9. J.W. Philpot, K.W. Heathington, D.B. Sontag, C.J. Culler, and J.L. Cunningham. Use of Telephone Surveys to Determine Awareness of Tennessee's Child Passenger Protection Law. National Highway Traffic Safety Administration, U.S. Department of Transportation, Rept. DOT HS-805 804, Sept. 1980.
10. D.B. Sontag, K.W. Heathington, and M. Lo. Enforcement of the Child Passenger Protection Law. National Highway Traffic Safety Administration, U.S. Department of Transportation, Rept. DOT HS-805 802, Oct. 1980.
11. D.B. Sontag, K.W. Heathington, E.C. Hughes, C.J. Culler, and L.S. Geiss. Organizational Networks for Promoting Child Passenger Safety. National Highway Traffic Safety Administration, U.S. Department of Transportation, Rept. DOT HS-805 806, Oct. 1980.
12. D.A. Wyrick, D.B. Sontag, and K.W. Heathington. Development of Materials and Public Relations Efforts to Promote Child Passenger Safety. National Highway Traffic Safety Administration, U.S. Department of Transportation, Oct. 1980.
13. Tennessee Statistical Abstract, 1977. Center for Business and Economic Research, Univ. of Tennessee, Knoxville, 1977.
14. Insurance Institute for Highway Safety. Status Report, Vol. 15, No. 10, June 25, 1980.

Publication of this paper sponsored by Task Force on Occupant Restraint Systems.

Automobile-Restraint Controversy: Analysis and Recommendations

DOUGLAS B. BRITTAIN AND YOSEF SHEFFI

Some of the costs and benefits of motor vehicle passenger-safety systems and policies, including passive seat belts, air bags, and a mandatory seat-belt-use law, are analyzed. This paper argues that since the last alternative is significantly more cost effective than the first two, the federal government should have offered it as an option to states instead of abolishing the passive restraint requirement.

In October 1981 (1), the Reagan Administration abolished the most significant regulatory action of the National Highway Traffic Safety Administration (NHTSA) by eliminating the passive restraint requirements from Federal Motor Vehicle Safety Standard (FMVSS) 208 (2). This regulation required cars manufactured after September 1982 to be equipped with passive restraints for front-seat occupants. Unlike conventional seat belts, passive restraint systems require no action by either driver or passenger in order to be activated, thus providing automatic protection to automobile occupants in almost every accident. These systems are aimed at the heart of the problem with current seat belt systems--the low use rate. Only about 10 percent of U.S. drivers wear their seat belts.

Manufacturers are planning to meet the pending requirement by using one of two systems: passive belts or air bags. Passive belts are standard seat belts that are automatically buckled up as the occupant enters the vehicle while air bags consist of large pillows that inflate in case of an accident, thus restraining the occupants' movement. A more detailed technical description of these systems is provided later in this paper.

The analysis offered in this paper shows that the recent action by the Reagan Administration can be easily justified on the basis of cost-effectiveness considerations. In order to be justified, though, it has to be compared with an alternative course of action--the implementation and enforcement of a mandatory seat-belt-use law. A comparison of this alternative with the passive belt and air bag solutions suggests that the federal government should have complemented its recent action by instituting a seat-belt-use law.

The federal safety concern is motivated by the high number of automotive accidents, which cause more than 50 000 deaths and 2 million injuries every year in the United States (3,4). The regulation under consideration concerns roughly 60 percent of the fatalities (or about 30 000 deaths) that are automobile occupants; the others include mainly pedestrians, bicyclists, motorcyclists, and streetcar occupants. All the alternative courses of action mentioned above are designed to save as many of these lives as possible as well as reduce the number and severity of injuries and ease the economic hardship associated with automotive accidents. This paper chooses the number of automobile-occupant fatalities as the key criterion in evaluating the effectiveness and costs of the three aforementioned alternatives. This criterion should, however, be treated only as a measure of effectiveness; the reduction in the number and severity of injuries may be a much stronger impact of these courses of action.

The paper is organized as follows. First, the passive restraint provisions set forth in FMVSS 208 are summarized, some background on the functioning of seat belts is presented, and the concept of effective use rate that is used in the analysis that follows is described. Second, analyses of the three alternatives are presented, i.e., passive belts, air bags, and mandatory belt use. This presentation includes a technical description as well as a discussion of effectiveness, costs, and other considerations. Third, the three alternatives are compared with each other in terms of several measures and, finally, the last sections summarize and conclude the paper with an outline of an implementation strategy.

The paper does not report new experimental results but rather tries to shed light on the controversy through a comparative evaluation of the major alternatives by using existing data. [An abridgment of this paper is given elsewhere (5).]

BACKGROUND

This section provides background information for the analysis described later in this paper. First, a review of the passive restraint requirements set forth in FMVSS 208 is presented. This is followed by a short description of how restraint systems work by using conventional seat belts as an example. Finally, the concepts of effectiveness and use rate are discussed; these are major factors in evaluating alternative restraint systems.

Regulations

The first large-scale federal regulation of the automobile industry was initiated in 1966 with the passage of the National Traffic and Motor Vehicle Safety Act. In this Act, many automotive safety requirements were established, most of which were introduced on 1968 model-year vehicles.

Most of the more recent safety regulations have been devised by NHTSA, an agency of the U.S. Department of Transportation (DOT) established by Congress in 1970. Although NHTSA has been involved in several areas over the years, its most significant regulatory action was the promulgation of the passive restraint law, officially referred to as FMVSS 208.

The passive restraint provisions of FMVSS 208 were originally scheduled to take effect as early as 1973, but the effective date has been postponed several times. As the law stood until October 1981, large and intermediate-sized cars built after September 1, 1982, were required to be fitted with passive restraints, as were small cars beginning in September 1983. In October 1981, however, the Reagan Administration abolished this law, citing the expected use of passive belts (rather than air bags) by manufacturers as one of the reasons.

Currently, all passenger cars sold in the United States are equipped with a three-point seat belt (one that incorporates both a lap and a diagonal shoulder belt) for the driver and front-seat occupant as well as with lap belts for rear-seat occupants. FMVSS 208 incorporated a number of provisions dealing with vehicle-occupant protection in several types of accidents. For front-seat occupants, passive protection (measured by injury criteria for head, chest, and femur) should have been provided in a frontal ($\pm 30°$) barrier-crash test at 30 mph. In addition, passive protection should have been provided for a 20-mph lateral-impact test (within specified head and chest injury criteria) and for a 30-mph rollover test (during which the occupants must remain inside the car). A vehicle did not have to be subjected to the last two types of tests if active or passive lap belts (or three-point belts) were provided in conjunction with the passive restraint system. Note that this requirement virtually guaranteed that all manufacturers would have chosen the latter approach, typically by offering active lap belts.

How Seat Belts Work

In a frontal crash against a solid object at 30 mph, the vehicle comes to a complete halt in about 0.1 s, during which time the front of the car is crushed approximately 20 in (6). In such a crash, an unrestrained front-seat occupant continues forward at nearly 30 mph, leaving his or her (quickly decelerating) seat behind him or her. By the time he or she arrives at the dashboard, however, the vehicle is almost stopped. The result is the so-called second impact, in which the occupant must decelerate from close to 30 to 0 mph in the space of about 1 in. The resulting forces can cause massive injuries. The alternative outcome, in which the occupant is thrown through the windshield, can be equally disastrous.

If the occupant is wearing a three-point seat belt, he or she is subjected to much lower forces. As the seat decelerates, the occupant decelerates along with it (the so-called ride-down effect). In addition, belt stretch allows an additional 8 in or so of forward movement. Even when the car's post-impact recoil is taken into account, this still allows 12-16 in for the occupant to come to a halt, which is much more desirable than the 1-in deceleration space available without belts. Also note that with the use of the belts the head is prevented from contacting any unforgiving surface. Instead, the head's deceleration is partly absorbed by the neck movement without resulting in serious injuries (6).

In addition to providing protection in frontal collisions, a properly worn belt reduces injuries in practically all other collisions as well (7). Not only does a seat belt decrease the decelerative forces on the body, but it also dramatically reduces the possibility of occupant ejection. This is particularly important for accidents that involve rollovers.

The effectiveness of seat belts has been demonstrated and reported in several European and American research projects. Grime (6) analyzes many of these studies, observing that the estimated reduction in serious injuries varies from 45 to 70 percent, depending on the type and severity of the accidents investigated. One study found that for accidents equivalent to barrier crashes at approximately 35 mph, the probability of fatal or serious injury was six times greater without a seat belt. Also, the various studies showed that head injuries were reduced by half and ejections are practically eliminated with belt use.

Restraint-System Effectiveness

In discussing the effectiveness of any restraint system one has to distinguish between two components: (a) the effectiveness of the system given that it is activated and ready and (b) the activation rate or the rate of vehicles on the roads in which the system is active. These two components are discussed in turn in this section.

The first component of effectiveness may be termed technical effectiveness (or conditional effectiveness) to emphasize the fact that it measures reductions in death and serious injury given that vehicle occupants enter an accident with the restraint system in an active mode. (This means that if one considers a seat belt system, it is buckled and properly tightened and if one looks at an air-bag system, it is armed and ready for use.) The technical effectiveness depends on three major factors: accident-type effectiveness, accident-type frequency, and system reliability. These factors are explained below.

1. Accident-type effectiveness--The various restraint systems are clearly not equally effective in all types of accidents. The accident-type effectiveness is the fraction of cases where a restraint system would prevent death or serious injury for an accident of a particular type. Thus, accident effectiveness of 80 percent in a frontal crash at 35 mph means that, on average, four out of five occupants who use the system are likely to escape death or serious injury. As another example, note that the effectiveness of any restraint system at a frontal accident at a speed of 60 mph or more is about 0.

2. Accident-type frequency--Different types of accidents (with different accident-type effectiveness measures) occur at different frequencies. In order to get a summary measure applicable to all types of accidents, one has to compute the average

accident-type effectiveness weighted by the accident frequency.

3. System reliability--The probability of a restraint-system malfunction could also be included, and the effectiveness measure described in 2 above could be reduced to account for it. This paper assumes that the reliability of all the systems considered is very high; thus, this factor can be ignored in the comparative evaluations.

In order to compare the effectiveness of the various policy options with regard to restraint systems, it is important to recognize that any system has to be in working order and operative in order to function. As shown later, the activation rate of the passive restraint systems is not 100 percent as argued by some proponents but significantly lower than that due to deliberate deactivation (mainly of passive belt systems) and low maintenance level (mainly of the air-bag systems). The low use rate of current seat belts was, of course, the motivation for FMVSS 208. Thus, one can define an activation rate as the proportion of vehicles on the road with active and operative restraint systems.

The product of the two above mentioned components--conditional effectiveness and activation rate--is a possible measure of effectiveness of a given automotive restraint policy option. Note, though, that these two components are not independent, as it is reasonable to assume that people who do not use their restraint system are more accident-prone than people who do (this effect is discussed in more detail later). The above measure of effectiveness should thus be scaled down to account for this selectivity bias. In this paper, the estimated activation rate for each system is modified to give a virtual activation rate that is always lower than the activation rate itself, thus accounting for this bias. The measure of effectiveness is thus the product of the technical effectiveness and the virtual activation rate.

As an example, one can calculate the effectiveness of the standard seat belt system. The conditional effectiveness of this system has been estimated by various sources to be around 70 percent. In 1976, then Secretary of Transportation William T. Coleman used a seat belt conditional effectiveness of 60 percent (and a lap belt conditional effectiveness of 40 percent) in evaluating various restraint alternatives (8). Thus, one can assume that if activated, the standard seat belt may be effective in, say, between 45 and 65 percent of the cases as a conservative range. The use rate of seat belts in the United States is only about 10 percent; thus, the combined measure of effectiveness is expected to be in the range of 4.5-6.5 percent. If one believes, now, that drivers who wear seat belts are more safety conscious and thus less accident-prone than the rest of the population, the use rate can be adjusted from 10 percent to, say, 9 percent. Multiplying this virtual use rate by the technical effectiveness, one gets a range of 4-6 percent. This range represents the effectiveness of the standard seat belt without mandatory activation regulation.

The measure of effectiveness described in this section and all its components are used in the analysis described in the next sections.

ANALYSIS OF ALTERNATIVES

This section presents safety, cost, and implementation-related aspects of the three major alternative approaches to occupant protection: passive belts, air bags, and (active) seat-belt-use laws. As mentioned above, the first two represent the current technology that manufacturers were planning to use for compliance with government regulations. The third is an alternative that has been implemented in many locations outside of the United States.

Note that these three alternatives are not the only methods of protecting automobile occupants or for increasing restraint use. Several other restraint designs exist, and the systems discussed here show potential for significant technical improvements. The focus of this paper, however, is on currently available options.

Passive Belts

Passive or automatic belts require no buckling or other passenger action to make them operative. The most familiar example of this is the Volkswagen VWRA passive shoulder belt system available on most of its models sold in the United States. A diagonal belt is attached to the upper rear of the door and runs down across the front of the seat back to a take-up reel positioned between the front seats. As the door is opened, the belt unrolls from its reel and moves forward away from the seat, thereby allowing the driver or front-seat passenger room to enter the vehicle. As the door is closed, the belt returns to restrain the seated individual. The spring-loaded emergency-lockup reel keeps the belt snug so that no manual adjustment of the belt is necessary. In addition, an emergency release of the belt is provided so that the occupant may still escape the vehicle in the event that the door becomes inoperative in a collision.

Although a single diagonal belt can effectively restrain the torso in a frontal crash, there is little to keep the front-seat occupant from sliding down under the belt, a phenomenon known as submarining. A lap belt is effective in preventing submarining, but the Volkswagen system does not incorporate a lap belt. Instead, a padded knee bolster is positioned under the dashboard and runs the width of the vehicle. Since this bolster prevents substantial forward movement of the knees, the possibility of submarining is practically eliminated.

Door activation of passive belt systems, as employed by Volkswagen, is an easy system of belt activation, but there are other possibilities as well. There now exists automatic belt systems that use electric motors to correctly position the belts during vehicle operation while still allowing sufficient belt-to-seat clearance for easy ingress and egress (9). Also, some manufacturers have designed three-point passive belts that need no knee bolster in order to be effective.

It should be noted here that the current belt and bolster design as employed by Volkswagen and other manufacturers seem to be less effective than the lap belt in four aspects:

1. The bolster can be depressed only 1-2 in while a belt can stretch and allow 4-8 in of body movement;
2. Bolsters must allow for normal vehicle operation and, unlike snug belts, therefore subject knees to a loading impact;
3. Bolsters transmit the impact to the knees, which are relatively fragile in comparison with the pelvis; and
4. Bolsters are of no use in other than frontal impacts; i.e., they do not provide protection on rollover or do not prevent ejections.

The remainder of this section discusses the effectiveness of the passive belt system and its costs.

Effectiveness

As mentioned previously, the effectiveness of a restraint device is the product of its conditional effectiveness and its virtual activation, where both components are in turn a function of several factors. In evaluating the effectiveness of a passive three-point belt, it can be assumed that its conditional effectiveness would be similar to that of the standard three-point belt. The particular Volkswagen design may have a lower technical effectiveness due to the above mentioned disadvantages of the knee bolster and the possibility of the door opening, which would leave the occupant unrestrained. Thus, one may use a conditional effectiveness of 45-65 percent for a three-point system, and, maybe, 40-50 percent for a Volkswagen-like design.

In order to estimate the activation rate of a passive belt, one can look at cars that offer such a system, e.g., Volkswagen Rabbit and Chevrolet Chevette, which use a similar design. Field data show a 75 percent use rate (i.e., 25 percent of the drivers disconnect the system). (This seemingly high deactivation rate may be rooted in the ease with which the system can be disconnected; it is, in fact, as easy to disconnect as to debuckle the standard seat belt.) This activation rate may be a high estimate, though, since drivers of these models may be more safety conscious than the rest of the population. This is evident from the high activation rate of the same model cars with standard seat belts, which is higher than 30 percent, or more than three times the national average. Thus, the activation rate in the general population will probably be lower than 70 percent. A low bound for the estimated activation rate for the entire population may be obtained from the ratio 75/30, which depicts the activation rate with passive belts and without it for the Rabbit and Chevette models. When applied to the general population (with its current 10 percent activation rate), this bound translates to an activation rate of about 25 percent. This figure is undoubtedly low, since people may get used to the passive belts as time goes on. A reasonable estimate of the activation rate lies probably between the two bounds in the range of 45-65 percent.

As mentioned earlier, the people who actually will be using the system and not deactivating it may be more safety conscious than the people who purposely are deactivating the system. To account for this, the above mentioned activation rate of 45-65 percent may be adjusted to a range of, say, 40-60 percent. The overall effectiveness may thus be estimated at approximately 20-40 percent.

Costs

When Volkswagen introduced the passive belt as an option in 1975, it was priced at $30. Current estimates range between $30 and $150, depending on the complexity of the system (10). This is in addition to the $100 that is the approximate cost of the currently required active belts. A figure of $50 is used in this paper as a working hypothesis for the incremental cost of the passive belts.

Air Bags

Air-bag restraining systems are somewhat more complicated than passive belts. They consist of large inflatable pillows, usually made of nylon, that inflate when the car hits a solid object at a speed greater than 12 or 15 mph. The driver's air bag is stored folded in the steering-wheel hub and the bag for the other front-seat passenger or passengers is stored in the lower right end of the dashboard. Air-bag deployment is electrically triggered by sensors located in the front bumper.

Immediately on receiving the signal from the crash sensor the air bags begin to inflate, typically by burning sodium azide, which produces nitrogen to fill the bag (11). On the order of 40 thousandths of a second later, the air bags check forward movement by restraining the occupants' heads and torsos. As with seat belts, the occupants are allowed several inches of forward movement in order to moderate their deceleration rates but, with the bag system, the forces are distributed over a much larger area of the body. Submarining is prevented by knee bolsters or by two-part air bags that have an additional inflatable chamber that controls forward movement of the knees.

Deflation of the air bags begins almost immediately due to the use of porous bag material or bags with holes in them (10). Within 0.5 s or so after initial impact, the automobile occupants are seated with the deflated air bags lying in their laps. Note that air bags are not reusable and must therefore be replaced after each collision severe enough to cause inflation. The remainder of this section discusses the effectiveness, costs, and other factors associated with the use of air bags.

Effectiveness

In a frontal impact, the technical effectiveness of air bags should be equal to that of a seat belt and may be even slightly better due to broader impact distribution with the bag. The bags were found as effective as belts in controlled experiments, but limited evidence suggests inferior performance in actual accidents. As a working hypothesis it is assumed that the conditional effectiveness of air bags is similar to that of the standard three-point belt.

Air bags, however, unlike belts, work only in frontal impacts. No protection is offered in side impacts, rollovers, or other nonfrontal impacts. It should be noted that fewer than 57 percent of occupant injuries are the result of frontal or near frontal (±45°) impacts (12). Furthermore, air bags would not deploy in low-speed collisions, which cause a substantial number of injuries. Thus, it is clear that air bags may not provide protection in more than half of the injury-producing collisions. This problem can be partly remedied with a lap belt, and such belts probably would be included with most air bags. The lap belt (which should be manually activated) would eliminate injuries in most types of accidents where air bags do not offer protection. Thus, the air bag-lap belt combination may be as technically effective as the standard belt, with a rating of 45-65 percent.

Another factor, though, may still detract from the air bag technical effectiveness, and this is their lack of performance in multiple-impact accidents. Due to the rapid deflation of air bags, protection will not be offered during a secondary impact. A recent British study (7) noted that a third of the occupants in the accidents studied were involved in multiple-impact accidents or rollovers. In these types of accidents it is important that the restraint system operate continuously. The problem with the air bag can, again, be partly remedied with a lap belt, and fully solved with a standard three-point system that could be supplied in addition to the air bag.

Assuming that such a system would not be supplied with air bags (and if it would, its activation rate would be negligible), the estimate of the technical effectiveness should be lower than the technical effectiveness of the standard seat belt. This paper, however, uses a rate of 45-65 percent for this system. This rate is similar to the technical effectiveness of the standard belt and is, thus, a conservative estimate (from the point of view of this paper).

The activation rate of an air bag-lap belt system is not 100 percent as some proponents of this system believe. In the first place, the lap belt requires active buckling, and field observations suggest that less than 10 percent of the lap belts are used in air-bag-equipped cars. There is little reason to believe that this figure will grow in the future. Furthermore, in light of the high replacement costs of air bags (this point is discussed later in this section), it is expected that a large number of them will never be replaced once initially used. For this reason, the air bag's conditional effectiveness would be limited to the first frontal impact (of a multiple-impact collision) of the first accident that the car would experience.

In order to compute the activation rate of the air-bag system, one should distinguish between those accidents where it would inflate (which are less than 70 percent of the injury-causing accidents) and those where it would not. In the first category of accidents, the activation rate measures the fraction of the population who will drive with an operative system, which may be as high as 90-95 percent (especially if replacing used bags will be covered by insurance companies). Because between 15-20 percent of these accidents may involve multiple collisions and rollovers, where the air bag would not be operational after the fist impact, this rate can be assumed to be in the range of 80-90 percent. This rate can be further reduced to account for the selectivity bias in the replacement of used air bags to a range of say, 75-90 percent. For the (injury-causing) accidents where the air bag would not inflate, protection is provided by the lap belt that, as mentioned above, is likely to be activated in no more than 10 percent of the cases.

Thus, for about 70 percent of the accidents the conditional effectiveness is 45-65 percent and the activation rate is 75-90 percent. For the other 30 percent of the accidents, the lap belt (with technical effectiveness of 30-40 percent) is the only protection and, even so, its activation rate is only about 10 percent. One can thus assume a technical effectiveness of 35-50 percent and an activation rate of 60-75 percent. The resulting effectiveness rate is on the order of 20-40 percent. This figure is in line with the range of estimates included in the 1972 report by the Ad Hoc Committee on the Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT), which stated that pessimistic estimates predict air-bag benefits to be equal to a 33 percent seat-belt-use rate (10). The optimistic estimate included in the same report is of effectiveness equal to 80 percent that of a seat belt, a figure that seems a little high in light of the calculations above.

Costs

As with other air-bag-related issues, the issue of exactly how expensive air bags would be is open to great dispute, with NHTSA, consumer groups, and the insurance companies generally claiming relatively low costs and the automobile manufacturers predicting relatively high costs. Back in 1976, then Secretary of Transportation Coleman observed that estimated costs of air-bag systems ranged from $70 to $520 (13). (Note that these are estimates of the incremental cost of an air-bag system over the standard three-point belt.) The optional air-bag system being sold by General Motors at that time was a loss-leader at $315 (14).

Air-bag costs, like everything else, have increased with inflation. In 1978, NHTSA estimated the cost of air-bag systems in full production to be $200. Ford has recently recomputed its retail-price estimate for air bags and predicts that air bags would cost new car buyers $575 in 1982 for sales of 787 000 units annually. If most consumers prefer passive belts and only 200 000 air-bag-equipped cars were sold annually, then the retail price would rise to $825 (15).

The prices discussed so far are for air bags as original equipment. The costs of replacing air bags are expected to be considerably more, as is typical with the automobile repair business. The insurance coverage of some of these costs would, of course, be borne by consumers in the form of higher premiums.

In light of the above figures, it seems conservative to estimate the (incremental) costs of a car air-bag system at $500/car and, taking into account the fact that many cars would have to be equipped with the systems more than once, the actual life-cycle cost estimate may be twice that amount. For analytical purposes, this paper uses a working hypothesis of $600/car (borne either directly or in part in the form of higher insurance premiums).

Other Considerations

Many of the problems of the early air-bag systems have been solved. Two issues, however, still cloud the expected benefits of this system: their performance with respect to out-of-position children and the use of sodium azide as a gas generant.

The first issue is that children seated too far forward on the front seat can be subjected to unnecessarily high deceleration rates. This is because a child who is sitting on the front edge of the seat (so his or her feet can dangle over the edge) is pushed back into the seat (into the correct seating position) by the rapidly inflating air bag. Such a child has approximately 10 in less in which to decelerate. Children who are sitting more out of position, such as lying back with their feet up on the dashboard, can in some instances actually be hurt more by the inflating air bag than by the collision itself. Out-of-position adults present less of a problem due to their greater weight.

The problem of using sodium azide is not necessarily inherent to air bags, but the technology chosen by all American manufacturers is to inflate the air bags with nitrogen created during the combustion of sodium azide. Unfortunately, sodium azide is a class-B poison, a known mutagen, a suspected carcinogen, and becomes explosive when it contacts various metals. Although most car owners would have no contact with sodium azide, the use of this substance presents some real hazards to scrapyard workers.

The analysis presented later in this paper does not account for these issues; it is assumed that they will be solved in the future. Of course, the resulting air-bag costs may be even higher than $600/car.

Belt-Use Law

The effectiveness of automobile-occupant restraints has been recognized by many countries. Unlike the United States, more than 20 of these countries have chosen to enact a law that requires automobile drivers and passengers to wear their safety belts.

Most belt laws now in effect require front-seat occupants to have their seat belts buckled while their cars are in motion. Punishment for noncompliance can range from nothing to $300 or more and may also include a jail sentence, although the average punishment is a fine of approximately $10 (16). The degree of enforcement also varies widely, but in almost all cases no citations are issued unless the persons involved have already been cited for some other traffic-law infringement (8).

The remainder of this section discusses the effectiveness, costs, and constitutionality of a belt-use law.

Effectiveness

The technical effectiveness of the standard three-point seat belt was discussed earlier, where a range of effectiveness of 45-65 percent was suggested as a working hypothesis. The activation rate of the seat belt under such a law is not easy to estimate due to noncompliance problems. Foreign experience in countries where belt use is required by law suggests a use rate of 70-80 percent as typical (8,10), with considerable variation between countries. This number, however, has to be adjusted for selectivity bias that, in the case of this alternative, may be stronger than in the previous cases. The 20-30 percent of drivers who choose to violate the law may be significantly more prone to be involved in accidents than the average driver (17). If the accident likelihood of this group is, say, 25 percent higher than the population average, then the virtual activation rate is likely to be in the range of 55-70 percent instead of 70-80 percent.

Costs

A compulsory belt-use law would not add to the price of a new car but would instead cost state and local government additional money for enforcement. In the past, DOT estimated that enforcement of such a law would cost approximately $5 million annually (8). This figure may now be adjusted to $6 or $7 million to account for inflation; thus, a figure of $7 million is used in this paper.

Constitutionality

If belt-use laws were enacted, it seems probable that their constitutionality would be tested. Motorcycle-helmet-use laws have generally been found constitutional in the past, and thus it appears likely that belt-use laws would be upheld as well. The argument that belt wearing is a matter of personal safety and therefore not subject to state regulations is expected to be used, based on the Ninth and Fourteenth Amendments. The argument used by the courts in the case of the motorcycle-helmet-use law was that this action affects others in numerous aspects and therefore is subject to state regulation.

Even with the absence of belt-use laws in this country, some courts have held that failure to fasten an available seat belt constitutes negligence (e.g., Mount v. McClellan, 91 Ill App 2d 914). In most cases, neglecting to wear seat belts is not considered negligence that contributes to an accident but negligence that contributes to injuries.

Table 1. Effectiveness of alternative approaches.

Item	System		
	Passive Belts[a]	Air Bags[b]	Seat Belt Law
Technical effectiveness (%)			
Midrange	55	42.5	55
Range	45-65	35-50	45-65
Activation rate (%)			
Midrange	55	67.5	60
Range	45-65	60-75	55-70
No. of lives saved annually			
Midrange	9350	9040	10 395
Range	6380-13 310	6615-11 810	7800-14 330

[a]Includes passive lap belts. [b]Includes active lap belts.

Consequently, the question of belt use is typically only one that governs the extent of compensation for injuries and does not block the compensation itself. In a few cases, the nonuse of belts has not been allowed to have an effect on the extent of the compensation (e.g., Britton v. Doehring, 286 Ala 498). If nationwide belt-use laws were to take effect, though, one can expect more rulings of the former type, which should increase the use rate. This would make it practically impossible to collect damages for injuries that a seat belt could have prevented, although the nonwearing of a belt would probably not be considered criminally negligent unless failure to use the belt was felt to be the proximate cause of the accident. In many foreign countries with compulsory belt wearing, courts have issued similar rulings (16).

It should be noted that although more than 110 mandatory belt-use bills have been introduced and defeated in 32 states between 1972 and 1977, some forms of the law currently do exist. The Federal Highway Administration, for instance, requires all truck drivers engaged in interstate commerce to wear belts. Tennessee requires all children under four years of age to be properly restrained and California requires belt use in all driver-education vehicles. In addition, state employees, officials, and policemen must wear safety belts while on duty in many states (18). Thus, mandatory seat belt use has at least some important precedents in the United States at this time.

COMPARISON AND ANALYSIS

This section compares the three alternatives presented in the last section along three dimensions: effectiveness, cost-effectiveness, and personal freedom.

Effectiveness

In order to create a more vivid measure of restraint-system effectiveness, one can use the expected number of lives saved by each of the alternative systems. As mentioned in the first part of this paper, annual fatalities of car occupants amount to about 30 000. Before any of the alternative approaches to occupant restraint are evaluated, though, it should be recognized that the current arrangement, which includes mainly active belts, has some positive effectiveness. In fact, it was estimated at approximately 5 percent. The number of annual fatalities used in comparing the various alternatives should thus be adjusted to 31 500.

Table 1 presents the conditional effectiveness, activation rate, and the expected number of saved lives for each system. The table presents both a likely (or midrange) estimate for each figure shown and the range itself.

The number of lives saved shown in the table was computed as the product of the potential number of fatalities (31 500), the activation rate, and the technical effectiveness. Note that the ranges of estimated number of saved lives shown in Table 1 overlap with each other and, even though the mandatory belt-use alternative seems to be the best in terms of the midrange estimate, it does not dominate the other alternatives in absolute terms.

Note also that the table displays an approximate number of lives saved annually with all cars on the road equipped with the system. Since either passive restraint alternative would be introduced only gradually, an immediate compulsory belt-use law would mean a large increment of lives saved in the early years. If one assumes 10 years as the period in which the number of passive restraint-equipped

Table 2. Cost-effectiveness of alternative approaches.

Item	System		
	Passive Belts[a]	Air Bags[b]	Seat Belt Law
Incremental cost per new car ($)	50	600	-
Incremental total annual cost ($000 000s)	500	6000	7
Incremental no. of lives saved			
Midrange	8030	7540	8895
Range	4880-11 810	5115-10 310	6300-12 830
Cost per life saved ($)			
Midrange	62 300	796 000	790
Range	42 300-102 500	582 000-1 173 000	560-1100

[a]Includes passive lap belts. [b]Includes active lap belts.

cars would approach 100 percent and assuming linear growth to 100 percent, it can be calculated that the belt-use law would save more than 55 000 more lives than air bags or passive belts in the first decade.

Cost-Effectiveness

Due to the difficulty in quantifying the costs of loss of life and limb, one of the most widespread techniques of evaluating investment in safety is their cost-effectiveness. In other words, safety investments are compared with other safety investments in terms of expected number of lives saved per dollar invested. Alternatively, one can calculate the investment costs per life saved, as is done in Table 2. This table assumes annual new car sales of 10 000 000 and the cost figures presented earlier for each alternative approach. The calculations of cost per life saved require some explanation. As mentioned, the dollar figures attached to passive belts and air bags represent the incremental cost of these systems over the standard three-point seat belt. In order to be consistent, one has to compute the incremental number of lives saved by these systems. Since the estimate of the number of lives saved annually with the current system is approximately 1500, this figure should be subtracted from the estimated number of lives saved shown in Table 1. (In other words, the calculations are based on midrange estimates of 8030 lives saved by passive belts, 7540 by air bags, and 8895 by a seat belt law.) The cost per life saved shown in Table 2 is calculated by dividing the total incremental annual costs by the expected incremental number of lives saved. The range shown in Table 2 corresponds to the range of estimates of number of lives saved annually depicted in Table 1.

The figures that represent the incremental cost per added life saved for each of the alternatives in Table 2 speak for themselves. There are several orders-of-magnitude difference between the compulsory seat-belt-use alternative and the others. Any potential inaccuracies in the assumptions made in the course of developing these figures are dwarfed in comparison to the magnitude of the difference in the cost-effectiveness of the alternatives. The compulsory seat-belt-use alternative is almost a hundred times more cost effective than passive belts and more than a thousand times more effective than air bags. (Note that we do not present any incremental analysis of the cost-effectiveness between the alternatives presented since, if based on the midrange figures, it would show a negative benefit for any of the passive restraint alternatives over the seat-belt-law approach.)

The only possible drawback of such a law may be the implied loss of personal choice involved. This point is discussed next.

Personal Freedom

Any discussion of a mandatory safety-belt-use law invariably generates a debate on the question of personal freedom or the right to choose whether to buckle up or not. In these arguments, the situation under a mandatory seat-belt-use law (where a person can choose to either buckle up or risk a fine) is compared with the current situation (the do-nothing alternative) where a driver does not risk a fine for not using the seat belt.

This paper argues, however, for an alternative to the status quo, and the law should thus be compared with other alternatives such as the passive restraint option. Under a passive restraint course of action similar to the provisions of FMVSS 208, all consumers would be required to purchase passive restraints with their new cars. No alternative will be available.

Under a mandatory seat-belt-use law, consumers would be given the choice of whether to buckle up or pay the extra money for passive restraint and thereby avoid the bother of buckling up (one can also choose to risk a fine and not use any restraint system). (Admittedly, the extra money is a little more than if all cars were equipped but, then again, no consumer will be forced to buy it.) It is highly likely that manufacturers would not have to be regulated to provide such an option, as under a mandatory seat-belt-use law market forces would encourage it. With mandatory seat belt use, the choice of buying or not buying a passive restraint option will be reduced to a cost versus inconvenience trade-off, similar in principle to the trade-off between manual and automatic transmission, manual or remote-control side mirror, and many other options.

In conclusion, it seems that a well-written nationwide belt-use law would actually provide more personal freedom and choice opportunity than the situation that would have arisen under FMVSS 208.

CONCLUSIONS

As evident from the analysis presented in this paper, mandating the use of seat belts (or any other restraint system) should be preferred to requiring manufacturers to equip cars with passive restraints as required in FMVSS 208. The Reagan Administration has recently dropped the passive restraint requirements of FMVSS 208 but did not go all the way and institute a mandatory belt-use law.

By its action, the Administration missed a unique opportunity to implement a belt-use law without a lengthy repeal process and furor from consumer groups. Instead of abolishing the regulations, the Administration should have exempted states that passed such laws from the passive restraint provisions of FMVSS 208. States then could have chosen between passing a mandatory seat-belt-use law or forcing consumers to pay more for their new cars. It is reasonable to assume that most states would have chosen the former route.

This course of action should be considered if and when the passive restraint requirements are considered again. Without the carrot (or exemptions), the federal government does not have an effective means to get states to pass and enforce such laws. The stick approach of withholding highway funding aid was proven ineffective and unpopular in the case of the 55-mph speed limit and is not likely to work in the case of a mandatory seat-belt-use law.

Last, two notes are in order. First, the Administration may trade off an issue that is not directly related. Thus, for example, states that pass a mandatory seat-belt-use law may be exempted from the 55-mph speed limit. This course of action may be less elegant than the aforementioned one but still possible and very effective. Second, it may be interesting to know that, starting in the summer of 1982, all drivers in England will have to wear seat belts.

REFERENCES

1. Federal Motor Vehicle Safety Standards: Occupant Crash Protection. Federal Register, Vol. 46, No. 209, Oct. 29, 1981.
2. Federal Motor Vehicle Safety Standard 208: Occupant Crash Protection. Code of Federal Regulations, Title 49, Section 571.208, Oct. 1, 1980, pp. 313-325.
3. I.G. Black. Going After the Real Cause. Automotive Industries, Vol. 161, No. 3, March 1981, p. 7.
4. B. Carraro. Motor-Vehicle Deaths Edge Upward in 1980. Traffic Safety, Vol. 81, No. 3, May/June 1981, pp. 20-25, 30.
5. Y. Sheffi and D. Brittain. Motor Vehicle Safety: Passive Restraints Versus Mandatory Seat Belt Wearing. ITE Journal, Feb. 1982, pp. 26-29.
6. G. Grime. The Protection Afforded by Seat Belts. Department of the Environment and Department of Transport, United Kingdom, Supplementary Rept. 449, 1979. NTIS: PB80-127186.
7. C.A. Hobbs. The Effectiveness of Seat Belts in Reducing Injuries to Car Occupants. Department of the Environment and Department of Transport, United Kingdom, 1978. NTIS: PB-300334.
8. A.A. Altshuler, J.P. Womack, and J.R. Pucher. The Urban Transportation System: Politics and Policy Innovation. MIT Press, Cambridge, MA, 1979.
9. L. Givens (ed.). Occupant Protection: An Integrated Approach. Automotive Engineering, Vol. 85, Oct. 1977, pp. 44-47.
10. Safety Effectiveness Evaluation of the National Highway Traffic Safety Administration's Rulemaking Process, Volume 2--Case History of Federal Motor Vehicle Safety Standard 208: Occupant Crash Protection. National Transportation Safety Board, U.S. Department of Transportation, Sept. 1979. NTIS: PB80-114085.
11. A.D. Little, Inc. Identification of Approaches for the Control of Health, Environmental, and Safety Hazards Associated with Air Bag Use and Disposal. U.S. Department of Transportation, Final Rept., Aug. 1979. NTIS: PB80-129109.
12. R.L. Braun. Toward Safer Motor Vehicles. IEEE Spectrum, Vol. 14, Nov. 1977, pp. 81-86.
13. E.L. Bolton. Hill Unit Hits Coleman on Air Bag. Automotive Industries, Vol. 155, Nov. 15, 1976, p. 9.
14. L.J. Carter. Auto Safety: Coleman to Act on Controversial Air Bag Issue. Science, Vol. 193, Sept. 24, 1976, pp. 1219-1222.
15. P.D. Hodges. Air Bag Battle Erupts on Hill. Automotive Industries, Vol. 159, Sept. 1979, pp. 21-23.
16. F.G. Fisher, Jr. Effectiveness of Safety Belt Usage Laws. U.S. Department of Transportation, Final Rept., May 1980. NTIS: PB80-209901.
17. A.F. Williams and B. O'Neill. Seat Belt Laws: Implications for Occupant Protection. The Engineering Index Annual, 1979, p. 548.
18. W.G. Wilson. Occupant Restraint Legislation Handbook: A Guide for Proponents. U.S. Department of Transportation, Feb. 1979. NTIS: PB-298461.

Publication of this paper sponsored by Task Force on Occupant-Restraint Systems.