Side Impact Collisions with Roadside Obstacles

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Side impacts with fixed roadside objects appear to cost society more than $3 billion each year. Reducing the severity of this type of accident would clearly have a beneficial economic effect. Presented in this paper are the results of an investigation of the 1980–1985 Fatal Accident Reporting System and the 1982–1985 National Accident Sampling System data bases. These data bases are used to extract a variety of characteristics of side-impact accidents with fixed roadside objects. Most side impacts with roadside objects involve tall, narrow objects such as trees, utility poles, and luminaires. Young drivers account for the majority of side-impact accidents with roadside objects and such accidents typically occur late at night or early in the morning. These fixed-object collisions have characteristics that differ from those of vehicle-to-vehicle, side-impact collisions. Development of effective counter-measures for side-impact collisions with fixed objects requires an appreciation of their unique characteristics.

Every year approximately 225,000 people are involved in side-impact collisions with fixed roadside objects. One in 3 is injured and 1 in 100 is killed. This level of injury represents a societal loss of more than $3 billion, as shown in Table 1. (All quantities in figures and tables throughout this paper represent yearly averages.) These figures are based on the 1986 accident costs recommended by the Federal Highway Administration (FHWA) for cost-effectiveness analyses (*1*), so they are probably conservative. As shown in Table 2, approximately 910,000 vehicle occupants are involved in side-impact collisions with fixed objects each year, and almost 9,000 are fatally injured. Collisions with the sides of vehicles account for one quarter of the cases in both the National Accident Sampling System (NASS) and Fatal Accident Reporting System (FARS) data bases.

The 1980–1985 FARS data set was used to study fatal collisions. It is comprehensive in that it contains information about virtually every police-reported motor vehicle fatality in the United States. The weakness of the FARS data set is that it is based on police accident reports that vary in quality from report to report, officer to officer, and region to region. The amount of detailed information available in the FARS is also limited. For example, the first and most harmful events are coded but there is no information on the sequence of events. Side impacts in the FARS data were found using the impact location variable. This variable is coded as a clock direction, with 12 o'clock being the front center of the vehicle. Impacts that occurred primarily between the clock directions 2 and 4 or 8 and 10 were included in this study.

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To investigate injury severity and occupant involvement in side-impact collisions, the 1982–1985 NASS data were used. The NASS coding and sampling techniques have varied from year to year, but were thought to be most stable in the 4 years chosen. As with the FARS, the quality of the data depends on the skill of the data collector and other factors discussed later in this paper. Side impacts were identified using a variable that identifies the location of the most severe impact. When this variable was coded left or right side, that accident was included in the study.

The NASS data set is a sample of all accidents in the United States in a given year. The sampling method involves several steps. First, the entire United States is divided into geographical units. No more than 50 of the more than 1,000 geographical units are chosen for use in the NASS data to represent the accident population in all of the geographical units in a year. The units from which a sample is taken are called primary sampling units (PSUs). The selection of these PSUs is based on characteristics such as geography, urbanization, per capita gas station sales, and per capita road miles. The actual sample, then, was built using less than 5 percent of the possible geographic units. Within each PSU, all of the police agencies were categorized by the type and number of accidents reported to the police. A small number of police agencies were then selected randomly within each category. The accidents that were finally investigated were a small subset of all police-reported accidents within those police agencies. These accidents are not chosen at random because the large number of property-damage-only accidents would limit the number of more interesting injury accidents that could be investigated. The accidents included in the NASS data therefore contain an overrepresentation of injury accidents. To eliminate this bias toward injury accidents, an inflation factor is used so that when the sampled number of each accident type is multiplied by this factor, it will represent the total number of that type of accident occurring within that PSU. In order to obtain national estimates, the PSU estimates are then multiplied by an expansion factor based on the 1977 population of that PSU. All of the NASS data shown in this paper use these national estimates of accidents because they eliminate the bias toward severe injury accidents.

As with any statistical sample, the confidence that can be placed in a particular estimate is a function of the size of the sample in relation to the population. When sample sizes are very small, as is the case with the NASS data, the analyst should realize that the true value may be quite different from the value obtained using the sample. The standard error is a statistical parameter that measures the possible variability of the data. Large standard errors will result in wider confidence intervals.

TABLE 1 ESTIMATED YEARLY SOCIETAL COSTS OF SIDE-IMPACT, FIXED-OBJECT ACCIDENTS (1986 dollars)

Accident Severity	Single-Passenger-Vehicle Side-Impact Fixed-Object Accidents		
	Cost per Person($)	Number of Accidents	Societal Cost (x $1,000,000)
Property Damage Only	2,000	106,716	213.4
Injury	11,000	59,996	660
Fatality	1,500,000	1,647	2,470.5
Total		168,359	3,343.9

TABLE 2 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS IN FIXED-OBJECT COLLISIONS BY LOCATION OF IMPACT

Impact Location	1980-85 FARS		1982-85 NASS	
	Frequency	Percent	Frequency	Percent
Front	5,701	65	602,650	66
Side	2,241	25	226,470	25
Rear	168	2	27,135	3
Other	685	8	57,925	6
Total	8,795	100	914,180	100

Estimates of the standard errors are provided in National Highway Traffic Safety Administration's (NHTSA's) yearly NASS summary reports (*2*). These references provide the standard errors of estimates and percentages for the NASS data based on sampling variability. The standard errors of percentages are based on the national estimates of the number of accidents in the subgroup being studied. The standard errors of percentages for side-impact, fixed-object accidents were computed based on a national estimate of 673,436 (168,359 × 4 years) accidents of this type. The 95 percent confidence intervals for percentages are shown in the last column of Table 3. These intervals are quite large. When a smaller subset of accidents, such as passenger compartment collisions, is chosen, the standard errors become even larger. For this reason, no other tables include this confidence interval for percentages. The reader should recognize that the values shown in all the tables are, to a certain degree, speculative in that they are based on extrapolations of very small sample counts. On the other hand, the most probable value to be sampled is the mean, so the data shown represents the best available estimate of the fixed-object, side-impact problem.

Despite the large standard errors associated with small subgroups of the NASS data, this data set was used because of the lack of alternatives. The FARS data base is useful for studying fatal collisions, but does not provide the detailed information needed for this study. There is little to be learned from the FARS data beyond the information shown in Table 3. The NASS data provide the best available evidence for examining the total range of severity of accidents and for studying accident characteristics in depth, although it cannot be used with the same degree of statistical confidence as the FARS data. There were three choices open to the authors in performing this study:

1. Completely ignore the NASS data,
2. Use the biased, uninflated counts, or
3. Use the unbiased, inflated estimates.

The first alternative was rejected because nothing is gained by completely ignoring the data. The second alternative was also rejected because uninflated counts (i.e., not using the national estimates) would be seriously biased toward severe accidents and would not take advantage of any of the techniques employed by NHTSA to minimize sampling error and bias. The second alternative would have resulted in an interesting anecdotal set of data that could not be used to hypothesize about the national side-impact problem. The third alternative was chosen because it represents the best available estimate of the side-impact problem.

The number of cases excluded from the FARS and NASS data in assembling the study sample are shown in Table 4. After excluding accidents in which rollover was the most harmful event, the initial sample consisted of 914,180 occupants involved in fixed-object collisions, and 8,795 fatal fixed-object collisions. The occupants in nonside, multiple-vehicle, and nonpassenger car collisions were then eliminated. The final study sample consisted of occupants in single-passenger-car, side-impact collisions with fixed roadside objects.

THE FIXED OBJECT

Listed in Table 3 are the number of occupants involved in (i.e., the NASS data) and the number of occupants fatally injured in (i.e., the FARS data) side-impact collisions along with the types of objects that were most often struck. Occupants were most likely to be involved in collisions with narrow objects. There were three times as many occupants in collisions with narrow objects as there were with broad objects. Occupants who were exposed to fixed-object collisions hit narrow objects nearly 59 percent, broad objects 18 percent, and other objects 23 percent of the time. Trees and utility poles were the objects most often struck, accounting for nearly 50 percent of the occupant involvements in these collisions. Guardrails were hit in 10 percent of the accidents.

Not only were occupants exposed to more narrow-object collisions, they were fatally injured in narrow-object collisions more often than in collisions with broad or other objects. Eighty percent of the fatalities involved impacts with narrow objects, although only 60 percent of the occupant involvements were with narrow objects. In the cases of trees and poles, there are enough accident cases to show that the differences between the NASS and FARS data are statistically significant. For narrow objects as a class, the difference between the FARS and NASS data is also statistically significant. Although between 52 and 66 percent of all side-impact collisions involve narrow objects, 80 percent of the fatalities involve narrow objects. Narrow objects, then, seem to be especially hazardous objects to strike in side-impact collisions.

TABLE 3 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY MOST HARMFUL OBJECTS

Object Struck	1980-85 FARS Frequency	1980-85 FARS Percent	1982-85 NASS Frequency	1982-85 NASS Percent	1982-85 NASS 95% Confidence Range of Percent
NARROW					
Tree	785	48	41,517	25	19-31
Utility Pole	434	26	35,996	22	18-28
Light Support	45	3	5,519	3	1-5
Other Post/Pole	39	2	7,405	4	1-7
Sign Support	11	1	6,958	4	1-7
Mail Box	—[1]	—[1]	2,189	1	0-2
Delineator Post	—[1]	—[1]	413	0	0-1
SUBTOTAL	1314	80	99,997	59	52-66
BROAD					
Guardrail	70	4	15,996	9	4-14
Bridge Pier/Abutment	44	3	1,796	1	0-2
Bridge Parapet	24	1	414	0	0-1
Wall	18	1	2,288	1	0-2
Fence	15	1	4,572	3	1-5
Bridge Rail	11	1	1,921	1	0-2
Concrete Barrier	4	0	1,287	1	0-2
Impact Attenuator	1	0	239	0	0-1
Other Long. Barrier	2	0	1,851	1	0-2
SUBTOTAL	189	11	30,364	18	12-24
OTHER					
Culvert	30	2	970	1	0-2
Other Fixed Object	30	2	6,784	4	1-7
Building	25	2	1,063	1	0-2
Embankment, Unknown	21	1	—[1]	—[1]	—[1]
Embankment, Earth	13	1	6,608	4	1-5
Ditch	15	1	10,042	6	2-10
Embankment, Rock	6	0	1,480	1	0-2
Curb	2	0	11,051	7	3-11
Fire Hydrant	1	0	—[1]	—[1]	—[1]
Shrubbery	1	0	—[1]	—[1]	—[1]
SUBTOTAL	144	9	37,998	24	18-30
TOTALS	1,647	100	168,359	100	—[2]

[1]The object is not in the data set.
[2]Not Applicable.

TABLE 4 CREATING THE STUDY SAMPLE: YEARLY AVERAGES OF OCCUPANTS

Type of Collision	1980-85 FARS	1982-85 NASS
Fixed Object	8,795	914,180
Side Impact, Fixed Object	2,241	226,470
Single Vehicle, Side, Fixed	2,096	212,753
Passenger Vehicle, Single, Side, Fixed	1,647	168,359

Occupants were killed in 1 out of 75 (0.013) of the narrow-object collisions and in 1 out of 160 (0.006) of the broad-object collisions. Narrow-object collisions appear to be twice as likely to result in fatalities as do broad-object collisions. Even these results may understate the harmfulness of narrow-object side impacts because the two most harmful broad objects—guardrails and bridge piers or abutments—would be considered narrow object collisions if they were struck on the end.

Trees were the most numerous harmful objects. They were the objects struck in between 19 and 31 percent of the occupant involvements, but were responsible for 48 percent of the fatalities. Trees are especially dangerous because they are narrow, rigid, and tall. (A tall object in this context simply means one that is capable of striking an occupant's head in a nonrollover side-impact collision.) When the point of impact with the fixed object is adjacent to a vehicle occupant, these three characteristics combine to result in a dangerous accident scenario: during a collision a rigid object does not break, so a tall, rigid object such as a tree or utility pole may come into direct contact with the occupant's head and thorax.

Accidents involving guardrails accounted for 4 percent of fatal fixed-object, side-impact accidents, as shown in Table 3. They appeared to be the third leading cause of fixed-object, side-impact fatalities. The NASS data on guardrail collisions is divided into two categories involving midsections and three categories involving ends and transitions, as shown in Table 5. Guardrail ends are defined in the NASS coding manual (*3*) as sections within 25 ft of the upstream guardrail end—the end upstream from the direction of vehicle travel regardless of which side of the road the guardrail is located.

Codes found in police reports for measuring accident severity in the NASS data are shown in Table 5. All guardrail collisions were considered broad objects in Table 3, when in fact ends and possibly bridge transitions may have been narrow objects. It can be seen from Table 5 that there were more than 14,000 occupant involvements with midsections and fewer than 2,000 with end sections and transitions. Although the NASS data for this sample are not statistically significant, it

TABLE 5 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS IN GUARDRAIL COLLISIONS BY INJURY SEVERITY (1982–1985 NASS)

Guardrail Type	Police Reported Injury: No, Possible, or Minor Injury (0+B+C) Freq.	%	Incapacitating Injury (A) Freq.	%	Killed (K) Freq.	%	Total Freq.	%
Non-Median	11,402	75	374	60	0	0	11,776	74
Median	2,185	14	60	10	0	0	2,245	14
Bridge Transition	352	2	0	0	22	41	374	2
End(Non-Median)	1,309	9	61	10	18	33	1,388	9
End(Median)	14	0	127	20	14	26	155	1
Totals	15,262	100	622	100	54	100	15,938	100
Missing							58	

is interesting to note that not a single fatality was recorded for the estimated 14,000 involvements with midsections of guardrails. These data imply that the most effective countermeasures for guardrail side impacts would involve improving the performance of terminals and transitions. The performance of terminals in frontal collisions has also been an area of active research in recent years. Terminals that are characterized by better frontal performance may also help improve side-impact performance.

All of the fatalities involving guardrails were caused by collisions with end sections and transitions. This would seem to indicate that many, perhaps the majority, of the guardrail accidents in Table 3 could be considered narrow-object collisions. This would create an even wider gap between narrow-object fatalities and narrow-object involvements.

The following example illustrates why blunt-end guardrail accidents are especially dangerous in side impacts. This type of accident usually occurs when a vehicle strikes the end of a guardrail intended for traffic in the opposite direction. An example of this situation is shown in Figures 1 and 2. It is taken from a NASS Longitudinal Barrier Special Studies (LBSS) case. After traveling around the curve at a high speed, the driver lost control of the vehicle. The vehicle crossed over to the other side of the road and then onto the left shoulder. As the driver attempted to bring the vehicle back to the roadway, it struck the blunt end of the guardrail near the driver's side fire wall. The W-beam penetrated the occupant compartment and passed out through the passenger-side door, as shown in Figure 1. The potential for catastrophic injury in this type of accident is apparent from the photographs.

THE VEHICLE

In order to determine whether occupants in lighter vehicles were more at risk than occupants in heavy vehicles, the FARS and NASS data were compared to the Polk registration data. A comparison of the NASS data with registration data shows whether the percentage of occupants involved in collisions in a certain weight of vehicle is greater than the percentage of registered vehicles of that weight. A comparison of the FARS data with registration data shows whether the percentage of fatal collisions in a particular weight range is greater than the percentage of registered vehicles in that weight range. If the NASS data is assumed to be a reasonable representation of the occupants involved in each weight range, then a similar distribution of NASS and FARS would indicate that, given that an occupant is in a fixed-object, side-impact collision, the person is equally likely to be fatally injured in any weight of vehicle. Because the mean vehicle weight has been dropping each year, the FARS and NASS data from 1983 were compared with the 1983 registration data. The cumulative distribution function (CDF) of the weights of vehicles involved in all severities of side-impact collisions (NASS) and in fatal side-impact collisions (FARS), along with the CDF of the weights of registered vehicles, are shown in Figure 3. The FARS curve appears to vary from the registration curve in the 2,800- to 3,200-lb range. The maximum difference between the NASS and registration data sets was 4 percent, and 13 percent between the FARS and the registration data sets. The Kolmogorov-Smirnov and the Chi-squared goodness-of-fit tests were met at the 80 percent confidence level or greater for both the NASS-registration data and the FARS-registration data. This difference between the FARS and registration data may be further reduced by considering the differences in reporting vehicle weight in these two data sets. Partyka and Boehly state that the vehicle weights reported in FARS are generally 100 to 300 lb less than the Polk registration generated weights (*4*). She also notes that accounting for this difference significantly reduces the fatality rate in lighter cars. A correction of the FARS weights in Figure 3 would essentially move the CDF for the FARS data to the right 100 to 300 lb, producing a closer fit of this curve with the registration data CDF.

The issue of other variables, like age, masking the weight effect was not explicitly addressed in this research. Older occupants are more likely to be injured when they are involved in an accident, and they are more likely to drive large cars. These two characteristics combined can make large cars look more hazardous when, in fact, the higher injury rate may reflect the greater susceptibility of older drivers to injury. In this study, 92 percent of the occupants involved in fixed-object, side-impact collisions were under the age of 44 (see Table 6) and 84 percent were under 34 years of age. Because of the absence of elderly drivers, age-masking was not considered a problem.

The labels assigned to locations on the vehicle side indicating the most harmful impact location are shown in Table 7. The "*P*," "*Y*," and "*Z*" locations all involve the passenger compartment. Impacts in these locations account for 51 percent of the severe and fatal (A + K) injuries. Passenger compartment collisions alone account for nearly twice as many A + K injuries as impacts at other side locations. It can be seen in Table 8 that an occupant in this particular data set

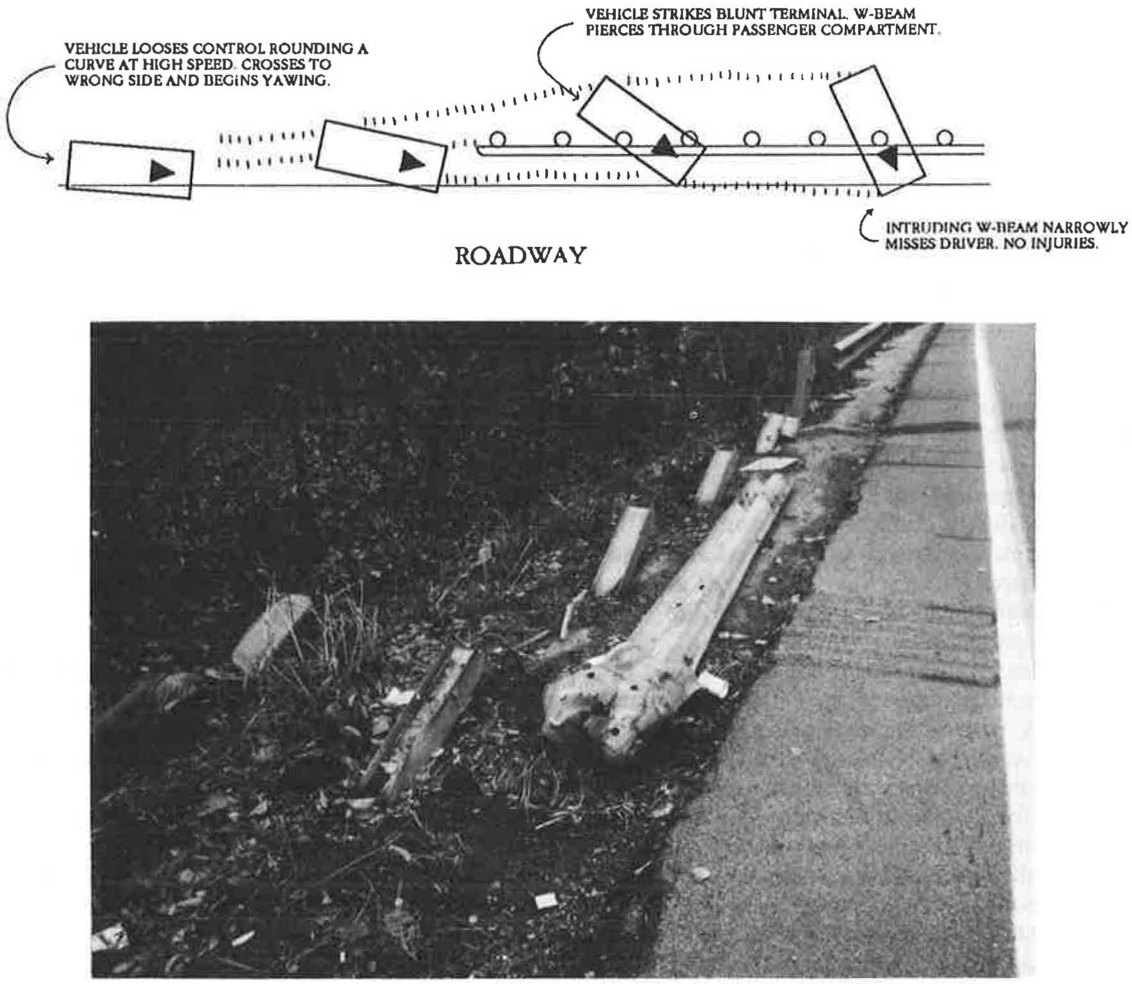


FIGURE 1 Vehicle path and guardrail end in collision: NASS-LBSS Case 83-08-512T.

had a nearly 1 in 100 chance of being fatally injured in a side-impact collision in general, but had more than 1 chance in 40 of being killed when the damage was located at the passenger compartment. A passenger compartment collision appears to be more than twice as likely to result in a fatality as a side-impact collision in general.

The importance of the location of impact was illustrated by the blunt-end guardrail accident in Figure 1. The location of the guardrail intrusion was crucial to the effect it had on the occupant. Another situation in which location of impact is critical is when a vehicle strikes a tall, narrow, rigid object at a point near the occupant. It is then possible for the occupant to directly contact the fixed object through the window.

The specific object in the vehicle that was the most probable injury source is shown in Table 9. To ensure that the injury is correctly attributed to a side impact, only single-event collisions were considered. For example, if a vehicle hit a bridge rail with the front of the vehicle, spun around and collided with a tree on the side, the worst injury may have been caused by either of the collisions. By limiting the study to single event collisions, the injury was correctly attributed to a side-impact collision with a fixed object. This exclusion of certain collisions further reduces the sample size, thus this NASS data sample has an even larger potential variation associated with it than have the previous samples. Those objects that caused injuries of all severities and those that caused injuries with an Abbreviated Injury Score (AIS) greater than three are listed in Table 10. The possible scores range from 1 to 6, with scores over 3 considered life threatening. Unfortunately, the cause of the injuries was unknown in 38 percent of the cases. The leading known cause of injury was a noncontact injury. The two most common known sources of contact injury were the windshield and the instrument panel, both of which are in front rather than on the side of the occupant.

The sources of injury for AIS-greater-than-three injuries differ significantly from those for injuries of all severities. The most frequent known source of injury was from an unknown object in the environment. In fact, all of the injuries caused by an unknown object had an AIS greater than three. These unknown objects may have been exterior objects that intruded into the passenger compartment. The other main sources of serious injury include the side hardware, the A pillar, and the window glass or frame, all objects on the side of the vehicle. Only three of the objects that caused AISs above three were not side hardware. These three—the steering assembly, seat back support, and floor transmission lever—together accounted for only 13 percent of the serious injuries; most side-impact injuries, therefore, appeared to result from

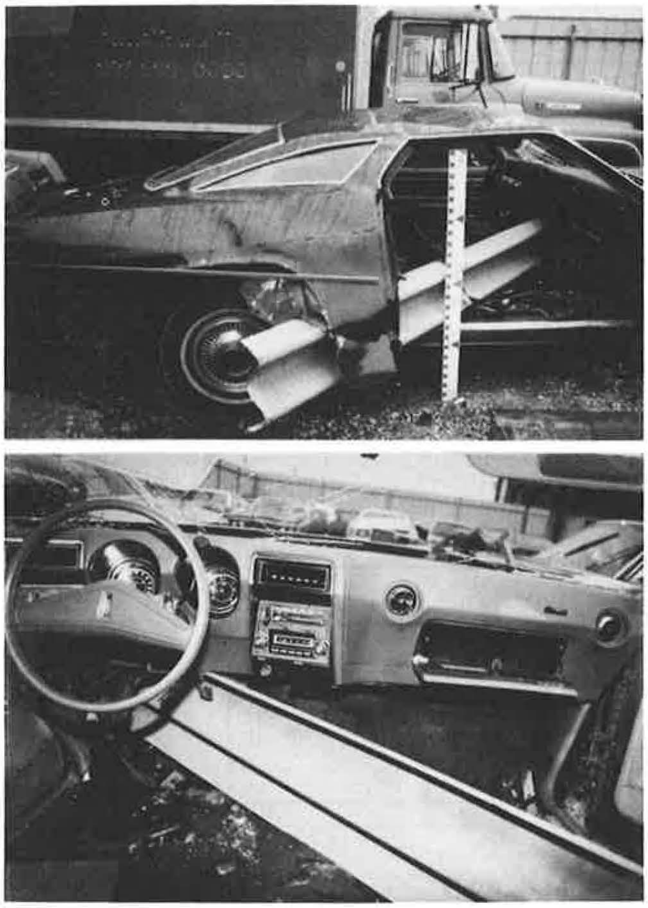


FIGURE 2 **Interior views of guardrail end collision: NASS-LBSS Case 83-08-512T.**

TABLE 6 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY AGE (1982–1985 NASS)

Age	Freq.	Percent	Cum. Percent
0-15	10,068	6	6
16-19	48,113	30	36
20-24	44,102	27	63
25-34	33,333	21	84
35-44	12,083	8	92
45-54	5,107	3	95
55-64	3,765	2	97
Over 64	5,454	3	100

the body striking an object on or near the doors. Although sampling restrictions preclude firm confidence, it is nonetheless interesting that the injury patterns observed in the data support the results of recent crash testing experiences and intuition. It is intuitively reasonable that the most serious injuries occur when the occupant hits the region of the vehicle experiencing intrusion.

THE OCCUPANT

The NASS data set contains information about which region of an occupant's body was most seriously injured. This sample is also limited to single-event collisions, so the results are also subject to wide variability. Presented in Table 10 is a list of the body regions with the highest AIS for each occupant injured in a single-event, side-impact collision with a fixed object. The first two columns of this table do not indicate severity of injury, rather they show those regions that were most frequently injured. The face, head-skull, and neck-cervical spine were the three areas observed in the data that were the most frequently injured. These three areas account for more than

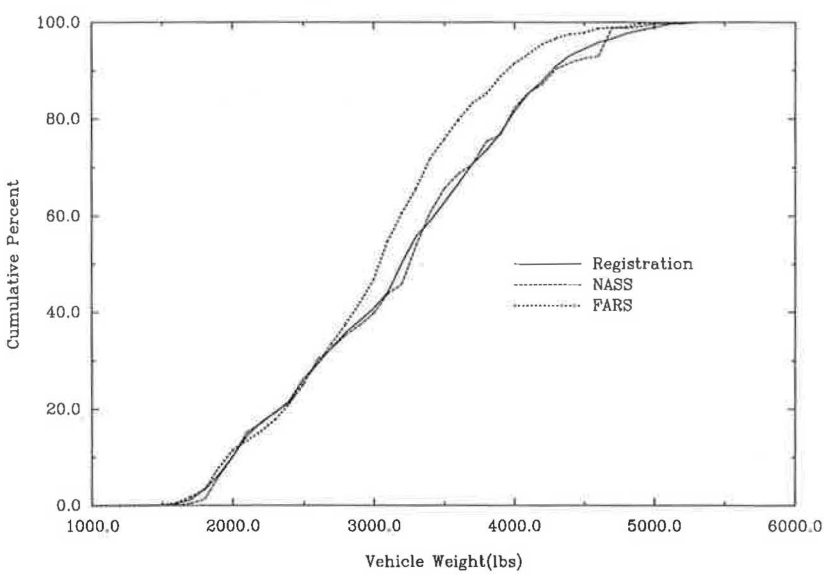
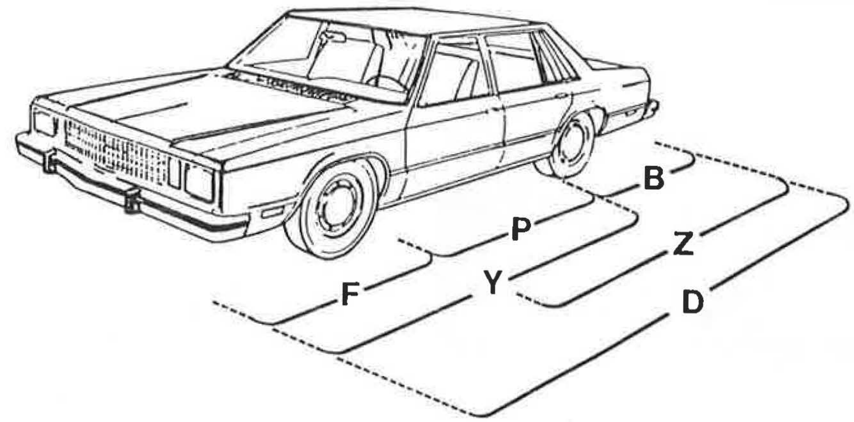


FIGURE 3 Cumulative distribution function for 1983 FARS, NASS, and registration data.

TABLE 7 AVERAGE YEARLY NUMBER OF OCCUPANTS BY LOCATION OF IMPACT (1982–1985 NASS)



Labels used in Location of Impact (7)

Location of Impact	Nonincap. (0+B+C) Freq.	Percent	Incap. A+K Freq.	Percent	Unknown Freq.	Percent	Total Freq.	Percent
Unknown	43,885	30	3,269	20	112	8	47,266	29
F	28,189	19	1,683	10	200	15	30,072	18
D	20,201	14	1,949	12	407	31	22,557	14
P	15,837	11	4,003	25	152	12	19,992	12
Z	14,972	10	1,744	11	310	24	17,026	10
Y	12,039	8	2,576	16	0	0	14,615	9
B	11,138	8	915	6	131	10	12,184	8
Total	146,261	100	16,139	100	1,312	100	163,712	100
Missing							4,647	

TABLE 8 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY INJURY (1982–1985 NASS)

Type of Injury	All Side Impacts Frequency	Percent	Passenger Compartment Only Frequency	Percent
No Injury – 0	102,071	62	9,271	46
Possible Injury – C	18,270	11	2,133	11
NonIncapacitating Injury – B	25,919	16	4,433	22
Incapacitating Injury – A	14,585	9	3,521	18
Killed –K	1,555	1	482	2
Unknown	1,312	1	152	1
Total	163,712	100	19,992	100
Missing	4,648			

TABLE 9 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY SOURCE OF INJURY (1982–1985 NASS)

Injury Source	All Injuries Freq.	Percent	MAIS over3 Freq.	Percent
Unknown Source	10,748	38	87	17
Unknown Object in Environment	74	0	74	13
Side Hardware	978	3	72	13
Window Glass/Frame	832	3	69	12
A Pillar	636	2	69	12
Non-Contact Injury	3,556	12	50	9
Steering Assembly	1,490	5	39	7
Side Interior	1,807	6	37	7
Roof Side Rails	321	1	24	4
Floor Trans.Lever	187	1	19	3
Seat Back Supp.	1,004	4	14	3
Windshield	3,082	11	0	0
Instrument Panel	2,004	7	0	0
Mirror	435	2	0	0
Roof/Conv.Top	411	1	0	0
Belt Restraint System	273	1	0	0
Other	752	3	0	0
Total	28,590	100	554	100
Missing	562		0	

TABLE 10 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY BODY REGION INJURED (1982–1985 NASS)

Body Region	All Injuries		AIS Over 3	
	Freq.	Percent	Freq.	Percent
Head-Skull	5,263	18	291	52
Chest	1,949	7	169	31
Whole Body	295	1	50	9
Abdomen	429	1	44	8
Face	6,472	22	0	0
Neck-Cerv.Spine	3,727	13	0	0
Injured, Unknown	1,746	6	0	0
Knee	1,397	5	0	0
Wrist	1,268	4	0	0
Shoulder	1,266	4	0	0
Back-Thorac.Spine	1,203	4	0	0
Ankle-Foot	910	3	0	0
Thigh	708	2	0	0
Unknown	562	2	0	0
Upper Limbs	493	2	0	0
Elbow	461	2	0	0
Pelvic-Hip	371	1	0	0
Upper Arm	279	1	0	0
Lower Leg	298	1	0	o
Forearm	55	1	0	0
Total	29,152	100	554	100

50 percent of the injuries. In the second group of columns in Table 10, the body regions most frequently injured of occupants whose highest AIS scores were greater than three are shown. Most of the serious injuries were to the head (53 percent) and chest (31 percent), presumably because vital organs are located in those regions.

It is not surprising that the areas above the shoulders are the most frequently injured body regions and that the head is the region most seriously injured. Passenger vehicles are not designed to travel sideways, so when they do they begin to roll. The top of the vehicle is usually the first to strike an object in side impacts. This type of accident possibly accounts for the dominance of head, face, and skull injuries in this sample of the NASS data. Other factors also add to this situation to make it more serious:

1. There is little or no lateral restraint for the upper body even when seat belts are used,
2. Side impacts cause the areas above the shoulders to collide with the interior of the vehicle or with exterior objects through the window, and
3. The head is offered little protection from exterior objects that strike the vehicle at the location of the passenger.

Here again, the sample data, even given its sampling restrictions, confirms intuition and crash test experience: namely, that the head and neck are most at risk in fixed-object collisions.

A list of some of the most frequently or most severely injured body regions in the sample and the type of object that caused the injury are presented in Table 11. Guardrail ends and transitions were considered narrow objects in this table. In three of the four body areas that have AIS scores greater than three—head-skull, chest, and abdomen—more than 84 percent of the injuries were caused by narrow objects. The objects most frequently struck for neck-cervical-spine injuries and whole-body injuries were broad objects.

The data suggest that most of the worst accidents could have involved an occupant hitting an exterior object directly. The majority of injuries with an AIS greater than three were to the head, and the type of object most frequently struck was narrow. Most of the narrow objects were tall, as shown in Table 3, and most of the serious injuries occurred at the passenger compartment, as shown in Table 7. These two findings are consistent with the large number of serious head injuries because a side-impact, passenger-compartment collision with a tall, narrow object would most likely cause damage to the head if the object directly contacted the occupant.

Two other notable characteristics of side-impact, fixed-object collisions are the ages of the vehicle occupant and the time of day of the accident. As shown in Table 6, 92 percent of the occupants involved in this type of collision were under the age of 44. The age group most frequently involved was 16- to 19-year-olds. Occupants in this age group, which spans only 4 years, were involved in nearly 30 percent of side-impact, fixed-object collisions. Almost 97 percent of the occupants were under 64 years of age.

Most of the side-impact collisions with fixed objects occur late at night (see Table 12). More than 50 percent of the occupants were involved in accidents that happened between 8 p.m. and 4 a.m.

TABLE 12 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY TIME OF ACCIDENT (1982–1985 NASS)

Time	Frequency	Percent	Cum. Percent
8pm-12am	38,422	23	23
12-4 am	45,913	28	51
4-8 am	16,884	10	61
8am-12pm	14,799	9	70
12-4 pm	19,931	13	83
4-8 pm	28,188	17	100

TABLE 11 ESTIMATED AVERAGE YEARLY NUMBER OF OCCUPANTS BY BODY REGION INJURED AND TYPE OF OBJECT STRUCK: ALL INJURY SEVERITIES (1982–1985 NASS)

Body Region	Type of Object Struck						Total	
	Narrow		Broad		Other			
	Freq.	Percent	Freq.	Percent	Freq.	Percent	Freq.	Percent
Face	4,638	72	862	13	971	15	6,471	100
Head-Skull	4,412	84	331	6	520	10	5,263	100
Neck-Cerv.Spine	1,124	30	2,278	61	325	9	3,727	100
Chest	1,713	88	0	0	237	12	1,950	100
Abdomen	409	95	0	0	19	5	428	100
Whole Body	95	32	124	42	75	26	294	100

FIXED-OBJECT VERSUS VEHICLE-TO-VEHICLE SIDE IMPACTS

Much of the literature about side-impact collisions groups vehicle-to-vehicle collisions with vehicle-to-fixed-object collisions, or neglects fixed-object collisions altogether. Although vehicle-to-vehicle collisions are the most common types of side-impact collisions, fixed-object collisions account for 37 percent of the serious-to-fatal injuries in side-impact collisions (*5*). The differences between these two types of side-impact collisions is discussed in the following section.

The weight of the vehicle appeared to have little, if any, effect on the fatality rate (see Figure 3). Partyka and Boehly (*6*) observe this same phenomenon for all single-vehicle nonrollover accidents. In contrast to this, the fatality rate in multiple-vehicle collisions is sensitive to vehicle weight. A decrease of 0.39 fatalities/100 lb increase in car weight in multiple-vehicle accidents is shown in Figure 4. The rate of decrease in fatalities for single-vehicle collisions, shown in Figure 5, is only 0.02/100 lb increase in vehicle weight—not a statistically significant amount. Although these figures include frontal, rear, and side collisions, they demonstrate the contrast between the effect of weight on multiple-vehicle collisions and the effect of weight on single-vehicle collisions. The weight of the occupant's vehicle is an important factor in multiple-vehicle collisions, but apparently it is not so in single-vehicle collisions, including side impacts with fixed objects.

The location of impact where the most severe injuries occurred in fixed-object collisions appeared to be the passenger compartment (see Table 7). In all types of side-impact accidents combined, however, Huelke (*7*) notes that collisions involving occupants with AISs greater than 3 have the most extensive damage at the "*D*" and "*Y*" locations. A comparison of impact locations by Hartemann et al. (*8*) is shown in Figures 6 and 7. Figure 6 is a distribution of impact points for vehicle-to-vehicle side impacts and Figure 7 is a distribution of vehicle-to-fixed-object side impacts. The distribution of impact points in multiple-vehicle collisions is more spread out. In this study, single-vehicle side impacts with severe injuries were characterized by localized damage to the passenger compartment. Because other vehicles are broader than most fixed roadside objects, the impact area in vehicle-to-vehicle accidents is usually spread out over a larger area. It is important when automobile designers attempt to improve passenger safety in the lateral direction that they realize that there are a significant number of injuries that are caused by impacts with localized damage to the passenger compartment.

Studies by Partyka and Rezabeck (*9*), Frost (*10*), and Dalmotas (*11*) have all concluded that the body regions most likely to be injured in multiple-vehicle side impacts are the chest and abdomen. Lozzi (*12*) noted that car-to-car side impacts resulted in a combination of head, thoracic and abdominal injuries, but that car-to-pole collisions produced mostly head injuries. Head injuries are by far the most common body region severely injured in this examination of NASS single-vehicle, fixed-object collisions, as shown in Table 10. The two types of side-impact collisions have different injury mechanisms that result in different body regions being harmed.

Frost (*10*) concluded that side-impact collisions usually involve older drivers, whereas frontal accidents involve younger drivers. Her data are presented in a graph, shown in Figure 8. Note that the frontal crashes are limited to single vehicles but that the side impacts are not. It is reported in *Fatality Facts*, published by the Insurance Institute for Highway Safety (*13*), that in 1989, occupants under the age of 35 accounted for 68 percent of all roadside-hazard fatalities, whereas occupants over 65 accounted for only 6 percent of these fatal-

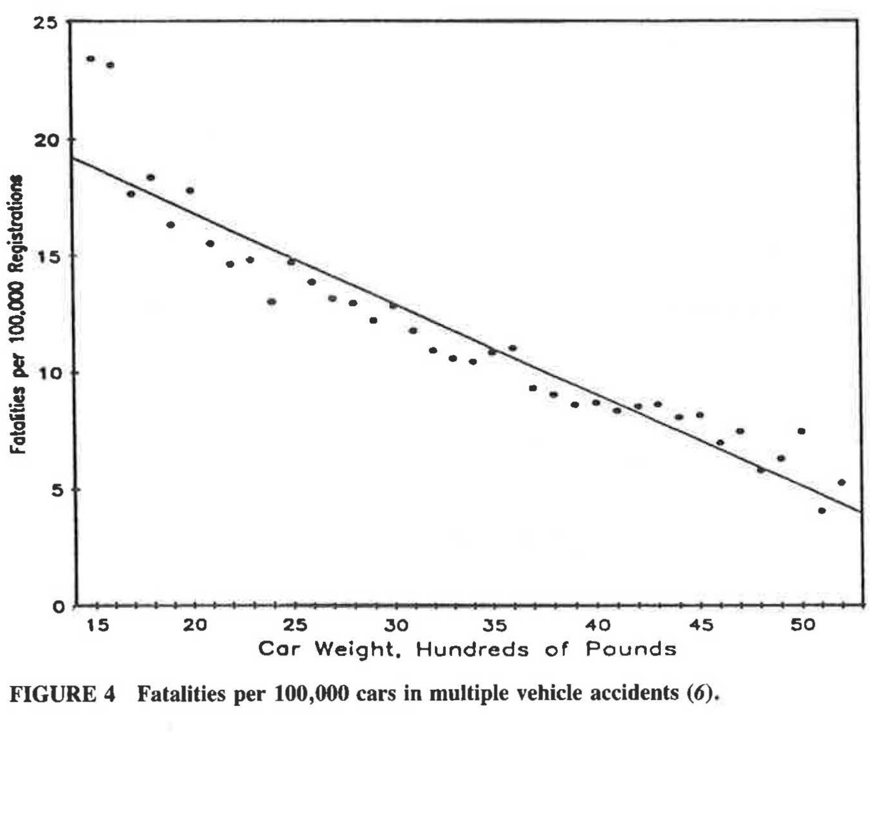


FIGURE 4 Fatalities per 100,000 cars in multiple vehicle accidents (*6*).

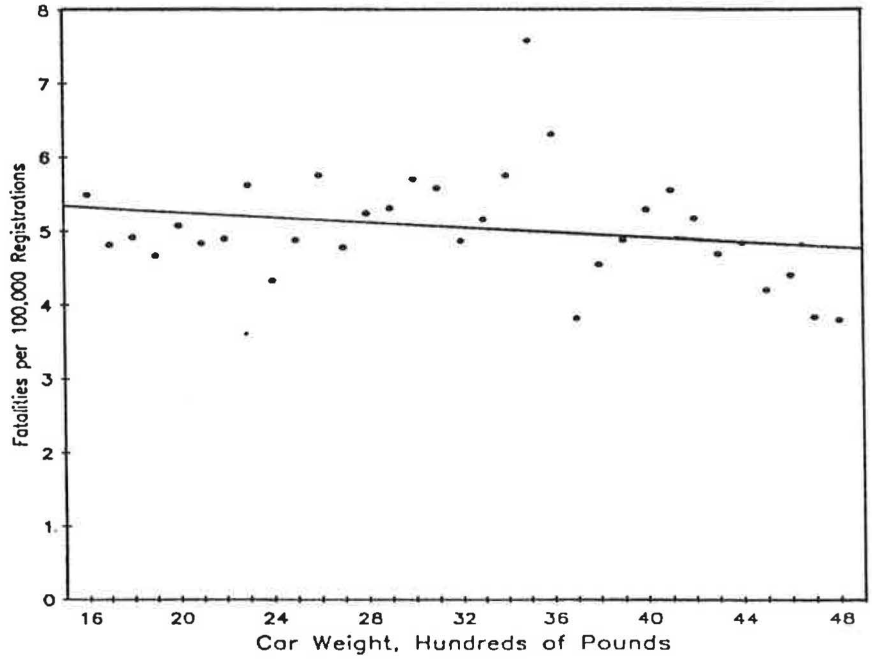


FIGURE 5 Fatalities per 100,000 cars in single vehicle nonrollover accidents (*6*).

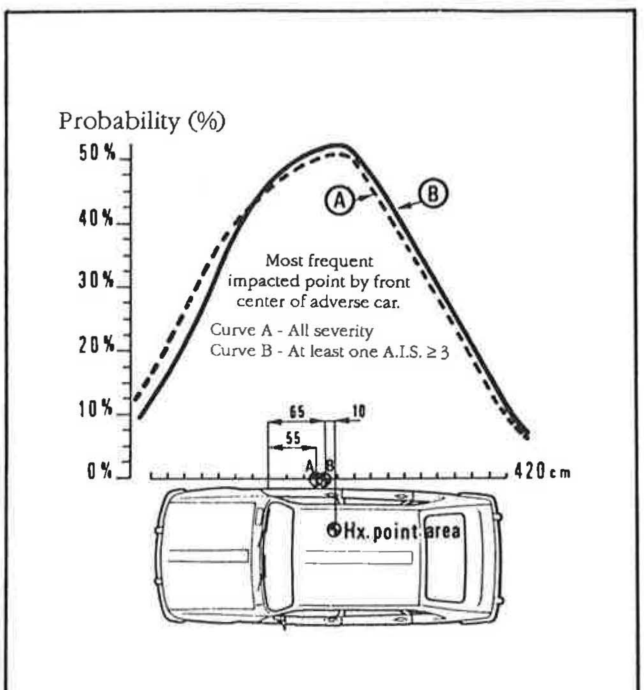


FIGURE 6 Distribution of impact along side of car in vehicle-to-vehicle accidents (*8*).

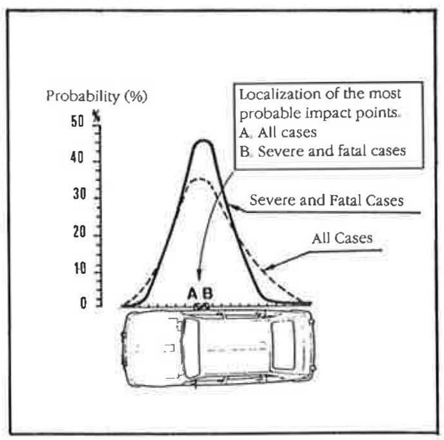


FIGURE 7 Distribution of impact along side of car in fixed-object accidents (*8*).

ities. In contrast, *Fatality Facts* also reports that fatality rates in all types of motor vehicle collisions combined are roughly equivalent for those under 35 and those over 65. These findings indicate that fatally injured occupants in fixed-object collisions are more likely to be young, whereas other types of collisions have a higher percentage of older drivers. The fatality rate per age group appears to be a function of the type of object struck more than a function of the location of impact.

Frost (*10*) also notes that side-impact collisions of all types usually occur during daylight hours. The Insurance Institute (*13*) shows that 42 percent of all roadside hazard fatalities occur between 9 p.m. and 3 a.m. Almost 50 percent of fixed-object, side-impact collisions occur between 10 p.m. and 4 a.m., as shown in Table 12. Fixed object collisions, including side impacts, usually occur at night.

CONCLUSIONS

Side-impact collisions with fixed objects cause a significant loss to society. The 1982–1985 NASS data used in this study

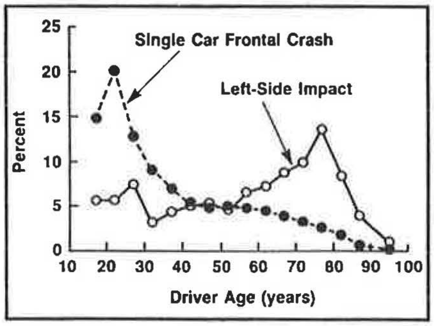


FIGURE 8 Driver age versus percent of occupants involved in single-vehicle frontal crashes and nearside side impacts with moderate damage (*10*).

of side-impact, fixed-object accidents suggested certain characteristics that should be considered when attempting to reduce injury in this type of accident.

Object Characteristics

- The most serious injuries were caused by tall, narrow, rigid objects.
- Guardrail ends caused more serious injuries than midsections.

Vehicle Characteristics

- Heavy vehicles were at no less risk than light vehicles.
- The most harmful injuries occurred in impacts located at the passenger compartment.
- The main injury sources were unknown objects in the environment and side hardware.

Occupant Characteristics

- The majority of serious injuries involved the head-skull area.
- Young drivers at night were involved in the most collisions.

As discussed frequently throughout this paper, these results should be viewed as pointers toward the characteristics of side impacts with fixed objects. The results shown, though not statistically significant, confirm both recent testing experience and intuition about this type of collision.

Side-impact collisions with fixed objects represent one-third of the side-impact problem. The effects of vehicle weight, injury source, injured body region, age of the injured occupants, and time of the accident in fixed-object, side-impact collisions differ significantly from those characteristics in vehicle-to-vehicle, side-impact collisions. For the vehicle design community to improve occupant safety in side impacts, these two types of collision must be approached individually. Improvements in occupant protection in vehicle-to-vehicle collisions may not reduce risks for occupants in fixed-object collisions. The roadside safety community must be aware of these differences also in order to design roadways that are safer for side-impact collisions. Both single-vehicle and multiple-vehicle collisions account for great losses to our society. A clear understanding of the differences between these two important scenarios is necessary if effective countermeasures are to be developed that promote the safety of vehicle occupants.

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