Learning from the Past: Revisiting Expert Judgments Related to the Lifesaving Potential of Air Bags

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Abstract

In 1984 the official U.S. government estimate, based largely on experimental data and expert judgment, suggested that 4,500 to 9,000 lives could be saved annually if full frontal air bags were installed in all passenger vehicles. In contrast, the current official estimate of lifesaving potential, based on extensive real-world crash experience, has now been reduced to approximately 3,000 lives saved annually. This article pinpoints and discusses the sources of errors made in the early predictions of lifesaving potential for air bags.

1 Introduction

When faced with uncertainty, technical experts are prone to varying degrees of overconfidence and bias in their predictions [1,2,3]. These errors in judgment call into question the validity of the predictions, and in a broader arena, they call into question the validity of relying on expert judgment and risk analysis to support decision-making. Improvements in validity may result from revisiting previous assessments where the performance of the experts is critically evaluated and efforts are made to avoid similar errors in future predictions. This article explores errors in judgment made in the assessment of the lifesaving potential of air bags.

With approximately 40,000 to 50,000 motor vehicle-related deaths occurring each year [4], airbags represent an important engineering innovation and lifesaving intervention. Although current estimates [5] suggest that full-frontal airbags will save only approximately 3,000 of the 4,500 to 9,000 lives annually that they were expected to save [6], a recent analysis suggests that airbags compare favorably with other medical lifesaving technologies based on their cost-effectiveness [7]. Nonetheless, their performance has been disappointing to safety advocates who expected more from the technology. Further, the ability of airbags to cause death, as well as to prevent death, has started safety specialists and become the subject of widespread media attention. Investigators from the National Highway Traffic Safety Administration (NHTSA) now attribute 96 deaths to airbag deployment in minor to moderate severity crashes (13 infants in rear-facing child seats, 42 forward-facing children, 4 adult passengers, and 37 drivers) [8].

2 Estimation of the Air Bag's Lifesaving Potential

Auto safety experts have long recognized that the lifesaving potential of an intervention or restraint system depends on its rate of use in vehicles (u), the net effectiveness of the system for reducing fatalities when used (e), and the baseline number of fatalities that the intervention can reduce (n). Thus, the fatalities prevented by intervention j (F_j) would be predicted as:

$$F_j = u_j \cdot e_j \cdot n \tag{1}$$

In addition, each of the variables in equation 1 may depend on a number of factors. For example, u_j may depend on whether or not the system requires action on the part of the user, the user feels an obligation to use the system, and/or the user perceives incentives to use the system. The numbers of fatalities that could be reduced (n) depend on numerous factors such as the number of cars on the road, the number of miles driven per car, the age and blood alcohol levels of drivers, the speed limit and other laws, and many other safety interventions. Effectiveness is typically expressed as the net percentage reduction in fatalities for an individual with the intervention compared to an individual without the intervention. Effectiveness of restraint systems (e.g., air bags) may depend on the design of the technology and the way in which individuals interact with it, and on the use of other interventions (e.g., safety belts).

When multiple interventions are available, analysis of lifesaving potential typically focuses on estimation of the incremental effects of the different strategies. Safety belts, which were required prior to air bags and are both cheaper and more effective than airbags when used, represent the baseline technology or *status quo* to which airbags are compared. Assuming that n represents the number of front-seat fatalities that could be prevented for occupants of a fleet of air bag-equipped vehicles, every occupant is protected by the air bag alone (a) or by an air bag combined with a safety belt (a+b) (i.e., $u_a + u_{a+b} = 1$). The lifesaving potential of belts (F_b) and the incremental lifesaving potential of air bags (F_a) for this n are:

$$F_b = u_{a+b} \cdot e_b \cdot n \tag{2}$$

$$F_a = ((1 - u_{a+b}) \cdot e_a + u_{a+b} \cdot (e_{a+b} - e_b)) \cdot n \tag{3}$$

where u_{a+b} = the percentage of vehicle occupants using air bags and safety belts, and e_a, e_b, e_{a+b} = the effectiveness of air bags alone, safety belts, and air bags combined with safety belts, respectively.

Simple bounding analysis shows that the maximum ($F_a = e_a \cdot n$) and minimum ($F_a = (e_{a+b} - e_b) \cdot n$) incremental lifesaving potential of air bags occur at the minimum ($u_{a+b} = 0$) and maximum ($u_{a+b} = 1$) usage of safety belts, respectively, for $e_a > e_{a+b} - e_b > 0$. Table 1 summarizes the estimates of the five model inputs used by the NHTSA to assess the incremental lifesaving potential of air bags in 1984 [6] and in 1997 [5].

Table 1: Estimates of Inputs Used to Assess the Lifesaving Potential of Air Bags

Year	1984	1997
Front-seat occupant fatalities	24,600	27,000
n^*	26,000	35,000-39,000
u_{a+b}	12.5%	68.0%
e_a	20-40%	9-13%
e_b	40-50%	45%
e_{a+b}	45-55%	50.5%
F_b (from equation 2)	1,500	10,700-11,900
F_a (from equation 3)	4,700-9,300	2,200-3,000
* Indicates estimated by authors. Otherwise 1984 from [6], 1997 from [5].		

3 Key Differences and Possible Sources of Misjudgment

Two of the inputs in Table 1 remained remarkably constant between 1984 and 1997. Given the relatively large amount of safety belt efficacy data available in 1984, it is not surprising that the 1984 estimate of the effectiveness of safety belts (e_b) appears to have been very accurate. More remarkable is the fact that the estimate of the effectiveness for the air bag and safety belt combination (e_{a+b}) was also very accurate. Although experts underestimated the number of fatalities (n) that could be reduced by the interventions (by failing to credit safety belts for their role in maintaining the constant number of fatalities), this error plays a relatively minor role in the current estimates of the lifesaving potential of airbags. In contrast, the remaining two inputs showed poorer correlation between the predictions and reality.

Predictions of Future Safety Belt Use

In 1984, the NHTSA considered the possibilities of voluntary behavioral changes in safety belt usage and of mandatory state safety belt use laws. However, the agency and other technical experts were generally pessimistic about the potential for increased safety belt use due to earlier experience of public outrage related to ignition interlock systems and the apparent decreasing trend in safety belt use at the time [8,9]. For example, one of five experts refused to offer judgment about the proportion of motorists that would be belted in crashes if there were strict mandatory belt use laws because he believed that probability of such laws withstanding political opposition was virtually nil [9].

Nonetheless, 49 states (all but New Hampshire) now have mandatory safety belt usage laws (11 of them have strict primary enforcement) and usage has increased steadily since 1984. Figure 1 shows the increase in safety belt usage recorded in the NHTSA's Fatal Accident Reporting System (FARS) for front-seat occupants in vehicles involved in fatal accidents and for front-seat fatalities. Observational surveys give slightly higher estimates of belt use (e.g., the 68% given in Table 1 is based on roadside observation).
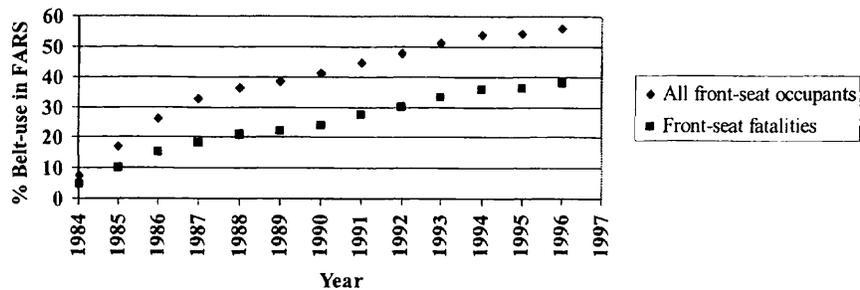
Figure 1: Increase in Safety Belt Usage for Motorists Involved in Fatal Crashes

Several factors influenced the dramatic growth in safety belt usage. First, when the NHTSA mandated air bags in 1984, the decision included a provision that would void the air bag requirement if two-thirds of the U.S. population became subject to mandatory safety belt laws by April 1, 1989. Thus, the decision to mandate air bags, which was motivated by the very low safety belt usage rates, came with an incentive to vehicle manufacturers to stimulate passage of mandatory safety belt use laws. Second, the attitudes of motorists toward safety belts has probably become more favorable as educational campaigns have highlighted the benefits of safety belts and informed motorists about state laws [8]. The increased safety belt usage accounts for a large decrease in the lifesaving potential attributed to air bags since more motorists are saved by safety belts directly and have less need for air bag protection.

Predictions of Air Bag Effectiveness for Unbelted Front-Seat Occupants

The large decrease in the estimated lifesaving potential of air bags is also due to the lower air bag effectiveness than was predicted. As shown in Table 1, in 1984 experts believed that the air bag alone would be two to four times more effective than the current field data now suggest.

Why was the air bag's effectiveness in protecting unbelted adults so overstated? For starters, there was little quantitative thinking in 1984 about the potential of air bags to cause fatal injuries. There was also an assumption (at least implicitly) that air bags would be equally effective for all vehicle occupants. Indeed, in testing, air bag systems are optimized to protect the chest, neck, head, and face of unbelted 50th-percentile male crash dummies from minor and moderate injuries in a 30 mph frontal crash into a fixed barrier. In order to meet this criterion, air bag systems use propellants that deploy very quickly and with a great deal of force, which can be quite hazardous to occupants that are close to the deploying air bag. By 1984 numerous experimental crash tests with dummies, cadavers, and animals had instilled confidence in the NHTSA's engineers that an unbelted occupant could be protected by a rapidly inflating air bag. It now appears that many unbelted occupants are

improperly positioned and are consequently not protected by the air bag. Thus, it seems that the experimental crash tests were not accurate indicators of the extent of air bag effectiveness in real-world crashes.

Even before the NHTSA's 1984 decision, automobile manufacturers had highlighted the potential hazards posed by air bags to out-of-position occupants (most notably to children). Several papers presented at a conference in 1980 suggested disagreement about the potential magnitude of the problem [10,11,12]. For example, one analysis found that children could be seriously or fatally injured by air bag deployment forces that are required to protect adults and concluded that children should be restrained in the rear seat [11]. In contrast, another analysis (by NHTSA analysts) suggested that it was more likely that children would be protected from injury than harmed by the air bags, particularly if they were secured in a child restraint [12]. The same analysis further acknowledged that while air bags would induce small numbers of fatalities and injuries among occupants of all ages, the net effect at all ages would be fatality risk reductions of 30-50% [12]. The NHTSA appears to have been optimistic about the ability of air bag engineers to protect adults without harming children.

By 1984, estimates of air bag net effectiveness had dropped from 30-50% to 20-40% based on limited field data that suggested lower estimates. In particular, surveillance of a small General Motors fleet of air bag-equipped vehicles suggested a best estimate of effectiveness of 0% (with a 90% confidence interval of −70% to +46%) [6]. However, the NHTSA noted that these estimates were too uncertain to use as a basis for extrapolation, but used this information to modify the judgment of effectiveness by bounding its estimate below the original upper limit [6].

Another explanation for the overestimation of effectiveness may have resulted from application of the same air bag effectiveness estimate for driver and passenger air bags. Current evidence suggests that air bags are differentially effective for different age groups (e.g., air bags are now believed to kill more children than they save [13]). There are at least two reasons that air bags might differ in effectiveness by seating position. In particular, one might expect air bags to be relatively more effective for drivers because children do not drive (and consequently children in the driver seat would not be expected to reduce the net effectiveness). In contrast, one might expect that passenger air bags might be less effective due to the degree of out-of-position behavior allowed by the seating position (i.e., drivers must operate the vehicle while passengers are not so constrained). In the case of drivers, some people might sit very close to the steering wheel (and the air bag) in order to operate the vehicle (e.g., particularly short-statured people) and this can lead to fatal injuries. Passengers tend to be out-of-position if they lean forward or interact with the dash board (e.g., operate the radio, get into the glove compartment, sit with their feet on the dash board). More research on the relative effectiveness of the passenger air bag is needed.

Finally, another important factor that may explain the reduced effectiveness of air bags is the low deployment threshold. Since air bags are designed to deploy in relatively minor crashes, they are causing serious and fatal injuries in accidents where the occupants might not otherwise have been injured. In addition, while experts

assumed that air bags would only deploy in frontal crashes (where they are believed to be effective), evidence suggests that they are deploying in many non-frontal crashes as well. Thus, the overall lifesaving effectiveness of the aggressive deployment of air bags designed to protect 50th-percentile males in high-speed frontal collisions is reduced by the occurrence of children and out-of-position occupants who are killed (or not protected) by air bags in low-speed and non-frontal crashes.

4 Conclusions

Overall, experts provided estimates of the lifesaving potential for air bags that were too optimistic and too precise. The most significant errors were associated with optimistic estimates of the effectiveness of air bags for unbelted individuals and pessimistic estimates about safety belt usage rates. As air bag designs are changed to explicitly address the variability of occupant sizes and seating positions and as deployment thresholds are increased to prevent serious and fatal injuries in low severity accidents, the effectiveness of air bags may increase.

References

1. Mosleh A, Bier VM, Apostolakis G. A critique of current practice for the use of expert opinions in probabilistic risk assessment. Reliab Engng & System Safety 1988; 20:63-85
2. Morgan GM and Henrion M. Uncertainty. Cambridge, New York, 1990
3. Cooke, RM. Experts in Uncertainty. Oxford, New York, 1991
4. Traffic Safety Facts, Wash, DC: NHTSA, US DOT, annual.
5. NHTSA. Air Bag On-Off Switches; Final Rule. 62 Federal Register 62405-62455, 1997.
6. Amendment to Federal Motor Vehicle Safety Standard 208 Passenger Car Front Seat Occupant Protection, Fed Reg Impact Anal, Wash, DC: NHTSA, July 1984.
7. Graham JD, Thompson KM, Goldie SJ et al. The cost-effectiveness of air bags by seating position. JAMA 1997; 278:1418-1425.
8. Graham JD. Auto safety: Assessing America's performance. Praeger, Westport, Connecticut, 1989.
9. Graham JD, Henrion M. A probabilistic analysis of the passive-restraint question. Risk Analysis 1984; 4:25-40.
10. Montalvo F, Bryant RW. Mertz HJ. Possible positions and postures of unrestrained front-seat children at instant of collision. Proc 8th Intl Tech Conf on Experimental Safety Vehicles (ITCESV), Wolfsburg, Germany, 1980; 317-325.
11. Takeda H, Kobayashi S. Injuries to children from airbag deployment. Proc 8th ITCESV, Wolfsburg, Germany, 1980; 325-332.
12. Hitchcock RJ, Nash CE. Protection of children and adults in crashes of cars with automatic restraints. . Proc 8th ITCESV, Wolfsburg, Germany, 1980; 317-324.
13. Graham JD, Goldie SJ, Segui-Gomez M et al. Reducing risks to children in vehicles with passenger air bags. Pediatrics. 1998; July, In press.