The article below appears in ***Handbook of Transportation Science, Second Edition***, R.W. Hall Editor, Kluwer Academic Publishers, Norwell, MA, 67-112, 2002. Most of the topics in it are now treated in more depth and detail in ***TRAFFIC SAFETY*** (Copyright © 2004 by Leonard Evans). Click for ***TABLE OF CONTENTS***

4 TRANSPORTATION SAFETY

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4.1 Introduction

Specialists and the public widely use the term *safety*. Such use rarely generates serious misunderstanding even though there is no precise, let alone quantitative, definition of *safety*. The general concept is the absence of unintended harm to living creatures or inanimate objects. Quantitative safety measures nearly always focus on the magnitudes of departures from perfect safety, rather than directly on safety as such. Depending on the specific subject and on available data, many measures have been used.

A feature that measures of safety have in common is that they are, in essentially all cases, rates. That is, some measure of harm (deaths, injuries, or property damage) divided by some indicator of exposure to the risk of this harm. For example, rates related to driver deaths include the number of driver deaths per kilometer of travel, per vehicle, per licensed driver, and per year. Note that the number of driver deaths per year is just as much a rate as any of the other examples.

Even within a narrow portion of transportation (say, scheduled airlines or motorcycles), there is no one rate that is superior to others in any general sense. Which rate is appropriate depends on what question is asked (and also on what data are available).

While safety is an important consideration in many human activities, it has a particularly prominent role in transportation. Every type of transportation system involves some risk of harm, as has been the case since antiquity, and seems likely to remain the case in the future. The primary goal of transportation, the effective movement of people and goods, is better served by ever increasing speeds. A substantial proportion of technological innovation for the last few thousand years has focused on increasing transportation speeds, from animal-powered to supersonic flight. In general, as speed increases so does risk.

The Sinking of the Titanic

Some safety concepts can be illustrated by the best known of all unintended events in transportation safety -- the sinking of the *Titanic*. (We have no way to know whether in 90 years the intrinsically more important intentional events of 11 September 2001 will have left as indelible an impression on the world's consciousness). On Sunday 14 April 1912 the 47,000-ton liner *Titanic* maintained its top speed of 22.5 knots (42 km/h) despite receiving nine ice warnings. At 11:40 p.m. the crew reported an iceberg directly ahead. Despite vigorous evasive action, a glancing impact ripped a 90 m gash in the starboard side. The *Titanic* sank at 2:20 a.m. on Monday 15 April, 2 hours and 40 minutes after the impact, with the loss of over 1500 lives, including that of the 62-year-old captain, Edward J. Smith, on his scheduled last voyage (Company captain, 1998).

What if? Any unintended incident leading to harm begs a series of "what if" questions. What if, by chance, the *Titanic* had been a few dozen meters north or south of its actual position? What if the lookout had spotted the iceberg a few seconds earlier? What if there had been more effective procedures for deploying the available lifeboats? What if there had been more lifeboats? US law prohibits 62-year-olds from piloting passenger-carrying aircraft. So, was it an older driver problem? It is generally concluded that if the ship had maintained its initial high speed, the resulting increase in rudder effectiveness would have prevented contact with the iceberg. It is also claimed that cutting the speed to half rather than stopping completely after impact forced additional water into the vessel. Another hour afloat could have substantially reduced casualties as the liner *Carpathia* arrived less than two hours after the *Titanic* sank.

What if impact had been head-on? One "what if" given less attention than others is: What if no one had detected the iceberg and the *Titanic* had crashed head-on into it at 42 km/h? When a car traveling at 42 km/h strikes an immovable barrier, about 8% of its total length (or about 0.4 m) is crushed (Wood, 1997). The uncrushed portion of the car experiences an average deceleration of 167 m/s^2, equivalent to 17 times the acceleration due to gravity, or 17 g. The associated forces of the occupants against their safety belts are likely to produce some injuries (unbelted occupants would sustain greater levels of injury as they continued to travel at 42 km until abruptly stopped by striking the near stationery interior of the vehicle). Assume, as a very rough approximation, that 8% of the *Titanic's* 269 m length would have been crushed by the head-on impact. This 21.5 m of crush would generate an average deceleration of 3 m/s^2, or about 0.3 g. The energy dissipated, equivalent to 30,000 cars crashing (in the 4 seconds during which crush occurred) would have made an enormous noise. Those in the 92% of the liner that was not crushed by the impact would have experienced a mild deceleration, not too unlike that of a car or train coming to a gentle stop at a traffic light or station. Anyone in the portion that was crushed would likely have been killed or seriously injured. As few crew members, and even fewer passengers, would be close to the front of the ship at near midnight, casualties would have been light. The ship would have been in no danger of sinking because of its watertight compartment structure. It would likely have returned to its maker in Belfast for repairs, and today almost nobody would have heard of it.

Number of fatalities – reliability of data. Immediately after the sinking, official inquiries were conducted by a special committee of the U.S. Senate (because American lives were lost) and the British Board of Trade (under whose regulations the *Titanic* operated). The total numbers of deaths established by these hearings were:

U.S. Senate committee:	1,517 lives lost
British Board of Trade:	1,503 lives lost

Confusion over the number of fatalities was exacerbated by the official reports to the U.S. Senate and the British Parliament, which revised the numbers to 1,500 and 1,490, respectively. Press reports included numbers as high as 1,522. Additional revisions cement the conclusion that we will never how many people died on the *Titanic*. (We do know that there were 705 survivors). Likewise, we will never know how many people were killed in the 11 September 2001 terrorist attacks.

The uncertainty regarding the number of deaths in exhaustively investigated prominent events alerts us to the likelihood of uncertainties in even the most seemingly reliable data. At some intuitive level, one might expect the number of deaths to be generally determinable without mistake. For various reasons, this is rarely the case. Arbitrary criteria are often necessary even to classify whether a death should be counted as a transportation death. Drivers may have fatal heart attacks at the wheel prior to crashing; vehicle occupants may be transported to hospital after a crash and die later for reasons, such as pneumonia, that may not be strongly linked to the crash. While there is uncertainty associated with fatality data, such data constitute, by far, the most reliable safety data available. Hence, much of the scientific study in safety focuses on fatalities.

Crashworthiness and crash avoidance. Neither builder nor owner ever used the term "unsinkable." However, the claim of a high level of design safety was well justified, notwithstanding many later questions about the quality of the steel sheeting, the absence of tops on the watertight compartments, and the number of lifeboats. The *Titanic* contained the best *crashworthiness* that had ever been engineered into a ship. However, engineering safety must be viewed in the context of the way it is used. Interactions between *crashworthiness* and crash *avoidance* are examples of more general behavior feedback effects (or technology/human interface effects) that are important in safety (Evans, 1991; 1996). If the *Titanic* had not processed such superior crashworthiness, it would have sunk in minutes rather than hours, with the near-certain loss of all on board. Indeed, its fate may have remained a mystery to this day. Less confidence in *Titanic's* crashworthiness would likely have led to more caution on the bridge. Shakespeare writes, "Best safety lies in fear" (Hamlet, Act I, Scene 3). Because of the ice conditions less safe vessels were waiting for dawn before proceeding. The sinking of the *Titani*c raises a fundamental safety question with parallels in other areas, such as the effect of airbags on fatalities: "Did the *Titanic's* superior crashworthiness save 705 lives or cause over 1,500 deaths?"

Terminology

The above discussion has already introduced a number of terms, which we now discuss more fully.

A vehicle striking anything is referred to as a *crash*. The widely used term *accident* is unsuitable for technical use (Pless and Davis 2001, Evans, 1994; Langley, 1988; Doege, 1978). *Accident* conveys a sense that the losses incurred are due exclusively to fate. Perhaps this is what gives *accident* its most potent appeal -- the sense that it exonerates participants from responsibility. *Accident* also conveys a sense that losses are devoid of predictability. Yet the purpose of studying safety is to examine factors that influence the likelihood of occurrence and resulting harm from crashes. Some crashes are purposeful acts for which the term *accident* would be inappropriate even in popular use. There can be little doubt that at least a few percent (perhaps as much as 5%) of driver fatalities are suicides (Hernetkoski and Keskinen, 1998; Ohberg et al., 1997; Bollen and Philipps, 1981; Philipps, 1979). Although the use of vehicles for homicide may be less common than in the movies, such use is certainly not zero. Popular usage refers to *the crash of Pan Am flight 103*, now known to be no *accident*, in any sense of the word. Even more so, the events of 11 September 2001, known to be intentional acts immediately after the second plane crashed into the World Trade Center.

Generally the term *cause* is avoided, in large measure because it all too often invokes the inappropriate notion of a single cause. Crashes result from many factors operating together. To say that the loss of life on *Titanic* was caused by the absence of a mandatory retirement age for captains, the owner being on board, the look-out being too alert or not alert enough, by climate conditions, or by poor quality steel may generate more confusion than clarity. Instead of focusing on a single cause, we generally think in terms of a list of *factors,* which, if different, would have led to a different outcome. The goal in safety analysis is to examine factors associated with crashes with the aim of identifying those which can be changed by countermeasures, or interventions, to enhance future safety.

Collections of observed numbers are referred to as *data* and not *statistics*. Since *statistics* is the name of a branch of mathematics dealing with hypothesis testing and confidence limits, using it to also mean data invites needless ambiguity.

We follow common usage in referring to ages; age 20 means people with ages equal to or greater than 20 years, but less than 21 years. This is plotted at 20.5 years, very close to the average age of 20-year-olds; 40-year-olds are not quite twice as old as 20-year-olds, which might come as good news to some!

The consequences of crashes include fatalities, injuries and property damage. Useful terms encompassing all of these are *harm* and *losses*. Measures that reduce harm can be placed into two distinct categories.

Crashworthiness refers to engineering features aimed at reducing losses, given that a specific crash occurs. Examples are improved occupant protection by making the structure close to the occupant less likely to crush, and devices such as collapsible steering columns; other examples of crashworthiness include reducing risks of post-crash fires, or of ships sinking from crash impact.

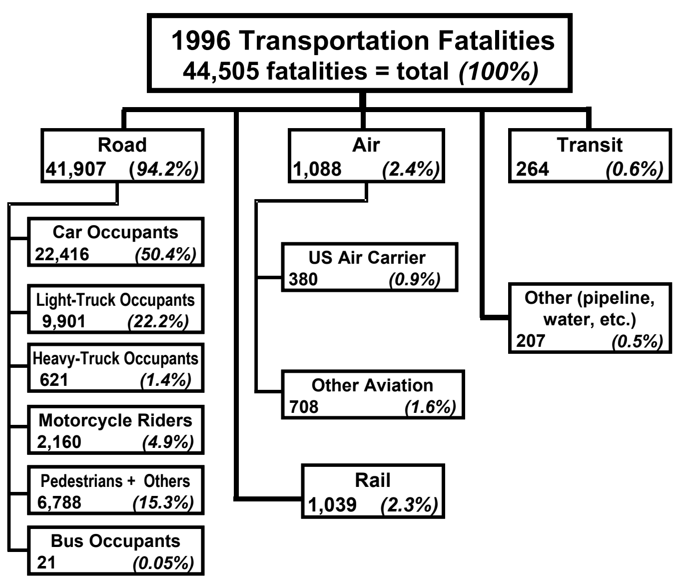
Crash prevention refers to measures aimed at preventing the crash from occurring. Such measures may be either of an engineering nature (making vehicles easier to see, better braking, radar, etc.) or of a behavioral nature (driver selection, training, motivating and licensing, traffic law enforcement, etc.).

A fundamental difference between *crashworthiness* and *crash prevention* is that when a crash is prevented all harm is reduced to zero. Improved *crashworthiness* rarely eliminates harm in a severe crash, but does reduce the level of harm (say, converting a fatality into a severe injury, or a severe injury into a less severe injury, or an expensive vehicle-repair into a less expensive repair). The finding that safety belts reduce car-driver fatality risk by 42% means that out of 100 drivers who would have been killed without belts, 42 would have survived if all had worn belts. However, the 42 survivors would sustain injuries, in many cases very severe injuries. *Crashworthiness* is measured by the percent reduction in risk for some specific level of injury, such as fatality or minor injury. A *crash prevention* measure that reduces crash risk by some percent is necessarily a far more effective intervention than a *crashworthiness* measure with the same percent effectiveness.

4.2. Overview of Transportation Fatalities

The US Department of Transportation (1998) estimates that 44,505 people lost their lives in connection with transportation in the United States in 1996. The distribution of these by transportation mode is presented in Table 4-1. The numbers in Table 4-1 in a few cases differ slightly from those in the original source because of minor corrections to achieve consistent totals.

Table 4-1. Distribution by mode of transportation fatalities in the United States in 1996. (Based on US Department of Transportation, 1998).



These 44,505 deaths occurred in a system in which vehicles traveled over 4 billion km in 1996, as detailed in Table 4-2. As there is, on average, more than one person per vehicle, the distance traveled by all people will exceed the distance traveled by all vehicles (details in Table 4-3.) The unfortunate term *passenger miles* (or *passenger km)* appears often in the literature, even though most travel is in vehicles containing no passengers. People traveling in (or on) road transportation vehicles are more appropriately referred to as *occupants*. Occupants are either *drivers* or *passenger*s. Vehicles referred to in the literature as "passenger cars" will here be called simply "cars." Because different situations arise for different modes, additional categories (such as *crew*) are also used.

Table 4-4 shows the number of deaths per billion vehicle miles derived by dividing the estimates in Table 4-1 by those in Table 4-2. No estimates are given in Table 4-4 if the definitions for the categories of distance of vehicle travel and the fatalities were substantially different, or the estimates of travel are too uncertain. Even without problems of data availability and reliability, it is surprisingly difficult to define categories that apply across all modes. For US road traffic, a fatality is counted if the crash occurs on a US public road, without regard to the origin of the vehicle or its occupants, whereas for air traffic factors such as the home base of the airline are relevant while the location of the crash may not be. Rail rates are not given as most fatalities occur to people outside the train (at grade crossings), and passenger and freight-train data are collected in different ways. A car driver killed in a car-train crash is likely to be added to both the road traffic and the train totals. A worker killed in a fire unrelated to transportation in a railroad facility is counted as a railroad fatality. Tables 4-4 (and 4-5) should be interpreted in the context of these uncertainties.

The overall national rate for all modes of transportation is 11.1 fatalities per billion km of vehicle travel. The road transportation rate of 10.5 fatalities per billion km is equivalent to 1.7 fatalities per hundred million miles (conversion factor is 1.609334/10 exactly). As vehicles with high occupancy travel with more people at risk, it is appropriate to examine the deaths for the same distance of occupant travel.

Table 4-5 shows the number of deaths per billion km of travel, derived by dividing the estimates in Table 4-1 by those in Table 4-3. The cross-modal comparisons in Tables 4-4 and 4-5 are sufficiently unreliable that they should be interpreted as little more than suggestive. Scheduled airline rates are much lower than the average for all airline travel. As one or two major airline crashes have a large influence on this rate, it is highly unstable from year to year. The rate averaged over 1990-1996 is 0.2 deaths per billion aircraft km. The overwhelming majority of those killed in airline crashes have minimal control over events. All are at similar risk, regardless of behavior or personal characteristics. While the average rate for road-vehicle occupants is much higher, this rate varies greatly according to such characteristics as driver age, use of alcohol, safety-belt use, conformance with traffic law, etc. A car driver with many characteristics associated with lower crash risk can drive a 1,000 km trip with no more risk of death than taking a plane for the same trip. The longer the trip the greater is the safety advantage of air travel, because nearly all the risk is concentrated in the take-off and landing phases, whereas the ground vehicle risk is approximately proportional to the distance traveled.

Table 4-2. Distribution by types of vehicles of the total distance traveled by all vehicles in the United States in 1996. (Based on US Department of Transportation, 1998).

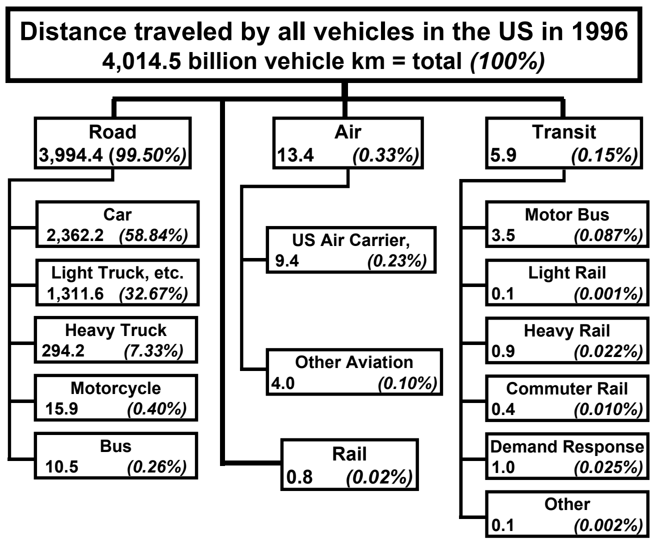


Table 4-3 Distribution by vehicle types of travel by all vehicle occupants in the United States in 1996. (Based on US Dept. of Transportation, 1998).

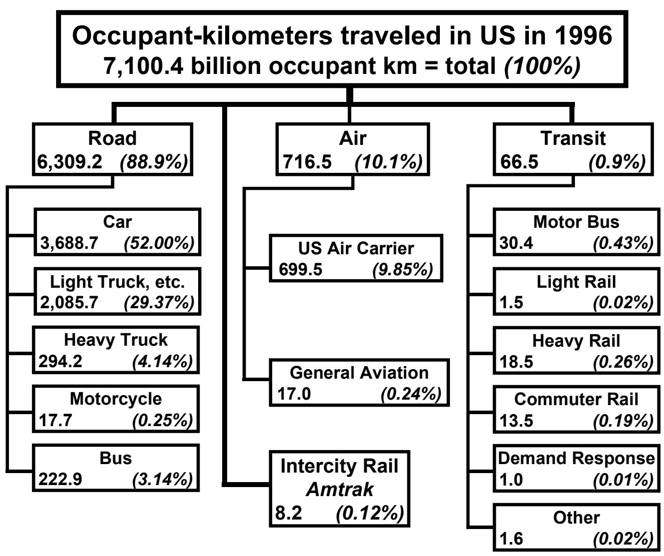


Table 4-4. Death rates for the same distance of vehicle travel, computed from Tables 4-1 and 4-2.

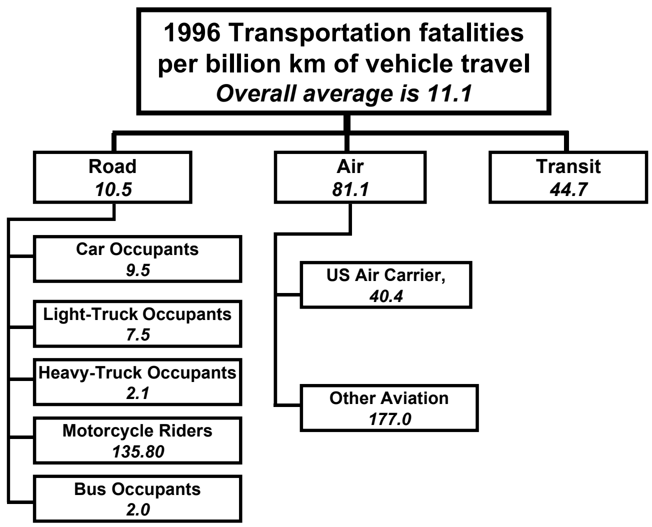
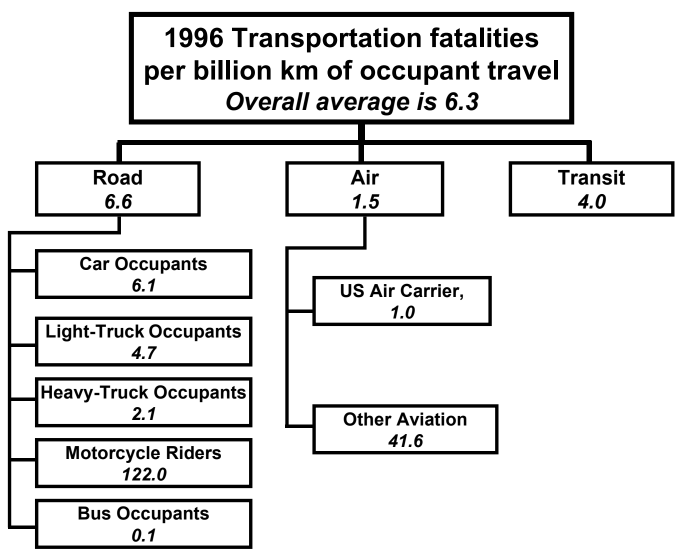


Table 4-5. Death rates for the same distance of occupant travel, computed from Tables 4-1 and 4-3.



Within the road transportation mode, the comparisons are more reliable. The risk of occupant death depends systematically, and very strongly, on the mass and size of the vehicle (Evans, 2001a). For a same distance journey, a motorcycle rider is about 20 times as likely to be killed as a car occupant, and about a thousand times as likely to be killed as a bus occupant.

Tables 4-1 through 4-5 underline the dominance of road transportation over all other modes combined in the US. Road transportation accounts for over 99% of all the distance traveled by vehicles, and almost 90% of all the distance traveled by people. It accounts for 94% of all transportation deaths, and for an even higher percent of injuries and property damage. Because of its dominant role, most of the rest of this chapter is devoted to road transportation. Unless otherwise apparent, the term *vehicle* denotes an engine-powered vehicle designed to travel on a road, and the term *traffic crash* denotes a crash involving at least one such a vehicle. *Traffic crashes* also generally involve non-vehicles (pedestrians, bicycles, animal-powered vehicles, and fixed objects –trees being the most common).

4.3 Introduction To Road Traffic Fatalities

Road traffic deaths and injuries constitute one of the largest public health problems in industrialized countries. In the US, traffic crashes account for half of all injury deaths (National Safety Council 1997), and 94% of all transportation deaths. In a typical two-week period, more people are killed on US roads than the 1500 lost on the *Titanic*. In a typical month, more Americans die on US roads than were killed in the terrorist attacks.

In the US, traffic crashes account for half of 19-year-old female deaths and a third of 19-year-old male deaths (Evans, 2000). The fraction is lower for males because of so many male deaths from firearms. The total number of pre-retirement years of life lost due to traffic crashes is similar to that due to the combined effects of the two leading diseases, cancer and heart disease. Worldwide, about a million people are killed annually in traffic crashes (WHO, 2001), with injuries about 70 times this number. The victims are predominantly young, and about 65% are male. As motorization increases, totals are expected to increase.

Analysis of road safety differs from that for the other modes in that enormous quantities of relevant data are available, most commonly based on police reports. The *Fatality Analysis Reporting System* (FARS – before 1998 called *Fatal Accident Reporting System*) documents over a million people killed on US roads since 1975. The availability of large quantities of data lead to safety for roads being better understood than safety for any other transportation mode.

Variables coded in large data sets generally include gender and age of crash participants, weather, make and model of vehicle, etc. Variables not known include vehicle speed at onset of crash event, vehicle speed just prior to impact, amount of vehicle crush, and medical details of injuries. Such details can be estimated only after expensive post-crash investigations, which are not routinely performed. For other transportation modes, nearly all information comes from intensive in-depth analysis of the few crashes that occur.

Historical Trends

In the early decades of the twentieth century few people were killed on US roads because there were few motorized vehicles (Figure 4-1). As vehicle ownership increased rapidly, so did traffic deaths, peaking in 1972 at 54,589, and declining later to a present fairly stable rate of just over 40,000 per year. The rate in China and other rapidly industrializing countries continues to increase rapidly.

The number of traffic deaths per year shows little in the way of a pattern. However, if we instead examine the number of traffic deaths in the US for the same distance of vehicle travel, a clear trend emerges (Figure 4-2). Ever since 1921 when data on the total distance traveled by all vehicles were first collected, the number of traffic deaths for the same distance of travel has trended downwards at an average decrease of about 3.5% per year. The 2000 rate of 9.7 traffic deaths per billion km of travel is 94% below the 1921 rate of 150. If the 1921 rate were to apply today, the number of US traffic fatalities would exceed half a million. The downward trend in the number of deaths for the same distance of travel is observed in all countries for which data are available (Evans, 1997). As motorization continues, the fraction of all deaths that are pedestrians trends downwards (Figure 4-3).

The number of traffic deaths for the same distance of travel can be measured only after a nation instigates a procedure to estimate the distance all vehicles are driven. Even when available, estimates of distance of travel differ greatly in reliability from country to country. A useful universally available measure is the number of traffic deaths per thousand registered vehicles. The registration, and thereby counting, of vehicles is routinely performed by nearly all jurisdictions. The number of deaths per thousand vehicles varies greatly between countries -- by more than a factor of one hundred (Table 4-6 and Figure 4-4). In general, the higher the degree of motorization (as indicated by the number of vehicles per 1000 people), the lower is the number of traffic fatalities per thousand vehicles. Another key factor is mix between rural and urban driving. Fatality risk tends to be lower in urban areas where speeds are lower. Within the US, the fairly urban states of Rhode Island, Massachusetts and Connecticut have 0.09, 0.11 and 0.12 deaths per thousand vehicles, respectively, whereas the more rural states of Mississippi and Arkansas have 0.39 deaths per thousand vehicles. While the rate for China, the world’s most populous nation, is substantially higher than that for more motorized countries, it is dropping at a much faster rate than in the US and other more motorized countries (Figure 4-5). Although the rate is dropping, the dramatic growth of vehicle ownership in China (Figure 4-6) and in other countries that are rapidly industrializing will inexorably increase casualties.

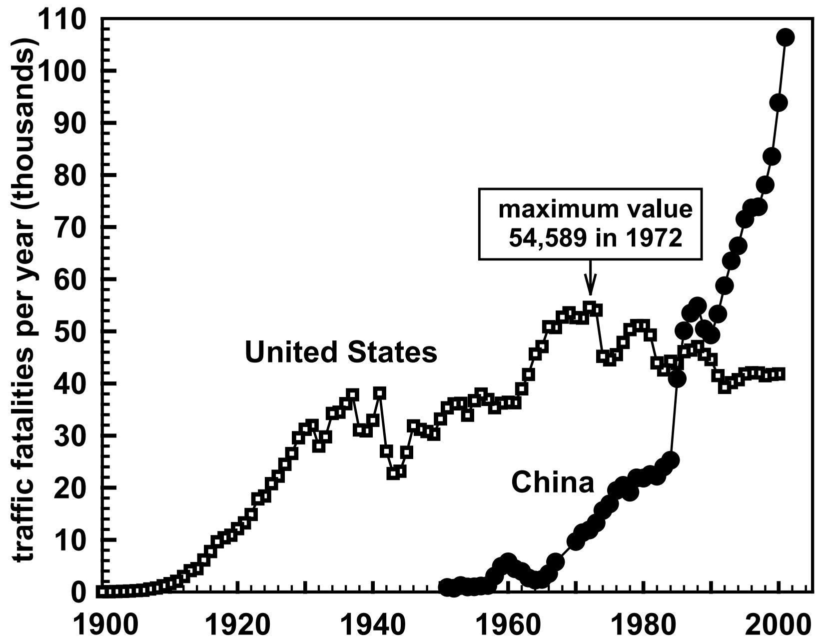


Figure 4-1. Total annual traffic fatalities in the US and China.

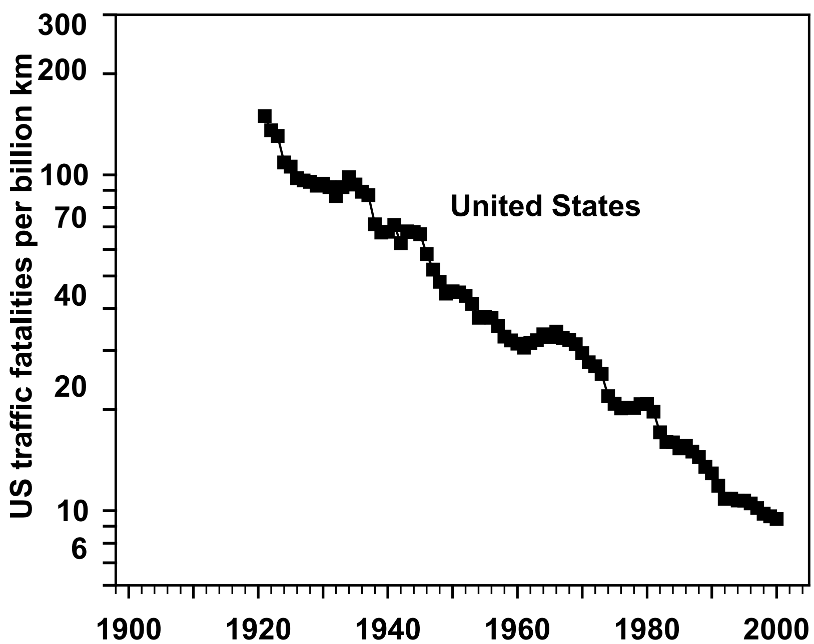


Figure 4-2. Total annual traffic fatalities per billion kilometers of vehicle travel in the US.

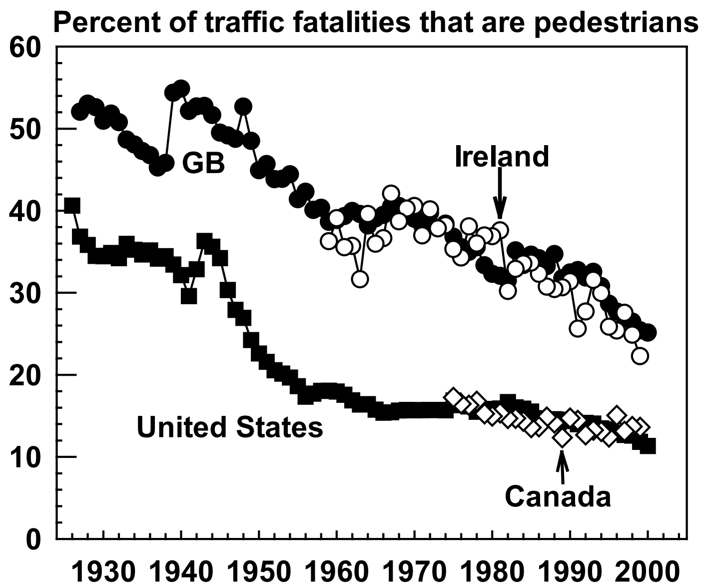


Figure 4-3. The percent of all traffic fatalities that are pedestrian fatalities.

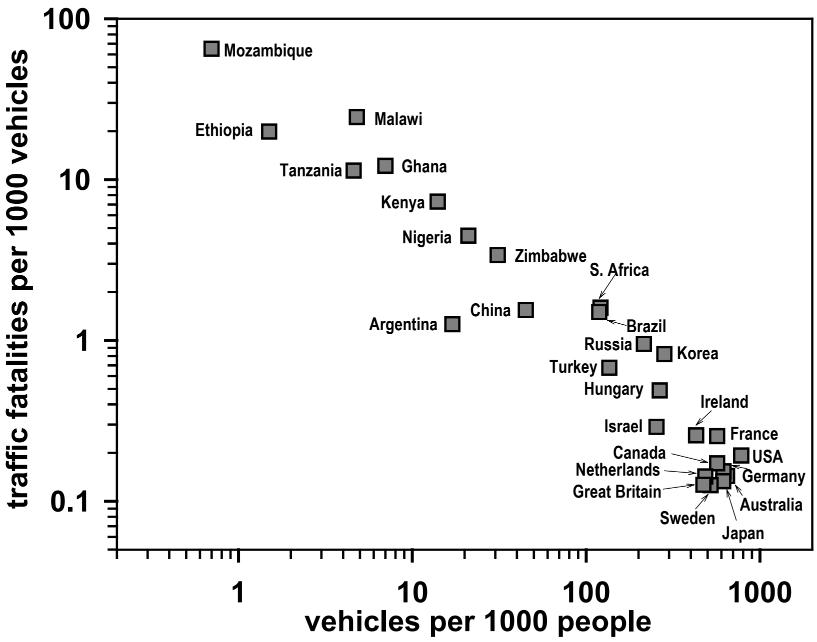


Figure 4-4. Safety related to degree of motorization

Table 4-6. Various rates for a number of countries.

Country	Vehicles per 1000 people	Fatalities per 1000 vehicles	Fatalities per million people	Fatalities per year	Data year
USA	790	0.19	153	41,821	2000
Australia	647	0.14	93	1,763	1999
Germany	617	0.15	95	7,772	1999
Japan	614	0.13	82	10,372	1999
Canada	567	0.17	97	2,972	1999
France	567	0.25	144	8,487	1999
Sweden	520	0.13	66	580	1999
Netherlands	485	0.14	69	1,090	1999
UK	473	0.13	60	3,564	1999
Ireland	429	0.26	110	413	1999
Korea	282	0.82	232	10,756	1999
Hungary	265	0.49	129	1,306	1999
Israel	254	0.29	74	469	1999
Russia	215	0.95	204	29,600	2000
Turkey	136	0.68	92	5,975	1999
South Africa	121	1.60	193	9,068	1998
Brazil	119	1.50	179	30,000	1998
China	45	1.55	70	83,529	1999
Zimbabwe	31	3.39	106	1,205	1996
Nigeria	21	4.49	94	6,185	1995
Argentina	17	1.26	210	7,545	2000
Kenya	14	7.29	103	2,617	1995
Ghana	7.0	12.19	86	1,646	1998
Malawi	4.8	24.49	119	1,382	1996
Tanzania	4.6	11.39	53	1,583	1998
Ethiopia	1.5	19.91	29	1,693	1998
Mozambique	0.7	65.18	43	805	1997

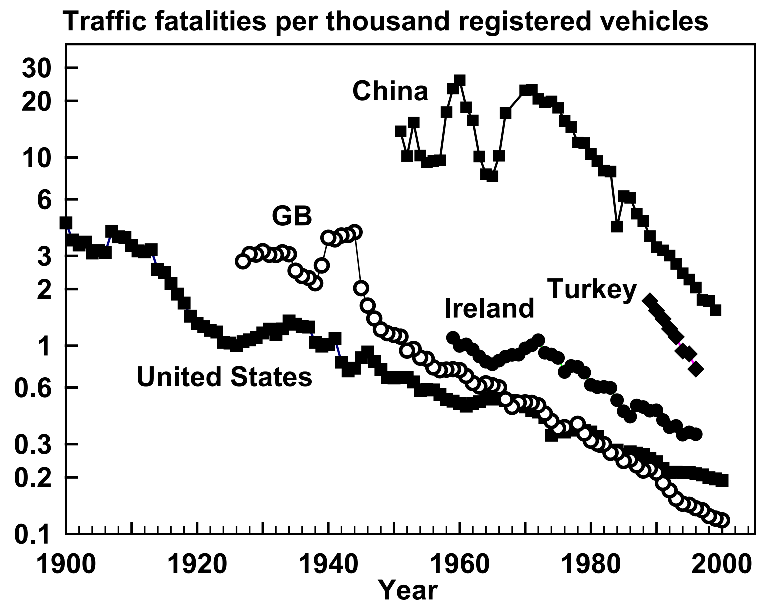


Figure 4- 5. Total annual traffic fatalities per thousand registered vehicles in some countries.

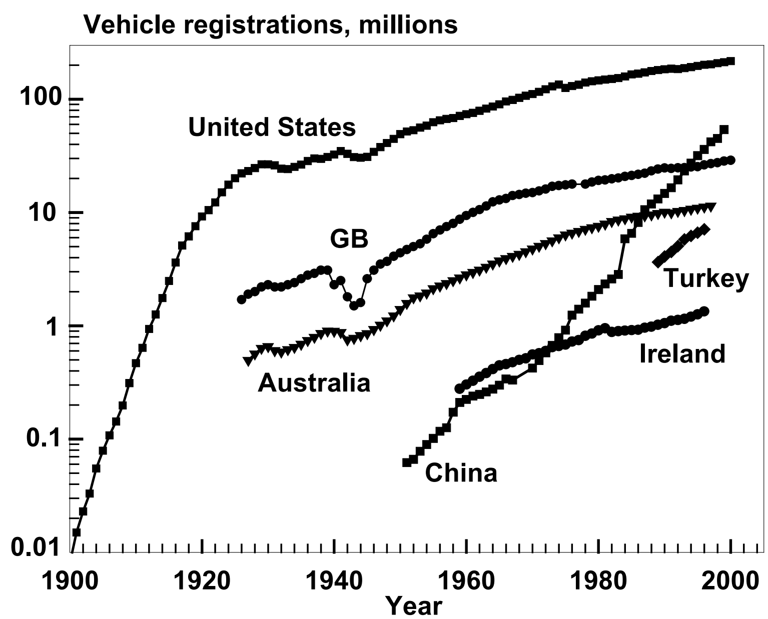


Figure 4- 6. Vehicle growth in some countries.

Approaches To Reducing Harm From Traffic Crashes

Why do fatality rates decline in time and vary so much from country to country? This question is somewhat akin to asking why average longevity increases in time and varies so much from country to country. Such effects are due to many factors – public health policy and implementation, availability of and advancements in drugs, surgery, preventative medicine, plumbing, nutrition, hygiene, etc. In the traffic crash and longevity cases it is difficult to assign in any quantitative way the relative contributions of the different factors. The structure in Table 4-7, which is one of a number of possible categorizations, is aimed at clarifying some of the main factors that contribute to traffic safety. Not reflected, because it is somewhat outside the scope of this chapter, are the important contributions from improved medicine, which reduce average harm from all sources. As medical science continues to advance, those injured in any transportation crash are less likely to die. Indeed, it is often claimed that if a victim can be transported alive to a modern well-equipped emergency trauma center, the probability of survival is extremely high. This places high value on rapid transportation from the crash site to the hospital. Here the infrastructure of vehicular transportation contributes in a fairly direct way to reducing the severity of the harm from the crashes that occur on it.

<u>Factors Influencing Traffic Safety</u>

- **Engineering**
  - **Roadway and Traffic Engineering**
  - **Automotive Engineering**
- **Road User**
  - **Driver Performance**
  - **Driver Behavior**

Table 4-7. One way to categorize the main factors central to road traffic safety.

4.4 Engineering Factors

Roadway Engineering

On rural two-lane roads, vehicles traveling in opposite directions pass each other only a meter or so apart. Even if speed limits are obeyed, the combined relative speed may still far exceed 150 km/h. A head-on crash at such relative speeds will likely prove fatal, yet such crashes occur due to, for example, improper overtaking or loss of control on curves. On freeways where there is physical separation between traffic traveling in opposite directions, the only vehicles permitted to drive close to each other are traveling in the same direction at similar speeds. Fixed objects, such as trees, are far removed from the path of vehicles. Risk of side-impact at intersections is eliminated through the replacement of intersections by under- or over-passes.

The roadway engineering improvements typified by the differences between freeways and rural two-lane roads constitute one of the most effective engineering countermeasures available. In the US, fatality risk on interstate rural freeways is 55% lower than the average for all non-interstate rural roads (Table 4-8). The lowest rate in Table 4-8 is 85% lower than the highest rate. Such dramatic safety effects dependant on roads and road use bring one face to face with the types of tradeoffs that often arise in traffic safety decisions. Freeways are expensive undertakings that are justified mainly to produce improved mobility. They can are rarely installed primarily to improve safety. Additional considerations may argue against building freeways, including their effect on city neighborhoods, landscape aesthetics, and wild life. Better roads generate more traffic and stimulate urban sprawl, increasing pressure on resources and the environment. The additional travel that freeways stimulate generates additional travel risk, but this effect is small compared to the risk reduction resulting from replacing rural two-lane roadways by freeways.

Table 4-8. Fatality rates on different types of US roads for 1998 (Bureau of Transportation Statistics, 2000)

Roadway category	**Fatalities per billion km**	
	Rural	**Urban**
NON-INTERSTATE:		
Arterial	14.8	7.1
Collector	18.3	4.9
Local	23.0	7.9
NON-INTERSTATE AVERAGE	**17.2**	**7.0**
INTERSTATE	**7.7**	**3.8**

Vehicle Engineering

In the earliest days of the auto industry, crashes often resulted from the mechanical failure of such key components as wheels, tires or brakes. As component reliability increased, focus shifted towards fundamental understanding of injury mechanisms and on technologies aimed at protecting occupants of vehicles when crashes occur.

Biomechanics – the science of relating injury to mechanical force. Biomechanics is the bridge that links engineering and medicine. Trauma surgeons distinguish between penetrating trauma and blunt trauma. Penetrating trauma occurs when small objects exert sufficient localized force to penetrate the human body, an obvious example being a bullet. Blunt trauma occurs when an object of larger area applies sufficient force on the body to damage its structure, such as occurs when someone falls from a building. Nearly all traffic injuries, whether to vehicle occupants or to pedestrians, involve blunt trauma. Consider a vehicle traveling at, say, 50 km/h and crashing into a perfectly rigid horizontal barrier. An unbelted driver would, in accord with elementary physics, continue to travel at 50 km/h until stopped by a force. Such a force occurs when the driver impacts, at a speed of 50 km/h, the interior of the now stationary vehicle. It is this so-called *second collision* that causes injuries, not the first collision of the vehicle striking the barrier. A person falling from a fourth floor window would strike the ground at a similar speed and be subject to similar injury forces. While evolution has provided humans with a protective fear of heights, no corresponding fear exists for the relatively new experience of traveling at speeds faster than can be produced by muscle power.

Goal of occupant protection. The theoretical best protection would be for the occupant to slow down from the initial speed of 50 km/h to zero at a constant deceleration using the entire distance between his or her body and the barrier. The engine and other rigid components make it impossible to achieve this ideal goal. The practical goal is for the vehicle structure to crumble in such a way as to provide as much ride-down distance as possible, and for the occupant to travel this distance at as uniform a deceleration as possible. In addition, a strong "safety cage" that does not crumple reduces the risk of occupants being crushed.

Engineering changes that have contributed to reductions in driver risk include collapsible steering columns, lap/shoulder safety belts and design changes in the structure surrounding the occupants to reduce intrusion. When a driver's chest strikes a steering wheel, the collapsible steering column allows the steering column to compress and thereby reduce the maximum force on the chest. This simple device is estimated to reduce overall driver fatality risk in a crash by about 6%.

Estimates of the effectiveness of occupant protection devices are summarized in Table 4-9. The interpretation is that if 100 fatally injured drivers not wearing belts had been wearing belts, 42 would have survived. This is equivalent to saying that wearing a belt reduces a driver's risk of being killed in a crash by 42%.

Table 4-9. Effectiveness of safety belts and airbags in reducing driver fatality risk.

Occupant protection device	***Effectiveness in preventing driver fatalities***
Lap/shoulder belt alone	**42 %**
Lap/shoulder belt plus airbag	**47 %**
Airbag alone*	**13 %**

* No manufacturer offers the airbag for use alone. Its stated aim is to increase the effectiveness of the primary restraint system, the lap/shoulder belt (Sources: Kahane, 1996 for airbag-only estimate, others from Evans, 1991).

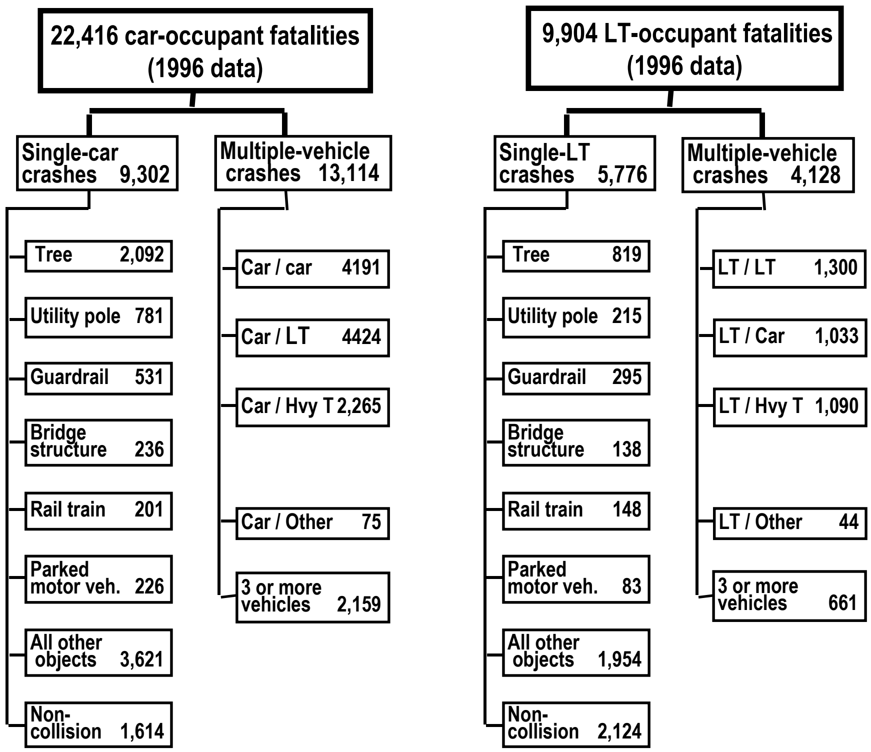
By far the most effective occupant protection device is the familiar lap/shoulder safety belt. This not only reduces the likelihood and severity of impact with the interior of the vehicle, but is highly effective at preventing ejection from the vehicle. Ejection quadruples the risk of death in a crash -- about one in four unbelted drivers killed are ejected from their vehicles. The effectiveness of the lap/shoulder belt is, on average, enhanced by airbags.

In this chapter airbag refers to frontal airbags, which are designed to inflate rapidly in order to place a cushioning barrier between occupant and vehicle structure when sensors detect a frontal crash with severity exceeding some pre-set limit, typically equivalent to striking a barrier at a speed in the range 10 to 20 km/h. The driver rides down the crash in contact with the airbag, which spreads the impact forces over a larger area and reduces forces due to the belt. Side airbags are being introduced without any estimate of their overall effectiveness, which is expected to be, at most, far lower than for frontal airbags.

Increased size and weight of a vehicle increase protection. Doubling the weight reduces occupant risk by about half. All vehicles being heavier does not eliminate the safety benefits of increased vehicle weight (Evans, 1994; 1995), because, in the US, 41% of car drivers and 58% of light-truck drivers who are killed are killed in single-vehicle crashes (Table 4-10). The drivers of two large cars crashing into each other are at lower risk than the drivers of two small cars crashing into each other (Evans, 2001a, Wood and Simms, 2002).

The influence of weight on crash risk is so great that even adding the weight of a passenger generates clearly measurable effects. If a car with a passenger crashes into a car with a lone driver, the accompanied driver is 14.5% less likely to be killed than the unaccompanied driver (Evans, 2001).

Table 4-10. Distributions of 32,320 occupants killed in cars and light trucks. (Data from FARS 1996).



Riders of two-wheeled vehicles are at dramatically higher risks than occupants of even the smallest four-wheel vehicle. Helmets reduce motorcycle driver or passenger fatality risk by 28%. An unhelmeted motorcyclist is about 22 times as likely to be killed as is an average car driver. Wearing a helmet reduces this risk to 18 times that of the car driver. Riders of two-wheeled vehicles (whether engine or human powered) and pedestrians are particularly vulnerable road users. Such road users account for a large fraction of all traffic deaths in the early stages of motorization.

While much attention has been devoted to possible modifications to vehicle design to better protect pedestrians in crashes, the opportunities are intrinsically much less than for vehicle occupants. The main opportunity to prevent such harm is by changing how pedestrians and drivers behave.

4.5 Human Factors Of Road-Users

Discussion of the influence of human factors of drivers (and of road users in general) on road safety must make the clearest distinction between two deceptively similar but fundamentally different concepts:

- Driver performance -- what the driver can do, or is capable of doing
- Driver behavior -- what the driver in fact does

Driver Performance

Studies have concluded that driver error is a contributory factor in over 95% of traffic crashes. Such findings have generated suggestions that the first priority for better safety is to teach higher levels of skill and knowledge about driving. That is, to improve levels of driver performance. While driver training, especially of motorcycle riders, has reduced crash rates in some cases, it has not generally been found to do so. A number of considerations show why crash risk is not determined mainly by driver performance.

Everywhere young male drivers have the highest crash rates (see also section 4-6, Older and younger drivers). Yet this is the very age group with the best visual acuity, swiftest reaction times, and fastest cognitive processing skills. Males tend to be more knowledgeable about and interested in driving and automobiles. Racing-car drivers have higher on-the-road crash rates than average drivers. Much more important than what the driver can do is what the driver chooses to do.

Driver Behavior

The average driver has a crash about once per decade (usually a minor property damage crash -- for fatal crashes it is about one per 4,000 years). Drivers tend to dismiss their crashes as unpredictable and unpreventable bad luck, or the other involved driver's fault. A more appropriate interpretation is that average driving produces one crash per ten years. Feedback once per decade is unlikely to affect behavior. Every crash-free trip reinforces the driver's incorrect conclusion that average driving is safe driving. Individual experience is a false teacher. I wonder how many of us would fly on commercial aircraft if a pilot's method of learning how to avoid crashes was by experiencing them?

A crucial factor that contributes to the high level of commercial airline safety (Table 4-5) is that pilots follow procedures based on expert analyses of the experience of many. For road vehicles, traffic law attempts to fulfill a parallel role. However, ground vehicle drivers routinely violate such laws. Table 4-11 compares various safety characteristics of road and air traffic.

Two of the factors most affecting road-traffic fatality risk are travel speed and alcohol consumption. Research indicates that the risk of crashing increases approximately in proportion to travel speed, injury risk in proportion to travel speed squared, and fatality risk in proportion to travel speed to the fourth power. When

Table 4-11. Comparison of safety characteristics of US commercial air carriers and road transportation.

	Commercial Airline	Road Traffic
Deaths per billion km of occupant travel	1.0	6.6
Countermeasures with most success and potential	Crash prevention	Crash prevention
Main US policy emphasis	Crash prevention	Crashworthiness
Impact of vehicle design or manufacturing flaws	Very important	Minimally important
Driver selection	Strict	Essentially everyone
Importance of driver skill and knowledge	High	May increase or decrease crash risk
Main influence on driver behavior	Following increasingly effective procedures	Experience and personal judgment
Violations of pertinent laws	Rare	Typically, many times per trip
Use of alcohol/drugs	Rare	In about 40% of fatalities
Value of high technology driver training simulators	Enormously high value	Zero or minimal value
Time to react to crash-threatening situations	Often more than many seconds or minutes	Usually less than a second
Value of crash-avoidance advanced technology	Enormously high value	Minimal value
Key to making largest improvements in safety	Safer aircraft flown by better trained pilots adhering to better procedures	Behavior changes resulting from changes in social norms, legislation and enforcement

speed limits on the US rural intrastate system were reduced in 1974 from 70 mph to 55 mph following the October 1973 Arab oil embargo, average travel speed dropped from 63.4 mph to 57.6 mph. This change leads to a predicted fatality risk decrease of 32%, remarkably close to the 34% decline observed. Case-control studies found casualty crash to double with each 5 km/h increase in speed (Kloeden et al., 1997).

Drunk driving is a major traffic safety problem in all countries in which alcohol is used widely, often accounting for about half of all fatalities. Reducing the availability of alcohol has in many cases led to reduced traffic deaths. When all US states increased the minimum age to purchase or consume alcohol to 21 years, from earlier ages of 18 to 20 years in various states, a 13% reduction in fatal-crash involvements of affected drivers followed. Police use of random breath testing to enforce drunk driving laws more effectively has reduced casualties. The Australian state of New South Wales tests about a third of all drivers each year, many of them more than once. This intervention decreased overall fatalities by about 19%.

Driver behavior is a crucial factor in occupant protection because the most effective occupant protection device, the safety belt, works only when fastened. Mandatory wearing laws have been introduced in most countries, though wearing rates and level and type of enforcement vary greatly. The best evaluated wearing law was that for the United Kingdom, where fatality rates for drivers and left front passengers declined by about 20%.

Vehicles are used for purposes that go beyond transportation, including competitiveness, sense of power and control, or more generally, hedonistic objectives -- the pursuit of sensual pleasure for its own sake. Speed and acceleration appear to produce pleasurable excitement even when no specific destination lies ahead and there is no point in haste. While most drivers are motivated by non-transportation motives at some times, as they mature the mix of motives evolves in a more utilitarian direction. This is likely one reason why crash risk is so much lower for 40-year-olds than for 20-year-olds. It seems plausible that as a nation's motorization matures, a similar evolution occurs and contributes to a lowering of crash rates. Drivers in newly motorized countries are likely to be the first generation to drive, and to approach the activity with a sense of novelty, excitement and adventure. In motorized countries, children grow up with the motor vehicle playing an essential role in even the most routine and mundane aspects of daily life.

Crash risk relates to the deepest human characteristics. Factors at the very core of human personality influence behavior in traffic. A comparison of the gender and age dependence of involvement rates in severe single-vehicle crashes and in crimes unrelated to traffic offenses (say, burglary, as a typical example) show remarkable similarities (Figure 4-7). No one would suggest seriously that 40-year-olds commit fewer burglaries than 20-year-olds solely because the 40-year-olds have learned how not to commit burglaries! This should invite a parallel caution against interpreting lower crash rates for 40-year-old drivers compared to those for 20-year-old drivers to mean that the 40-year-olds have simply learned how to not crash. The most compelling interpretation of the similarity between the two curves in Figure 4-7 is that there are fundamental human characteristics related both to involvement in severe crashes and arrests for offenses unrelated to driving; neither conduct is likely to be changed dramatically by increasing knowledge or skill.

Figure 4-8 compares male and female pedestrian deaths. If male and female rates were similar, the data would lie randomly above and below the dotted line indicating equality. An entirely different, and remarkably consistent, picture emerges. At all ages, plotted in one-year intervals, the male rate exceeds the female rate, including the first year of life. For this first year, with average age close to six months, there were 93 male deaths compared to 59 female deaths, or 93/59. The corresponding numbers of fatalities for ages 1.5, 2.5, and 3.5 years are 590/418, 1131/730, and 1353/741, respectively. Such large robust differences suggest an intrinsic gender difference at the most basic level, likely linked to testosterone.

In driving behavior, as in most human activities, social norms play a central role. People drive in a way that they think will win the approval of those whose approval they desire. A change in social norms regarding drunk driving has taken place in the

US. The drunk driver is no longer the amiable comic character of the past, a change that has contributed to reductions in drunk driving. While the fictional portrayal of drunk driving as a harmless activity has become uncommon, the same cannot be said for the portrayal of illegal and life-threatening driving in general, which is often presented as humorous or heroic in television programs and movies specifically aimed at young people. The possibility that such behavior may lead to tragic consequences is rarely addressed. Claims that fictional portrayals do not influence behavior ring hollow in the light of the billions of dollars spent for television advertising. These expenditures are predicated on the firm belief that they do influence behavior. Surely the programs must have a dramatically greater influence than the advertisements. Shaming the entertainment industry into desisting from some current practices would, in my view, save the lives of many young people.

The dominant role of driver behavior. As discussed above, reducing the speed limit from 70 to 55 miles per hour reduced fatality rates on US rural interstate roads by 34%, mandatory safety-belt wearing in the United Kingdom reduced front-seat occupant fatalities by 20%, and random breath testing for alcohol in the Australian state of New South Wales reduced driver fatalities by 19%. Hingson et al. (1996) report similarly large changes in risk in response to programs aimed at changing behavior.

In the 1970s, major independent studies in the US and in Britain identified factors associated with large samples of crashes. The US study found the road user to be the sole factor in 57% of crashes, the roadway in 3%, and the vehicle in 2%; the corresponding values from the British study were 65%, 2% and 2% respectively. In nearly all cases the vehicular factor was in fact a vehicle maintenance problem, such as bald tires or worn brake linings. The road user was identified as a sole or contributing factor in 94% of crashes in the US study and in 95% of crashes in the British study.

4.6 Older And Younger Drivers

Much information is available on how various rates depend on age and gender because these variables are nearly always coded in large data sets. Little additional information on the personal characteristics of people involved in road crashes is available, in large part because of privacy concerns.

Demographic projections of increasingly large numbers of increasingly older drivers have generated concerns captured in the phrase “the older-driver problem”. Examining how rates depend on age and gender addresses the older driver problem and the younger-driver problem. Behavior is already identified above as the

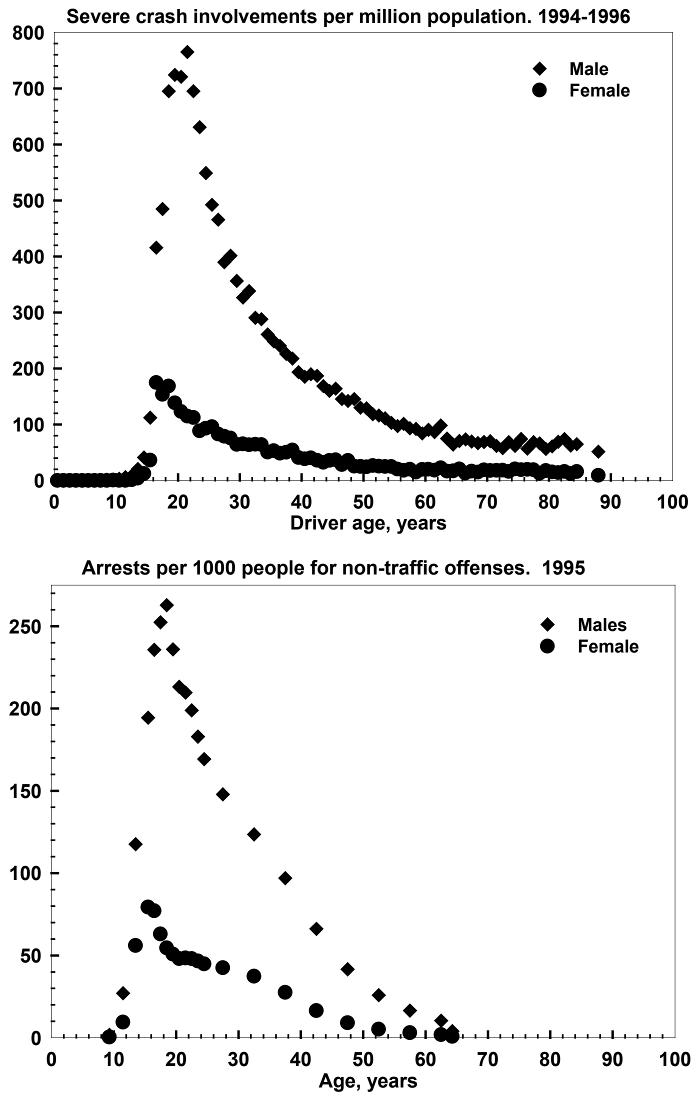


Figure 4-7. _Top:_ Estimated driver involvements per capita in severe single-vehicle crashes. _Bottom:_ Number of arrests per capita for non-traffic-related offenses.

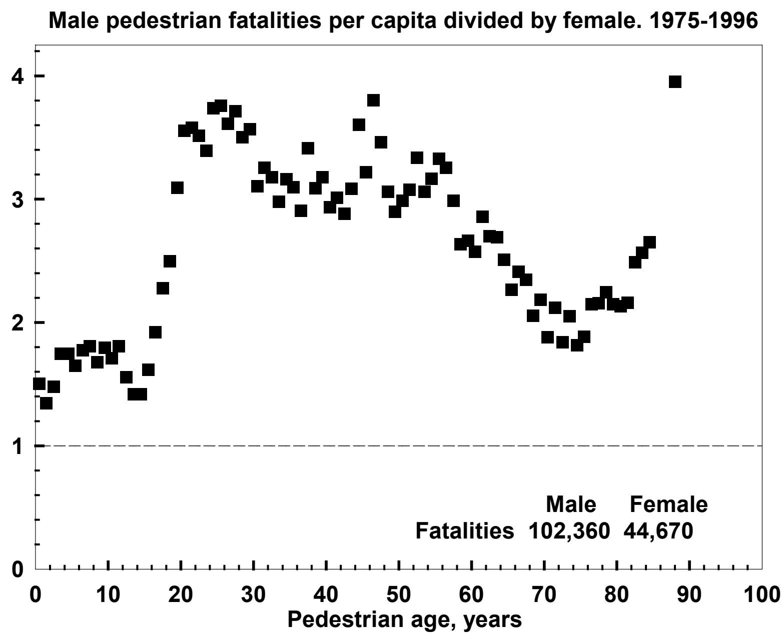


Figure 4-8. Male pedestrian deaths per capita divided by female pedestrians per capita.

as the dominant factor in the elevated rates of younger drivers, but performance becomes more critical with increasing age. Because age effects include *performance* and *behavior* factors, the topic is treated in this separate section. The material presented is based on Evans (1991) and Evans (2000).

Changes in driving risk with increasing age are best separated into two distinct components:

- Changing risks to the drivers themselves, and
- Changing risks they impose on other road users.

These risks are of a different nature. There is near universal agreement that society should take stronger measures to prevent its members from doing things that endanger others than to prevent them from doing things that endanger only themselves. Public safety makes a stronger claim on public resources than does personal safety, which can be supported often using personal resources. Differences between the risks we assume ourselves and those we impose on others impact legislation, licensing policy, police enforcement, and so on.

Changing Risks Drivers Face As They Age

Figures 4-9 to 4-12 show fatality data normalized for the same length of time, the same number of people, the same number of licensed drivers, and for the same distance of travel. Three of the relationships exhibit a characteristic “U-shape,” exhibiting particularly strong increases at the oldest ages.

Involvement rates in severe crashes. Increases with age like those in the above figures have often been interpreted in terms solely of the older drivers’ risk of involvement in a crash. Such an interpretation misses the crucial point that the number of drivers of given age and gender killed is the product of two factors:

1 The number of involvements in very serious crashes, and

2. The probability that involvement proves fatal.

The first factor reflects influences due to all use and behavioral factors, such as amount and type of driving, driver capabilities, type of vehicle driven, time of day, degree of intoxication, and driving risks. The second factor can be influenced also by such behavioral factors as safety belt wearing and alcohol consumption. Apart from such considerations, the probability that a given crash results in death is essentially physiological rather than behavioral in nature. The graphs that follow are based on the relationships given on page 26 of Evans, 1991. These are not materially different from more recent more precise estimates (Evans 2001b, 2001c):

$$R_{males}(A) = \text{Exp } 0.0252\ (A - 20)$$

$$R_{females}(A) = 1.311 \text{ Exp } 0.0216\ (A - 20)$$

where R(A) is the fatality risk to an individual of age A compared to the risk to an individual of age 20 when both are subject to the same physical insult, or impact. When driver age is 16 to 20, we assume R = 1 for males and R = 1.311 for females; that is, the fatality risk from the same severity crash is the same as for a 20-year-old driver of the same gender. These relationships are applicable from age 20 to age 80. Fatality rates focus on the outcome, not the severity of the crash that led to the death. Figures 4-13 and 4-14 show involvement rates in crashes of similar severity by considering crashes in a severity range greater than or equal to that sufficient to likely kill 80-year-old male drivers, for which case R has a value of 4.0. Comparing Figures 4-13 and 4-11 shows that most of the increase in the fatality rate per licensed driver results from the same severity crash being more likely to lead to death. When this is factored out, an increase at older age remains, but of smaller magnitude. The rate of involvement for the same distance of travel increases with increasing driver

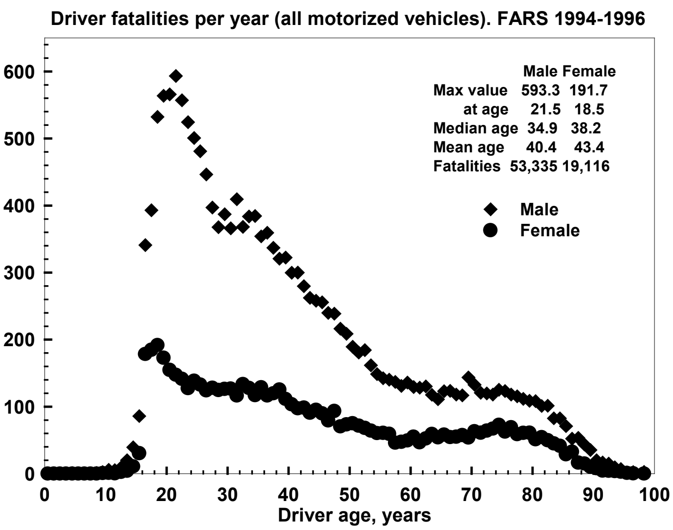


Figure 4-9. Average number of driver fatalities per year (all motorized vehicles) versus gender and age. (Based on FARS, 1994-1996).

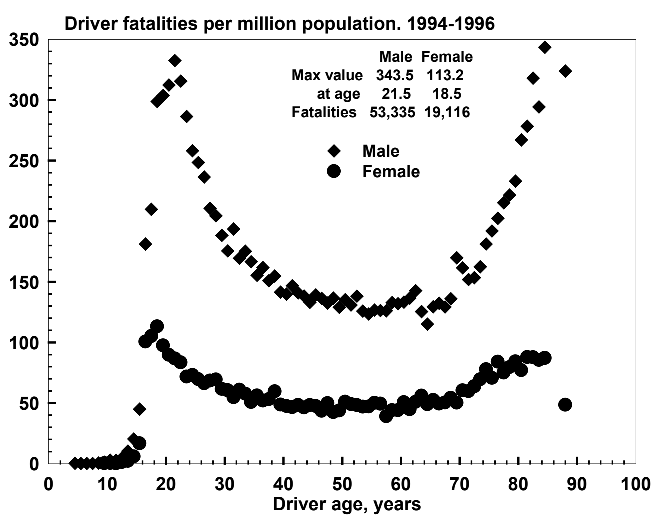


Figure 4-10 Driver fatalities (all motorized vehicles) per million population versus gender and age. (Based on FARS and US Bureau of the Census, 1994-1996).

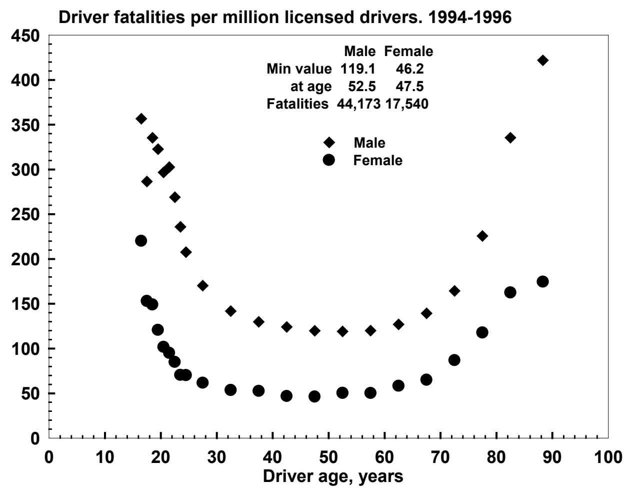


Figure. 4-11. Fatally injured drivers (all motorized vehicles) with valid driver licenses per million licensed drivers versus gender and age. (Based on FARS and Federal Highway Administration data, 1994-1996).

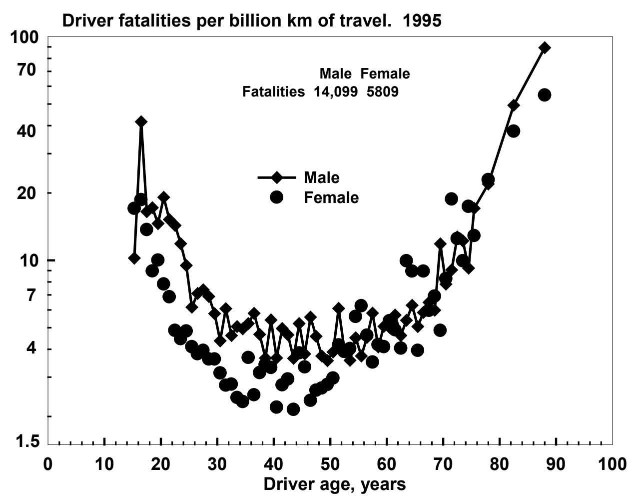


Figure 4-12 Driver fatalities (all motorized vehicles except large commercial trucks) per billion km of travel versus gender and age. (Based on FARS 1995, National Personal Transportation Study 1995).

age for ages above about 60. However, the increase is smaller than in Figure 4-12; even at the oldest age plotted, the rates for males and females are still less than those for male drivers under 30.

Threat To Other Road Users

All the above focused on how the age and gender of a driver influence the threat to the driver's own life. Here we investigate the threat to other road users by examining, in Figures 4-15 and 4-16, the number of crashes in which pedestrians are killed as a function of the age and gender of drivers (of any type of motorized vehicle) involved in the crashes. No assumption is made regarding responsibility in pedestrian fatality crashes; the FARS data show about one third of fatally-injured pedestrians have blood alcohol concentrations in excess of 0.1 percent by volume, the legal limit for intoxicated driving in most US states (in Sweden the legal limit is 0.02 percent).

Figures 4-15 and 4-16 may be compared to Figures 4-13 and 4-14. Figure 4-16 indicates that very old drivers may pose an increased risk to other road users for the same distance of driving. However, the risk posed per licensed driver shows no such trend. The difference arises because as drivers age, they drive much less. The similarity of Figures 4-13 and 4-15 supports the interpretation that each is measuring, approximately, the risk of involvement in crashes in general (likewise Figures 4-14 and 4-16).

Table 4-12 addresses the risks that drivers impose on other road users by comparing the rates of 80-year-olds to drivers of age 40 and 20. For male drivers, licensing an 80-year-old poses 26% less risk than licensing a 40-year-old. Licensing a 20-year-old poses 140% more risk than licensing an 80-year-old. In terms of the

Table 4-12. Risks* 80-year-old drivers pose to other road users compared to the risks posed by 40-year-old drivers contrasted to the risks posed by 20-year-old drivers compared to the risks posed by 80-year old drivers. The first two values for male drivers indicate that licensing an 80-year-old driver poses 26% ***lower*** risk to society than licensing to a 40-year-old driver, whereas licensing a 20-year old male driver poses a 140% ***higher*** risk to society than licensing an 80-year old driver.

	Male		**Female**	
	Age 80 / Age 40	Age 20 / Age 80	Age 80 / Age 40	Age 20 / Age 80
Per licensed driver (Fig. 4-15)	**0.74**	**2.40**	**0.70**	**3.67**
For same distance of driving (Fig. 4-16)	**3.71**	**0.91**	**1.88**	**2.01**

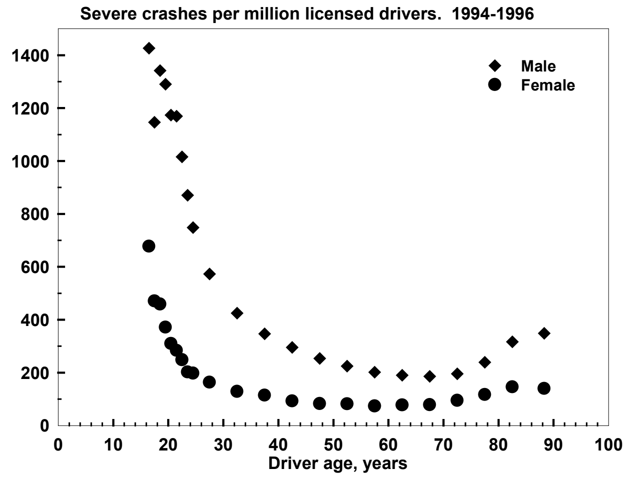


Figure 4-13. Estimated licensed driver involvements (all motorized vehicles) per million licensed drivers in crashes of sufficient severity to likely kill 80-year-old-male drivers versus gender and age of the driver. (Based on FARS and Federal Highway Administration data for 1994-1996).

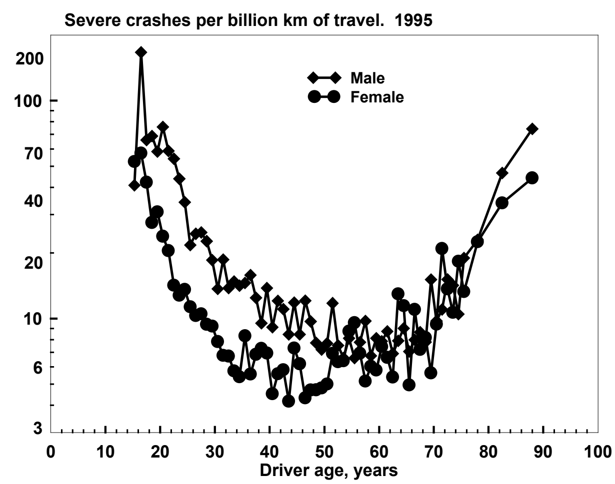


Figure 4-14. Estimated driver involvements (all motorized vehicles) per billion km of travel in single-vehicle crashes of sufficient severity to likely kill 80-year-old-male drivers versus gender and age.

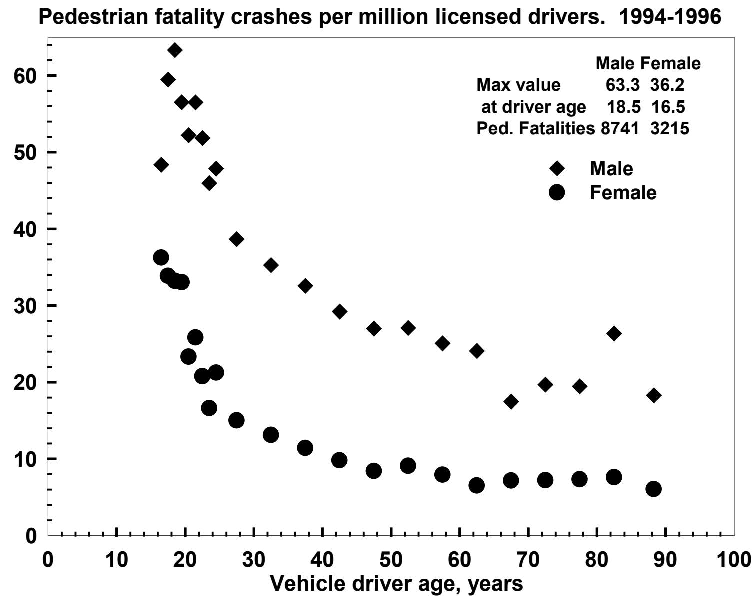


Figure 4-15 Number of single vehicle crashes per million licensed drivers in which one or more pedestrians was killed versus the age and gender of driver.

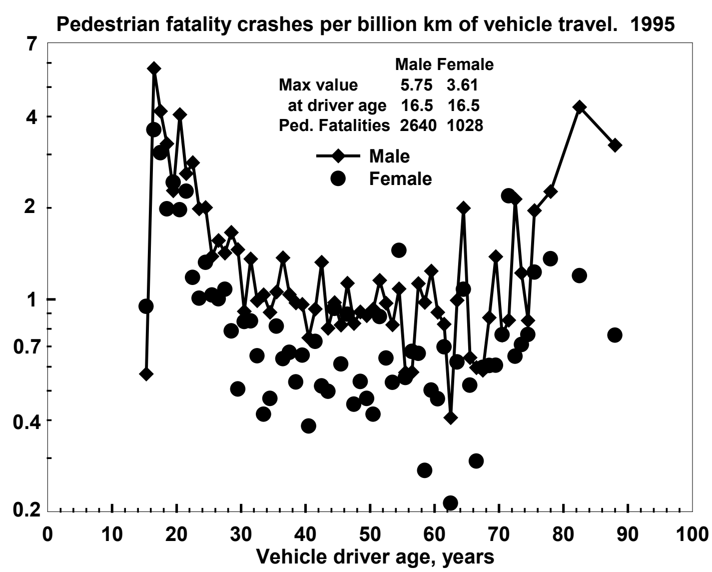


Figure 4-16. Number of single vehicle crashes per billion km of travel in which one or more pedestrians was killed versus the age and gender of the driver. (Based on FARS, and Nationwide Personal Transportation Study, 1995).

threat posed for the same distance of travel, the 80-year-old is 271% more likely to harm someone else than is a 40-year-old. The 80-year-old male driver's risk is, nominally, larger than the 20-year-old male driver's risk (by 9%). For females drivers, the 80-year-old risk is approximately double that of the 40-year-old, but about twice that for the 20-year-olds per unit distance.

Traffic Deaths Relative To All Deaths

A noticeable feature of the ratio of traffic deaths to all deaths (Fig. 4-17) is the lack of a clear difference between the genders. Indeed, from the 20s through the 70s the fraction of all deaths that are traffic deaths declines at an approximately constant rate of 8% per additional year of life for both genders.

Conclusions Regarding Age Effects

The relationships presented here suggest: 1. Licensing an older driver (data goes up to age 80) does not pose a greater threat to other road users than licensing younger drivers -- indeed it poses substantially less risk than licensing a 20-year-old.

2. As drivers age, most measures indicate that they face an increased risk of becoming a traffic fatality, with the increase accelerating at very old ages.

3. Given that a death occurs, the probability that it is a traffic fatality declines steeply with age, from well over 20% for late teens through mid twenties, to under one percent at age 65, and under half a percent at age 80.

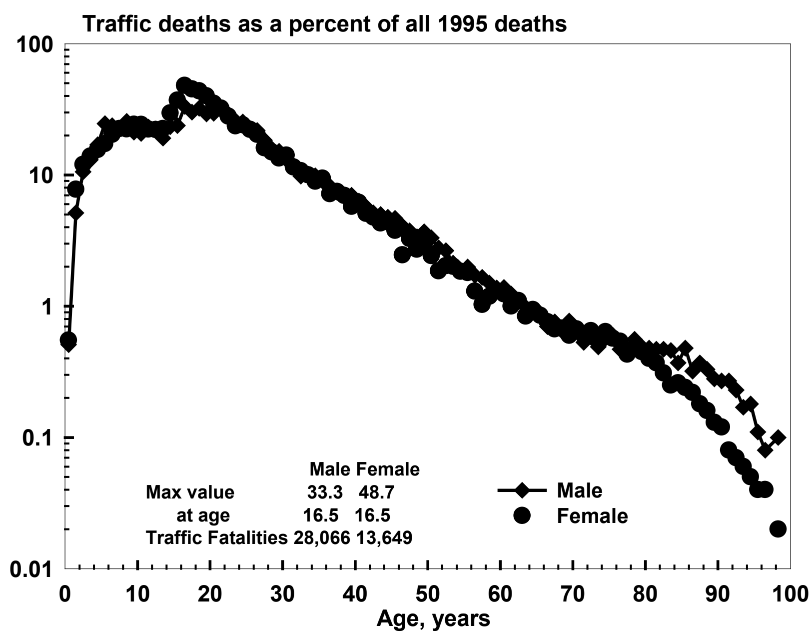


Figure 4-17. Traffic deaths expressed as a percentage (on a logarithmic scale) of total deaths from all causes (including traffic). All data are for 1995.

4.7 US Safety Compared To Safety In Other Countries

In the 1960s the US had, by far, the lowest fatality rates in the world, whether measured by deaths per same distance of travel or per registered vehicle. A series of tabulated rates for the US and 11 other major industrialized countries for the years up to 1978 justified the headline "U.S. the Safest Place for Driving" (Motor Vehicle Manufacturers Association, 1981, p. 52). For every year, the US rate was substantially lower than for any of the other countries listed. The remainder of this section focuses mainly on one rate, the number of deaths per thousand registered vehicles, which will be called the fatality rate. The US began to fall from its leadership position in the late 1970s. Now the International Road Traffic and Accident Database (2001) lists 12 countries (Australia, Canada, Finland, Germany, Iceland, Japan, Luxembourg, Netherlands, Norway, Sweden, Switzerland and the United Kingdom) with rates lower than the US.

Table 4-13 compares US safety in 2000 to safety in 1979, and contrasts the US changes to those occurring in Canada, Great Britain, and Australia. These three comparison countries were chosen because they have much in common with the US.

Table 4-13: Comparison of traffic safety changes, 1979-2000, in the US and other "similar" countries.

	USA	Canada	GB	Australia
1979				
Traffic Fatalities	51,093	5,863	6,352	3,508
Vehicles (thousands)	144,317	13,329	18,600	7,358
Fatalities/(thousand vehicles)	**0.354**	**0.440**	**0.342**	**0.477**
2000				
Traffic Fatalities	41,821	2,917	3,409	1,818
Vehicles (thousands)	217,292	18,772	28,898	12,477
Fatalities/(thousand vehicles)	**0.192**	**0.155**	**0.118**	**0.146**
Change in rate, 1979-2000	**-45.6%**	**-64.7%**	**-65.5%**	**-69.5%**
Calculated 2000 US rate if it had declined by same % since 1979	(0.192)	0.125	0.122	0.108
Estimated 2000 US fatalities with above rates	(41,821)	27,176	26,574	23,511
Number of US lives that would have been saved/year if US fatality rate had declined by same percent as in the comparison countries	**0**	**14,645**	**15,247**	**18,310**

The 45.6% decline in the US rate in this 21-year period might seem substantial. It corresponds to an average reduction of 2.9% per year. However, this is less than the average reduction of 3.2% over the entire prior period, 1900 to 1978.

Canada, Great Britain and Australia all had fatality rate reductions of more than 64%. If the US rate had declined by the same 64.7% experienced by Canada, then 2000 fatalities would have been 27,176, rather than the 41,821 that occurred. That is, 14,645 fewer Americans would have been killed in 2000. Matching the British and Australian performance would have reduced 2000 US road deaths by 15,247 and 18,310 respectively.

The calculation is reasonably robust with regard to choosing other approaches and reference years different by a few years from 1979. A calculation based on the changes in total fatalities from 1979 to 2000 (data in Table 4-13), rather than on the rates, gives similar estimates. For the US, the 2000 fatality count is 23.4% below the peak value of 54,589 attained in 1972. For Canada, Britain and Australia, the corresponding reductions are 56.5%, 57.3% and 52.1% below their respective peaks. All three comparison countries more than halved their peak fatalities. If US fatalities had declined by half of the peak value, the 2000 total would be 27,300. The observed number exceeds this by more than 14,000. The overall conclusion is that if US safety performance had matched that in any one of the three comparison countries, substantially more than ten thousand Americans who were killed in 2000 road traffic would now be alive.

The calculation in Table 4-13 was repeated to compare every year from 1979 through 2000, with the results shown in Table 4-14. Summing over the period gives estimates of the total numbers of American lives that would have been saved over the period 1979-2000 if US safety performance had matched that in the comparison, countries as follows:

If US matched Canada,	196,604 fewer US fatalities
If US matched Great Britain	146,733 fewer US fatalities
If US matched Australia	226,796 fewer US fatalities.

In Britain, the rate for the same distance of travel (Road traffic statistics, 2000) declined by 70.5% from 1979 to 2000, compared to a 54.54% drop in the US (Fig. 4-18). If each year from 1979 through 2000 the number of traffic deaths for the same distance of travel had declined in the US by the same percent as occurred for Britain, then 185,913 fewer Americans would have been killed in the 21-year interval. This is larger than the estimates based on fatalities per vehicle because the average distance traveled per vehicle per year increased more in Britain than in the US from 1979 to 1997. While estimates of distance traveled per vehicle per year are unavailable for Canada and Australia, it is expected that estimates based on fatalities for the same distance of travel would likely also generate corresponding larger estimates of additional US fatalities.

Table 4-14: Calculated reductions in US traffic fatalities if US fatality rate (in the comparison countries. The calculation is based on standardizing all rates to the value 1 for 1979.

Year	Observed US fatalities	Calculated US fatalities if US rate change had matched that in:			Calculated reduction in US Fatalities if US rate change had matched that in:		
		Canada	GB	Australia	Canada	GB	Australia
1979	51,093	51,093	51,093	51,093	0	0	0
1980	51,091	47,247	47,652	47,108	3,844	3,439	3,983
1981	49,301	46,761	46,650	46,510	2,540	2,651	2,791
1982	43,945	35,442	46,960	43,734	8,503	-3,015	211
1983	42,589	35,699	42,987	36,636	6,890	-398	5,953
1984	44,257	36,574	44,342	37,698	7,683	-85	6,559
1985	43,825	39,359	41,938	39,771	4,466	1,887	4,054
1986	46,087	36,241	43,336	38,904	9,846	2,751	7,183
1987	46,390	37,562	41,343	37,934	8,828	5,047	8,456
1988	47,087	36,319	39,888	39,861	10,768	7,199	7,226
1989	45,582	36,098	41,699	38,427	9,484	3,883	7,155
1990	44,599	34,631	40,394	31,641	9,968	4,205	12,958
1991	41,508	33,669	36,007	29,437	7,839	5,501	12,071
1992	39,250	31,420	32,659	26,456	7,830	6,591	12,794
1993	40,150	32,773	29,967	26,186	7,377	10,183	13,964
1994	40,716	29,762	28,869	25,759	10,954	11,847	14,957
1995	41,817	31,179	29,160	26,991	10,638	12,657	14,826
1996	42,065	29,193	28,594	25,871	12,872	13,471	16,194
1997	42,013	28,648	28,157	22,913	13,365	13,856	19,100
1998	41,501	27,316	26,797	22,472	14,185	14,704	19,029
1999	41,717	27,638	26,605	22,695	14,079	15,112	19,022
2000	41,821	27,176	26,574	23,511	14,645	15,247	18,310
Total US lives saved if changes in US fatality rate (fatalities per thousand vehicles) had matched changes in the indicated country.					**196,604**	**146,733**	**226,796**

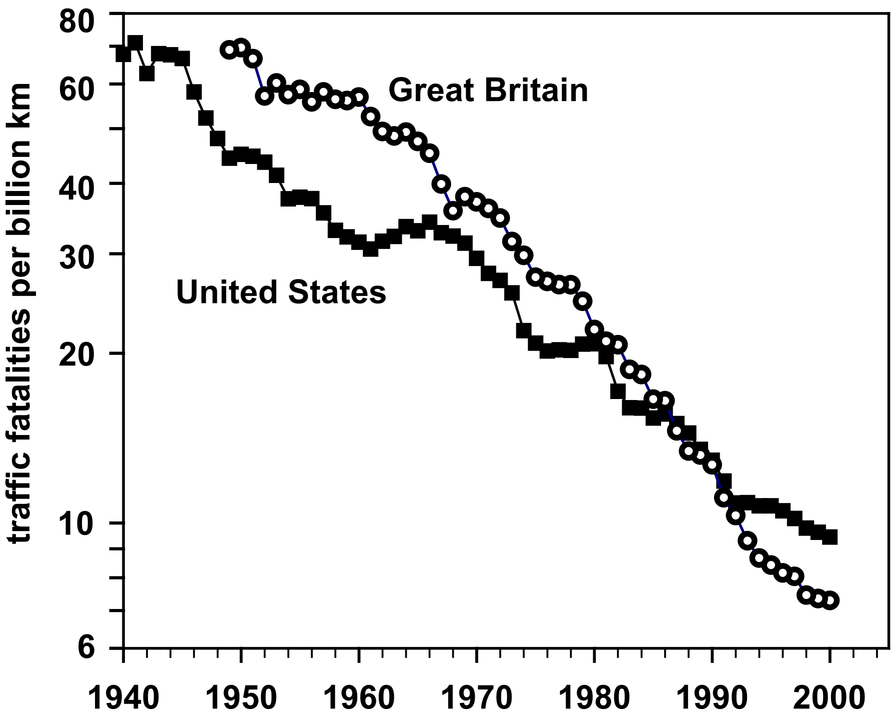


Figure 4-18. Fatalities for the same distance of travel in the US and Great Britain

While there is uncertainty in all the above estimates, they do justify the conclusion that, if US safety performance had been similar to that in any of the three comparison countries, well over one hundred thousand Americans who are now dead would be alive. An additional 100,000+ Americans being killed so overshadows any other transportation safety matter that it is treated in some detail below in an attempt to reach for explanations.

Airbag Mandate And Vehicle Factors At Core Of US Policy

No safety issue has consumed so much time and effort as the requirement that all new cars (plus some other vehicles) sold in the US must come equipped with frontal airbags (hereafter called airbags). This mandate makes the US the only nation in the world whose inhabitants are prohibited from purchasing a new vehicle without an airbag.

Claims

The mandate was enacted because advocates claimed that airbags:-

1. Are passive (require no user knowledge or action)

2. Replace belts (permit vehicles to not have belts)
3. Reduce driver fatality and injury risk by 40%
4. Reduce risk regardless of gender, age, etc.
5. Hurt nobody

Reality

All 5 claims are false.

1. Are passive. Drivers, passengers, and parents must know an ever-increasing list of rules on how to avoid death and injury from deploying airbags. Arguably, airbags are the least passive safety device ever installed on vehicles; they might better be called *belligerent restraints*. The manual belt is far more passive, requiring only one simple rule, "buckle up."

2. Replace belts. The government's estimate of airbag cost included $18 saved by not installing belts (FR Doc.77-19137, 1977). Yet today no manufacturer in the world offers airbags as complete occupant protection devices. In all cases they are offered as supplemental devices to increase the effectiveness of the primary occupant protection device, the lap-shoulder belt.

3. Reduce driver fatality risk by 40%. This claim is not merely incorrect – it is absurd, and was know to be absurd when the claims were made. Airbags deploy only in frontal-impact crashes, which are responsible for just over half of fatalities. For an airbag to be 40% effective, its effectiveness in frontal crashes would have to be nearly 80%, a performance level that 1970's knowledge readily dismissed as impossible. The government disparaged a well-executed study (Wilson and Savage, 1973) reporting an overall effectiveness of 18% (the latest government estimate (Kahane, 1996) is 13%). Using data from a fleet of 10,000 airbag-equipped cars sold in the mid 1970s, Pursel et al. (1978) estimated that the airbag alone reduces severe injury risk by 9%.

Table 4-15 summarizes estimates of the effectiveness of airbags in reducing risk to belted drivers (driving unbelted is illegal in all US states except New Hampshire). Barry et al. (1999) claim that these estimates are too high.

The 9% fatality reduction for belted drivers is consistent with the finding (Table 4-9) that adding an airbag increases the effectiveness of safety belts from 42% to 47%, a difference of 5 percentage points. Figure 4-19 clarifies the difference, and shows that as belt use rates increase from 0% to 100%, deaths prevented by airbags decline from 13 to 5 per original 100 fatalities.

Table 4-15. Effectiveness of airbags in reducing fatality risk to <u>belted</u> drivers.

Author (s)	Airbag effectiveness estimate*
Evans, 1991	9 %
Zador and Ciccone, 1993	9 %
Kahane, 1996	9 %

*All estimates based on "naïve assumption" (discussed later) that occupant protection does not influence driver behavior.

<u>4. Airbags reduce risk regardless of gender, age, etc</u>. All the above estimates are averages for all drivers. There is now considerable evidence that airbags increase risk to many large portions of the population, including possibly older drivers (Kahane, 1996). Dalmotas et al. (1996) find that while airbags reduce net harm to males by 12%, they increase net harm to females by 9%. The evidence that airbags increase risks to children is clear (Kahane, 1996, Graham et al. 1998.) Graham et al (2000) find that airbags increase fatality risk to unbelted children by 84% and to belted children by 31%.

<u>5. Airbags hurt nobody.</u> More than 200 people in the US have been killed by the forces of deploying airbags in crashes they otherwise would have survived, in many cases uninjured. The victims have been mainly children and babies in the front passenger seat, and short female drivers. Vastly larger numbers have sustained many other types of injuries, including eye injuries, hearing loss and respiratory disease.

Well prior to the airbag mandate technical information raised questions regarding risks airbags posed to children. Papers were published with titles including *Possible effects of air bag inflation on a standing child* (Aldman, 1974) and *Airbag effects on the out-of-position child.* (Patrick and Nyquist 1972). Yet the agency responsible for mandating airbags writes "air bags will provide substantial crash protection to otherwise unrestrained small children in crashes" (National Highway Traffic Administration, 1980, p. 71). On page 70 of the same document the agency cites, and dismisses, statements by General Motors, based on their own animal testing and other technical considerations, that a "child might be injured by an inflating bag". Ralph Nader, while engaged in promoting airbags, is photographed in July 1977 demonstrating an airbag "safely" deploying into the face of an unbelted three-year old girl (Photograph reproduced in Evans, 2002; see also http://www.scienceservingsociety.com/nader.htm). Airbags in fact increase fatality risk to unbelted children by 84% (Glass et al., 2000). Even for belted children, airbags increase fatality risk by 31% (Glass et al., 2000).

Airbags cause additional harm, including eye injuries (Duma et al., 1996), hearing loss (Yaremchuk and Dobie, 1999; Buckley, 1999) and asthmatic attacks (Gross et al., 1994; 1995).

All the above relates to frontal airbags. Many manufacturers now offer side airbags. It is difficult to see how they could be more than about 10% as effective as frontal airbags, given how much less deployment space is available. This means that the theoretical maximum reduction in overall occupant fatality risk can be no more than a percent or so. It seems almost inevitable that a child asleep against the deploying unit will be killed.

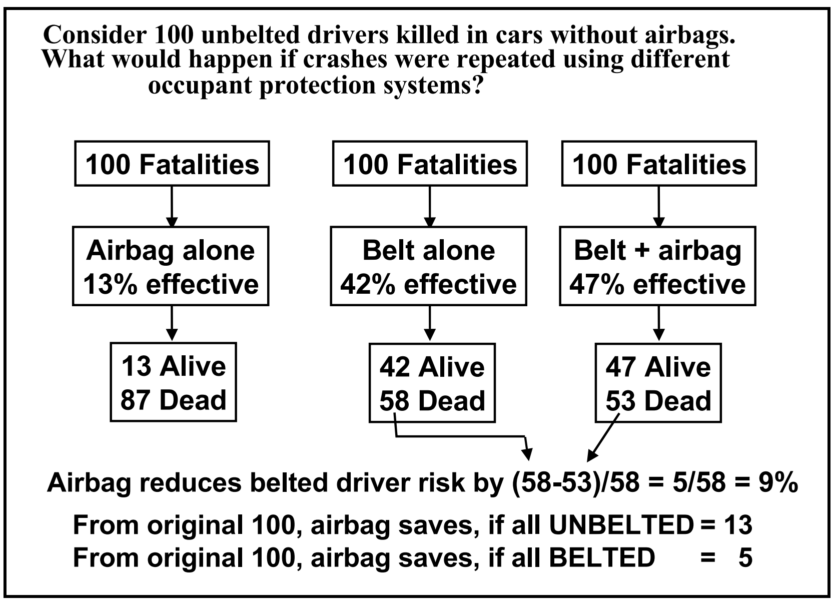


Figure 4-19. Number of belted and unbelted driver lives saved by airbags, (based on the "naïve assumption" that occupant protection does not influence driver behavior).

Airbag Mandate and the Technology/Human Interface

The conclusion that airbags reduce belted driver risk by 9% refers strictly to the change in risk, given identical numbers of identical crashes. From this, one cannot infer the change in fatalities due to a policy requiring universal airbag installation. Such an inference requires a crucial, and false, assumption (one which is implicitly included, without comment, in all estimates of lives saved by airbags). The false assumption is that beliefs about airbag effectiveness have zero effect on driver behavior.

Table 4-16 compares two models of how technological changes affect safety. An analysis of 24 studies (Evans, 1996) shows that the naive model can be grossly in error, even to the point of estimating increases in safety when reductions actually occur, and vice versa.

Driver behavior changes have been reliably observed in response to technologies that provide clear feedback. Anti-lock brakes provide a clear example (Evans, 1999, Farmer et al., 1997). For technologies that affect only injury risk, behavior effects are expected to be smaller and therefore difficult to measure. While behavior responses to injury risk are generally difficult to determine empirically, the following construct establishes that they occur.

Consider two hypothetical cars, identical in all respects except that one has the magical property that its occupants cannot be hurt in any crash, while the other is wired with dynamite to explode on the slightest impact. No one would claim that the two cars would be driven in identical ways. The same conclusion applies even if the cars were in fact identical, but falsely believed to possess the hypothesized properties. Changes in perceived protection can be viewed as lying along a continuum bounded by hypothetical extremes.

While there are no empirical estimates of changes in driver behavior in response to US airbag policy, the considerations below suggest that the airbag mandate not only increased driver risk-taking, but by more than the meager actual benefit of the device in a crash. For over 30 years the public was inundated with messages grossly overestimating the benefits and ignoring the negatives of airbags. It was widely believed that airbags were so effective that belt wearing was unnecessary. Slow-motion movies convinced many that in a crash they would glide forward into the gentle caress of a soft cushion. Such massive inputs must lead to outputs, most likely including less belt wearing and faster speeds.

When it became clear that airbags were killing short ladies, a number of short ladies told me “When I discovered the airbag could kill me, I started to drive more cautiously.” If one accepts this statement, it is hard to dispute the corresponding conclusion that a belief that the airbag dramatically reduces risk must lead to less cautious driving.

If beliefs about airbags led to an undetectable 3% increase in average speed, a 13% increase in fatality risk would result. Instead of reducing fatalities by 9%, the intervention would increase fatalities by 4%. Government calculations, based on assuming the naïve model, that airbags have saved over 2,000 lives (mainly of unbelted male drivers) in the more than ten years since 1986, should not be accepted even as gross approximations. They are, however, closer to the truth than the claims made to support the airbag mandate (Federal Register 1977) that driver and passenger airbags would prevent 12,100 deaths per year (or 120,000 per decade, the unit apparently adopted today in order to associate larger numbers of lives saved with airbags). Even assuming the naïve model, the calculated benefits are relatively small, and, as discussed above (Figure 4-19), will decline sharply as belt-wearing rates increase.

Table 4-16. Contrast between the naïve model, which ignores the technology/human interface, and the realistic model, which attempts to take into account the technology/human interface.

1. Naïve model	2. Realistic model
Also called ■ Non-interactive ■ Zero feedback ■ Engineering	Also called ■ Interactive ■ Human behavior feedback ■ Assorted misleading names
Assumes	**Assumes**
Users do not change their behavior in response to safety technology	Users do change behavior in response to perceived changes in safety
Validity	**Validity**
Generally overestimates safety benefits (may predict wrong sign)	Provides correct estimates IF parameters can be determined

The question "Did the US airbag mandate increase or decrease traffic fatalities?" cannot be answered without knowing the magnitude of its effect on driver behavior. However, the airbag mandate offers insight into why 100,000 more Americans died in traffic than would have been killed if US safety performance had matched that of Canada, Britain, or Australia.

Priorities In US Safety Policy

The relative contributions of different factors to traffic safety discussed earlier are synthesized in the non-quantitative sketch in Figure 4-20. Not reflected in this sketch is another large and fundamental distinction between engineering and human-factors interventions. Even if a regulated vehicle design change actually reduces risk, it takes a number of years to incorporate it into a vehicle, and another decade before essentially all vehicles on the road have it. Belt wearing and drunk-driving legislation start reducing harm from the time the laws take effect (perhaps even from the time it is discussed).

While other countries formulated effective policies consistent with Figure 4-20, US priorities were ordered almost perfectly opposite to where benefits are greatest. An obsessive focus on the airbag mandate and on minimally important vehicular factors misled the public into making more dangerous choices than would otherwise have occurred, and largely precluded the adoption of effective countermeasures.

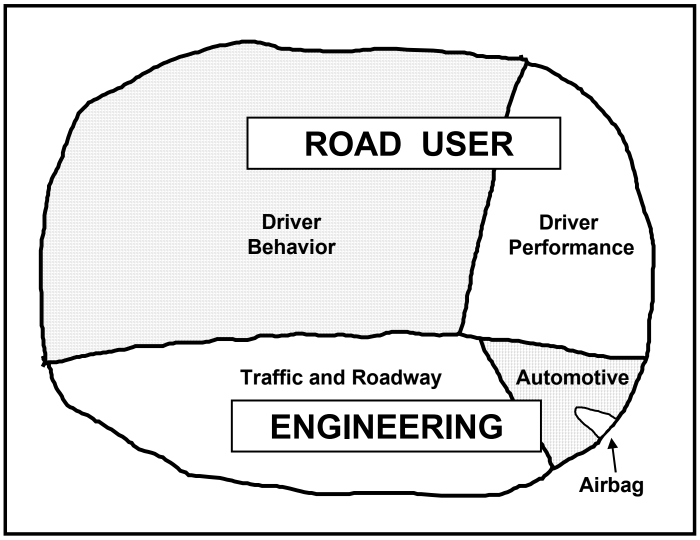


Figure 4-20. Sketch of non-quantitative judgmental estimate of relative importance of different factors.

The decision makers, and those whose council they welcomed, neither understood nor respected technical information. By the early 1970s there was already more than sufficient information in the technical literature to dismiss the claims of airbag performance offered to justify the mandate.

Why does technical knowledge influence safety policy in the US so much less than in other motorized countries? It seems to me that the explanation is, in part, because no other nation bears a burden resembling the US legal system. In other democracies, elected legislators with varied backgrounds are influenced by inputs from diverse sources, including the technical community. In the US, lawyer legislators get nearly all their inputs from other lawyers. It is therefore not too surprising that measures that open deep pockets for legal assault are more appealing than measures, which reduce harm. Only the most gullible can imagine that any net good emerges from the resulting system which lavishly supports an enormous community of the richest people in America, "expert" witnesses, consultants skilled at identifying jurors lowest in knowledge and reasoning skills, and a vast court superstructure, all of which are, in their scope, unknown anywhere else on earth. Even advocates of the US system rarely conclude that US cars must be much safer than Swedish cars because the US spends astronomically more per capita on litigation than does Sweden.

It is only in the US that traffic crashes serve as catalysts to transfer vast wealth from the public to the legal system. Even if all alleged defects in the engineering or manufacture of the vehicle, road, or traffic control system could be miraculously fixed, it is hard to see how this could reduce fatalities by as much as a percent or so. However, I am convinced that indirect effects of US litigation are enormously greater. The broad message from so much litigation is that crashes flow from the failings of asset-rich institutions, a factor over which drivers have no direct control. Even believing a little in this may tend to make drivers less responsible and careful, factors that have an enormous influence on crash risks.

It is only in the US that citizens asked to identify anyone important in traffic safety would produce a list comprised almost exclusively of lawyers. It was a lawyer, Joan Claybrook, who, when head of the National Highway Traffic Safety Administration (NHTSA) from 1977 to 1980, spearheaded the airbag mandate with the five false claims discussed above. A NHTSA official is quoted as saying "Joan came to NHTSA with a mission and that mission was air bags" (Graham, 1989, p. 109).

In a November 1983 television interview Joan Claybrook says of airbags:

> **"They're much better than seat belts, according to the government's most recent data"**

and continues to dismiss safety belts as

> **"the most rejected technology we have. So I believe that airbags would add a great dimension to cars and car safety, would protect all front seat occupants in those types of crashes where 55% of the public is now killed"**

Claybrook continues

> **"Airbags are really the best solution -- they fit all different sizes and types of people, from little children up to 95th percentile males, very large males. … So they really work beautifully and they work automatically and I think that that gives you more freedom and liberty than being either forced to wear a seat belt or having a car that's not designed with the safety engineering we know today."**

The main pressure to retain the airbag mandate and keep it the focus of national safety attention, rather than let consumers choose whether or not they wish to purchase the device, still comes from the non-technical lawyers responsible for the mandate. They now have allies in the massive airbag industry, which has been likened to the military/industrial complex of an earlier era. What industry would not enthuse over a government requirement that everyone must purchase their expensive product, regardless of whether they want it or are even prepared to pay to have it disconnected? The purchasers of the vehicles that comprise the current US fleet paid about 25 billion dollars for airbags. A microscopic fraction of such a sum properly applied could generate far larger safety benefits than those claimed (falsely) for airbags.

The uniquely US fixation on vehicle factors can be traced to the mid-1960s efforts of lawyer Ralph Nader and his proteges, including Joan Claybrook. Legislation focussing overwhelmingly on the vehicle followed, starting with the 1996 National Traffic and Motor Vehicle Safety Act and the Highway Safety Act. As discussed above, it takes about a decade or so before any reductions claimed for vehicle safety improvements could begin to show. Let us refer to the period before about the mid 1970s as the *Pre-Naderite* period, and the period after about the mid 1970s as the *Post-Naderite* period. During the *Pre-Naderite* period, US traffic was, by a large margin, the safest in the world. In the *Post-Naderite* period the US has dropped from the number one ranking to number 13, and is still sinking. As a result of the US following the lead of lawyers rather than adopting policies illuminated by technical understanding, well over ten thousand additional Americans are being killed in traffic each year. The number, equivalent to an additional 30 deaths per day, will increase if current trends continue.

One of the great ironies is that the very same lawyers responsible for this disaster continue to exercise decisive influence to keep US safety policy on the same wrong track. What is even more ironic is that the media continue to respectfully refer to these same non-technical architects of policies that have killed over a hundred thousand Americans as *safety advocates*.

4.8 Bibliography

Many of the topics in this chapter are treated in greater detail in *Traffic Safety and the Driver* by Leonard Evans (Van Nostrand Reinhold, NY, 1991). In order to reduce repetition, the absence of a citation in the text implies that additional information and references are available in this book. *Traffic Safety and the Driver* is available from *amazon.com, bn.com* and directly from the author at *scienceservingsociety.com*. Many of the themes treated here will be expanded in the author's forthcoming book *Traffic Safety*, expected in 2003.

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