CTRF

Transportation: Emerging Realities

Les Transports: realités en puissance

VOLUME 2

Canadian Transportation Research Forum
Proceedings of the 32nd Annual Conference
Toronto, Ontario May 25-28, 1997

Le Groupe de Recherches sur les Transports au Canada
Actes de la 32ième conférence annuelle
Toronto, Ontario 25 au 28 mai, 1997

Overblown: Examining the Costs and Benefits of Automotive Air Bags

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One of the major safety innovations on automobiles in recent years are "air bags," rapidly-inflated air cushions which deploy in a collision to help reduce injury or prevent death. Air bags are credited with saving a number of lives. "More than 1700 people are alive today because of their airbags." (Insurance Institute..., 1997). However, air bags are not a panacea for accident/injury reduction. They are effective primarily for frontal collisions (although side impact air bags are also starting to emerge). Air bags are intended to be a "supplementary restraint system" (SRS) and not an alternative to seat-belts.[1] However, controversy is emerging about some technical characteristics of current air bag technology. North American air bag technology is dominated by United States' regulatory requirements, which in turn reflect U.S. test criteria. U.S. drivers are less likely than Canadians to use seat-belts; hence U.S. air bag testing requirements (using "crash test dummies") are designed for non-belted car occupants, specifically the fiftieth-percentile-size male driver. The air bags must deploy at relatively low impact speeds *and* inflate very rapidly. These aggressive air bags have become the source of injury and even deaths. "Sixty one deaths have been reportedly have been caused by airbags inflating in low severity crashes." (Insurance Institute..., 1997). Many were infants in rear-facing infant carriers or unbelted young children in the front passenger seat. Particularly for Canada with our high use of seat-belts, there is at least some question about whether or not current air bag technology is cost-effective.

This paper reviews the issues and some of the available evidence regarding the costs and effectiveness of automotive air bags and the

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[1] The term "seat-belts" is understood here to include shoulder restraints as well as the lap belt.

implications for Canada. It begins with a brief summary of how air bags work. Part II summarizes evidence on the effectiveness of air bags. Part III addresses the costs and benefits of air bags; despite the wide publicity of lives saved, doubts are raised about the overall net benefits of air bags. Some research needs are identified and brief conclusions follow.

1.0. Automotive Air Bags

An air bag consists of the air bag itself, folded in a module on the steering wheel or dashboard; a propellant (usually nitrogen released by sodium azide pellets despite some toxicity) to inflate the bag; and a sensing mechanism to detect sharp acceleration or deceleration which triggers the firing mechanism. (See Breed, 1993, for an explanation of how air bags function).

What Takes Place during a Collision:

By way of illustration, at a speed of 48 kph (30 mph), the driver and passengers continue to move forward at 48 kph at the instant of impact. If the car stopped instantly, it would take the driver about .12 seconds to hit the steering wheel (Evans, 1991, p.221); similarly for the front passenger. The energy-absorbing design of the automobile, progressively collapsing upon impact, adds a bit of time (for a total of about .15 seconds, *Ibid.*) before the driver and passengers hit the steering wheel or dashboard, respectively (the collapsing car also absorbs some of the energy on behalf of the driver and passengers but this effect may be partially offset by the vehicle re-bounding). Seat-belts restrain the driver and passenger, absorbing some of the sudden deceleration, and reduce injury from hitting the steering wheel or dashboard. If the driver (or passenger) is not belted, the design criterion is that the air bag must inflate before the driver travels more than 13 cms (Breed, 1993, p.S70), which would take about .05 seconds. The air bag can inflate in about .03 seconds hence the sensor mechanism must function in less than .02 seconds to deploy the air bag (*Ibid.*)[2] All this happens, literally, quicker than the blink of an eye. Figures

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[2] The sensor mechanism has a complex task because early in a collision the passenger compartment is not yet decelerating due to the impact. Hence most sensor mechanisms include sensors located near the front of the car which detect the crash impact first, supplemented by a more sensitive motion-change sensor in

1 and 2 illustrate the air bag deployment sequence and initial position of the driver.

Potential dangers of air bags

The air bag needs to inflate very rapidly hence it is potentially very powerful. A second and partly related consideration is the threshold speed of impact required to trigger the bag. As noted in the introduction, the present air bag technology conforming to U.S. regulations triggers at a relatively low threshold, many as low as 12 to 15 kph, because unbelted drivers could be injured at this speed. But the power of the inflating air bag can be a source of injury itself. The outer edge of the air bag is inflating at a speed of about 300 kph. If a person is hit by the air bag during the inflation process, substantial injury and even death can result. If drivers or passengers are out of position, or sit closer to the steering wheel/dashboard (which is the

FIGURE 1
Air bag deployment sequence

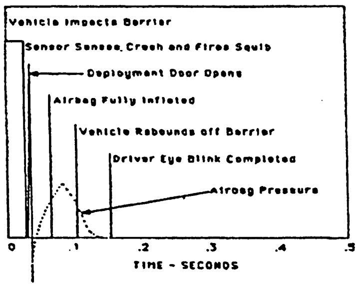
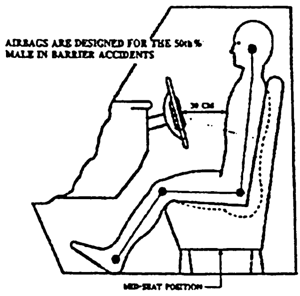


FIGURE 2



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the passenger compartment. Both sensors must detect the crash for the air bag to deploy.

case for many females and smaller-stature individuals), the air bag deployment is potentially harmful.[3] In time, "smart bags" may be developed which could sense the nearness of the driver/passenger and avoid deploying the bag or alter the deployment rate as required, but these are not available at present. As a result, there are many documented instances of harm and even death resulting from air bags (54 deaths attributed to air bags in the U.S. and three in Canada, reported in the *Vancouver Sun*, November 28, 1996; the Insurance Institute for Highway Safety, 1997, reports a total of 61 deaths attributed to air bags deploying in low-severity crashes). This issue of threshold speed to trigger the air bag is raised later after reviewing the general evidence on the effectiveness of air bags at reducing fatalities and injuries.

2.0 Air Bag Effectiveness

There is no doubt that air bag technology can save lives and reduce injuries, although there are different estimates of its effectiveness. Early predictions were based on crash test simulations and subjective assessments of the survivability of different types of accidents. Now that air bags have been in use for some years, one can compare actual experience from accidents with and without air bags. The latter might seem the most useful guide but there are many variables to control for and biases in the data collected from actual crashes. There are known sources of error in recording data (e.g., seat-belt use is over stated in non-fatal accidents) (see Evans, 1991, Chapter 9 for a discussion). Crashes do not provide a random sample of drivers and vehicles.

> "For example, air bags originally were offered in the larger, more expensive and the sporty, high-performance model lines. These vehicles may be driven much differently than, for example, station wagons or family-size sedans.... some make/models will experience more single-vehicle crashes on rural, higher speed roads, which tend to be more severe than the average two-vehicle crash in an urban, lower speed environment.... heavier cars, on average, offer greater protection to their occupants than do lighter

[3] "Both the U.S. and Canadian data agree that female drivers are at higher risk of sustaining bag-induced injuries." Dalmotas (1996), p.7.

> cars (which were generally not included in the early introduction of air bags)."
>
> NHTSA (1996) p.7-8.

Certain groups are more crash-prone than others. For example, "There is copious evidence that belt wearers are more careful drivers than nonwearers [citations follow]" (Evans, 1991, p.226).

Nonetheless, analyzing actual crash results is a valuable data source for analyzing the effectiveness of air bags. "As of July 1996, NHTSA's Fatal Accident Reporting System (FARS) contained records of nearly 10,000 fatally injured front-seat occupants of cars and light trucks ... equipped with air bags." (NHTSA, 1996, p.9). This enables examination of several driver/passenger characteristics (age, size) and fatality rates with and without seat belt use and air bags.

Air bags and fatality rates.

There is no doubt that air bags can and do reduce fatalities. Air bags are most effective for direct, frontal collisions; they are less effective for "partially frontal" crashes, and generally assumed to have little or no benefit for side collisions or roll-overs. In a study of crashes with and without air bags including situations where the driver had air bags but front passengers did or did not have them, the data show a 34 percent reduction in the fatality rate for head-on collisions compared to no air bags present. This drops to an 18 percent reduction for all frontal collisions, and a 10 percent reduction for all crashes (NHSTA, 1996, p.11). However, these statistics include both those using and not using seat belts. Examining crashes where seat belts were in use, the NHSTA data still show a 21 percent improvement in fatality rates for belted drivers in full frontal ('head-on') crashes. That is, air bags help both belted and unbelted drivers in head-on collisions.

The NHSTA results are similar to their own previous analysis and those found by other researchers. Examining crashes for air-bag-equipped cars, 1985-91, O'Neill and Lund (1993) report a substantial reduction in fatalities for air-bag-equipped cars (29 percent reduction compared to seat-belt-equipped cars for frontal collisions). In a similar study incorporating additional years' data, Lund and Ferguson (1995) report a 24 percent reduction in fatalities in frontal crashes, and 16 percent reduction in all crashes, for air bags compared to seat-belt only automobiles.

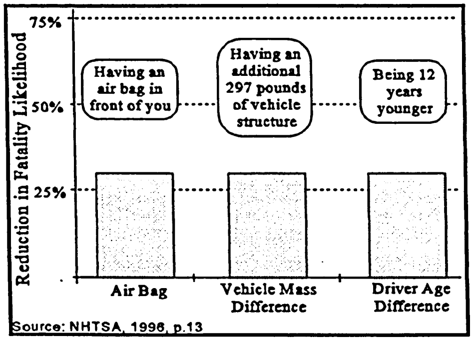
Whereas air bags offer protection primarily for frontal collisions, seat belts offer protection in all manner of crashes. **Table 1** summarizes NHTSA's estimates of the effectiveness of air bags, seat belts and their combination averaged over all accident types. These are "when used" estimates, i.e., these are the probabilities assuming that seat belts are actually used. In practice, many drivers do not use seat belts which makes air bags more valuable than the figures in Table 1. The combination of belts and air bags amounts to a 50 percent reduction in fatality rates compared to 45 percent reduction obtained by proper use of seat belts (including shoulder strap). The findings in Table 1 correspond closely to the figures used by Lawson (1993) in his analysis of whether or not Canada should adopt mandatory air bag requirements (he recommended against it; more later).

Table 1
Estimated Effectiveness of Occupant Protection Systems in Reducing Fatality Risk for Passenger Car Drivers

System Used	Fatality Reduction
Air bag alone	13%
Manual lap-shoulder belt	45%
Air bag plus shoulder belt	50%

source: NHTSA (1996) p.14.

The NHTSA data permit analysis of some other driver and vehicle characteristics including age of driver/passenger and size of vehicle. Elderly drivers have higher fatality rates, which is not too surprising. More worrisome is that: "Every analysis that includes frontal crashes shows a higher fatality risk for the children in cars with dual air bags than for children in comparable cars without air bags." (NHTSA, 1996, p.15-16.) Larger, heavier vehicles are also associated with lower fatality rates, i.e.,



the larger mass absorbs more of the energy from the collision. The forgoing is summarized in **Figure 3**. Particularly striking is the significance of vehicle weight, although one must be cautious about drawing conclusions from data with a high variance.

Air bags and injury rates.

Usually, safety features which reduce fatalities also reduce injuries; more specifically, there is a cascading effect of former fatalities who now are in "critical" or "severe" injured category, but correspondingly more people previously injured "severely" are reduced to a "moderate" category, with corresponding displacement and reductions to the "minor" injury category.

> "Historically, if an occupant protection system was effective in reducing the risk of fatal injury, it was also effective in preventing serious non-fatal injuries. The present findings indicate that this is not likely to prove true in the case of air bag systems, at least as presently designed."
>
> Dalmotas (1996) p.7

The NHTSA (1996) report on their examination of the NASS (National Accident Sampling System) data on crashes of all types, using the standard Abbreviated Injury Scale (AIS) rating of the severity of injuries (AIS 6 is an injury so severe it cannot be treated, down to AIS 1 or "minor" injuries; note that fatalities are included in this classification and can occur with injury levels 4 and 5 as well as 6). NHTSA examined the effect of air bags with and without belts for two injury categories, "moderate" or worse (AIS 2+) and "serious" or worse (AIS 3+). They also examined the data on specific types of injury: head, chest, upper and lower extremities, as well as by age and sex of the driver. They included car crashes with frontal damage only as well as all damage areas (the former are more relevant for air bags). Only some results are summarized here.

Table 2 shows the percentage reduction in injury probability for three occupant restraint alternatives based on car damage areas (columns 2 and 3) and for specific bodily-injury area (right four columns), for "moderate" and greater injury (AIS 2+) and "serious" or greater injury (AIS 3+).

Table 2
Estimated Effectiveness of Occupant Protection Systems
(percentage reduction in injury probability relative to no protection)

	vehicle damage		injury area			
System used: Moderate injury+	all damage areas	front damage	head	chest	uppe r	lower
air bag + belt	60	61	83	59	45	37
air bag alone	18	6	46	-31	25	21
manual lap-shoulder belt	49	56	59	59	14	53
Serious injury +						
air bag + belt	59	69	75	66	-40	78
air bag alone	7	- 8	16	18	-14	- 5
manual lap-shoulder belt	60	74	38	54	28	79

source: NHTSA (1996), pp.17-20

The air bag plus seat belts show slightly greater injury prevention than seat belts alone, but the air bag alone is much inferior to seat belts. Of particular interest are the figures for frontal damage accidents; these are ones where air bags are more likely to have deployed as these are the type of accidents they are designed for. The air bag alone shows only a 6.0 percent likelihood of preventing this injury level. The results are more striking for the "serious" injury accidents (bottom three rows of columns 2 and 3). Seat belts and air bags combined are not better and possibly worse than seat belts alone, as indicated by the negative impact of air bags alone. Although this is not significantly different from zero, it does reveal a minimal if not adverse effect of air bags on injuries.

The rightmost four columns in Table 2 show the impact of air bags and seat belts on specific types of injuries. Air bags perform well at reducing head injuries, and substantially improve the performance compared to seat belts alone. They have some effect on chest injuries, but keep in mind that seat belts are likely to 'cause' some "moderate" chest injuries because they effectively substitute these injuries for more severe ones sustained if the driver is not restrained. But for injuries to extremities, air bags have a low and even negative effect, i.e., aggravating injuries particularly for upper extremities.

Dalmotas (1996) has also examined the NASS data base focusing particularly on the impact of air bags on lower level injury categories (AIS 1, AIS 2 and AIS 3, "minor," "moderate" and "serious," respectively), including a calculated "harm index" which weights various injury categories according to a dollar valuation relative to the AIS 6 category (essentially equivalent to a fatality). The paper focuses on frontal or partial frontal collisions. The total sample of crashes was 7,336. This included 2600 cases of unbelted occupants without air bags; 3683 cases of seat belts used without air bags; 276 cases of unbelted drivers but with air bags; and 777 incidences where both air bags and belts were used. The data were analyzed in various ways, e.g., excluding cases where vehicle speeds were not known (the "delta v" or estimated impact speed, an index of accident severity), adjusting for delta v's to correct for potential distortions (e.g., unbelted drivers are over-represented in high speed crashes). We only report the initial table of results here as **Table 3**.

Dalmotas' analysis shows that the presence of air bags generally aggravates rather than reduces injury probabilities for "minor" to "serious" categories of injuries. For example, over all crashes in the sample, the probability of an unbelted driver without air bags receiving minor injuries or worse is 69.8 percent. An air bag without wearing belts increases the probability of injury to 75.6 percent, whereas use of seat belts without air bags reduces the probability of injury to 46.4 percent. Note that for all three injury categories, air bags are associated with higher injury rates on average. An analysis by specific injury type (head, upper extremity, etc.) confirmed that air bags have some positive effects besides preventing fatalities in frontal collisions:

> "The present findings suggest that these fatality reductions are being achieved through the decreased likelihood of AIS $\geq$3 head injuries in the case of the belted and the decreased likelihood of AIS $\geq$3 chest/abdomen injuries in the case of the unbelted. The findings ... also suggest that these reductions are likely to be accompanied by a substantial increase in the overall incidence of non-fatal serious injuries, particularly among belted occupants." (Dalmotas, 1996, p.7).
>
> "The problems associated with overly aggressive air bags are compounded by deployment practices that, in low-speed collisions, can expose a belted occupant to a greater risk of injury from the air bag than from the collision itself.... In jurisdictions such as

Canada, that have achieved seat belt use rates approaching 95%, it is counterproductive to seek to increase the safety of the unbelted occupant at the expense of the belted." (*Ibid.*)

TABLE 3
Injury Probability with and without Air Bags and Seat Belts

Injury Probability	no air bag, belts not worn	air bag, belts not worn	no air bag, belts worn	air bags and belts worn
AIS >= 1	69.80%	75.60%	46.36%	46.04%
AIS >= 2	19.26%	19.70%	7.36%	7.65%
AIS >= 3	5.33%	8.17%	1.62%	2.90%

source: Dalmotas (1996) Table 1A.

In sum, the crash data reveal safety tradeoffs accompanying air bag requirements. North American cars employ air bags which meet U.S. requirements. These are designed to protect the average unbelted male driver. Air bags must deploy at relatively low speeds (many as low as 12-15 kph) and deploy at a very aggressive rate. But these air bags are causing some deaths and a rise in injuries compared to using seat belts. These increases in injury rates associated with current air bag technology must be weighed against reductions in fatalities and/or "severe" and "critical" injuries brought about by air bags.

3.0 Considering Costs and Benefits of Air Bags

The foregoing concentrate on estimating the effectiveness of air bags at reducing fatalities and their effect on injury rates. But the fact that some lives are saved is not a sufficient economic justification for the adoption of air bags. A crude calculation of costs and benefits is to compare the estimated number of fatalities avoided thus far, times a value of life saved, and compare this with the expenditures on air bags over the same period.

"More than 1700 people are alive today because of their air bags." (Insurance Institute, 1997). Using a value of life of $2.0 million (and ignoring discounting), this is an economic benefit measure of $3.4 billion.

"About 55 million ... cars now on U.S. roads have driver airbags. About 28 million also have passenger airbags." (Insurance Institute..., 1997). Because the proportion of airbag-equipped cars is rising, this figure will overstate the costs to compare with the number lives saved. Nonetheless, multiplying the 55 million cars times $375 average cost per car (Lawson, 1993 used $500 as a resource cost of two air bags, and about half of the existing cars have two air bags),[4] equals $20.6 billion. This crude calculation shows a benefit cost ratio of .165. The overstatement of costs because the now-expanded total fleet cost is used could be corrected by using only half of the fleet (the average between close to zero in 1987 to the present 55 million cars). This doubles the benefit cost ratio but it is still only .33. This calculation is crude and based on fatalities only, but it serves notice that more careful examination of benefits and costs of air bags are called for.

One indicator of the valuation of safety benefits is consumer acceptance of air bags. Many people have demonstrated a willingness to pay for air bags as optional equipment. Assuming that buyers are well-informed about the safety benefits (a big assumption but one commonly made in other market analyses), this reveals that many people value air bags highly. An analysis yields an implied value of life of $3.0 million (Mannering and Winston, 1995). But not everyone purchases air bags; this leaves a large segment of the population who apparently value it less highly. Analysis of the market for air bags is greatly complicated by (U.S.) regulations which are requiring air bags as standard equipment, i.e., eliminating the consumer choice. (However, Mannering and Winston, 1995, argue that consumer preferences would have led to widespread use of air bags even without the regulatory requirements).

But safety decisions usually are not left to individual valuation. Buyers might not be well informed about safety features, and there are externalities (careless drivers impose risks on others), hence government intervenes on safety.

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[4] This probably is a low estimate of air bag costs. Manufacturers differ in the price for air bags where they are optional equipment, but most are standard equipment now.

Graham (1993) summarized a range of cost effectiveness calculations for air bags and showed that the magnitudes were consistent with other expenditure programs and regulations regarding road safety, although this begs the question of whether or not air bags truly are economically justifiable.

Fildes, et al. (1994) evaluated various size driver air bags for Australia, a country with very high seat belt use. They constructed a "harm index" which assigns a monetary value for various type injuries; then the benefits are the sum of monetized changes in the probability of injury associated with the different air bag designs. They concluded that only the largest driver air bag showed a benefit cost ratio greater than one. This was predicated on the assumption that air bags brought a net reduction in injuries, but the North American data show mixed results on this.

The costs and benefits of air bags in Canada (Lawson, 1993)

A careful analysis of costs and benefits of air bags was carried out by Lawson (1993). He reviewed whether or not Canada should adopt mandatory air bag requirements consistent with those in the U.S. He combined estimates of reduced fatalities as well as reduced injuries based on data available at the time. **Table 4** shows his assumptions about the effectiveness of air bags relative to seat belts, both for reducing fatalities and injuries. The assumed reduction of fatalities is quite consistent with the estimates cited above (Table 1) from recent NHTSA studies, although Lawson may have over-stated the effectiveness of air bags alone at reducing fatalities. Lawson's figures for injury categories cannot be compared exactly to those cited earlier in this paper. Dalmotas' figures on injuries (Table 3) are for frontal collisions and not all crashes. The closest figures would be those in column 1 of Table 2 which shows the estimated effectiveness at "moderate" and "serious" (AIS 2 and AIS 3) injuries. Those results suggest that air bags may actually cause net harm, or at least offer very low injury reduction. If so, Lawson's (1993) analysis based on Table 4 would overstate this aspect of the benefits of air bags.

TABLE 4
Estimated Effectiveness of Restraint Systems for Front Seat Occupants
(percentage reduction compared to unrestrained occupants, by injury class)

Restraint type	AIS 1	AIS 2-5	AIS 1-5	Fatal
3 point seat belt	10-20%	45-55%	15-25%	45-50%
air bag, no seat belt	5-10%	20-40%	7-15%	15-30%
air bag plus seat belt	15-25%	55-60%	20-30%	45-55%

source: Lawson (1993) p.S94.

Because most Canadians will purchase cars meeting U.S. standards which include air bags, Lawson (1993) estimated the incremental reduction in fatalities and injuries if Canada made air bags mandatory, and compared this to the incremental costs of adding air bags to cars that would have been purchased without them. Using a value of life of $1.5 million, and an average cost per accident of $11,000, he concluded that the benefits did not justify the costs. He carried out various sensitivity analyses but in virtually no case did he show a positive net benefit. He included lower assumed seat belt use (as low as 60 percent). If one combined low seat belt use with a higher value of life ($2.5 million), this might justify the decision to require air bags. This is relevant to the U.S. with their lower seat belt usage, but not to Canada.

The costs and benefits of drivers' side only air bags are more attractive. The passenger seat often is not occupied therefore the cost per passenger fatality avoided is much higher than that for drivers. Examining Lawson's (1993) calculations, using the higher value of life might justify driver air bags, but marginally so. But if air bags are causing injury costs rather than benefits, this would weaken the case for air bags even for drivers.

An important consideration in the U.S. air bag requirements is the design criteria which assumes that the vehicle occupants do not use seat belts. Despite many years of campaigning and seat belt laws in all but one U.S. state, average seat belt use is estimated at 68 percent (NHTSA, 1996, p.4). Seat belt use is much higher in Canada, 86 percent by 1992 and was then projected to reach 95 percent by 1995 (Lawson, 1993, p.S94); it was at 88 percent in late 1993 (Transport Canada, 1994) and is reportedly is now over 90 percent. The overall or average effectiveness of air bags depend crucially on whether or not seat belts are used. What may be appropriate for the U.S. may not be appropriate for Canada.

Complications and information needs in evaluating air bag costs and benefits

There are more issues involved than just establishing that there is an overall average improvement due to air bags. There are a number of additional questions about air bag costs and effectiveness. Existing studies show the effectiveness of air bags *given* that a crash has occurred, and given the population of vehicles and drivers in the data base. But there are subtle additional considerations, such as whether or not the presence of air bags (or other safety features) are modifying people's driving behaviour. If so, it may be embodied in the frequency and severity of crashes, but it requires separate study to identify these behavioural influences.

Air bags give rise to some familiar dilemmas in safety regulation: viz., the problem of moral hazard and externalities (drivers may not recognize risks imposed on others). By making cars safer, some safety benefits may be nullified because motorists may compensate by driving faster and more aggressively (the moral hazard problem). Insofar as consumers choose to consume potential safety benefits in the form of time savings, the economists' interpretation is that this is their prerogative and it shows that people value time savings more than safety (e.g., Lave and Weber, 1970). That is, the safety benefits are real and valuable even if they are not consumed as safety. But if externalities are involved, as they often are in safety issues, the "offsetting behaviour hypothesis" does at least partially undermine the benefits of safety measures. That is, offsetting behaviour means the external benefits of safety improvements (reduced risks to others on the road) are reduced. These aspects of driver behaviour must be taken into account in evaluating costs and benefits of air bags or other safety features.

In the case of air bags, evidence suggests that the offsetting behaviour hypothesis is at work. Peterson, Hoffer and Millner (1995) review crash records from two sources and find that:

> "... risk to drivers of cars equipped with air bags in single car crashes *is not* diminished, that the percentage of occupants killed in single car air bag crashes *is* unusually high, and that drivers of air-bag-equipped cars initiate an unusually large percentage of

such crashes. We conclude that drivers of air-bag-equipped cars tend to be more aggressive than drivers of cars not so equipped, that their added aggressiveness diminishes the protection afforded drivers of cars equipped with air bags and imposes additional risks on occupants and passengers in other vehicles." (Peterson, Hoffer and Millner, 1995, p.262) (see also Peterson and Hoffer, 1994).

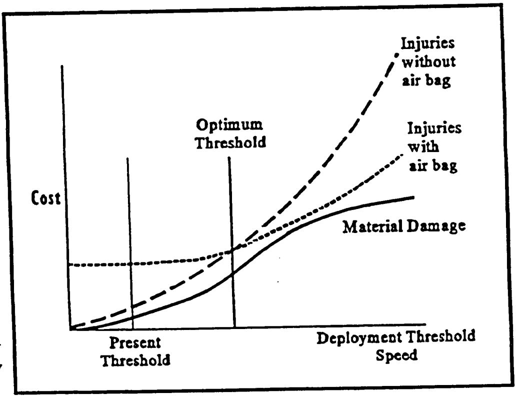
A further complication involves the interrelationship between seat-belts and air bags. As noted in the introduction, air bags are intended to supplement seat-belts. But there is the possibility that some drivers might rely on air bags instead of using seat-belts. Because seat-belts themselves are highly effective at reducing deaths and injuries, a shift to air bags from seat belts could actually reduce safety and associated net benefits. Lawson (1993) included an illustrative calculation in his sensitivity analysis of the costs and benefits of air bags. If air bags induce even a modest reduction in seat belt use, this may be sufficient to undermine the safety contribution of air bags.

More is needed on the costs of installation and replacement costs of air bags. The actual production costs of air bags is not well-known, but manufacturers were charging on the order of $500-$1000 for air bags as optional equipment when the car is first built (the passenger-side air bag is slightly larger and more costly). The replacement costs are much higher. The air bags often cause damage to the interior of the car (windshields, dashboards) and the sensors may have to be replaced. The Insurance Corporation of British Columbia (ICBC) reports an average cost of $3400 to replace 1995 model air bags (driver and passenger side) (personal interview). The costs sometimes are more than twice this amount.

Another cost component of air bags has received little recognition thus far. As vehicles age and their market value declines, insurance companies will be reluctant to replace the air bags and will scrap the car instead (this presumes that cars will not be placed back on the road without the air bags). That is, the presence of air bags may cause a de facto reduction in the economic life of some cars which have been in a crash. Ordinarily, cars will be scrapped if repair costs are greater than the wholesale value N. The wholesale value N is a function of age and the initial value. Suppose air bag replacements costs are $2000. Recognizing the replacement cost of air bags means that the same damaged car will be scrapped at (N+$2000). Expressed another way, the full additional costs of air bags are not only the initial costs of the bags, but also their replacement costs after they have been deployed, or the lost value due to premature scrapping of damaged vehicles not worth the air bag replacement costs.

Another characteristic of most safety interventions is that they have an effect over a whole range of injury severities. Safety measures usually have a cascading effect whereby some deaths are prevented and replaced by some level of injury, otherwise-"severe" injuries are now less-severe, and otherwise-"minor" injuries may be avoided altogether. There are additional complications in that different types of injuries may be substituted within the same AIS classification. Evaluation of safety interventions requires incorporating the gamut of injury and damage severity in accidents. The current North American air bags do not have a simple cascading effect on injuries. While some deaths are prevented and the people injured instead, the current aggressive air bag technology in North America is actually worsening some injury rates. More analysis is needed to clarify the injury rates and shifts among injury categories resulting from the various combinations of air bags and seat belts and their use or non-use.

The foregoing raises the need to study the optimal threshold speed for deploying air bags. Part of the costs of present air bag systems arise because deployment at relatively low speeds may be causing as many or more injuries as they prevent, especially for belted drivers, not to mention the costs of air bag replacement in otherwise relatively minor accidents. There is a tradeoff which needs to be studied. To put it simply: if air bags deployed at very low impact speeds, the injuries from the air bag would greatly exceed injuries which would be sustained otherwise. As impact speeds increase, there are progressively greater injuries. Material damages also increase progressively with impact speeds, but taper off once substantial damage has been done to the vehicle. Theoretically, there is some optimal deployment threshold speed where injury



probabilities from the accident exceed those which may be inflicted by the air bag. This is illustrated in Figure 4. Injury rates rise progressively without air bags, whereas low speed air bag deployment would cause injuries at first but these would be overshadowed by crash injuries as impact speeds increase, indicating the optimal threshold speed. Adding the costs of air bags (not shown) would raise the optimal threshold speed still more.

4.0 Conclusion

There has been substantial media attention recently to some deaths caused by low speed deployment of air bags, and the injuries sustained by many others due to the aggressive rate of expansion of air bags. Official warnings have been issued about children in the presence of air bags. There is also concern for people of small stature who may sit closer to the air bags (e.g., many women). There are steps underway to correct for some of these problems. Raising the air bag deployment threshold speed is the most important thing for belted drivers. Reducing the expansion rate of the bag might assist unbelted drivers and low speeds, but this will tend to be offset by reduced effectiveness of the bag for higher speed crashes.

But this recent debate over the potential harm of air bags in low speed impacts has not stimulated much debate about the overall merits of air bags. Indeed, spirited defence of air bags has been the norm. The exploratory calculations here suggest that the benefits of air bags might not warrant their costs, particularly for those who use seat belts properly. There is a great deal of effort going in to monitoring air bag experience and improving the technology. But there is a case for more economic analysis of air bags to go along with the extensive engineering analysis which is already taking place.

ACKNOWLEDGEMENTS

The author wishes to thank Trevor D. Heaver, John Lawson and Mike Macnabb for helpful conversations and advice, and Tony Kan and Shawn Tay for very capable research assistance. The author remains responsible for the interpretations and viewpoints expressed.

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