Environmental Activities Week

Title:

RESTRAINT SYSTEM EFFECTIVENESS - A STUDY OF FATAL ACCIDENTS

Author:

R. A. Wilson and C. M. Savage
Safety R & D Laboratory
Environmental Activities Staff
General Motors Corporation

Automotive Safety Seminar • GM Training Center • General Motors Corporation • Warren, Michigan • June 20-21, 1973

June 20-21, 1973

Restraint System Effectiveness - A Study Of Fatal Accidents

Richard A. Wilson – Engineer in Charge
Carl M. Savage – Project Engineer
Safety R & D Laboratory
GM Environmental Activities Staff

One facet to the effectiveness of automotive occupant restraint systems is their potential to reduce the number of fatalities which are occurring. Accidents involving over seven hundred fatally injured occupants in 1967 to 1972 cars were examined case-by-case and occupant-by-occupant to assign the fatality reduction potential of four candidate restraint systems.

- Lap Belt Alone
- Lap and Shoulder Belt
- Air Cushion Alone
- Air Cushion Plus Lap Belt

The primary results of this field accident study are as follows:

If all the fatalities had been wearing a lap belt, 17% could have been saved.

If all the fatalities had been wearing a lap and shoulder belt, 31% could have been saved.

If all the cars had been equipped with air cushions, 18% of the fatalities could have been saved.

If all the cars had been equipped with air cushions, and all the fatalities had been wearing a lap belt, 29% could have been saved.

INTRODUCTION

The choice of occupant restraint systems for cars has been the subject of much debate in recent years. Although the ultimate choice will involve many factors, fatality reduction seems to surface whenever discussions on restraint system alternatives arise. The national highway fatality figures keep coming up as the one visible statistic upon which goals are set and performance is judged. For this reason, the General Motors Safety Research and Development Laboratory initiated an in-depth, case-by-case field accident fatal study. Utilizing technical expertise from GM's Fisher Body Division, and the Safety Research and Development Laboratory, 706 fatalities in 1967 through 1972 passenger cars were studied. The *specific* and *unique* details surrounding each fatality were carefully studied. Using this information, an estimate was made of the ability of the four candidate restraint system combinations to mitigate each fatality.

Knowing the ability of a restraint system to prevent fatalities is very important. The extent of this particular study attests to that. However, the *overall* effectiveness of a restraint system must include other facets: How often will it be used?, How soon can it be put into all cars?, What is its *injury* reduction potential?, Can it cause injuries?. These and other issues must be remembered in order to keep the implications of this *fatal* case study in perspective.

RESTRAINT SYSTEM EFFECTIVENESS

Each passenger car fatal collision is a discreet and unique chain of events which can only partially be described by such measurements as impact speed, crush, acceleration, etc. The merits of air cushion and belt systems have been primarily compared by the use of these measurements as they perform under limited, controlled, test conditions; conditions which are not necessarily representative of all real-world accidents. The uniqueness of this study is that actual in-the-field fatalities were studied in depth to determine what caused each fatality. After determining the series of events and complications which led to an occupant's death, each restraint system considered was rated for its likelihood of fatality prevention for each *particular* fatal case. The restraint systems chosen for evaluation during this study were:

a) Lap belt alone
b) Lap and shoulder belt
c) Air cushion alone
d) Air cushion with lap belt

This study was limited to these four systems since they are either in production today, or are being considered for production, and they appear to be the most likely candidates for occupant restraint in the future.

DATA FILES USED

A jury of four engineers, whose backgrounds included experience in the design, development, and testing of both active and passive restraint systems, were chosen to conduct this study. These individuals, working together, analyzed accident cases involving the 706 fatally-injured occupants.

Accident information available to GM was searched for passenger car fatal cases. The cases used had sufficient information to permit analysis of the crash and resultant injuries. Typical information included Collision Performance and Injury Reports (CPIR), Multi-Disciplinary Accident Investigation reports (MDAI), 35 mm slides, photographic prints, and the like.

CPIR's are filled out by Motors Insurance Corporation Adjusters while they are investigating claims involving an injury-producing accident in a current model vehicle. Included in a

CPIR is information on environmental conditions, locality, alleged mechanical malfunctions, collision details, vehicle damage, steering wheel and column performance, occupant statistics, occupant injury, and so on. This information is compiled from police reports, medical reports, witness accounts and measurements taken of the vehicle and at the accident scene.

MDAI reports are in-depth studies of highway crashes compiled under government contract by Multidisciplinary Investigation teams. These teams consist of various medical specialists such as pathologists, toxicologists, and psychiatrists, and members of other safety-related disciplines, such as highway or traffic engineers, mechanical or automotive engineers, human factors engineers, police technicians, lawyers, and psychologists. The result was 706 passenger car fatalities:

File	No. of Cases
Motors Insurance Corporation (CPIR)	309
Department of Transportation (MDAI)	157
University of California (MDAI)	80
University of Michigan (MDAI)	64
Miscellaneous GM files (CPIR)	51
Cornell Aeronautical Laboratories (MDAI)	31
D. F. Huelke (pre-U of M file) (MDAI)	6
Oakland County (MDAI)	5
GM Company Fleet Cars (CPIR)	3
Total Cases	706

We believe that this collection of 706 fatals in late model year passenger vehicles represents a valid sample that can be used to extrapolate results.

Although there are continuing efforts to establish a National Accident Data Survey, no such *national* accident file yet exists to compare the representativeness of this study.

FATAL CASE PROFILE

The results of this study will have more meaning if the type of accidents that are causing fatalities are understood. Figure 1 shows the distribution of fatals by collision configuration.

This study's proportion of frontals in fatal accidents may appear a bit low. Three factors account for this difference: first, the in-depth analysis of this study allowed the determination of a more valid category for each case. Other studies have defined collision configuration by the vehicle's area of damage. This study defined collision configuration by occupant trajectory. For instance, a side impact to the front 1/3 of the car would have primarily frontal damage, but the occupant would have the lateral trajectory of a side impact. For a restraint system to be effective, it would have to offer lateral (side) restraint. We, therefore, would classify this as a side impact, although some studies may have classified it as a frontal.

Fatals by Collision Configuration

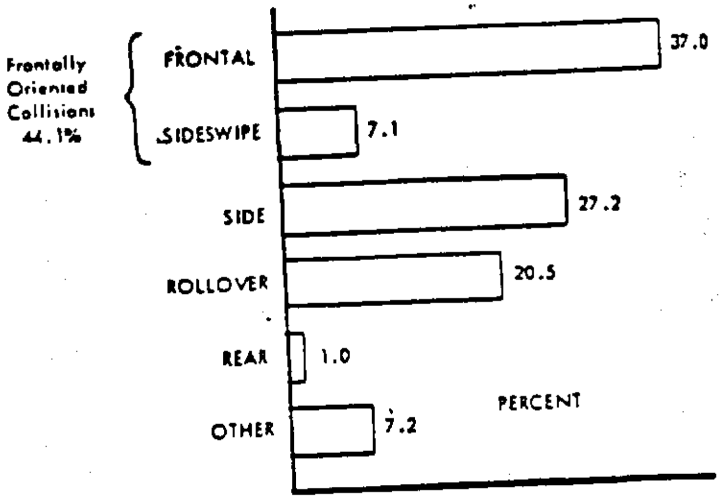

Figure 1

A second factor producing differences is that this study has two categories that involve frontal kinematics: frontals and sideswipes. These categories were separated because frontals were defined as involving major structural components of the car, whereas sideswipes were defined as involving only sheet metal parts, missing the frame and engine. This differentiation was made since these differences can significantly affect sensing times for the air cushion and passenger compartment intrusion.

A third factor was that this study contains exclusively 1967 through 1972 vehicles which possess safety features beyond those in the total car population used in other studies. Many of these improvements deal with frontal collisions and would tend to reduce the proportion of frontals in a newer-car fatal file. This study focused on newer cars to allow for more accurate extrapolation into the future.

Whether or not an accident becomes a fatal accident is greatly influenced by the objects the vehicle strikes and by the objects that the passengers strike. A breakdown of objects contacted by the automobile involved in this fatal case study is shown in Figure 2. It is interesting to note that 51% involve objects that are *not* on the roadway. This is also implied by the result that 52.4% of the fatal accidents involved only *one* motor vehicle.

Number of Vehicles Contacted by Case Vehicle in Fatal Accidents

	(Case Vehicle Only)					
umber of vehicles contacted	0	1	2	3	4	5+
umber of Fatals	370	288	38	9	1	0
ercent of 706 Cases	52.4	40.8	5.4	1.3	.1	0

Objects Contacted by Automobile Containing Fatality

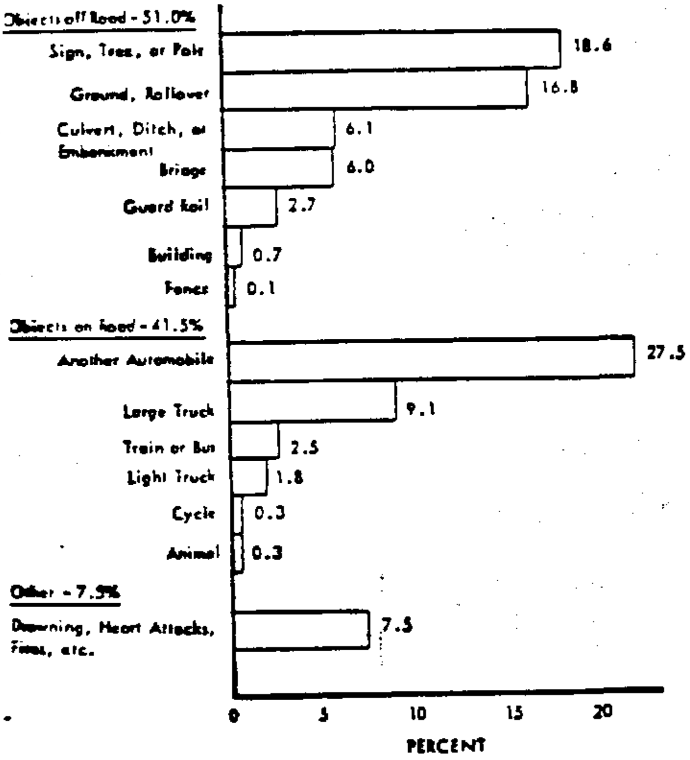

Figure 2

What the automobile strikes, along with the impact speed, determines the severity of the crash; and whatever the occupant strikes during the crash sequence influences the fate of the occupant. Figure 3 shows the objects which were involved with the occupants' fatal injuries by their frequency of occurrence.

Objects Involved with Occupants' Fatal Injuries

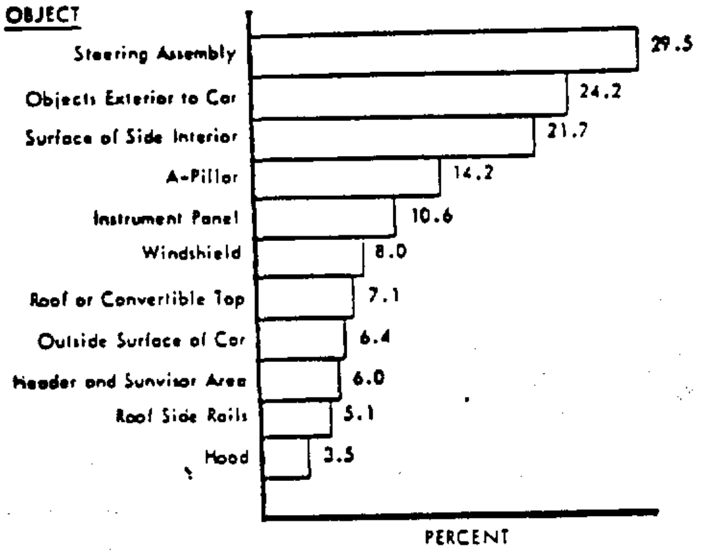

Figure 3

This distribution is influenced by the number of occupants using each seating position as shown in Figure 4.

Distribution of Fatalities by Occupant Seating Position

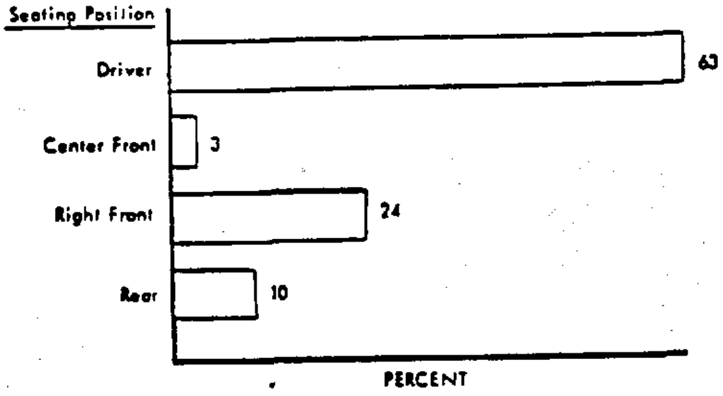

Figure 4

There were 74 fatalities actually using belt restraints in the 706 cases; three were lap and shoulder belted, and 70 were lap belted only. This represents 10.5% of the study. Figure 5 shows the distribution of actual belted fatalities by collision configuration.

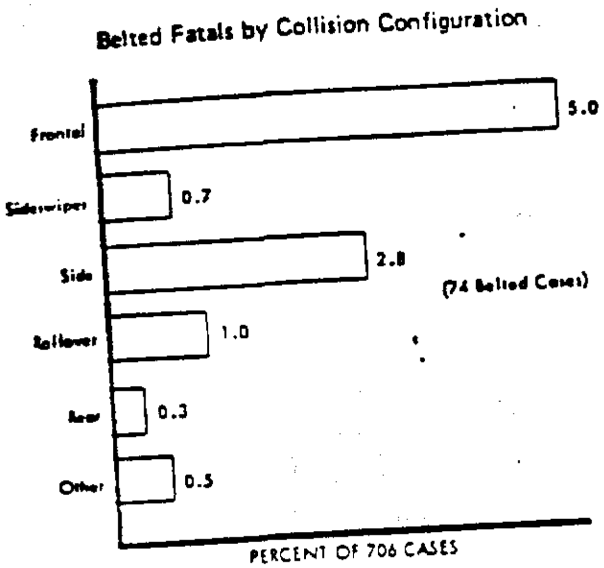

Figure 5

A distribution of actual belted fatalities by seating position is shown in Figure 6.

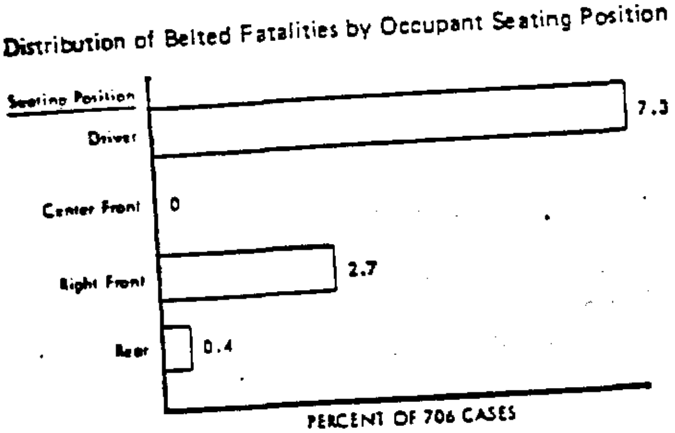

Figure 6

BELT RESTRAINTS – DEFINITIONS AND ASSUMPTIONS

To establish the fatal case profile accurately required careful study of each fatal accident, but to rate each restraint system's fatality reduction potential required more information than was supplied by the accident files alone. Realistic definitions and assumptions of restraint system performance were necessary to permit a meaningful and consistent analysis. Considerable effort went into summarizing available information on each restraint system and its performance. The following is a summary of the definitions and assumptions which were derived from this investigation and were used in this study.

The 1973 General Motors 3-point belt system was chosen to represent a typical belt restraint system. This system has a detachable shoulder belt and can be used as a lap belt only, or as a lap and shoulder belt combination. It provides performance typical of other belt designs currently being produced and can be considered as a representative belt system. No attempt was made to estimate the performance of possibly more advanced future belt systems.

To maintain continuity throughout the study, the belt system performance was carefully defined. The belt system was assumed to be worn properly unless the case being studied actually indicated improper usage. When improper usage was identified, the effects of this improper usage were considered in rating the restraint systems. This guideline was established to help reflect any possible belt-induced injuries.

Present belt systems are designed to remain intact over 5,000 lbs., which is in excess of expected belt loading. For this reason, the webbing and associated hardware were assumed to remain intact unless the case indicated that they would have been obviously damaged by the accident.

Although information is limited, searches of accident files do not indicate that belt rebound contributes significantly to occupant injury. Since accurate analysis of occupant rebound would have been very difficult, if not impossible, occupant rebound was assumed *not* to contribute to injury.

The vehicles in this study were all equipped with an energy-absorbing (EA) steering column of some type. To simplify analysis, they were all assumed to be equipped with a 1973 General Motors EA steering column, regardless of the vehicle's actual make or model year.

When a fatally injured occupant was actually wearing a seat belt system, *that* system was rated as being 0% effective for *that* single accident.

There is a lack of knowledge on small children wearing belt restraints. Because of this, and the fact that small children do have soft bone structures, it was assumed that belts worn by small children would not be as effective in mitigating injury as those worn by adults. As the severity of accidents increased, the child's save rate was sharply decreased. The exception to this assumption was in rollovers, where ejections could be prevented by the use of belts. Special child restraints were not evaluated in this study.

R CUSHION RESTRAINTS — FINITIONS AND ASSUMPTIONS

ining the air cushion system for this study proved to be icult. No rear seat air cushion system was developed at the e of this study, and there was no field experience on the posed front seat air cushion. As a result, the following mptions had to be based on a considered judgment of the mated performance of a front and rear seat air cushion tem.

e front seat air cushion was assumed to be composed of neral Motors proposed components which included: a third eration, step-load steering column; a Delco Electronics sh Sensing System with a 10 mph equivalent barrier impact e level sensor, and an 18 mph equivalent barrier impact high el sensor; a steering wheel air cushion with a metal and m knee restraint for the driver, and a separate air cushion the front seat passengers. The third generation step load lumn is a revision of the present energy-absorbing ball lumn used in GM vehicles. Included in the design is an EA ember and an improved column mounting. A companion er prepared by Oldsmobile explains details and significance hese revisions. The imaginary rear seat system was assumed provide performance comparable to a front seat air cushion.

e total air cushion system was assumed to meet FMVSS 208 jury criteria which included the requirements of meeting jury criteria in a 30 mph frontal barrier, angled up to 30° d in 20 mph side moving barrier tests. Frontal impacts at ngles that exceeded 30° from head-on were rated as follows:) 30° to 60° impacts with sufficient longitudinal acceleration deploy the air cushion were treated with sharply reduced ffectiveness; b) Impacts that exceeded 60° were generally onsidered not to have produced deployment. These assumptions were based on present sensor design and are supported y Hyge sled tests and full scale crash tests.

n frontal impacts of a 30 mph barrier equivalent severity or ess, survival was considered to be virtually certain unless there were extenuating circumstances. As the case severity exceeded 30 mph frontal barrier equivalent, the ratings were reduced until a 60 mph barrier impact severity was reached. In excess of a 60 mph equivalent barrier speed, survival was considered to be virtually impossible due to the lack of survival space as shown in Figure 7.

It should be stressed that there is a difference between field tential and barrier-dummy test performance as discussed in "Occupant Protection Research Needs," D. E. Martin, Manager, Automotive Safety Engineering.

Assumed Air Cushion Fatality Reduction Ratings in Frontal Impacts

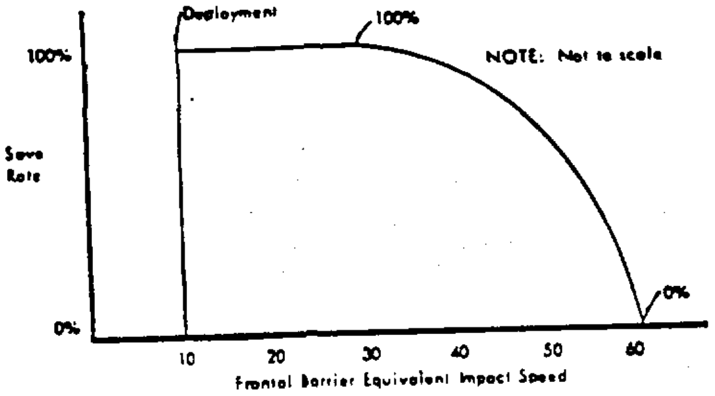

Figure 7

There is considerable air cushion test information available on the performance of three 50th percentile dummy occupants, and less performance knowledge on other sizes and combinations of occupants. But, for the sake of simplicity, the air cushion was assumed to provide equal protection for all sizes and combinations of normally-seated occupants.

The air cushion system was assumed to offer multiple impact protection, for though limited, the test data that does exist shows that the proposed air cushion system offers potential for multiple impact protection.

High reliability is essential in any air cushion system. Therefore, it was assumed that this air cushion system had no component defects and remained intact unless it would obviously be damaged by the impact. In other words, the air cushion was assumed to deploy, whenever the sensor threshold was reached. When the sensor threshold was *not* reached, the occupant's injury was assumed to remain unaltered unless he was also considered to be lap belted.

Hyge sled and full scale crash tests indicated that when the air cushion is deployed, it could prevent ejection through the windshield. This factor was included in air cushion assumptions on ejection prevention. The air cushion was generally assumed *not* to prevent ejections through side windows, doors, roofs, etc., since the present design is primarily a frontal impact protection device.

ACCIDENT CONSIDERATIONS

As discussed earlier, each passenger car fatality is a distinct and unique series of events. For instance, in any given accident, different people would have different likelihoods for survival simply because of their unique physical characteristics. Add this to all the other variables in a passenger car fatality and it arly shows why as many factors as possible were included in s restraint system effectiveness study. The following is a ting of some of the accident considerations that were plied:

1. Interior compartment intrusion – was there sufficient survival space at each case occupant's seating position?
2. Crash severity – very severe accidents (beyond 60 mph frontal barrier equivalent) were rated as having little chance for survival.
3. Age of occupant – for older occupants (65 years and older) the survival potential was lowered.
4. Health of occupant – including the effects of medication, alcohol, or drugs.
5. Occupant height and weight, and his likelihood of striking objects in the interior.
6. Effects of other occupants in vehicle on the occupant being evaluated.
7. Interior loose objects which struck the occupant.
8. After-market add-ons – These were assumed not to interfere with restraint system hardware or bag deployment. If they contributed to the injury, their effect was considered in evaluating restraint system performance.
9. Non-collision related causes of fatality – heart attacks, drownings, fire, etc.

TING METHOD

er applying the restraint system assumptions and accident siderations, the evaluation team arrived at a fatality-uction effectiveness rating for *each* restraint system when lied to *each* fatality, regardless of seated position. Because the many factors which influence occupant injury, simply ng the occupant as surviving or not surviving was not sufent. Rather, each fatality was given a probability of survival he been using each restraint system in turn. The range of babilities was defined as:

% – Essentially no chance for survival;

0%, 20%, 30% – Survival possible, but unlikely;

0%, 50%, 60% – Survival definitely possible;

70%, 80%, 90% – Survival very likely;

00% – Survival essentially certain.

verall process is shown schematically in Figure 8. Case er 1 was analyzed and the effectiveness estimates were tabulated for each restraint system in turn. For example, lap belt was rated 0%, lap and shoulder belt, 70%; air cushion, 90%; and air cushion with lap belt, 90%.

RATING METHOD

CASE NO.	LAP	LAP/SH.	AIR	AIR/LAP
1	0%	70%	90%	90%
2	10%	30%	0%	20%
–	–	–	–	–
–	–	–	–	–
706				

$$\text{POTENTIAL EFFECTIVENESS} = \frac{\text{SUM \%}}{706}$$

Figure 8

This is about the same as saying that if this identical accident with an identical occupant were to happen 10 times, there would still have been no survivals with a lap belt only, maybe 7 survivals with a lap and shoulder belt, 9 survivals with an air cushion, and 9 survivals with an air cushion plus lap belt. This process was repeated for Case Number 2, and so on, until the analysis was complete on all 706 occupants. The potential effectiveness of each restraint system was then calculated by summing the effectiveness percentages for all occupants and dividing by the total number of occupants.

EXAMPLE CASES

A list of all 706 fatal cases included in this study is provided in the appendix. Included in this list are a few of the many parameters which were recorded for each case. What this listing does not show is the inter-action of these parameters and how they jointly affected the analysis of each case. A brief discussion of some example cases can give a better idea of how the parameters were considered, and how the analysis was made.

The first case is a frontal collision involving a 1972 Chevrolet Impala (Figure 9). The vehicle was driven off the right side of the road and collided with the left rear of a car parked on the shoulder.

The estimated speed at impact was 70 mph, or equivalent to a 35 mph barrier impact. The driver was the only occupant, a 49-year-old, 5 ft. 11-inch tall, 165 lb. male. He was in good health and had no unusual physical or mental characteristics that should have adversely affected his chances for survival.

Th
be
he
wc
loa
lap
wa
me
90
ass
bel
hig
sur

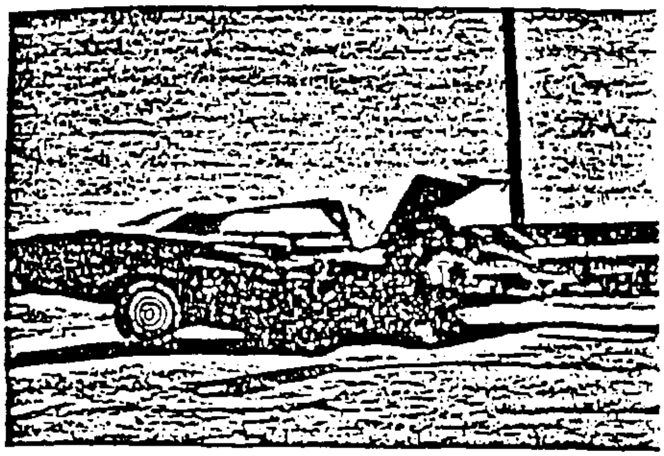

Figure 9

His fatal injury was a ruptured aorta resulting from a chest impact with the steering system, shown in Figure 10. The E/A column compression was 3.5 inches.

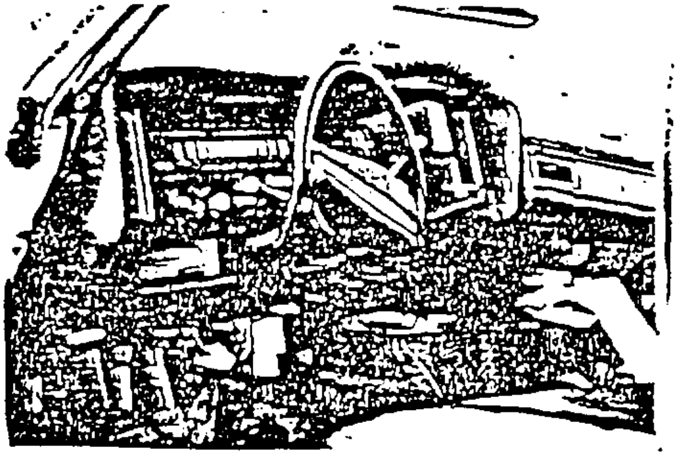

Figure 10

The driver had defeated the belt buzzer system and was not belted at the time of the collision. If he had been lap belted, *he would have loaded the column more* axially. This probably would have increased column collapse and reduced his chest loading. It was estimated that his chance for survival with the lap belt was better than 50-50, so a 60% chance for survival was given. With both the lap *and* a shoulder belt, the involvement with the column would have been greatly reduced. A 90% chance for survival was assigned. A 90% survival was also assigned to the air cushion only and to the air cushion with lap elt for the same reason as the lap and shoulder belt. The nigher severity of this case did not support a 100% chance of survival for the last three conditions.

The second example is a 1972 Oldsmobile Delta 88 shown in Figure 11 which was struck in the side by a pickup truck traveling at 35 mph. Impact was centered on the rear passenger compartment.

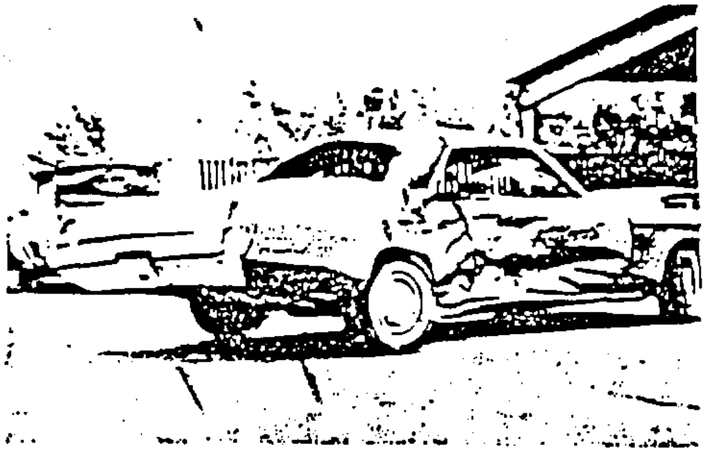

Figure 11

There were four occupants in this car. The right rear passenger, a 63-year-old female died from chest injuries. Her fatal injury resulted from chest impact with the stub B-pillar and/or side interior shown in Figure 12.

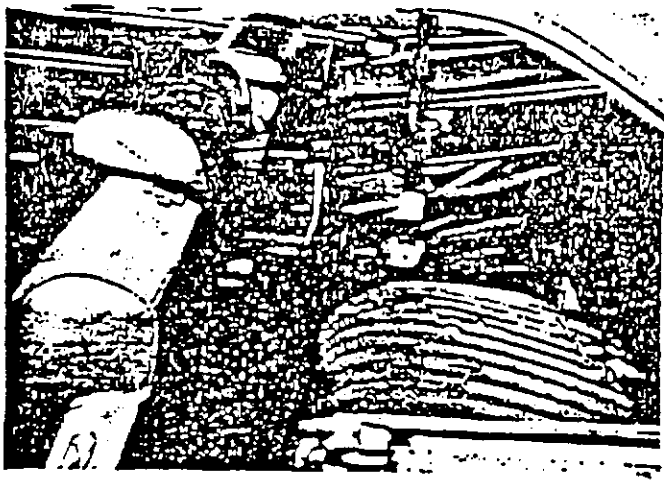

Figure 12

It is significant to note that a small child was sitting on the lap of the fatally injured woman. Furthermore, the child received *no* serious injuries, even though the child probably struck the same area of the car as was contacted by the fatality. This implies that the fatality was particularly susceptible to chest injury. A lap belt would *not* have prevented or reduced the oman's impact with the side interior so it was rated as being % effective. The lap and shoulder belt was rated at 20% since would only slightly reduce the severity of impact with the de interior, and survival would still be unlikely. The air ushion ratings were 0% since the sensors are not designed to re in this type of impact, and the addition of a belt would ot have helped.

he third case involved a 1972 Chevrolet station wagon shown Figure 13, which went off the road in a curve, and rolled ver in a field. The 51-year-old male driver and only occupant this vehicle was partially ejected through the left front indow opening and was crushed by the vehicle.

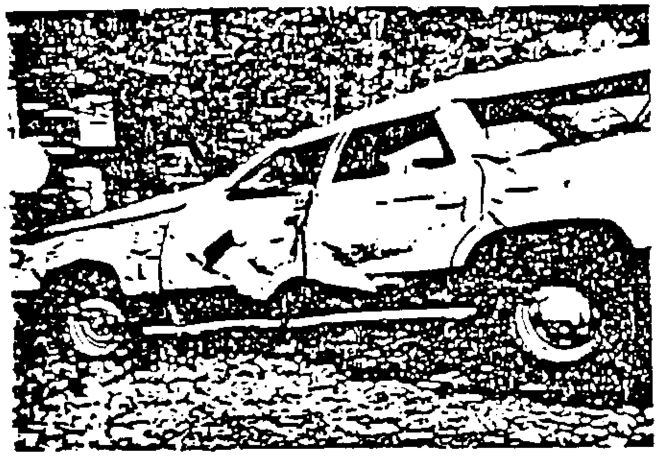

Figure 13

he indentation in the door was made by the occupant. If he ad been wearing a lap belt, this driver's chances of survival ould have been improved. A 40% effectiveness rating was signed for the lap belt because test experience has shown at partial ejection with a lap belt still can occur in rollovers. he lap belt and shoulder belt was assigned a 60% rating ecause it was felt that the added torso restraint would have educed ejection potential, but not necessarily have prevented . The air cushion alone was rated as 0% effective because urrent sensors do not fire on this type of rollover. The air ushion with lap belt was rated the same as the lap belt only. he ratings were affected by the fact that even if ejection were ly prevented, there is some chance that he could have fatally injured inside the car.

ll 706 cases underwent this sort of analysis, but in much ore detail. The whole spectrum of passenger car fatalities was eviewed and studied. This study confirmed something that we ave been suspicious of for some time. Forty-six percent of he 706 fatalities had no chance for survival with any of the restraint systems considered. These accidents are either very severe, or involve unusual circumstances such as heart attacks, drownings, fires, etc. They look like the ones shown in the next two figures.

Example Case No. 4, a 1972 Chevrolet, shown in Figure 14, ran under the rear of a slow-moving truck at a closing velocity of 65+ mph.

Figure 14

The fatally injured driver suffered massive head and chest injuries directly from the truck bed, and was given 0% chance for survival with any of the restraint systems considered.

Figure 15 shows a 1968 Camaro traveling at 60 mph, which skidded sideways into a tree. The right passenger suffered a crushed chest due to intrusion of the tree. He was wearing a lap and shoulder belt.

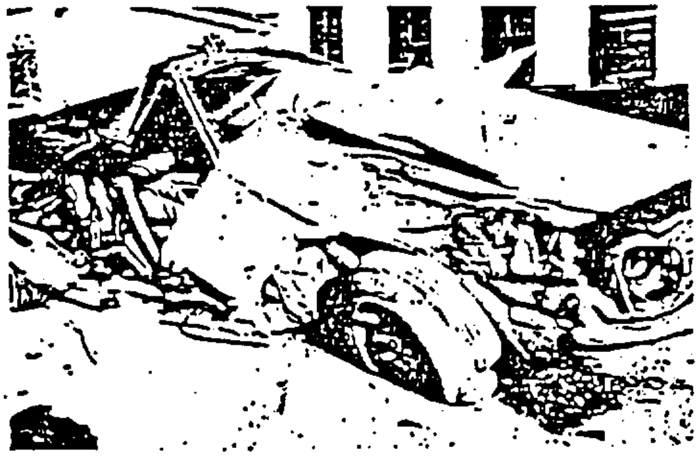

Figure 15

He also was rated 0% chance of survival for the restraint sys-

RESULTS AND CONCLUSIONS

The potential fatality reduction for each restraint system, *if it were used*, was as follows:

Restraint System	Potential Fatality Reduction (% of Lives Saved, Rounded off to Nearest Percent)
Lap Belt	17%
Lap and Shoulder Belt	31%
Air Cushion Only	18%
Air Cushion Plus Lap Belt	29%

If a person wears his lap belt, his potential for fatality reduction is 17%. If he wears his lap and shoulder belt, his potential for fatality reduction is 31%. If his car is equipped with an air cushion, his potential for fatality reduction is 18%. If his car is equipped with air cushions and he wears his lap belt, his potential for fatality reduction is 29%.

As these results were studied further, it was realized that for the restraint systems considered, fatality protection could be separated into three categories:

- Ejection Control — keeping the occupant inside the vehicle.
- Constraint — reducing the occupant's excursion within the vehicle's interior.
- Frontal Impact Protection — reducing the acceleration the occupant experiences during impact but not necessarily reducing occupant excursion.

The lap belt benefits primarily from the effect of ejection control and constraint, while the air cushion benefits result primarily from the effect of frontal impact protection. These effects produce about equal benefits for lap belts or air cushions. The lap and shoulder belts or the air cushion plus lap belts combine these effects to produce nearly double the benefits of either the lap belt or air cushion alone. These conclusions are supported by this effectiveness breakdown.

Potential Fatality Protection by Collision Configuration*

	Lap Belt Only	Lap and Shoulder Belt	Air Cushion Only	Air Cushion w/Lap Belt
Frontals	14%	37%	38%	40%
Sideswipes	9%	21%	10%	18%
Sides	12%	12%	3%	14%
Rollovers	36%	48%	9%	40%
Rear	14%	20%	0%	14%
Other	4%	6%	8%	9%

*Rounded off to nearest percent.

The lap belt alone does little to reduce the head and torso accelerations the occupant experiences during frontal impacts and is less than half as effective as the other systems.

Air Cushion with a lap belt	40%
Air Cushion only	38%
Lap and Shoulder Belt	37%
Lap Belt only	14%

In sideswipes, ejection control, constraint, and frontal impact protection are all important, so the restraint systems which offered all three did best.

Lap and shoulder belt	21%
Air Cushion with lap belt	18%
Air Cushion only	10%
Lap belt only	9%

In side impacts, constraint was most important. The air cushion offered little constraint, whereas the lap belt offered considerably more. Combining the two resulted in the best combination.

Air Cushion with a lap belt	14%
Lap and shoulder belt	12%
Lap belt only	12%
Air Cushion only	3%

The lap and shoulder belt did not perform better than the lap belt only in side impacts because the shoulder belt offers little in the way of lateral constraint.

In rollovers, ejection prevention was the most significant; therefore, any system using a lap belt performed better than the air cushion alone.

Lap and shoulder belt	48%
Air Cushion with lap belt	40%
Lap belt only	36%
Air Cushion only	9%

In rear impacts, constraint again proved to be the most important factor. By keeping the occupant in his designated seating position, head restraints could perform as designed. Due to the complexity of the rear impacts and the small sample size, the lap and shoulder belt was rated better than the lap belt alone.

Generalizations about the reasons for restraint performance in the "Other" category would not be proper because of the many unrelated types of fatalities in this category. It will suffice to say that air cushion restraints were slightly more effective in reducing fatalities in this category.

Air Cushion with lap belt	9%
Air Cushion only	8%
Lap and shoulder belt	6%
Lap belt only	4%

Figure 16 shows the percentage of air cushion deployments as a function of collision configuration.

Percent of Air Cushion Deployments

by Fatal Collision Configuration

KEY: Deployment as Percentage of Collision Configuration

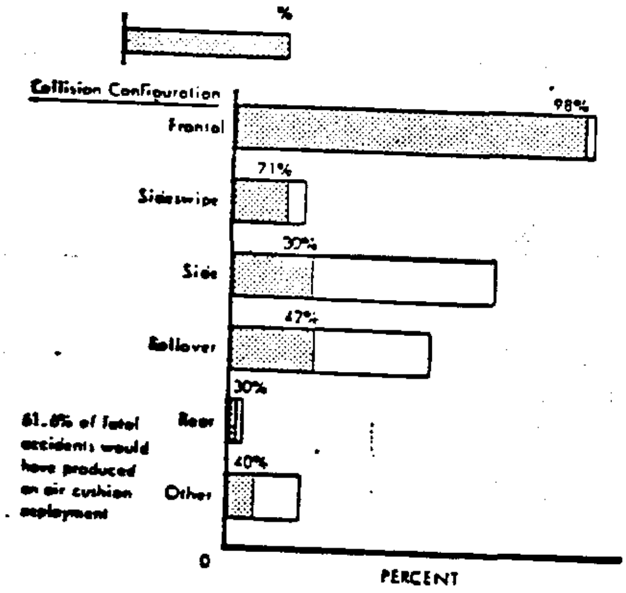

Figure 16

e restrain system effectiveness numbers assumed that each ally injured occupant in a designated seating position had h restraint system available. Figure 17 shows the net effecs for a variety of restraint system mixes.

Restraint System Combinations

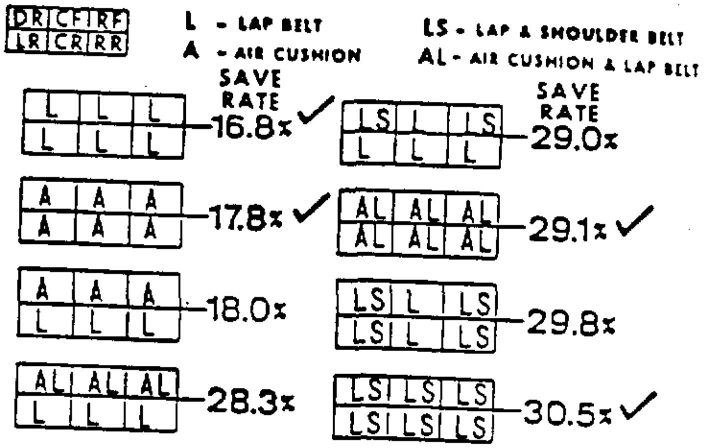

Figure 17

The differences in the save rates reflect both the judged effectiveness and seat position occupancy rate for the 706 fatality cases. A check is placed next to the numbers that were rounded off and shown above. These values do not reflect current belt or bag usage.

SUMMARY

Fatality reduction is important. Projecting this study to the real world, however, is a complex process influenced by factors such as current belt usage, the effect of belt usage incentives, air cushion introduction timetable effects, injury reduction, the possibility that various restraint systems can cause injuries, cost of the various systems, and dollar benefits of injury and fatality reduction. A subsequent paper has taken this fatal case study as a starting point to factor these and other issues into an overall, nationwide benefit comparison of various restraint system concepts.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to the following engineers for their time and effort in making this study possible:

Robert Krug	Project Engineer	Fisher Body Division
Dale A. Webber	Sr. Design Engineer	Fisher Body Division
Terry G. Wingblad	Project Engineer	Safety Research and Development Laboratory Environmental Activities Staff
Robert A. Sinke	Section Engineer	Safety Research and Development Laboratory Environmental Activities Staff

---

Richard A. Wilson

Richard A. Wilson is Engineer-in-Charge of the Safety Research and Development Laboratory at the General Motors Proving Ground, Milford, Michigan. He is responsible for all laboratory activities which include crash safety evaluation, damage and repair evaluation, field accident research, and crash test operations.

Mr. Wilson joined General Motors Proving Ground in 1955 after receiving a Bachelor of Science in Mechanical Engineering from Bucknell University.

In 1965, Mr. Wilson supervised instrumentation, data analysis, and impact dynamics work. He assumed the position of Staff Engineer for Impact Testing in 1968 when the department was designated as the Safety Research and Development Laboratory.

Mr. Wilson is a member of the Society of Automotive Engineers and has served as Chairman of the Passenger Compartment Energy Absorption Subcommittee. Presently, he is Chairman of SAE's Safety Test Instrumentation Subcommittee, and is a member of the Automotive Safety Committee and the Human Factors Engineering Committee. Mr. Wilson has authored numerous papers about safety and impact testing.

Carl M. Savage, Jr.

Carl M. Savage, Jr. graduated from the University of Toledo where he received the degree of Mechanical Engineering (B.S.M.E.) in 1968. He joined General Motors Safety Research and Development Laboratory in 1968 where he was involved with Fisher Body air cushion testing, Oldsmobile air cushion testing, air pillow design and development, Engineering Staff air bag development testing and lap and shoulder belt testing. Mr. Savage is currently project engineer with the Safety Research and Development Laboratory and active in the areas of the field trial program (1000 car air cushion accident investigation) and vehicle structural crashworthiness. He has authored papers involving air pillow concept development.

APPENDIX I

A List of the 706 Fatal Cases Including Ratings For Potential Fatality Protection

KEY

Restraint System Actually Used

None – No restraint used
Lap – Lap belt only
L/S – Lap and shoulder belt

Air Cushion Deployment

Hi – High Level Deployment
Lo – Low Level Deployment
None – No Deployment

Fatal Occupant Seating Position

DR – Driver
CF – Center Front
RF – Right Front
LR – Left Rear
CR – Center Rear
RR – Right Rear

System Considered

LB – Lap Belt
L/S – Lap and Shoulder Belt
AC/L – Air Cushion and Lap Belt
A/C – Air Cushion Only

AREAS OF CONTACT INVOLVING FATAL INJURIES TO HEAD AND TORSO

CODES FOR AREAS OF OCCUPANT CONTACT

Front of Passenger Compartment

(05) Instrument Panel
(09) Steering Assembly
(12) Windshield
(02) Glove Compartment Area
(03) Hardware Items (Ashtray, Instruments, Knobs, Etc.)
(01) Air Conditioning or Ventilation Outlets
(06) Mirrors
(07) Parking Brake
(08) Radio
(10) Sunvisors & Fittings, and/or Top Molding (Header)
(11) Transmission Selector Lever

Sides

(20) Surface of Side Interiors
(19) Hardware
(13) Armrests
(22) Window Glass
(21) Window Frames
(14) A-Pillar
(15) B-Pillar
(16) C-Pillar
(17) D-Pillar
(18) Courtesy Lights

Interior

(29) Back of Seats
(33) Restraint System Hardware
(34) Restraint System Webbing
(30) Head Restraints
(32) Other Occupants
(31) Interior Loose Object

Roof

(16) Roof Side Rails
(10) Sunvisors & Fittings and/or, Top Molding (Header)
(25) Roof or Convertible Top
(24) Coat Hooks

Floor

(11) Transmission Selector Lever
(40) Floor
(28) Foot Controls
(27) Console

Rear

(23) Backlight (Rear Window)
(39) Backlight Header

Exterior to Passenger Compartment

(35) Hood
(36) Objects Exterior to Car
(37) Outside Surface of the Car

(38) Other:
(May indicate more than one item)

(00) Unknown.

FILE NAME: 1967 MIC

Case No.	Fatal Collision Configuration (Multiple Impacts (*))	Restraint System Used	Fatal Occup. Stg. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (1)			
				Head	Torso				LB	L/S	AC/L	AC
E-396	Rollover, Hi speed down embankment	None	DR	00	00	Yes	None		0	0	0	0
"	"	"	CR	00	00	No	"		0	0	0	0
"	"	"	RF	00	00	"	"		0	0	0	0
564	Right front to bridge abutment. 70% overlap	"	DR	00	00	"	Hi		0	10	30	20
560	Frontal to truck	"	"	00		"	"		10	20	40	40
495	Frontal to pole & tree	"	"	10		"	"		20	40	60	50
406	SS median curb & light pole	"	"	36		Yes	None		70	90	70	0
324	Hit @ 10:00 front left door	"	"	00	00	"	Hi		0	0	0	0
"	"	Lap	RF	00	00	"	"		0	0	0	0

FILE NAME: HIC '68

Case No.	Fatal Collision Configuration (Multiple Impacts (*))	Restraint System Used	Fatal Occup. Stg. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Potential Fatality Reduction Rating(%)			
				Head	Torso				LB	L/S	AC/L	AC
A-139	Intersection--lf.frnt. impact to car	None	DR		9	No	Hi	Possible rear pass to A-pillar contact. Possible heart attack prior to impact	90	100	100	100
611	Frontal to ditch	"	LR	14		"	"	"	100	100	100	100
615	Head on, car-to-car*	"	DR			"	"	"	50	90	100	90
628	Left offset, head on, car-to-car	"	DR	14		"	"		0	0	0	0
823	Head on to side of parked truck	"	DR			"	"		0	0	0	0
863	Car to rear of car	"	RF		5,3	"	"		80	90	100	100
1470	Car to side of car	"	RF	36	20,36	"	None		0	0	0	0
2004	Head on, car-to-car *	"	DR			"	Lo	Probable heart attack prior to impact	0	0	0	0
2072	Car to rear of parked truck	"	DR	12,36	5	"	Hi	14-year-old driver	0	0	0	0
"	" " " " " "	"	RF	12,36	5	"	"		0	0	0	0
2170	Car airborne to tree (Left Front)	"	DR	00		Yes	"		0	20	20	10
"	" " " " "	"	LR	00		Yes	"		20	50	50	50
"	" " " " "	"	RF	00		No	"		0	30	30	30
"	" " " " "	"	CR	00		Yes	"		20	50	50	50
2365	Head on to bridge abutment	"	DR			No	"		0	0	0	0
"		"	RF			"	"		0	0	0	0
2410	Left front to right side of car	"	DR			"	"		20	40	50	40
"	" " " " " "		RF			"	"		50	80	80	70
2543	Left side roll	"	DR	36		Yes	None		90	90	90	0

FILE NAME: HIC '68

Case No.	Fatal Collision Configuration (Multiple Impacts [*])	Restraint System Used	Fatal Occup. Sgt. Pos.	Areas of Contact Involving Fatal Injuries: Head	Areas of Contact Involving Fatal Injuries: Torso	Ejection	Air Cushion Deployment	Comments	Potential Fatality Reduction Rating (%): LB	L/S	AC/L	AC
A-2667	Rollover	None	DR			No	None		0	0	0	0
2669	Right sideswipe to bridge	"	RF	36		"	Hi		0	0	0	0
2702	Right sideswipe to guard-rail	Lap	RF		34	"	None		0	0	0	0
2878	Multiple rolls *	None	DR	30		Yes	Lo		80	90	80	40
"	" " *	"	RF	36		"	"		0	60	0	0
2880	Right side roll *	"	RF	5,25		No	Hi	Head pinned between IP & roof	0	60	0	0
2931	Left offset, head-on, car-to-car	Lap	DR		00	"	"		0	40	50	50
2933	Multiple right side roll *	None	DR	00		Yes	None		50	60	50	0
"	" " " " *	"	CF		00	"	"		60	70	60	0
2954	Left offset frontal	"	DR		9	No	Hi		60	70	80	80
2970	Left 75% offset frontal	"	DR			"	"		0	0	0	0
"	" " " "	"	CF			"	"		0	50	10	10
"	" " " "	"	LR			"	"		0	0	0	0
"	" " " "	"	CR			"	"		0	60	20	20
"	" " " "	"	RR			"	"		0	NA	NA	NA
HIC '69												
B3014	Left side-car @ door to tree	None	DR	99	99	No	None		0	0	0	0
2698	Left side-car to embankment	Lap	"			"	"	Driver died from old age complications after accident. Thought to have had heart attack prior to impact	0	0	0	0

FILE NAME: HIC'69

Case No.	Fatal Collision Configuration (Multiple Impacts [*])	Restraint System Used	Fatal Occup. Seg. Pos.	Areas of Contact Involving Fatal Injuries: Head	Areas of Contact Involving Fatal Injuries: Torso	Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (%): LB	Restraint Effectiveness Rating (%): L/S	Restraint Effectiveness Rating (%): AC/L	Restraint Effectiveness Rating (%): AC
3044	25% offset to right *	None	DR			No	Hi		0	0	0	0
0017	Car to rock embankment	"	"	00	00,9	"	"	Fire	0	0	0	0
0093	75% left head-on car to car	None	DR		9,5	"	"		0	30	30	20
0176	SS car to trunk *	"	DR	00		"	"		0	0	0	0
0357	Rt. front corner to bridge	Lap	"		00	"	Lo	Driver's back & spine broken	0	30	20	40
0434		None	RF	00		"	None	Probably murdered	0	0	0	0
0443	Rt. side impact *	"	"	32,37	32	"	"	Possible heart attack	0	10	0	0
0554	Ground Rollover *	"	DR		9	Yes	"		40	50	40	0
2454	Hit in RF by car	"	CF	38		No	Hi		0	20	10	10
0573	Struck in right rear	"	RF	12,5,25		"	"		30	40	40	10
2959	Lf. side off road rollover	"	DR	25		Yes	Lo		50	70	50	0
0821	Frontal to Pole *	"	"		20	no	None		0	20	0	0
0832	Rt. side car to pole	"	RF	00		No	None		0	10	0	0
0838	Lf. side off-road rollover	"	DR	20,38		Yes	"		60	90	80	0
1274	Stuck LF by truck *			26,36		No	"		0	0	0	0
1344	Rt. side rollover *	Lap	"	22,38	9	"	Hi		0	70	50	40
1356	Rt. side car mid to pole											
1367	Lf. car to guard rail *	Lap	DR	00		Yes	None		0	0	0	0
1500	Lf. car to bridge support	None	"	12,5		No	Hi		10	30	30	20
1929	Lf. car to guard rail	"	"	9		"	"		0	0	0	0

FILE NAME: HIC'69

Case No.	Fatal Collision Configuration (Multiple Impacts (*))	Restraint System Used	Fatal Occup. Seg. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (%)			
				Head	Torso				LB	L/S	AC/L	AC
2037	Rt. Frnt. car to bridge support	None	DR	9	9	No	Hi		40	80	80	60
2085	LT. side door area to parked car	"	"		20	Yes	None		20	40	20	0
2161	Hit in rt. side by car *	"	RF	38	20	No	"		0	0	0	0
2220	Center Front car to bridge abutment	"	DR		9	"	Hi		0	20	30	30
3057	Rt. side sliding car to dirt embankment	"	"	14		"	None		90	100	90	0
1171	Spun and hit pole	"	"	00		"	"	Fire	70	90	70	0
1545	Hit lf. side by 1/2 ton	"	"		20	"	"		0	0	0	0
2064	Rt. side to guard rail & Post	"	RF	00	00	Yes	Hi		0	0	0	0
2695	Frontal to embankment	"	DR	9	9	No	"	Severe vertical component	0	0	0	0
2698	LT. side hit wall of ditch	Lap	RF			"	None	Death probably caused by old age	0	0	0	0
3052	1/4 roll to lt. side *	None	DR			"	"		0	0	0	0
HIC '70												
C-0198	Offroad rollover	Lap	RF	25,26	25,26	No	None		0	0	0	0
0290	Offroad to concrete culvert	None	DR	00,14	00	Yes	Hi		0	0	0	0
0632	12:30 frontal into overturned truck	"	"	00	00	No	Hi		0	30	30	20

FILE NAME: MIC'70

Case No.	Fatal Collision Configuration (Multiple Impacts (*))	Restraint System Used	Fatal Occup. Seg. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (%)			
				Head	Torso				LB	L/S	AC/L	AC
0632	12:30 frontal into overturned truck	None	RF	00	00	No	Hi		0	20	30	20
3194	Car went in water, front first	"	DR			No	None	Panic caused drowning	0	0	0	0
3273	Rollover *	"	LR		36	Yes	Hi		70	90	70	20
3465	Hit depressed median	Lap	DR	00		No	Lo		0	0	0	0
3615	Head-on into gas pipe	None	DR	38	38	No	Hi	Explosion	0	0	0	0
3692	Offroad frontal into tree	"	"		9	No	Hi		40	60	80	80
4058	Side impact	N/A	RR	00		Yes	None		0	0	0	0
3857	Side impact into Rt. Front	None	LR			No	"		100	100	100	0
4302	Down bank into lake	"	DR		00	"	"	Drowned	0	0	0	0
		"	RF		00	•	"	Drowned	0	0	0	0
4373	Frontal into oncoming car	Lap	RF	5		No	Hi		0	60	80	80
4463	Sideswiped by truck	None	DR		00	"	"		0	0	0	0
4499	Rollover *	"	"	00	00	Yes	"		10	40	80	60
4575	End over end roll	"	DR	00		"	Lo		0	0	0	0
4933	Offroad frontal into pole	"	DR	00,25	00	No	Hi		10	40	50	50
4945	Rear impact	"	RR	00	00	"	None		10	10	10	0
4980	Hit tree, front Lt.Ctr.	"	DR	00	09,05	"	Hi		0	20	40	40
5059	Very minor guardrail SS	"	DR		00	No	None	Fatality unrelated to accident—heart attack after accident	0	0	0	0
5191	Hit in lt.side by car	"	DR		00	No	None		0	0	0	0
"		"	RR		00	"	"		10	20	10	0

FILE NAME: HIC'70

Case No.	Fatal Collision Configuration (Multiple Impacts [*])	Restraint System Used	Fatal Occup. Stg. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (%)			
				Head	Torso				LB	L/S	AC/L	AC
5201	50% offset frontal to left	Lap	DR	00	00	No	Hi		0	0	0	0
5223		None	DR	9		No	Lo		0	90	100	100
3021	Frontal car to back of moving semi truck	None	DR		9	"	Hi		20	20	20	20
3069	Side--car to side of moving car	"	"		20,14,9	"	None		0	0	0	0
3409	Rollover into ditch	"	"	37		Yes	"		70	70	70	70
3073	Frontal car to culvert	"	"	9	9,20	No	Hi		2	9	9	9
3212	Car to offset truck,head-on	"	"	14	9,5	"	"		0	0	0	0
3238	Rear car to bridge support	"	"	38,30		"	None		0	0	0	0
3258	Side Slide into oncoming car	"	RF	5,12	20,12,5	"	"		0	0	0	0
3268	Head-on	"	DR		12	"	Hi		0	0	0	0
3322	Head-on	"	"	12,32	9	"	Hi		0	0	0	0
3358	Side to tree *	"	"	0	0	"	"		0	0	0	0
3363	End over end roll *	"	"	0	0	Yes	Lo		70	90	70	20
3070	Head on	"	"		9	No	Hi		0	0	0	0
			RF	0	0	"	"		0	0	0	0
3431	Frontal, Car to pole	"	DR		9	"	"		30	70	70	70
3531	Head on bus	"	"	12	9	"	Hi		70	100	100	100
3657	Side impact *	"	"	0		Yes	"	Fire	0	20	30	20
3685	Car to pole sideswipe *	"	"	12,14		"	"		20	40	50	40

FILE NAME: MIC '70

Case No.	Fatal Collis. Configuration (Multiple Impacts [*])	Restraint System Used	Fatal Occup. St. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (%)			
				Head	Torso				LB	L/S	AC/L	AC
3731	Rt. front to tree	None	RF	0		No	Hi		0	0	0	0
3771	Lft. side rollover	"	DR	00		Yes	None		60	80	60	0
3903	Rt. side rollover	"	"	14		"	Lo		60	80	60	20
4010	Head on to truck	"	"	0	0	"	Hi		0	0	0	0
			CF	0	0	"	"		0	0	0	0
			RF	0	0	"	"		0	0	0	0
4031	Rollover to other car *	"	DR			No	None		0	0	0	0
4063	10° Rt. angle, 50% offset to DR side	"	"	12	9	"	Hi		20	90	90	90
4151	Frontal car to side of horse	"	DR	9,14		No	Lo		0	0	0	0
4216	Side of car to tree	"	"	25	14,20	"	None		70	70	70	0
4270	Rt. corner to tree	"	RF	0	0	"	Hi		0	50	50	30
4282	Rollover into creek *	"	DR			"	Lo	Drowning	0	0	0	0
		"	RF			"	"		0	0	0	0
4317	Head-on car to car	"	DR	0	0	"	Hi		0	0	0	0
4335	Rollover into ditch	"	DR		00	Yes	None		70	80	70	0
4348	Rt. front side swipe by car	"	"	26		No	Lo		20	60	40	30
4537	Rt. side to side of truck *	"	RF		00	Yes	None		100	100	100	0
4642	Lf. Frt. offset to guardrail	"	DR	00	00	"	Hi		0	0	0	0
4673	Head-on car to car	"	"		9	No	"		30	80	90	90
4693	End over end roll *	"	"	0	0	Yes	Hi		60	80	80	50

FILE NAME: MIC '70

Case No.	Fatal Collision Configuration (Multiple Impacts (A))	Restraint System Used	Fatal Occup. Seg. Pos.	Areas of Contact Involving Fatal Injuries		Ejection	Air Cushion Deployment	Comments	Restraint Effectiveness Rating (%)			
				Head	Torso				LB	L/S	AC/L	AC
4716	Moving car side impact	None	DR	36		No	None		0	20	0	0
4752	Sideswipe -- Driver side	"	"	20		"	Hi		0	30	30	10
4785	Rt. side impact -- Large truck	"	"	20		"	None		30	60	30	0
4794	Side car to side of moving car	"	"	20,36	36	Yes	"		0	0-	0	0
4868	Frontal car to bridge	"	"		9	No	Hi		10	20	30	20
4872	Frontal car to 30° LF offset--ltruck	"	"	00		"	"		0	0	0	0
5041	End roll *	None	RF	36	36	Yes	"	Driver had lap belt on	60	90	80	60
4611	LF side sliding car to oncoming truck	Lap	DR	9		No	"	Fire	0	0	0	0
		"	LR	38	38	"	"		0	0	0	0
5050	Head-on 10% offset to DR side	None	DR		9	"	"		0	0	0	0
5053	Rollover	"	"	37		Yes	None		80	90	80	0
5088	Rollover	"	"	00	00	"	Hi		20	40	30	20
			RF	00		"	Hi		20	30	40	40
5239	Rollover *	"	DR			No	"		20	80	60	0
5121	Head-on 10% offset to DR side	"	"	9		"	"		0	60	60	60
5133	Side slide into tree	"	"	20,25		"	None		0	0	0	0
			CF	12	32	"	"		20	30	20	0
			LR	00	00	"	"		40	60	40	10
5211	Car to ditch to culvert	"	CF			"	Hi		0	50	80	80