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Airbag benefits, airbag costs

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ABSTRACT

This paper estimates that currently there are 250 million frontal airbags in the United States, which cost their owners $54 billion. In 2003 about 1.7 million of these deployed, 19,000 in fatal crashes in which over 8,000 vehicle occupants were killed sitting in seats protected by airbags that deployed. To date over 40,000 occupants have been killed sitting in seats protected by airbags that deployed. The growth of airbags increases the need to revisit the question of their cost-effectiveness, and also provides the data to do this. The cost-benefit comparison presented here relies on airbag effectiveness estimates and injury cost estimates published since 2000. Even after the deployment of 10 million airbags, their effect on injury risk remains uncertain, and the results presented here are sensitive to the injury-effectiveness values assumed. The benefits of airbags from changes in risk (fatal and injury) are estimated to be $1.60 billion for drivers and $0.34 billion for right-front passengers. The annual cost of replacing airbags after deployment is estimated as $0.46 billion for driver airbags and $0.47 billion for passenger airbags. For passengers, annual replacement costs alone exceed benefits. For drivers there is net annual benefit of 1.60 – 0.46 = $1.14 billion produced by airbags that cost $30 billion. This cost can be considered approximately $3 billion per year over a 10-year vehicle life. This cost exceeds the $1.14 benefit by almost a factor of three, indicating that the driver airbag falls short of being cost effective.

INTRODUCTION

No safety device has consumed more attention and resources than the airbag. A massive literature exists covering a plethora of technical and policy subjects. The highlights of this literature are summarized in an excellent recent compendium.[1] Despite so much information, many of the most basic questions relating to airbags still lack confident answers. In particular, the most central question of all does not have an agreed answer. Are the benefits of airbags commensurate with their costs?

It is known with high confidence that when a crash occurs, the presence of an airbag reduces fatality risk to drivers, whether belted or unbelted. Even after about ten million airbag deployments, the effect of airbags on different levels of injury risk is known only approximately.

The purpose of the present paper is to extract from the mountain of complexity reasonable estimates of quantities that are central to addressing the benefits and costs of airbags. The estimates are for July 2003, which will generally require projecting from earlier data.

The cost-effectiveness of airbags has been previously examined, particularly in a detailed study published in 1997[2]. With so much more information now available, it is appropriate to revisit this issue. More information could invite yet more complexity. For example, a major cost of airbags is the cost of replacing them after deployment. There is a specific estimated parts replacement cost for every make and model year. The labor-cost component for replacement varies throughout the nation and between one type of repair business and another. Whether a vehicle is repaired or scrapped depends on these same factors. It is, for example, estimated that nearly all vehicles more than seven years old are scrapped if their airbag deploys.[3] Rather than becoming submerged in such detailed calculations, we here concentrate on average values in order to keep the overall pattern in focus. For example (based on material in the literature[2,3]) we assume that half of the airbags that deploy are replaced, and apply the same replacement cost to all.

Another reason for avoiding detail is that the values of so many key quantities, particularly the effect of airbags on injury risk, are highly uncertain. It serves little purpose to embark on a detailed calculation requiring a complex chain of assumptions to estimate less central quantities that are determined with adequate precision by a simple approximate estimate. In the same spirit, we assume that cost estimates published for 2000 apply to July 2003 without fine-tuning to account for inflation. This makes it easier to retain a clear connection with the original sources.

OVERVIEW OF FRONTAL AIRBAGS

This paper focuses exclusively on frontal airbags, which are designed to deploy only in frontal impacts with severity exceeding a set threshold value. By deploy we mean that the airbag inflates, or fires. Hereafter we use the term airbag to refer only to frontal airbags.

NUMBER ON ROADS IN JULY 2003 – Data on the growth of airbags in the US vehicle fleet[4,5] provide the estimates for July 2003 shown below: -

Driver airbags	139 million
Passenger airbags	118 million
Total number of airbags	257 million

NUMBER OF AIRBAG DEPLOYMENTS - The National Highway Traffic Safety Administration (NHTSA) estimates 520,300 airbags deployed in 1996.[6] On July 1996 there were an estimated 74.6 million airbags on US roads[4], leading to a deployment rate of 6.97 deployments per 1000 airbags per year.

Elsewhere NHTSA estimates 3.8 million deployments from the 1980s to 1 October 1999[7]. From the data in Reference 4 we can estimate exposure of 606.9 million airbag-years. This implies 6.26 deployments per 1000 airbag years.

Let us take the average of these as the best estimate, leading to an airbag deployment rate of 6.6 deployments per 1000 airbags per year. Applying this rate to the number of airbags leads to the following estimates for the number of airbag deployments in 2003.

Driver airbag deployments	917,000
Passenger airbag deployments	778,000
Total airbag deployments	1,695,000

AIRBAG DEPLOYMENT AND NON-DEPLOYMENT IN FATAL CRASHES - Fig. 1 shows the growth of deployments in fatal crashes as recorded in FARS data[8]. Deployments in fatal crashes are in close proportionality to the growth of airbags in the fleet -- indeed for the nine years plotted, the probability that a crash was fatal given that the airbag deployed varied only from 1.06% to 1.19%, with an average of 1.12%. Thus about 18,700 of the 1.7 million deployments in 2003 are expected to occur in fatal crashes.

Similarly stable was the probability of death, given that the airbag deployed in a fatal crash. Over the nine years plotted this varied only from 42.9% to 44.8%, with an average of 43.5%, so that we expect about 8,200 occupants to be killed in 2003 in crashes in which their airbags deploy. The data plotted reflect 37,223 occupants killed in seats in which airbags deployed, so that by mid 2003 well over 40,000 occupants will have died in seats protected by airbags.

There is no way to know how many of the 40,000 people who died in crashes in which their airbags deployed would have died if there had been no airbag present. NHTSA reports[9] that, as of the end of 2002, there were 230 confirmed deaths caused by airbag deployments in crashes that would otherwise not have been life threatening. Most of those killed were children. However, 77 drivers were killed,[10] 58 of them female, and 28 of these of height 62 inches or less[9].

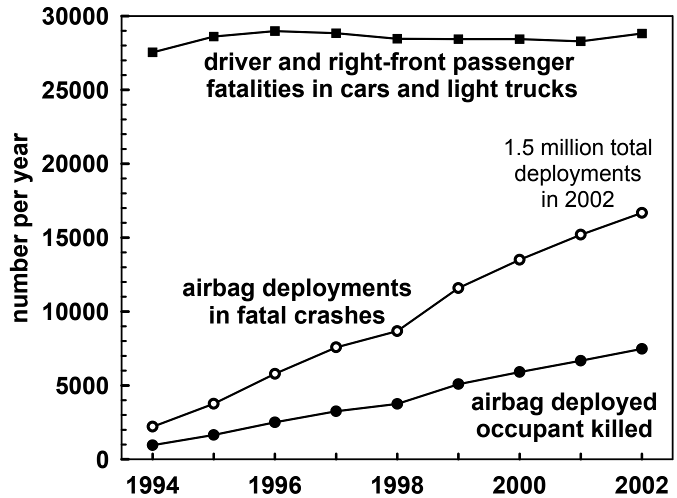

Figure 1. The number of fatalities in seats protected by airbags, and overall, as coded in FARS[8] data.

It is incorrect to assume all of the 40,000 except those specifically identified as being killed by the airbag would still have been killed even if there had been no airbag present. Survival or death depends on many details of the occupant's trajectory that are influenced by airbag deployment, and on possible injuries from airbag deployment. An undeterminable number of people (say N_1) die in crashes that they would have survived if no airbag had been present. The number (say, N_2) who survive because of the airbag is likewise undeterminable. Effectiveness estimates address only the difference $N_2 - N_1$ but provide no information on the values of N_1 or N_2

The total number of driver and right front passengers fatalities in cars and light trucks remained relatively unchanged from 1994 through 2002 even as the percent of drivers with airbags increased from 13% to 60% and the percent of passengers with airbags increased from 3% to 50%.[4]

DIRECTION OF IMPACT - While airbags are designed to deploy only in frontal crashes, in fact deployments occur for impacts in many directions. Fig. 2 presents driver fatalities in FARS 2002 for drivers of cars and light trucks using according to the principal impact point, the point associated with most harm. The logarithm scale is used because of the wide variation, from 3154 driver deaths at 12 o'clock to 36 at 5 o'clock. For all 16,682 airbag deployments in FARS 2002 (driver or passenger, any injury outcome): -

62% are for principal impact 12 o'clock

70% are for 11, 12 or 1 o'clock, and

75% are for 10, 11, 12, 1, or 2 o'clock.

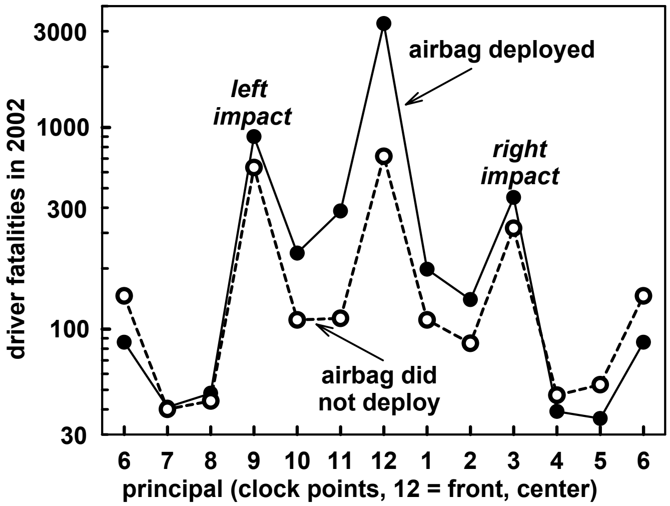

Figure 2. The number of driver fatalities in cars and light trucks according to principal impact point (FARS 2002).

Thus, 25% are for crashes that are not by any criterion even approximately frontal impacts. These include the side and rear crashes shown in Fig. 2 plus a number of categories not shown, including non-collision, top, and undercarriage.

The principal impact and initial impact variables in FARS relate to the region of damage on the vehicle. The direction of force is not normally known, as it would require a detailed post-crash investigation to determine it. The data above are not materially different if the initial impact point is used instead of the principal impact point. These variables have identical values for over 90% of the vehicles in FARS 2002.

FATALITIES WHEN AIRBAGS DO NOT DEPLOY -

FARS 2002 codes 4770 drivers of cars or light trucks killed in seats for which airbags were available and which had principal impact point at 12 o'clock. The FARS coding for these 4770 fatalities is: -

Deployed	3274 fatalities
Available-No Deployment	719 fatalities
Available-Unknown if Deployed	777 fatalities

Thus the airbag does not deploy for 719/4770 = 15% of drivers killed in frontal crashes in seats with airbags. This is a lower bound, because unknown deployment cases will include some non-deployments. Over the wider definition of frontal, clock points 10, 11, 12, 1 and 2, there were 6357 drivers killed, 4235 with deployments and 1139 with non-deployments. A central problem for airbag system design is setting deployment thresholds. Lower thresholds lead to more deployments with the potential that the airbag might produce serious or fatal injuries in minor crashes. As the threshold is increased the airbag becomes unavailable for more crashes in which it has the potential to reduce injury severity. Regardless of what threshold is chosen, it is inevitable that there will be crashes that would have had better outcomes if the threshold had been different.

BENEFITS AND COSTS OF AIRBAGS

Airbags are installed for one purpose -- injury reduction. (The term *injury* includes *fatal injury* unless the context implies otherwise). Their costs are mainly (but not exclusively) monetary. In comparing benefits and costs it is necessary to use a common metric. This is facilitated by a recent important and much cited study supported by NHTSA which finds that traffic crashes cost the nation $230 billion in 2000.[11] All injury harm is converted to a dollar cost. For example, the lifetime economic cost to society of each fatality is estimated at just under a million dollars, over 80 percent of which is attributable to lost workplace and household productivity. As the original authors[11] present reasoned discussion for the difficult decisions necessary for such conversions, their results, as summarized in Table 1, are accepted here as the basis for estimating benefits of airbags.

Table 1. Estimates of economic costs of motor vehicle crashes in 2000 from Ref. 11

source	*cost, billions of dollars (2000)* *injury components*	*non-injury*	*total*
fatal	40.1	0.8	40.9
MAIS 5	10.2	0.2	10.4
MAIS 4	12.3	0.4	12.7
MAIS 3	22.5	1.0	23.4
MAIS 2	27.0	2.1	29.1
MAIS 1	27.7	21.5	49.2
MAIS 0	0.4	4.6	5.0
property damage only	5.8	54.0	59.8
TOTAL	146.0	84.6	230.6

FATALITY RISK

Most airbag-effectiveness literature has focused on fatalities, the most severe and permanent consequence of a traffic crash. A central aim of airbag introduction was fatality reduction. Some estimates of airbag effectiveness are summarized in Table 2.

The first estimate listed is from a study conducted by General Motors published in 1973 before airbags were available to provide field data.[12] A panel of four expert engineers examined in details of fatal crashes in which 706 occupants were killed. Using crash reports, medical and/or autopsy reports, photographs and other such information, the panel discussed the injury mechanisms for each fatally injured occupant, and arrived at a judgment about whether an airbag would have prevented the fatality. The method has a built-in systematic bias. All 706 subjects were dead, so that the only influence of the airbag considered was its potential to reduce fatality risk. The probability that an airbag would kill an occupant who would otherwise not be killed was implicitly assumed to be zero.

Table 2. Some estimates of the effectiveness of airbags in reducing fatality risk. The first four estimates are for unbelted occupants, and the last three for all drivers, whether belted or not.

source	*year*	*effectiveness*
Wilson and Savage (GM)[12]	1973	18%
NHTSA[13]	1977	40%
NHTSA[14]	1984	20-40%
Evans[15]	1990	17%
Kahane (NHTSA)[16]	1996	11%
NHTSA[17]	2001	12%
Cummings et al.[18]	2002	8%

The 1977 NHTSA estimate of 40% effectiveness formed the basis for airbag mandate, the requirement that most vehicles be equipped with airbags.[13] The 1990 Evans estimate of 17% was essentially a calculation focusing on the types of crashes in which airbags had the potential to reduce risk.[15]

As more FARS data became available, more reliable empirical estimation became possible. The 1996 Kahane study estimated effectiveness in two ways.[16] First, by comparing the ratio of fatality risk in frontal crashes to fatality risk in other crashes for occupants in vehicles equipped and not equipped with airbags. As the airbag is designed to reduce risk only in frontals, differences in this ratio were attributed to the airbag. Second, fatality risks to drivers protected by airbags were compared to accompanying passengers not so protected. The published values reflected combining estimates from both methods.

In what follows we use only the two most recent studies, which are more reliable and based on far more data than any of the earlier. The 2001 NHTSA estimate[17] is based on an update of the 1996 Kahane study. The 2002 study by Cummings et al.[18] takes advantage of the large numbers of passenger airbags now available to estimate effectiveness of driver airbags. Vehicles containing a driver and a right-front passenger, at least one of whom was killed, were selected. Many of the vehicles included in the study had a driver airbag but no passenger airbag. These cases provided the core information to estimate effectiveness of driver airbags. Vehicles, which had no airbags, or airbags for both the driver and passenger, provided data to control for other driver-passenger differences in risk, unrelated to risk changes associated with driver airbags. Because there are no vehicles with passenger airbags but without driver airbags, the method cannot estimate airbag effectiveness for passenger air bags.

The effectiveness estimates reported in the two studies are summarized in Table 3. Both studies find effectiveness nominally higher for unbelted than for belted drivers, but in both cases the difference is stated to be not statistically significant. The estimates for all drivers in the two studies are in good agreement within error limits. We accordingly take the average of the two, 10%, as the estimate of fatality reducing effectiveness, and apply it to passengers as well as drivers.

Table 3. Summary of the results of the two most recent estimates of airbag effectiveness in reducing driver fatality risk.

	effectiveness in reducing fatality risk		
source	*belted*	*unbelted*	*all*
NHTSA[19]	11%	14%	12%
Cummings et al.[18]	7%	9%	8%

INJURY RISK

While fatal injuries conceptually involve only a yes or no determination, non-fatal injuries lie along a severity continuum. Accordingly, effectiveness must relate to some range of injuries, as can be categorized by the Abbreviated Injury Scale (AIS).[20]

Another difference between injuries and fatalities is that a data file comparable to FARS does not exist for injuries. This makes determining effectiveness for injuries even more difficult than for fatalities. The best estimates that have been made rely on the National Automotive Sampling System Crashworthiness Data System. The NASS CDS is a stratified probability sample of all US crashes involving a passenger vehicle that required towing due to damage. The probability that a crash is included depends strongly on crash characteristics. For example, the more severe the crash the more likely it is to be included (otherwise the system would include mainly crashes of minor severity). This makes the raw data unsuitable for most studies. Instead, the sampled crashes are scaled up to national estimates based on the structure of the sampling protocol. Such a process necessarily injects substantial additional uncertainty.

A 2000 study[21] using 1993–1996 NASS data found that airbag deployment reduced driver fatality risk and risk of the most severe injuries (AIS$\geq$4). However, airbag deployment was found to increase the probability that a driver (particularly a woman) sustained AIS 1-3 injuries. The results were presented in terms of the delta-v at which airbag deployment produced a net increase or decrease in risk for female and male drivers rather than an effectiveness for different AIS levels.

A 2002 study[22] using 1995-2000 NASS data examined the effect of airbag deployment for belted and unbelted drivers and right-front passengers. Effects of vehicle mass, delta-v, passenger compared to driver, and gender were controlled. The overall result was that in frontal collisions, front-seat occupants whose air bags deployed had increased risk of AIS>2 injury. The above two studies based on the effect of deployment may tend to bias effectiveness estimates downwards. Let us imagine a set of vehicles without airbags but equipped with airbag sensor systems. Assume we have a sample of crashes by such vehicles all with the same indicated delta-v, as measured by the usual post-crash procedures. I suspect that the crashes in which the sensors called for deployment would, on average, produce higher levels of injury than the non-deployment cases. If so, this would imply that even after controlling for delta-v, airbags will be more likely to deploy in crashes associated with higher levels of injury, and such higher levels of injury might be inappropriately attributed to the airbag rather than to the higher severity.

This problem was addressed in a later study[23] using the same 1995-2000 NASS data to compare outcomes for occupants in vehicles with and without airbags. The analysis controlled for vehicle mass, delta-v, passenger compared to driver, and gender. The results for belted and unbelted occupants are presented in the top plot in Fig. 3 in a different format than in the original paper.[23] Relative risks are converted to effectiveness, and 95% confidence intervals converted to standard errors (essentially 68% confidence intervals) in keeping with the common practice in the physical sciences. The values in Fig. 3 also reflect multiplying each effectiveness and error by the percent of all crashes that were frontal, as recorded in the original data (the values varied between 50% and 70%).

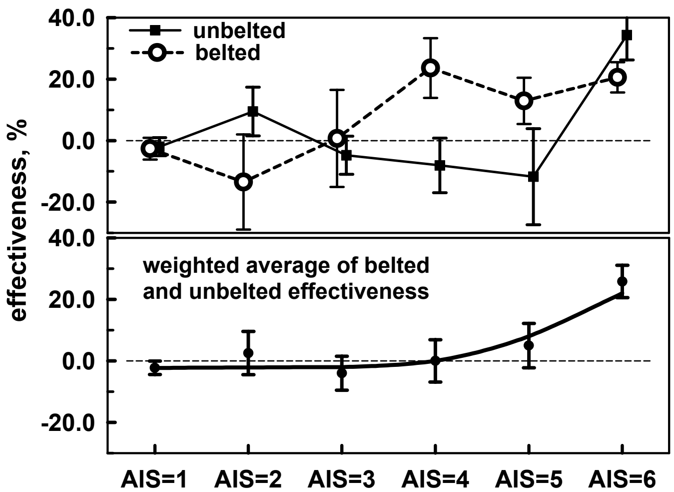

Figure 3. Estimates of the effectiveness of airbags in reducing injury risk, based on the results in Ref. 23

The noisy nature of the results illustrates how difficult it is to determine effectiveness at this detailed level. However, a number of features are apparent. Airbag effectiveness tends to increase with increasing severity for belted and unbelted occupants. In this study (unlike Table 1) fatalities are not excluded from the AIS levels – there is some probability of a fatality for any AIS, increasing from near zero at AIS=1 to near 100% at AIS=6. There are no obvious large systematic differences in effectiveness between belted and unbelted occupants, in parallel with the fatality results in Table 3. Indeed, for the six AIS levels, the effectiveness estimate is higher for unbelted occupants in three cases, and lower in the other three. We use the absence of a systematic difference between belted and unbelted cases to compute the weighted average values shown in the bottom plot in Fig. 3. The curve is fitted to the data by eye.

Even though NASS over-samples more severe crashes, more than 50% of the raw data with injuries are for AIS=1. Thus effectiveness estimates for AIS=1 are more precise than for other levels. The effectiveness estimates for AIS=1 are $(-2.6 \pm 3.5)\%$ for unbelted occupants and $(-2.0 \pm 2.9\%)$ for belted. Both values consistently indicate increased harm associated with airbags. The weighted average is $(-2.24 \pm 2.18)\%$. We accordingly assume that for AIS=1 the effectiveness is -2%, and based on the relationship in Fig. 3, we assume the same value for AIS=2 and AIS=3.

The effectiveness estimates at AIS=6 (essentially all fatals) are substantially higher than the 10% value based on FARS data. The difference (more than 10 percentage points) most likely reflects unavoidable uncertainties inherent in making inferences from NASS data, which raises the possibility that effectiveness in reducing injuries could likewise be overestimated. Other research has associated larger increases in AIS=1 injuries with airbags.[24]

Estimates of airbag effectiveness for injuries remain highly uncertain even after 10 million deployments. The values given by the curve fit in Fig. 3 are consistent with (but perhaps higher than) the indications in peer-reviewed literature of negative effectiveness. The previously cited NHTSA report[19] also uses NASS data to address effectiveness in reducing AIS $\geq$ 2 injuries. While the nominal values reported indicate higher effectiveness than used here, the report states that effectiveness estimates for all damage area crashes are not statistically different from zero. AIS=1 crashes are not addressed.

BENEFITS OF AIRBAGS

In order to estimate the benefits of airbags we use the effectiveness estimates discussed above and listed in Table 4. For AIS=5 we use the same 10% value found for fatalities (typically, about half of AIS=5 injuries prove fatal). For AIS=4 we select a value half that for fatalities – somewhat higher than the value midway between the values for AIS=3 and AIS= 5. Knowledge limitations preclude making distinctions between values for MAIS and AIS, or between drivers, passengers or front occupants.

To complete the estimates of effectiveness we need to estimate the percent of all road users protected by airbags. Of all 2001 traffic fatalities, 61% were drivers and 15% right-front passengers.[8] The previously used data[4,5] estimates 64% of all driver seats and 55% of all passenger seats will be protected by airbags in July 2003. Thus the driver airbag is protecting 0.61 x 0.64 = 39% of all road users and the right-front passenger airbag 0.15 x 0.55 = 8% of all road users.

Table 4. Fatality and injury reducing effectiveness of airbags converted into dollar cost reductions.

injury level	*injury-reducing effectiveness (percent)*	*billions of dollars (2000)* total injury cost	*risk-reduction benefits to* drivers	passengers
fatal	10	40.1	1.57[a]	0.33[b]
MAIS 5	10	10.2	0.40	0.08
MAIS 4	5	12.3	0.24	0.05
MAIS 3	-2	22.5	-0.18	-0.04
MAIS 2	-2	27.0	-0.21	-0.04
MAIS 1	-2	27.7	-0.22	-0.05
	TOTAL	**139.8**	**1.60**	**0.34**

[a] computed as 0.10*40.1*0.61*0.64, etc.
[b] computed as 0.10*40.1*0.15*0.55, etc.

The conclusion is that the benefits of airbags in calendar year 2003 are: -

For drivers – $1.60 billion

For right-front passengers $0.34 billion

Total 2003 benefits $1.94 billion

The total annual benefits of airbags reduce the annual $230 billion cost of traffic crashes by about 1%.

COSTS OF AIRBAGS

Costs of airbags are in a number of categories in addition to the original purchase cost of the devices. First we first address a major annual cost associated with a fleet of vehicles equipped with airbags.

COST OF REPLACING AIRBAGS AFTER DEPLOYMENT

Airbags differ from most safety equipment in that after they do what they are supposed to do, they must be replaced. In 1998 the NHTSA published the following estimates of the costs of replacing airbags: -

Driver $400 to $550

Passenger $480 to $1,300 without windshield replacement; $1,130 to $3,350 with windshield replacement.

There are many changes since these estimates, especially increases in labor costs, and the increase in dual compared to driver only systems. In July 2003 I telephoned a number of automobile repair businesses in four states to obtain estimates for replacing airbags for the four highest volume cars sold in the US. The responses were variable in quantitative precision -- in some cases to the nearest cent, while in others nothing more precise than "$2400-$3000, depending on the vehicle". Based on the responses, I concluded that a typical cost of replacing a dual system was $2000 without windshield replacement. Estimates for driver-only replacement did not materially differ from half of the cost for the dual system. Hence, I will assume a replacement cost of $1000 for any driver airbag, and the same amount for replacing a passenger airbag without windshield replacement. I assume that the windshield is replaced for half of passenger airbag replacements at a cost of $400, so that the following values will be used:

Replacing driver airbag $1000

Replacing passenger airbag $1200

These estimates are based on information for the four highest selling cars, which all cost less than the average cost of a car. Airbag replacement for luxury cars costs much more -- up to $6,000 for dual systems -- so the assumed replacement costs are likely to be lower than actual.

We assume that after an airbag deploys either the airbag is replaced, or the vehicle is scrapped. In many cases the additional cost of replacing the airbag will lead to the decision to scrap rather than return the vehicle to service. This additional cost due to the presence of the deployed airbag will be ignored. These assumptions lead to the replacement cost estimates in Table 5.

Table 5. Estimates of airbag replacement costs for 2003

seat protected	*millions of airbags*	*number deployed*[a]	*number replaced*[b]	*unit cost*	*total cost*
driver	139	917,400	459,000	$1000	$0.46 billion
passenger	118	778,800	389,000	$1200	$0.47 billion
TOTALS	257	1,696,200	848,000		$0.93 billion

[a] assuming 6.6 deployments per 1000 airbags per year
[b] assuming half are replaced

These replacement costs are compared in Table 6 to the benefits listed in Table 4.

Table 6. Comparison of benefits and replacement costs of airbags for 2003

seat protected	*benefits*	*replacement costs*
driver	$1.60 billion	$0.46 billion
passenger	$0.34 billion	$0.47 billion
TOTALS	$1.94 billion	$0.93 billion

Table 6 shows that, for passenger airbags, just one of the costs, that of replacing them after deployment, exceeds the benefits they provide.

COST OF INSTALLING AIRBAGS

We assume the same cost estimates as used in an earlier study[2], although these were criticized[25] as being too low. These were that the driver only system cost $278 and the dual system $410. I could find no more specific or current estimates of cost. This amount represents about 2% of the cost of the typical $20,000 vehicle. A breakdown of all costs summing to the purchase cost of the vehicle could prove illuminating. Using the assumed costs (and splitting the duals system cost equally between driver and passenger) leads to the estimates in Table 7.

Table 7. Estimates of the purchase cost of the 257 million airbags on the roads of the United States in July 2003.

occupant and system	*millions of installations*	*unit cost*	*purchase cost to consumers*
driver only	21	$278	$5.8 billion
driver (portion of dual system)	118	$205	$24.2 billion
passenger (portion of dual system)	118	$205	$24.2 billion
TOTALS	257		$54.2 billion

These estimates imply that the total cost to consumers of the airbags on the roads of the US on July 2003 is over $54 billion. This exceeds the current Gross Domestic Product of more than half of the member-countries of the United Nations (estimated by converting data in Ref. 26 to current dollars).

COST-BENEFIT COMPARISON

Table 8 lists the net annual benefit (injury reduction minus replacement costs) and airbag purchase costs converted to a yearly basis. This conversion is achieved by amortizing the initial total purchase costs over an assumed 10-year life of the vehicle. The values in Table 8 are one tenth of the values in Table 7. This simple choice amounts to assuming a zero discount rate, or zero borrowing interest rate. This assumption will substantially underestimate of actual annual costs, but, because the cost to benefit ratio departs so much from unity, such underestimation does not affect the general conclusion. The net annual purchase cost of driver airbags of $3.00 billion exceeds the $1.14 billion benefits by nearly a factor of three. Thus the present analysis concludes that the driver airbag is not cost effective.

Table 8. The purchase cost of airbags, expressed on an annual basis by amortizing over a ten-year vehicle life span, compared to net annual benefits. The purchase cost per year is simply one tenth of the total initial purchase cost in Table 7.

occupant	*purchase cost per year to consumers*	*net annual benefit*
driver	$3.00 billion	$1.14 billion
passenger	$2.42 billion	-$0.13 billion
TOTALS	$5.42 billion	$1.01 billion

OTHER COSTS OF AIRBAGS

Monetary. As airbags increase the purchase cost of vehicles, they generate an extra cost for replacement if the vehicle is stolen or destroyed. If the owner carries comprehensive insurance, this additional cost will be converted to an unspecified premium increase.

Because of their explosive nature, additional disposal costs are associated with scrapping airbag-equipped vehicles.

If permission to disconnect is obtained, then a cost to disconnect (in addition to the original purchase cost) is paid.

As with any complex system, there is likely to be some maintenance or inspection cost over the life of the vehicle, as acknowledged by NHTSA[6] and prior cost benefit studies[2].

Children in rear seats. Because of the danger posed by airbags, children are placed in rear seats in situations in which they would otherwise be in front seats. This denies the driver (most commonly a parent) and the child the type of interaction that has been traditionally pleasurable and beneficial to both.

Placing children and infants in rear seats may increase crash risk because a child in distress is likely to receive driver attention. Such attention is one of the many types of distraction thought to increase crash risk (the only one for which there is clear evidence is use of a cell phone while driving[27]). Driver distraction was recently examined by placing video cameras in drivers' personal vehicles.[28] The data showed that children were about four times, and infants almost eight times, more likely than adults to be a source of distraction to the driver, based on number of distracting events per hour of driving. Effectiveness estimates address only differences in outcome, given that a crash occurs. If placing children in rear seats increased crash risk, this would increase casualties but not change effectiveness estimates. Likewise, if airbags were associated with changes in driver risk-taking.

When crashes do occur, risk is, on average, lower in rear seats for children.[29] However, (absent any airbag considerations) the safety benefits of moving to a rear seat are similarly large for adults.[30]zzzz[31] Even adults well aware of the increased safety of rear seats still choose front seats, as my wife and I do when we travel together.

Equity. A 10% effectiveness in fatality reduction is defined as follows. Consider a large sample of crashes by vehicles without airbags in which 100 drivers are killed. If all the crashes could be repeated with all vehicles equipped with airbags, 90 drivers would be killed. However, it is incorrect to consider these 90 fatally injured drivers to be a subset of the former 100. The 90 fatalities result from two components. The first is the number, say A, of the 100 who were killed without airbags but would survive because of them. The second component is the number, say B, of drivers who survived without airbags, but are killed due to their deployment.

A 10% effectiveness provides no information on A or B beyond the important fact that A - B = 10. The 230 deaths confirmed by NHTSA to be caused by airbag deployments[9] places a lower bound on B, and additionally establishes that the members of categories A and B are not random samples of drivers. Those more likely to be saved are young large males, while those more likely to be killed are short females. In any medical context this would raise formidable ethical questions.

COMPARISON WITH PRIOR ESTIMATES

The earlier study[2] found that airbags were clearly not cost effective for passengers, but might be for drivers. The major difference between that study and the present one is that the effectiveness estimates used here were not then available. The earlier study[2] used an effectiveness of 11% for fatalities[16], the best estimate then available (it is consistent within error limits with the latest values in Table 3). Given that there were no estimates of effectiveness in injury reduction, the earlier authors[2] made the then plausible assumption that effectiveness for injuries was the same 11% as for fatalities. The latest published research provides estimates inconsistent with this assumption.

DISCUSSION

The conclusion that airbags are not cost effective is based on calculations requiring many assumptions. The most uncertain area remains that of the influence of airbags on injury risk, especially the influence on minor injury. The influence on minor risk makes a large contribution to total benefits because so many minor injuries occur. Different assumptions of injury effectiveness can have a large influence on estimates. For example, if, contrary to the findings that injury effectiveness is generally negative (as reported in the only two recent papers in the peer-reviewed literature), one assumed that effectiveness at all injury levels was 10%, then substantially different benefits would be estimated. The passenger benefits would still fall short of costs, but the driver benefits, at $6.46 billion, would invite a more involved calculation involving a discount rate to the initial purchase cost, likely ending in the costs and benefits being similar, a result consistent with that in the earlier study.[2] Assigning a larger dollar amount to a fatality than that in Ref. 11 would likewise have an important influence on the results of this analysis (and also on the national estimate of the cost of traffic crashes). Assigning higher purchase and replacement costs would move the benefit to cost ratio in the opposite direction.

The data on which this paper is based are overwhelming on the older airbags that constituted most of those on the roads in 2003. In recent years different “depowered” and “smart” airbags have appeared. These will have different probabilities of causing and preventing harm, different costs to purchasers, and different fleet annual replacement costs, especially for passenger airbags. It will be many years before we know near as much about the effectiveness of newer airbags than even the meager knowledge we now have about the older ones.

The lack of a more detailed recent benefit cost analysis than this one seems surprising for devices that have cost the nation over $60 billion (when one adds the cost of those already retired to the cost of those now on the roads). Reliable determination of many of the highly uncertain elements, like the installation and replacement costs of airbags, would seem to require nothing more than modest resources and commitment.

Given how crucial effectiveness estimates are to any overall benefit estimates, it would be desirable if there were an ongoing effort to publish periodic updates in the peer-reviewed technical literature.

CONCLUSIONS

For the US in 2003, driver airbags produced an injury reducing benefit estimated at $1.60 billion, and a cost of replacing after deployment of $0.46 billion. The resulting net annual benefit of $1.14 billion is produced by airbags that cost their original purchasers $30.0 billion. If one assumes that the vehicles have a life of 10 years, this can be interpreted approximately as an annual expenditure of $3.0 billion for an annual return of $1.14 billion. Thus the cost of the driver airbag exceeds the benefit by almost a factor of three.

For passengers the $0.47 billion annual cost of replacing deployed airbags exceeds the injury reducing benefits of $0.34 billion.

The analysis is based on assuming values of many quantities that are known with inadequate precision. Different assumptions can lead to substantially different estimates.

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