THE APPLICATION OF CRASH VICTIM SIMULATION MODELS IN ASSESSING INJURY REDUCTION PRIORITIES

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ABSTRACT

The concept of "harm" has been recently used as a yardstick to assess injury prevention priorities. Harm provides an accounting unit by which injuries of different severities can be integrated. The total harm can then be subdivided by body region, part of the vehicle causing the injury, crash direction, crash severity, etc.

In searching for countermeasures to reduce harm, some mechanism for estimating the benefits is required. The use of occupant simulations is one useful method of making preliminary estimates of the countermeasures which might be most profitably applied. The purpose of this paper is to show how occupant models can be used in conjunction with the concept of harm to guide research priorities.

The paper summarizes the relative harm attributed to various vehicle components in frontal collisions and illustrates how models can be used in assessing alternative countermeasures for further research. The methodology is equally applicable to other crash modes and occupant positions.

INTRODUCTION

When evaluating alternatives for enhanced crash protection, the analysis can generally be divided into two phases--(1) Problem Definition and (2) Assessment of the Alternative Solutions.

The Problem Definition phase includes the characterization of the region of the human body being injured and the vehicle component causing the injury. This characterization requires some way to rank the injuries received by the population at risk as a function of crash severity, crash direction, seating location, vehicle type, and vehicle component causing the injury.

The Assessment of Alternative Solutions phase includes an evaluation of mitigation concepts to address the problems identified. Ideally, this phase would determine for each proposed countermeasure the reduction in injury to each body part as a function of crash severity, direction, etc.

Analysis of accident data forms the basis for the Problem Definition phase. However, accident data is seldom adequate to permit the evaluation of variables associated with vehicle crashworthiness countermeasures. Crash vehicle simulation models offer a mechanism for augmenting accident data so that benefits of alternative solutions can be estimated. Models, used in conjunction with accident data, can be very useful in guiding the selection of countermeasures for further test and evaluation.

PROBLEM DEFINITION

A number of surveillance data sets are available to assist in defining motor vehicle safety problems. The most important in the United States are the Fatal Accident Reporting System (FARS), the National Crash Severity Study (NCSS), and the National Accident Sampling System (NASS). All three data sources give information on a population of crashes involving motor vehicles and pedestrians. This information includes crash direction, body region injured, the severity of the injury, and the vehicle component causing the injury.

The Fatal Accident Reporting System is a census of data on all fatal accidents within the United States. To be reported in FARS, an accident must have involved a motor vehicle on a roadway and a fatality must have occurred as a result of that accident. FARS data include only those accidents where death occurred within 30 days. The data is collected from police accident reports, vehicle registration files, death certificates, and medical reports.

The National Crash Severity Study provides a data base of crash conditions of towaway passenger vehicle accidents. The study includes 12,050 accidents which occurred between January 1977 and March 1979. The data base was designed to be large enough to show a representative picture of these crashes, yet detailed enough to support extensive vehicle crash characteristics and the resultant occupant injuries.

The National Accident Sampling System is a probability sample of all police-reported accidents in the U.S. resulting in property damage and/or personal injury. The data collection began in 1979. The 1979 through 1984 file contains approximately 70,000 cases. The cases in the file can be weighted so that the population of injury events in all police-reported accidents in the United States can be estimated.

In order to provide a yardstick to measure the opportunities for safety countermeasures, the concept of "harm" was developed by Malliaris et al. (1)*. The total fleetwide harm is the sum of all injuries suffered by crash victims, with each injury weighted according to severity. Injury severity was based upon the AIS scale described in Reference 2. The relative economic losses attributed to injuries at each severity level specified by AIS have been estimated in Reference 3. The components of the societal losses are medical costs, productivity losses, and "other" expenses which include insurance and legal costs. Weighting factors for each injury level were suggested in References 1 and 4, based upon the relative cost of injuries as reported in Reference 3. Table I shows the harm weighting factors suggested in Reference 4. These weighting factors give a basis for combining the harm caused by injuries at various severities.

As discussed earlier, the events in the NASS file can be weighted to produce estimates of fleetwide injuries of all severities. Further, the annual files from the years 1979 to the present can be combined to permit a large data base. The total harm for such a data base can be calculated by

*Numbers in parentheses indicate references.

applying the injury weighting factors listed in Table I to each injury in the file and summing over all injury severities including fatality. This total harm can then be distributed on a percentage basis according to its source. The distribution of harm in the combined 1979-1983 NASS file due to source of injury, body region, accident severity, and seating position, is shown in Table II (4). The harm distribution can be further subdivided by crash direction so that the relative opportunities in frontal, side, rollover, etc., can be examined.

The distribution of the harm in frontal crashes for the 1979-1984 NASS file is shown in Table III. This subdivision directs attention to the interaction of the thorax and steering assembly, since more than 50 percent of the harm in frontal impacts is associated with this event.

Additional information is required to examine the nature of the harm and how it can be mitigated. This information can be obtained by further investigation of the accident data, supplemented by tests and modeling. The phase of the research dealing with these activities falls under the phase which was earlier referred to as Assessment of Alternative Solutions.

ASSESSMENT OF ALTERNATIVE SOLUTIONS

In order to examine the nature of the major causes of harm, further partitioning of the accident data can be made.

As an example, the distribution of a given type of harm with crash severity can be examined. Table IV shows the delta V distribution for harm associated with thorax to steering wheel frontal injuries. By including 6 years of NASS data, 114 complete data cases of serious thorax injury from steering assembly contact with known crash severity (delta v) can be found. This body of data gives a basis for estimating benefits which could be expected for hypothetical countermeasures designed to protect at various levels of crash severity. However, further enrichments are required to determine the effects of a specific countermeasure.

One approach for selecting vehicle crashworthiness countermeasures is to conduct crash tests of existing vehicles or components and of proposed countermeasures and compare the results. However, testing of the physical systems is relatively expensive, and additional insight into how to conduct an intelligent test program is desirable. Such an insight can be gained through modeling.

The normal use of occupant models involves an initial calibration of the model for a specific crash being simulated, followed by a variation of model parameters to study safety improvements. This type of use is discussed in papers by Cooper of General Motors (5) and Robbins and Viano of the University of Michigan Transportation Research Institute and General Motors (6).

Another approach is to model the crash events of an entire fleet of vehicles and calibrate the model using accident data. This approach was suggested by the Ford Motor Company in their Phase I RSV program (7), and further developed in a follow-on program with NHTSA (8).

The model developed by Ford was called the Safety Systems Optimization Model (SSOM), and its characteristics were summarized by Versace in Reference 9. The concept of the SSOM model is illustrated in Figure 1. In the original model, the exposure matrix consisted of 142 combinations of crash modes, car sizes, and crash velocities; three occupant sizes, and two occupant positions. The result was 852 classes of exposure.

Simulations which employed models of vehicle structure and occupant/restraint system interaction were conducted for the exposure matrix. The System Performance was evaluated based upon the number and severity of the injuries predicted. Parameter variation was then accomplished to seek a design which would minimize the injury function within weight and cost constraints.

A significant advantage of the SSOM model approach is that it allows an estimate of how the total harm produced by the vehicle fleet changes with alternative countermeasures. The SSOM model had the disadvantages of being overly complex, and it did not provide insights into the interactions which caused the system performance to improve or become worse.

The NHTSA has used both single event models and fleet models in evaluating frontal crash protection countermeasures. The first requirement in using either type of model is calibration.

The model calibration for specific events is relatively straightforward. It consists of conducting specific tests and verifying that the model predicts similar test results. A representative single event calibration was reported in Reference 10.

The use of fleet calibration is more complex. In addition to the single event calibration, it requires the selection of a crash exposure matrix which approximates that of the accident data base, the simulation of the entire exposure matrix, and the comparison of simulation results and the data base.

During the decade since Ford proposed the 852 event crash exposure matrix, changes have occurred in the vehicles in service, the accident data base, the vehicle test data base, the accuracy of occupant models, and the speed and economy of computations.

The NASS data system, begun in 1979, provides a representative sample of police reported accidents for the United States. This file provides data on more recent vehicles than those contained in the NCSS file which covered the years 1977-1979.

A sample of 27 make models of the 1975-1981 time period represents nearly 60 percent of the passenger car sales for the 1979-1982 period. The vehicles are listed in Table V. The accident cases involving these vehicles can be used to produce a subfile which is a significant fraction of the base file. The distribution of driver injuries in frontal collision as a function of crash severity is shown in Figure 2 for the NASS file, the NCSS file, and the NASS subfile for the 27 vehicles.

Also, since 1979, NHTSA has crash tested more than 150 makes and models of vehicles. These tests were principally in frontal barrier tests at 35 mph, but other speeds and test conditions were included. In addition, considerable research has been done in scaling the acceleration pulse from a 35 mph frontal barrier test to other frontal crash modes and speeds. Consequently, acceleration pulses for the exposed fleet can now be scaled from test data rather than generated from an analytical model as required in the Safety Systems Optimization Model. NHTSA Research and Development staff have used the existing crash test data base to serve as the basis for estimating the crash acceleration pulse for each of the 27 vehicles in the exposure matrix for crashes into a variety of vehicles and objects and at various speeds. The approach for scaling crash pulses is reported in Reference 11.

The exposure matrix for calibrating the model consists of the combinations of the following parameters:

27 vehicles	listed in Table V
6 velocities	10, 15, 20, 25, 30, 35 mph
3 damage locations	distributed, offset, center
3 occupant sizes	5th, 50th, 95th
1 occupant age	33 years
3 seat locations	aft, center, forward

Of course, not all combinations are required. For example occupant size and seat location are interrelated. However, the matrix involves 54 events for each vehicle or a total of 1,400 events for the 27 vehicle matrix.

In order to deal with the large number of occupant crash simulations required by the exposure matrix, NHTSA has developed an automated procedure for generating input data files. The procedure is discussed in Reference 11.

The initial application of the 27 vehicle exposure matrix employed the Passenger and Driver Simulation Model (PADS) and simulated unrestrained driver occupants. The effects of intrusion were neglected. Each simulation takes 1 to 2 minutes of VAX computer time or a total of about 23 to 46 hours for the 1,400 simulations.

The PADS model for driver simulation allows a detailed representation of the dashboard and steering assembly. Dimensions, masses, stiffnesses, friction and damping of the steering rim, hub, shear capsule, and column can be varied in the model. The model and its single event validation are discussed in References 12 and 13.

The detailed representation of the vehicle interior required a considerable amount of data on the vehicles in the fleet being modeled. Interior dimensions of the vehicles were collected and summarized (14). Static and dynamic component tests of steering assemblies, dashboards and windshields were conducted to provide the data for stiffness, friction, and damping properties required by the model. The data from these tests are summarized in References 15 and 16. Data for the occupant was based upon Reference 17. A summary of the methodology for model calibration is given in Reference 18.

MODEL CALIBRATION AND RESULTS

The model simulation of each event in the exposure matrix permits the estimate of injury measures for the head, thorax; abdomen, and femur. For example, model results include HIC, chest acceleration, abdomen penetration, and femur load. Several authors (19, 20) suggested relationships which can be used to establish relationships between injury measures from a dummy or model and human injury severity. These relationships can be used in conjunction with model results to calculate harm, which serves as the basis for calibrating the model and evaluating countermeasures.

Figure 3 shows the distribution of harm to the head vs. crash severity for the PADS simulation and for the NASS and NCSS data systems. Figures 4 and 5 show comparisons of harm distribution for the chest, and abdomen, respectively.

The model results shown in the above Figures generally produce harm distributions which are similar to the NASS data for head and chest injuries. However, for abdominal injuries, PADS predicts higher levels of harm at lower speeds than seen in the NASS data. These differences may be associated with occupant evasive action or bracing in real world crashes as compared to the model. Alternatively, adjustments in abdominal injury criteria could be made to improve abdominal injury calibration. However, the present level of calibration appears to be adequate to permit the model to be used in selecting steering assembly countermeasures for test and evaluation.

Although additional refinements could be made to improve the precision of the model calibration, a more useful effort would be to use the model to select countermeasures for laboratory testing. This approach has been undertaken. The general trends in the variables predicted by the model are summarized in Table VI.

In addition, examples of the results of studies for several different combinations of steering system variables are shown in Figure 6. The presentation of results shown in Figure 6 show how the harm to each component of the body can be estimated as a consequence of changes to steering system model parameters. Both Benefit 1 and Benefit 2 are better than the baseline; however, the distribution of the injury reduction is quite different. Benefit 1 significantly reduces abdominal harm, with lower reductions in head and chest harm. Benefit 2 reduces head and chest harm with lower reductions in abdominal harm. The overall harm reduction for the two is about the same; however, Benefit 1 reduces more of the harm associated with the more severe injuries.

The properties of the baseline, Benefit 1, and Benefit 2 steering assembly are shown in Table VII. The baseline vehicle was somewhat arbitrarily selected from the 27 vehicle fleet. Benefit 1 consists of production feasible properties, developed to provide maximum energy absorption while applying tolerable force levels to the impacted body region. Also, Benefit 1 includes geometry considerations for optimum load application. Benefit 2 consists of a wheel and column from the 27 vehicle group evaluated to have the best energy absorption and force limiting properties.

The next step in model validation is to construct and evaluate in the laboratory steering assemblies which are designed in the directions predicted by the model. Actual values of parameters selected for the design will, of course, be dependent on practical considerations of cost and functionality. The laboratory testing can be further enhanced by parameter variations studies using occupant models in the traditional way.

CONCLUSIONS

During the past 5 years the ability to use occupant models has improved significantly. The speed and economy of computation have greatly increased, and the sophistication and comprehensiveness of models have improved. Possibly more important, the data needed for the models are now available.

The use of occupant models to simulate large numbers of crash events allows a mechanism for augmenting the accident data base. Consequently, the nature of the injury to each body component can be further studied. Such a study provides valuable insight into the relative benefits of alternative safety improvements and provides a basis for selecting countermeasures for test and evaluation.

REFERENCES

1. Malliaris, A.C., Hitchcock, Ralph, and Hedlund, James [National Highway Traffic Safety Administration (NHTSA)], "A Search for Priorities in Crash Protection," SAE Paper 82024, February 1982

2. The Abbreviated Injury Scale 1980 Revision," American Association for Automotive Medicine, Morton Grove, IL, 1980

3. "The Economic Cost to Society of Motor Vehicle Accidents," NHTSA, January 1983

4. Malliaris, A.C., Hitchcock, Ralph, and Hansen, Marie (NHTSA), "Harm Causation and Ranking in Car Crashes," SAE Paper 850090, February 1985

5. Cooper, Gerald A. (General Motors Corporation), "A Driver Environment Design Parameter Study, SAE Paper 840865, May 1984

6. Robbins, D. H. and Viano, D.C. (University of Michigan Transportation Research Institute and General Motors), "MVMA 2-D Modeling of Occupant Kinematics in Rollovers," SAE Paper 840860, May 1984

7. "Research Safety Vehicle (RSV) Phase I Final Report Volume III of Three Volumes, Vehicle Characterization, Performance Specifications," NHTSA Contract No. DOT-HS-4-00842, Report No. DOT-HS-801-606, Ford Motor Company, June 1975

8. "Safety Systems Optimization Model (SSOM) Final Report - Volume 2. Methodology and Optimization Results," NHTSA Contract No. DOT-HS-6-01446, Report No. DOT-HS-804-772, Ford Motor Company, November 1978

9. Versace, John, (Ford Motor Company), "Safety Systems Optimization Model," Proceedings of the Seventh International Technical Conference on Experimental Safety Vehicles, NHTSA, June 1979

10. Digges, Kennerly H. (NHTSA), "Improvements in the Simulation of Unrestrained Passengers in Frontal Crashes Using Vehicle Test Data," SAE Paper 860654, February 1986

11. Cohen, Daniel, Stucki, Lee, and Ragland, Carl (NHTSA), "Development of Analytical Procedures to Characterize the Vehicle Environment in Frontal Impact Accidents, SAE Paper 850251, February 1985

12. "The Development and Use of PADS (Passenger/Driver Simulation) Computer Program," Final Report, NHTSA Contract Number DTNH 22-82-R-07017, Washington, D.C., March 1984

13. "Validation of the SCORES Computer Model," Final Report, NHTSA Contract Number DTNH22-83-P-08040, Washington, D.C., April 1983

14. "Motor Vehicle Attributes - Status Report," Transportation Systems Center, October 1983

15. "Vehicle Component Characterization, Volume I: Project Results," Final Report, Transportation Systems Center, Contract No. DTRS-57-84-C-00003, Cambridge, MA, January 1986, to be published

16. "Static Force-Deflection Properties of Automobile Steering Components," Transportation Systems Center, Cambridge, MA, July 1985, to be published

17. "Development of Anthropometrically Based Design Specifications for an Advanced Anthropomorphic Dummy Family," NHTSA Contract No. DTNH22-80-C-07052

18. Stucki, Lee, Cohen, Dan, and Ragland Carl (NHTSA), "Evaluation of Frontal Occupant Protection Using the Passenger/Driver Simulation Model," Proceedings of the Tenth International Technical Conference on Experimental Safety Vehicles, to be published July 1986

19. Langweider, Klaus, Danner, Maximilian, and Schmelzing, Walter, "Comparisons of Passenger Injuries in Frontal Car Collisions with Dummy Loadings in Equivalent Simulations," Proceedings of the Twenty-Third Stapp Conference, Society of Automotive Engineers, SAE 791009, pp. 199-231, 1979

20. Hackney, James A., and Quarles, Vincent, "The New Car Assessment Program - Status and Effect," Proceedings of the Ninth International Technical Conference on Experimental Safety Vehicles, Kyoto, Japan, pp 809-824, 1982

Table 1.

HARM

INJURY WEIGHTED BY THE ECONOMIC CONSEQUENCES ASSOCIATED WITH THAT INJURY

AIS VALUE	HARM WEIGHT FACTOR
6	264.9
5	232.5
4	56.7
3	9.2
2	3.0
1	0.7

Table II. Resolution of Car Occupant Harm Due to Principal Sources of Injury or Body Regions, Crash Severity and Seating Position (NASS 1979 to 1983 Combined)

Source of Injury	Body Region	Harm % of Total	Harm Percent of Row: By Crash Sev. Up to 20 MPH	30 MPH	40 MPH	By Seating Position: Driver	F.R. Pax	Other
Steering Ass-	Chest & Back	12.7	14.1	42.0	76.2	99.2	0.6	0.2
	Abdomen	6.1	12.4	42.9	73.5	100.0	0.0	0.0
	Face	2.6	40.2	58.1	62.8	99.6	0.3	0.1
	Shldr. & U. Extr.	1.6	53.7	73.8	80.1	98.1	0.6	1.3
	All	25.3	21.1	47.4	74.6	99.3	0.5	0.2
Instr. Panel	Pelvis & L. Extr.	7.3	42.3	67.5	78.8	69.7	26.3	4.0
	Chest and Back	2.3	10.2	31.7	33.1	8.9	89.0	2.1
	Shldr. & U. Extr.	1.8	41.5	73.3	78.7	40.4	54.5	5.1
	Face	1.2	53.1	65.9	70.6	31.7	56.0	12.3
	All	14.4	34.1	57.6	64.7	47.8	45.7	6.5
Windshield	Head	5.3	27.1	54.4	64.4	68.3	25.8	5.9
	Face	3.9	46.4	68.7	79.8	61.2	35.1	3.7
	Neck	1.7	5.1	60.9	96.4	79.2	20.8	0.0
	All	11.3	29.6	60.5	76.6	67.2	28.6	4.2
A-Pillars	Head	3.6	22.4	67.7	72.0	51.9	38.1	10.0
	All	4.5	20.2	66.2	70.4	48.1	42.7	9.2
Lower Side Int.	Chest & Back	3.3	30.3	86.3	89.3	50.8	36.9	12.3
	Abdomen	3.0	24.1	65.5	66.6	46.7	30.3	23.0
	Pelvis & L. Extr.	1.9	50.6	80.5	83.4	56.6	35.1	8.3
	Head	1.7	34.8	66.2	66.2	32.0	13.8	54.2
	Shldr. & U. Extr.	1.4	62.3	81.3	82.7	70.4	22.7	6.9
	All	11.6	33.9	76.2	77.9	49.2	28.8	22.0
Upper Side Int.	Head	2.0	59.1	65.2	87.2	56.1	13.7	30.2
	All	2.8	62.0	68.7	86.4	56.9	14.8	28.3
Hdr. & Side Rail	Head	3.9	9.4	31.6	36.8	83.7	9.6	6.7
	All	4.5	13.9	39.9	44.3	82.9	10.9	6.2
Roof	Head	1.8	----	----	----	76.1	19.7	4.2
	Neck	1.7	----	----	----	80.1	16.8	3.1
	All	3.9	----	----	----	76.9	18.3	4.8
Seat Backs	Abdomen	1.7	----	----	----	0.7	0.1	99.2
	Cheat & Back	1.6	----	----	----	18.3	5.1	76.6
	All	4.8	----	----	----	11.2	3.4	85.4
Other Interior	Pelvis & L. Extr.	2.0	----	----	----	78.1	16.3	5.6
	All	4.7	----	----	----	64.8	21.0	14.2
Noncontact	Neck	2.9	65.0	73.7	74.0	74.3	20.8	4.9
	Chest & Back	1.9	57.4	60.7	60.8	83.1	12.3	4.6
	All	6.2	57.7	73.2	73.5	74.9	19.3	5.8
Exterior	Head	4.3	----	----	----	70.0	7.1	22.9
	All	6.2	----	----	----	73.1	7.9	19.1

Table III. Percent of Harm for Frontal Impacts
Body Region by Injury Source

BODY REGION	INJURY SOURCE	HARM % OF TOTAL
Chest	Steering Assembly	26.6
	All	27.9
Head	Windshield	5.5
	Header	2.8
	A-Pillar	2.2
	Exterior	2.0
	Steering Assembly	1.6
	All	16.4
Abdomen	Steering Assembly	14.2
	All	14.6
Lower Extremities	Instrument Panel	9.5
	Other	2.1
	All	13.4
Face	Steering Assembly	5.3
	Windshield	5.2
	All	12.9
Neck	Windshield	3.4
	Non-contact	1.2
	Steering Assembly	1.0
	All	5.9
Upper Extremities	Steering Assembly	2.3
	Instrument Panel	1.1
	All	4.8

Table IV. Accident Data - Unweighted Cases (NASS 1979 to 1984)

	Unweighted Cases
- Occupants with serious injury (AIS 3+)	1,007
- Drivers with serious injury	693
- Drivers with serious injury and known delta-v	443
- Drivers with serious chest injury from steering assembly and known delta-v	114

DELTA-V (MPH)	
0 - 15	12
16 - 25	40
26 - 35	35
36 - 45	19
46 +	8

Table V. Representative Vehicles

	VEHICLE	% FLEET
1.	76-80 ASPEN/VOLARE	3.4
2.	77-81 LEBARON/CORDOBA/IMPERIAL	0.7
3.	75-76 DART/VALIANT	0.9
4.	78-81 OMNI/HORIZON	1.7
5.	75-80 PINTO/BOBCAT	1.7
6.	78-81 FAIRMONT/ZEPHYR	1.9
7.	79-81 MUSTANG/CAPRI	1.6
8.	79-81 FORD/MERCURY	1.1
9.	81 GRANADA/MONARCH	0.2
10.	80-81 T-BIRD/COUGAR	0.4
11.	78-81 MALIBU/CUTLASS/ETC.	9.4
12.	77-81 CHEVROLET	3.1
13.	80-81 CITATION/ETC.	3.2
14.	77-81 LESABRE/ELECTRA/ETC	4.7
15.	75-80 MONZA/SUNBIRD/ETC.	1.8
16.	75-79 NOVA/SKYLARK/ETC.	3.6
17.	76-81 CHEVETTE/T1000	3.0
18.	75-81 CAMARO/FIREBIRD	3.6
19.	75-81 HONDA CIVIC	1.5
20.	75-81 TOYOTA COROLLA	2.8
21.	75-81 SUBARU	1.1
22.	75-81 DATSUN	2.7
23.	79-81 VW RABBIT	0.8
24.	83 FUEGO	NA
25.	83 CONCORD	NA
26.	83 CELEBRITY	NA
27.	83 HONDA ACCORD	NA

Table VI. Trends of Simulation Results

Variable	Effect on Harm: Good	Effect on Harm: Bad
Chest		
EA Column	Moderate EA	Low EA
EA Force	Low	High
EA Friction	Low	High
Hub Recess	Fairly Deep	Shallow
Wheel and Column Mass	Low	High
Column Damping	Low	High
Abdomen		
Hub Recess	Shallow	Deep
Lower Rib Force	Low	High
Lower Rim Stroke	Long	Short
Head		
Windshield Force	Low	High
Windshield EA	Moderate	Low
Upper Rim	Low	High
Header	Low	High

TABLE VII

Force Deflection Properties
Baseline, Benefit 1 and Benefit 2

	Knee Panel		Lower Rim Tangent		Lower Rim Radial		Hub		EA Column	
	Force	Defl.	Force	Defl.	Force	Defl.	Force	Defl.	Force	Defl.
	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
	800.	1.5	200.	0.6	95.	0.13	400.	0.4	300.	0.2
Baseline	2750.	4.0	250.	0.9	520.	0.37	750.	0.6	60.	1.7
	3500.	6.5	330.	2.0			2500.	0.92	980.	3.7
	3600.	8.2	350.	3.6			4000.	1.1	790.	4.1
									1200.	6.0
	0.	0.0	0.	0.0	0.	0.0	0.	0.0	0.	0.0
	200.	0.75	250.	0.5	250.	1.0	300.	1.0	800.	2.0
Benefit 1	500.	3.0	350.	10.0	500.	5.0	500.	5.0	1200.	3.0
	1200.	5.0					2000.	5.5	1250.	8.0
	3000.	12.0							1600.	8.5
									5000.	9.0
			0.	0.0	0.	0.0	0.	0.0	0.	0.0
			250.	1.2	620.	0.5	450.	0.3	1300.	0.2
Benefit 2			400.	2.6	500.	0.8	680.	0.7	750.	1.1
			470.	3.7	380.	1.5	760.	0.9	1000.	2.0
			510.	4.7	360.	1.9	800.	1.2	670.	3.3
									680.	5.0
									1000.	5.3
									100.	6.0

Safety Systems Optimization Model

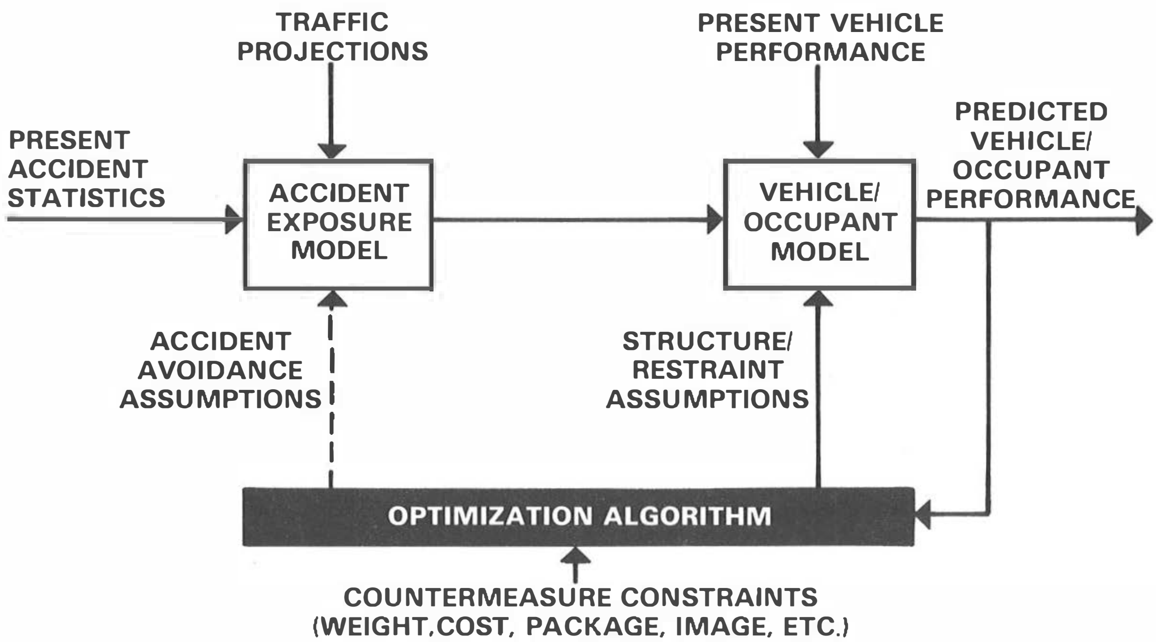

Figure 1

Distribution of Delta V Seriously Injured Drivers

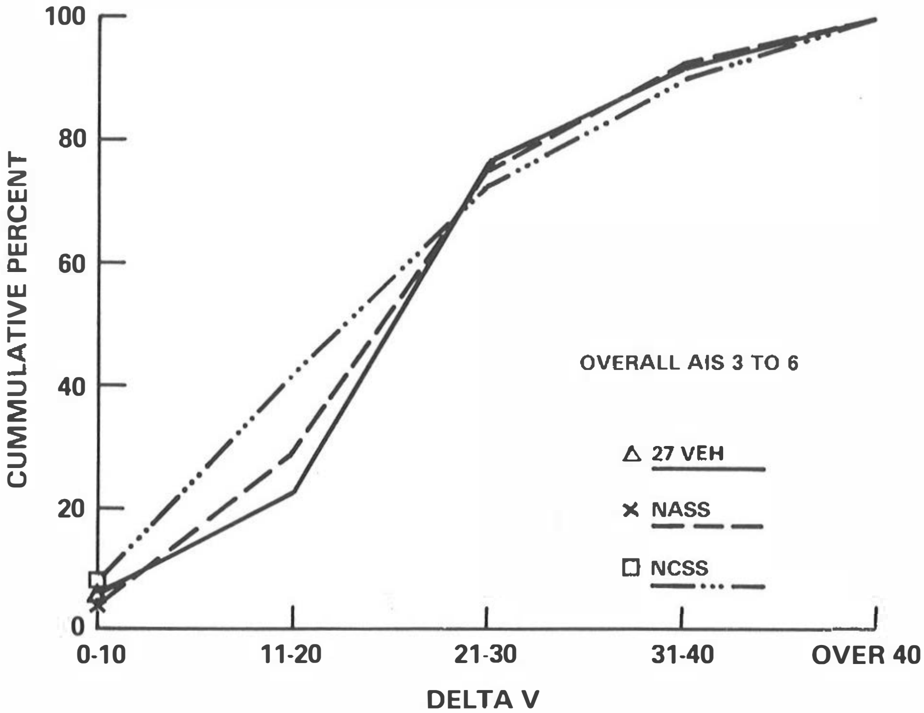

Figure 2

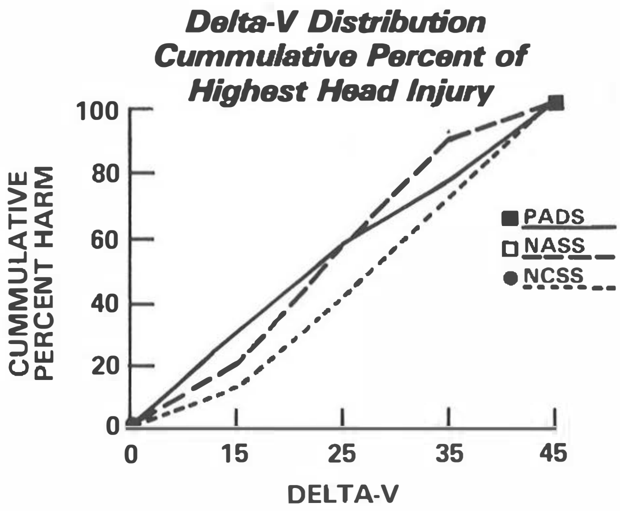

Figure 3

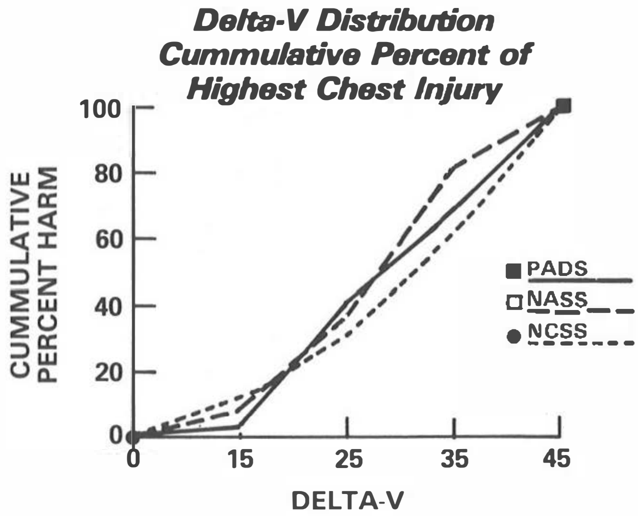

Figure 4

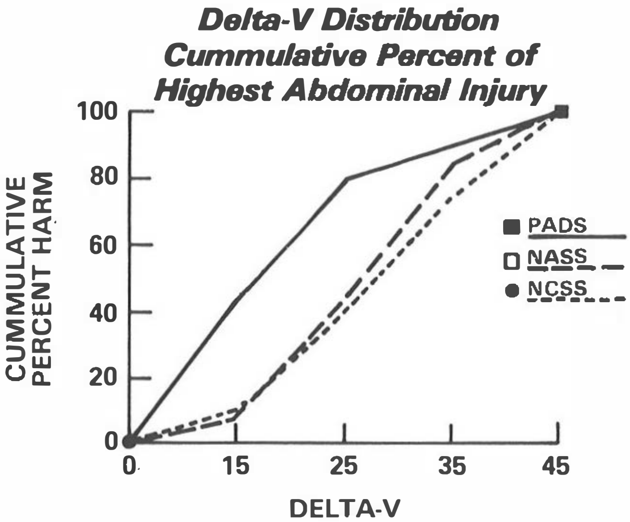

Figure 5

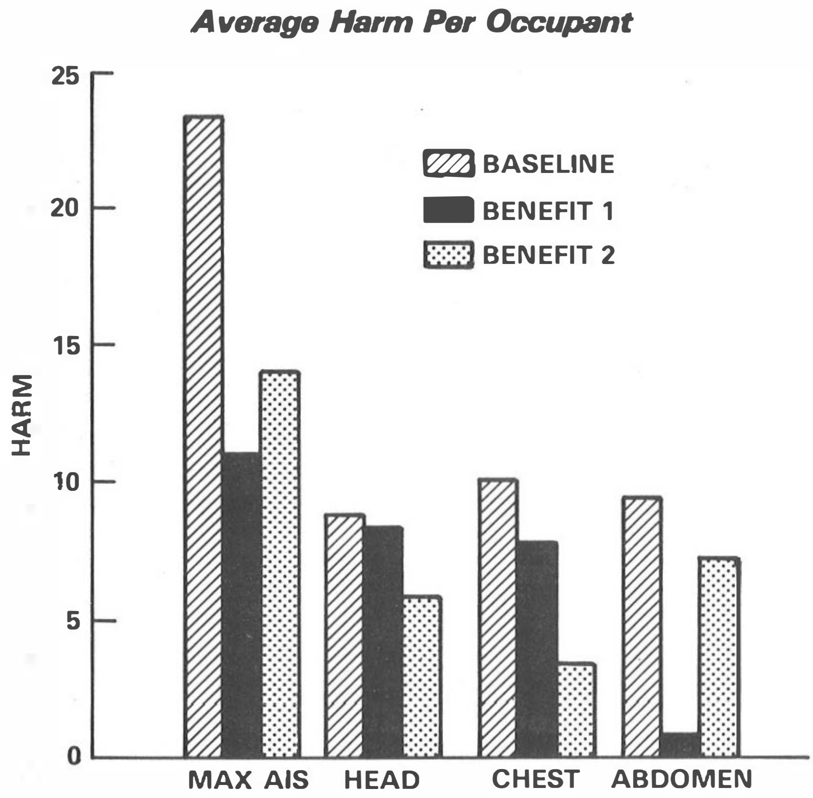
Average Harm Per Occupant
25
20
15
10
5
0
HARM
BASELINE
BENEFIT 1
BENEFIT 2
MAX AIS
HEAD
CHEST
ABDOMEN

Figure 6