are the more important.

To achieve accountability by manufacturers and better inform consumers, more empirically derived and discriminating criteria must be employed in vehicle safety ratings. The regression analysis of IIHS and NHTSA test results in this paper is not definitive because some of the differences among vehicles are embedded in aggregated data where the technology was optional and the ratings on all of the variables except weight are qualitative summaries of quantitative data. But the analysis illustrates a means by which IIHS tests could be used to develop a more valid assessment of road death risk among vehicles. A better model would employ quantitative data from test dummy instrumentation and control for weight or size by retaining it in the model rather than showing separate results by arbitrary size categories. AEB tests should be expanded to include speeds at which more severe injuries and deaths occur and should be repeated numerous times each to gauge system reliability. To the extent possible, a model that scores each vehicle based on the probability of a reduction in all fatalities related to individual technologies could influence manufacturer and consumer choices to reduce road deaths. The resulting predictions of death risk for each make and model could be summarized in a single score expressed as a percentile. Anyone who has attended school should understand a grading system that varies from zero to 100. If the "Top Safety Pick" distinction is retained, it could be based on the vehicles that score above a selected percentile. The European vehicle testing agency rates vehicle components on percentage scales but does not combine them into an overall risk score. The most recent ratings on AEB varied wisely, from 14 to 95 percent (Euro NCAP, no date) based on a much more detailed testing protocol (Euro NCAP, 2019) than that used by IIHS. Whether the higher-scoring AEB systems reduce death and injury could be investigated by a case-control study in Europe.

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