

The Likelihood of Human Casualty in Highway Crashes -- Fifteenth Briefing: Two of the Summary Papers

**Based on an Investigation Conducted for
the FHWA/NHTSA Crash Analysis Center
at George Washington University, Virginia**

**January 22, 1997
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Washington, D.C.**

Relationships between Crash Casualties and Crash Attributes

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ABSTRACT

This work addresses and evaluates the likelihood of human casualty in highway crashes, projected on the basis of field crash data that may become available electronically by sensors at crash time, and/or observed at the crash scene by emergency attendants. Termed collectively as a "crash signature", such data are treated as predictors and are selected from: crash severity, general area of damage, direction of force, occurrence of rollover, intrusion, vehicle crush and its specific horizontal location, collision partner, vehicle class and size, occupant age, gender, restraint use and type, seating position, and other. Crash signatures are converted into responses such as: (a) the likelihood of the most severe outcome, fatality or survived injury, by severity AIS per occupant; and (b) the same per vehicle. Cars are the vehicles selected for this investigation. A likelihood is quantified by a probability of occurrence, as a function of a string of predictors selected for maximum resolution and sensitivity, and minimum contribution to error. Likelihood determinations are performed via maximum likelihood based logistic regressions, best suited for treating dichotomous responses: "yes or no" such and such a response or outcome. Each likelihood is accompanied by a standard error or by upper and lower confidence bounds, and each procedure is evaluated by

pertinent scores. All cited procedures and findings are based on the data of the National Accident Sampling System (NASS) files 1988-1995, compiled by the National Highway Traffic Safety Administration (NHTSA). This provides a nationally representative sample of about 95,000 crash involved car occupants, and 190,000 incurred injuries, all with attributes that collectively encompass as a minimum the predictors and responses cited earlier. The paper provides pertinent predictive relations which, notwithstanding complexity, are fully programmable. Probabilities of specific outcomes may vary from nearly zero to virtually 100%, depending on circumstances. Detailed and illustrative findings are presented in tabular and graphic forms.

INTRODUCTION

The advent of high volume highway accident records, many of them nationally representative and of a research caliber, addressing a broad spectrum of crash, vehicle, occupant, and casualty attributes, makes it easier now to address and evaluate several important issues in highway safety.

At the same time, the wide scope and the complexities of the available data point to the need for developing ways and means in order to

capture the essential aspects of the highway crash environment in a succinct and insightful fashion. The purpose of this paper is to take a first cut in responding to the cited need.

BASIC DATA

The data compiled in the eight years, 1988-1995, of NASS/CDS are the basic data used. The NASS weights, necessary for national projections, are used as weighing factors in any data processing procedure.

Many outcomes and their severity may be considered individually or in combinations for the purpose of human casualty prediction. Also many crash, car, occupant, and injury attributes are in principle available in the accident experience to assist, as predictors, in the derivation of said algorithms on the basis of a crash signature. The number and type of predictors are often limited by practical considerations imposed by the type of contemplated applications, the strength of probability—predictor correlation, and by the amount and quality of available data for the derivation of the algorithms.

NOMINAL PROCEDURE FOR TREATING THE RAW DATA

In view of the dichotomous nature of the outcomes at issue (e.g. "Yes" or "No" Fatality or MAIS 3+) a maximum likelihood procedure, specifically a logistic regression with weighing factors, is used to fit various algorithms to the raw data. Essentially, the probability of casualty is projected as:

$$P = 1 / [1 + \exp(-w)] \quad (1)$$

$$w = A_0 + A_1 \cdot \text{PRED1} + A_2 \cdot \text{PRED2} + \dots \quad (2)$$

where PRED1, PRED2, etc are the selected predictors; and A0, A1, A2, etc are coefficients estimated by the logistic regression.

When dealing with analyses of data from the NASS, it must be taken into account that this file contains a sample as opposed to a census of national data. In order to deal with this, the applicable statistical procedures are those prescribed in "Survey Data Analysis" (SUDAAN) software, Research Triangle Institute, Research

Triangle Park, North Carolina, 1992. Such procedures are applicable in the analysis of data from multi-stage sample designs, like that of the NASS.

ESTIMATION OF STANDARD ERRORS AND CONFIDENCE BOUNDS

The SUDAAN logistic procedure yields values for coefficients: A0, A1, A2, etc appearing in (2). The same procedure provides also the covariance matrix: COV(Ai, Aj). This helps in the calculation of the variance of the argument w of the probability appearing in (1). Specifically, the variance of w is given by:

$$\text{var}(w) = \sum [\text{Cov}(A_i, A_j) \cdot x_i \cdot x_j] \quad (3)$$

over all i and j

Note that i or j assume the values: 0, 1, 2, etc, corresponding to the intercept and the predictors appearing in relation (2). When an analyst assigns desirable values to xi and xj, an application of (3) yields the variance: var(w).

Moreover, to a first approximation, the variance of the probability (1) is given by:

$$\text{var}(P) = \{\exp(-2w) / [1 + \exp(-w)]^4\} \cdot \text{var}(w) \quad (4)$$

and the standard error of P is:

$$\text{seP} = \text{square root} [\text{var}(P)] \quad (5)$$

Also to a first approximation, the 95% confidence bounds of P are given by: $P \pm (1.96 \cdot \text{seP})$

ADDRESSED PREDICTORS

In this paper the basic data, i.e. data concerning car occupants involved in towaway crashes, are used for the derivation of algorithms that estimate: (a) the probability of a crash involved occupant being a fatality; (b) the probability of a crash involved occupant with at least one injury of maximum severity MAIS 3+; and (c) the probability of a crash involved occupant with at least one injury of MAIS 2+. Extension to other outcome populations is readily evident. Short notation for the predictors addressed in developing algorithms is given below:

ONEVEH Single Car Crash
 BIGTRK Collision with Large Vehicle
 ROLL Planar Crash with Rollover Occurrence
 DELTAV Total Delta V, mph
 GADSP Side Damage, Passenger Compart.
 GADSNP Side Damage, Excluding Passenger
 Compartment
 GADB Rear Damage
 DOFS Direction of Force: 8-10 & 2-4 O'Clock
 DOFB Direction of Force: 5-7 O'Clock
 MAXC Maximum Crush, inches
 INTRU Intrusion, 6 inches or more, in Front
 CURBWT Car Curb Weight, in 100 lbs
 FRPAX Right Front Seat Passenger
 RRPAX Rear Seat Passenger
 BELT Safety Belt Use
 BEBA Air Bag Deployment & Belt Use
 AGE Car Occupant's Age
 FEMALE Occupant's Gender
 OCCWT Occupant's Weight, lbs
 OCCHT Occupant's Height, inches
 ENTRP Entrapment
 EJC Complete Ejection
 EJP Partial Ejection

These predictors are alternatives and operate in conjunction with a baseline that addresses unrestrained male car drivers, in primarily planar and frontal crashes with other cars. Thus, given the cited baseline, the only two alternatives addressed above for a collision partner are: ONEVEH and BIGTRK. Similarly GADSP, GADSNP, and GADB are the alternatives to frontal damage included in the baseline. Top damage is not addressed because of a relatively low incidence.

In fact it is important to note that rollover in general is not included in the development of the algorithms at issue. This is necessitated by the desire to include Delta V as a most influential parameter. This parameter is not defined in general rollover. Thus, predictor ROLL appearing in the above list covers the crashes which are initially planar, with a possible subsequent rollover.

Other implicitly understood alternatives not named in the above list are: direction of force 11 to 1 O'Clock, driver's seat, no restraint use, male occupant, and no ejection. These are baseline attributes. Most other attributes are either binary (yes or no), or continuous.

PROGRAMMABLE ALGORITHMS

Optimal algorithms are presented below in order of increasing complexity. Relation (1) is always the basic platform. The simplest way of formulating the exponent "w" is in terms of DELTA V, the most influential parameter, as shown below:

$$w = A0 + A1 \cdot \text{DELTAV} \quad (6)$$

where DELTAV=Total Delta V in mph continuously.

The logistic regression (1) and (6) applied on the basic data, seeking the probability for fatality or MAIS 3+ or MAIs 2+, yields the coefficients A0 and A1 and the associated standard errors, with numerical values shown in the first cluster of Table I. Next we address the more complex, but still relatively simple, fit shown in (7) below:

$$w = A0 + A1 \cdot \text{DELTAV} + A2 \cdot \text{DOFS} + A3 \cdot \text{DOFB} \quad (7)$$

where in addition to DELTAV we include:

DOFS = 1 if the direction of force is 8-10 or 2-4 O'Clock, else DOFS=0;

DOFB = 1 if the direction of force is 5-7 O'Clock, else DOFB=0; and if DOFS=DOFB=0 then the direction of force is 11 to 1 O'Clock.

Numerical values for the coefficients A0, A1, A2, and A3 appear in the second cluster of Table I.

In a similar fashion we augment the resolution of the algorithms by including additional predictors as shown in the following three progressively complex cases:

$$w = A0 + A1 \cdot \text{DELTAV} + A2 \cdot \text{DOFS} + A3 \cdot \text{DOFB} + A4 \cdot \text{AGE} + A5 \cdot \text{BELT} + A6 \cdot \text{BEBA} \quad (8)$$

$$w = A0 + A1 \cdot \text{DELTAV} + A2 \cdot \text{DOFS} + A3 \cdot \text{DOFB} + A4 \cdot \text{ROLL} + A5 \cdot \text{FRPAX} + A6 \cdot \text{RRPAX} + A7 \cdot \text{AGE} + A8 \cdot \text{BELT} + A9 \cdot \text{BEBA} \quad (9)$$

$$\begin{aligned}
 w = A0 + A1 \cdot \text{ONEVEH} + A2 \cdot \text{BIGTRK} + A3 \cdot \text{ROLL} \\
 + A4 \cdot \text{DELTAV} + A5 \cdot \text{GADSP} + A6 \cdot \text{GADSNP} \\
 + A7 \cdot \text{GADB} + A8 \cdot \text{MAXC} + A9 \cdot \text{INTRU} \\
 + A10 \cdot \text{CURBWT} + A11 \cdot \text{FRPAX} + A12 \cdot \text{RRPAX} \\
 + A13 \cdot \text{BELT} + A14 \cdot \text{BEBA} + A15 \cdot \text{AGE} \\
 + A16 \cdot \text{FEMALE} + A17 \cdot \text{OCCWT} + A18 \cdot \text{OCCHT} \\
 + A19 \cdot \text{ENTRP} + A20 \cdot \text{EJC} + A21 \cdot \text{EJP} \quad (10)
 \end{aligned}$$

where in addition to predictors defined earlier, AGE = occupant's age in years continuously; BELT = 1 if a safety belt is in use; else BELT=0; BEBA = 1 if an air bag deploys in addition to a safety belt in use; else BEBA=0;

ROLL = 1 if car rollover occurs; else ROLL=0;
 FRPAX = 1 if the occupant is in front seat right;
 else FRPAX=0;
 RRPAX = 1 if the occupant is in rear seat;
 else RRPAX=0;
 if FRPAX=RRPAX=0 then we deal with
 the driver;
 ONEVEH = 1 if this is a single car crash;
 else ONEVEH=0;
 BIGTRK = 1 if the collision partner is a big truck;
 else BIGTRK=0;
 if ONEVEH=BIGTRK=0 then
 the collision partner is a car;
 GADSP = 1 if the damage area is on the car's
 side and includes the passenger's
 compartment; else GADSP=0;
 GADSNP = 1 if the damage area is on the car's
 side but excludes the passenger's
 compartment; else GADSNP=0;
 GADB = 1 if the damage area is rear; else
 GADB=0;
 MAXC = maximum crush, in inches continuously;
 INTRU = 1 if 6 inches or more intrusion occurs
 in the front compartment;
 else INTRU=0;
 FEMALE = 1 if the occupant is female; else
 FEMALE=0;
 OCCWT = occupants weight in lbs continuously;
 OCCHT = occupants height in inches
 ENTRP = 1 if entrapment occurs; else
 ENTRP=0;
 EJC= 1 if a complete ejection occurs; else
 EJC=0;
 EJP=1 if a partial ejection occurs; else EJP=0;
 if EJC=EJP=0 then No Ejection Occurs.

Numerical values for the coefficients appearing in relations (8), (9), and (10) may be found in the third, fourth, and last cluster of Table I, respectively.

Note in the results shown in Table I that most predictors are **binary**, except for such predictors as Delta V, Age, etc which are continuous variables. The magnitude of coefficients for such continuous predictors must be interpreted in conjunction with the units of their measurement. Thus the coefficient value of 0.177 for Delta V in Table I (A) goes along with a Delta V in mph. It represents the increase per mph of the corresponding term in the algorithm. Similarly coefficients associated with: age, maxc, curbw, occwt, and occht elsewhere in the cited Table

must be interpreted on a basis of: per each year of age, per each inch of crush, per each 100 lbs of car curb weight, per each lb of an occupant's weight, and per each inch of an occupant's height, respectively.

GOODNESS OF FIT AND PREDICTED V. OBSERVED OUTCOMES

A car's crash severity, Delta V, is such a strong determinant of occupant casualty outcome that it covers most of the variability observed in the field experience with relatively small errors. See for example Table I (A). Nevertheless, both the predictive resolution of an algorithm, and the goodness of the fit to the field data improve as further predictors are included, even if they are less influential than Delta V.

However beyond a certain point, diminishing returns become evident as may be seen in the progression of algorithm complexity, from (A) to (E) in Table I. As more predictors are included in the analysis, some prove to be quite marginal, given that the error of their coefficient assumes values comparable to the coefficient proper. Thus caution is recommended in order to avoid misleading results and conclusions. Except for predictors with coefficient errors approaching the coefficient values, all predictors and all algorithms shown in Table I have been found statistically highly significant, on the basis of various statistical scores. Said algorithms account for most of the variability observed in the field experience. Discernible improvements are evident as one progresses from (A) to (C) in Table I, but beyond that point, further improvements are marginal and they may be misleading.

Quantitatively speaking, the bottom line for taking or not taking into account the influence of a predictor is the magnitude of the error relative to the coefficient of the predictor at stake.

In addressing the association of predicted probabilities of a certain outcome with actually observed outcomes we determined that the percentage of correct predictions varies from about 75% to 96%, depending on algorithm complexity and severity of predicted outcome. In addition, we used a score known as Somer's D that measures association on a 0 to 1 scale (no

association to perfect association). For the algorithms that project probability of fatality (A to E in Table I) the cited indicator was found to have values: 0.686, 0.727, 0.801, 0.803, and 0.850, respectively. The corresponding values for MAIS 3+ outcome are: 0.587, 0.626, 0.686, 0.691, and 0.748, respectively.

NUMERICAL APPLICATIONS & ILLUSTRATIONS

The probability of fatality among towaway crash involved car occupants, without any further qualification, is about 0.6%. For injured occupants at MAIS 3+, or at MAIS 2+ the probability is: 6.8% and 14.7%, respectively. These may be considered as alternative statements for casualty rates per 100 occupants.

Each of these rates may be resolved by crash severity, Delta V, with the help of algorithm (6). The results of this resolution are shown in Fig. 1. Further resolution, i.e. by direction of force in addition to Delta V, is provided when algorithm (7) is applied. Figure 2 illustrates results relevant to MAIS 3+. A similar algorithm may provide resolution by Delta V and restraint use and type. Results concerning MAIS 3+ are illustrated in Fig. 3. Resolution by Delta V and occupant's age is illustrated in Fig. 4.

The results obtained via relatively simple algorithms, as illustrated in Figs 1 to 4, could equally well and perhaps more appropriately be obtained from more complex algorithms that encompass the predictors at stake in the cited figures, plus additional predictors that could be influential.

More complex algorithms can be applied for obtaining results concerning one or a few predictors of immediate interest, with stipulated values. In practice this method is applied to a multi-predictor algorithm by assigning to predictors, other than those of immediate interest, their mean values on the basis of the field experience. The advantage of using this more cumbersome method is that the additional predictors are frozen at values common to the entire population under consideration, something that helps minimize possible confounding effects. It is also understood that no additional predictors should be entertained unless they have

statistically significant coefficients, i.e. small errors.

MULTI-PREDICTOR ALGORITHMS

Very long and cumbersome algorithms may result if one insists on including many interesting and available predictors, even if all are statistically significant. Applications and results may become intractable. For this reason we developed a good approximation to the projection of a casualty probability on the basis of a known coefficient, without having to make a full application of a cumbersome algorithm. As a first approximation, the following relation holds:

$$\Delta P = P(1-P)A \quad (11)$$

where ΔP is the casualty probability increment resulting from the inclusion of a predictor with coefficient A, in any case where a probability P has been projected in the absence of said predictor. Note that in relation (11) the probability P and the increment ΔP are on a 0 to 1 basis, as opposed to 0 to 100%. Also note that the increment becomes a reduction when coefficient A is negative.

It is evident that the increment or reduction varies from zero, at $P=0$, to a maximum at $P=0.5$, and back to zero at $P=1$. For convenience, relation (11) is graphically illustrated in Fig. 5, for four different values of regression coefficients: 0.25, 0.50, 1.0, and 2.0. Other values are readily obtained by interpolation.

The primary application of (11) is to assist in the quantification of effects described by the coefficients of multipredictor algorithms, such as those appearing in Table I (D) and (E). It is evident that (11) should be applied stepwise, especially when an one step application leads to the absurd result of $(P+\Delta P) > 1$. For the same reason (11) is applicable to individual evaluations, as opposed to an evaluation of several influences combined.

REVIEW OF THE RESULTS

It is informative to review the numerical results obtained by the algorithms in this paper, in comparison with results known from earlier and independent studies concerning factors that

influence the rates, or probabilities, of casualty. Note, for example in Fig. 1, that the probability of MAIS 3+ is about 50%, consistent with a widely held benchmark.

Resolution by direction of force, see Fig. 2, shows the 8-10 and 2-4 O'Clock impacts to dominate the threat of serious casualty, with the 11-1 O'Clock impacts second, and the 5-7 O'Clock impacts in the familiar distant third rank.

As recognized in several restraint effectiveness studies, the effectiveness of restraints is about 50% from about 10 or 15 mph DeltaV to about 30 mph. Thereafter, the effectiveness starts declining and becomes negligibly small at high crash severities. This is readily evident in the algorithm results shown in Fig. 3.

The small superiority seen for "belt & air bag" v. "belt only" in Fig. 3 is actually substantially larger when the results are controlled for possible confounders beyond crash severity only. This is evident in the relevant coefficients appearing in multi-predictor algorithms such as those shown in Table I (C) to (E).

Furthermore, by comparing the relevant restraint coefficients as a function of casualty severity, it appears that the superiority of "belt & air bag" v. "belt only" is dominant at high casualty severities, e.g. fatalities or MAIS 3+, but declines at lower severities, e.g. MAIS 2+. This situation, although still confused by the accompanying statistical uncertainties, is consistent with the notion that the air bag is very effective in preventing high severity injuries although it may cause lower severity injuries.

The multipredictor algorithm (10), with coefficients shown in Table I (E), reveals quantitatively several factors of strong influence, fully consistent with qualitative notions held intuitively. Beyond Delta V, age, and restraint use or type discussed earlier, strong influences are seen here associated with rollover, ejection (whether complete or partial), with entrapment, intrusion, and maximum crush. Recall that positive coefficients are associated with an increase of casualty probability that may be approximately, and one at a time, estimated via (11).

Such an estimation is illustrated in Fig. 6 for the strong influences cited above. Most other influences, as implied by their coefficients in Table I (E), are either weak when considered in conjunction with strong influences, or are not significant in view of the accompanying standard error.

CONCLUSIONS

Research reported in this paper, although still not fully mature, provides useful applications in succinct and insightful descriptions of the car crash environment. In addition, several further applications may be anticipated. For example, practitioners of post-crash emergency care for traffic accident casualties, from emergency vehicle dispatch centers to trauma centers and hospitals, could benefit from ways of projecting casualty severity on the basis of a crash signature.

Such adjunct information could supplement anatomical and physiological information, currently used, in order to enhance the timeliness and appropriateness of emergency care decisions. This is especially applicable if the additional information becomes available at crash time, well before the emergency care complex is fully activated. Essentially, the advent of high tech, low cost sensors and electronics that may soon be carried on cars and other vehicles, could allow the transmission, at crash time, of crucial information concerning crash circumstances, crashed vehicle(s), and crash involved occupants.

Irrespective of electronic acquisition of crash signatures at crash time, as discussed above, very similar information could be retrieved and transmitted by emergency attendants after they reach the crash scene. It becomes then a matter of translating this information into data useful to dispatch and emergency teams, either ready to attend the accident scene, or preparing for appropriate treatment(s) in emergency facilities. This paper has addressed and evaluated the state-of-the-art in translating advance notification data, either from vehicle mounted sensors at crash time, or from emergency attendants at the scene.

ACKNOWLEDGEMENT

The authors, solely responsible for the analyses, evaluations, and conclusions presented herein, acknowledge thankfully that this investigation has been supported by the Federal Highway Administration's / National Highway Traffic Safety Administration's National Crash Analysis Center at George Washington University

Table I. Logistic Regression Coefficients and Standard Errors

(A)	Fatality		MAIS 3+		MAIS 2+	
	Ai		Ai		Ai	
Predictor	Coeffcint	Std Error	Coeffcint	Std Error	Coeffcint	Std Error
Intercept	-8.252	0.326	-5.450	0.157	-3.761	0.148
DELTAV	0.177	0.011	0.178	0.010	0.136	0.011

(B)	Fatality		MAIS 3+		MAIS 2+	
	Ai		Ai		Ai	
Predictor	Coeffcint	Std Error	Coeffcint	Std Error	Coeffcint	Std Error
Intercept	-9.032	0.259	-5.820	0.139	-4.029	0.115
DELTAV	0.198	0.010	0.202	0.006	0.155	0.006
DOFS	1.462	0.189	0.556	0.099	0.465	0.083
DOFB	-1.921	0.343	-2.170	0.307	-1.177	0.245

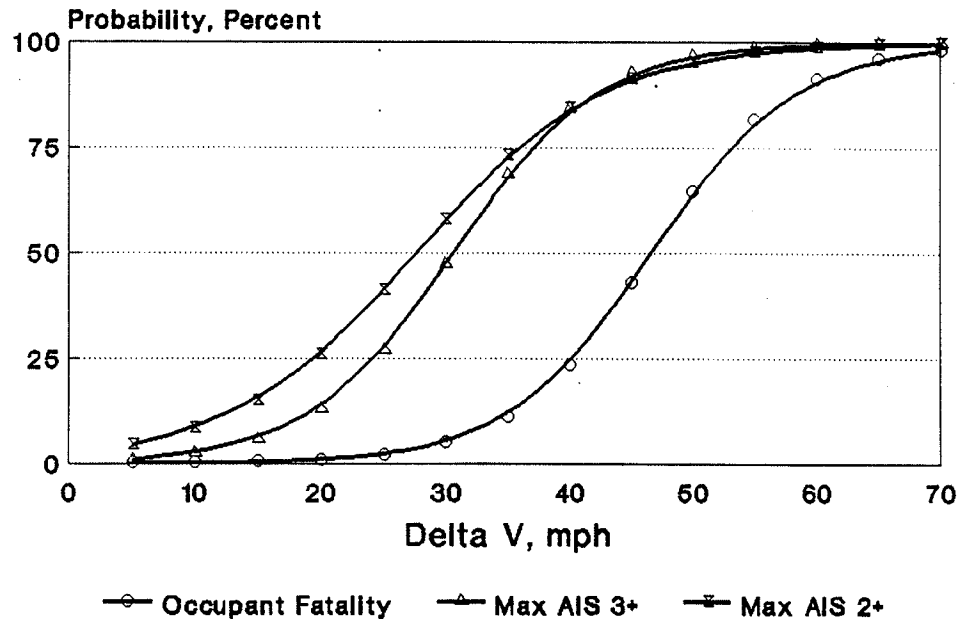
(C)	Fatality		MAIS 3+		MAIS 2+	
	Ai		Ai		Ai	
Predictor	Coeffcint	Std Error	Coeffcint	Std Error	Coeffcint	Std Error
Intercept	-10.830	0.293	-6.538	0.213	-4.393	0.143
DELTAV	0.211	0.009	0.208	0.007	0.157	0.006
DOFS	1.301	0.196	0.457	0.101	0.403	0.087
DOFB	-1.716	0.303	-2.025	0.240	-1.060	0.194
AGE	0.051	0.004	0.033	0.002	0.026	0.002
BELT	-0.859	0.234	-0.826	0.098	-0.839	0.082
BEBA	-1.478	0.684	-1.564	0.325	-1.001	0.330

(D)	Fatality		MAIS 3+		MAIS 2+	
	Ai		Ai		Ai	
Predictor	Coeffcint	Std Error	Coeffcint	Std Error	Coeffcint	Std Error
Intercept	-11.144	0.366	-6.710	0.211	-4.449	0.152
DELTAV	0.211	0.009	0.208	0.006	0.157	0.006
DOFS	1.298	0.203	0.432	0.102	0.397	0.087
DOFB	-1.781	0.317	-2.049	0.242	-1.068	0.195
ROLL	1.280	0.322	1.758	0.237	1.339	0.271
FRPAX	0.890	0.323	0.251	0.113	0.156	0.100
RRPAX	-0.186	0.350	0.263	0.231	0.016	0.149
AGE	0.053	0.005	0.035	0.002	0.026	0.002
BELT	-0.887	0.224	-0.811	0.095	-0.840	0.081
BEBA	-1.353	0.667	-1.518	0.327	-0.990	0.334

Table I Cont'd. Logistic Regression Coefficients and Standard Errors

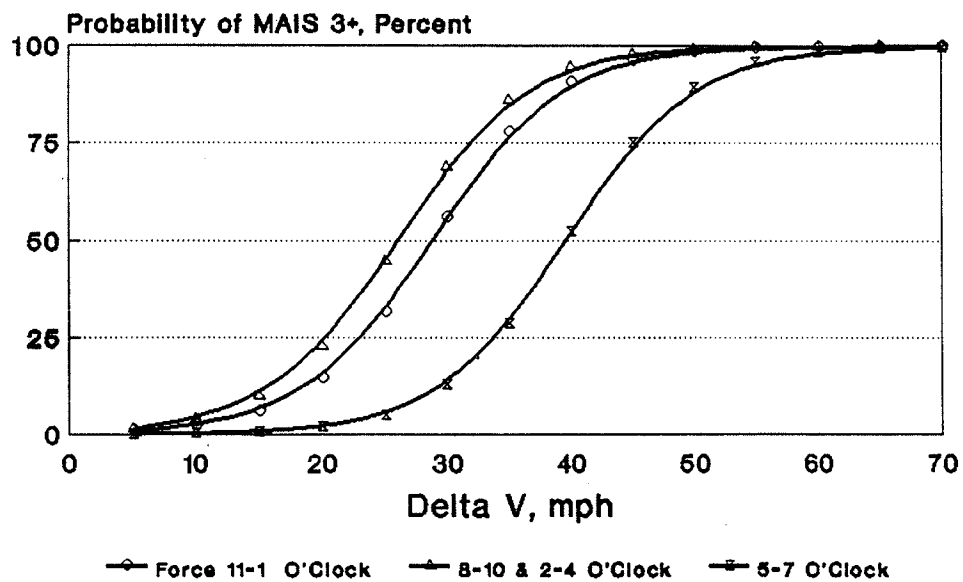
(E) Rel (10) Predictor	Fatality		MAIS 3+		MAIS 2+	
	Ai Coefficient	Std Error	Ai Coefficient	Std Error	Ai Coefficient	Std Error
Intercept	-11.901	3.094	-6.118	0.703	-4.584	0.600
ONEVEH	0.259	0.230	0.322	0.152	0.155	0.134
BIGTRK	0.312	0.280	0.002	0.124	0.084	0.132
ROLL	0.764	0.357	1.157	0.284	1.086	0.316
DELTAV	0.135	0.014	0.164	0.010	0.126	0.010
GADSP	1.113	0.224	0.219	0.131	0.260	0.122
GADSNP	-0.076	0.496	0.057	0.241	0.256	0.183
GADB	-2.046	0.553	-1.793	0.254	-1.237	0.206
MAXC	0.056	0.011	0.037	0.007	0.039	0.007
INTRU	1.076	0.335	0.807	0.128	0.648	0.119
CURBWT	-0.012	0.031	-0.027	0.009	-0.031	0.008
FRPAX	1.034	0.341	0.232	0.138	0.017	0.118
RRPAX	0.348	0.347	0.103	0.203	-0.209	0.164
BELT	-0.512	0.275	-0.650	0.111	-0.691	0.093
BEBA	-1.341	0.405	-1.356	0.373	-0.698	0.400
AGE	0.060	0.005	0.042	0.003	0.030	0.003
FEMALE	0.334	0.268	0.464	0.115	0.396	0.102
OCCWT	0.002	0.004	0.003	0.002	0.001	0.002
OCCHT	-0.004	0.038	-0.014	0.011	-0.000	0.009
ENTRP	0.932	0.294	2.378	0.480	2.358	0.511
EJC	2.896	0.506	1.859	0.838	1.270	0.886
EJP	1.915	0.368	1.468	0.368	1.166	0.414

Fig. 1. Probability of Shown Outcome,
as a Function of Car Crash Severity



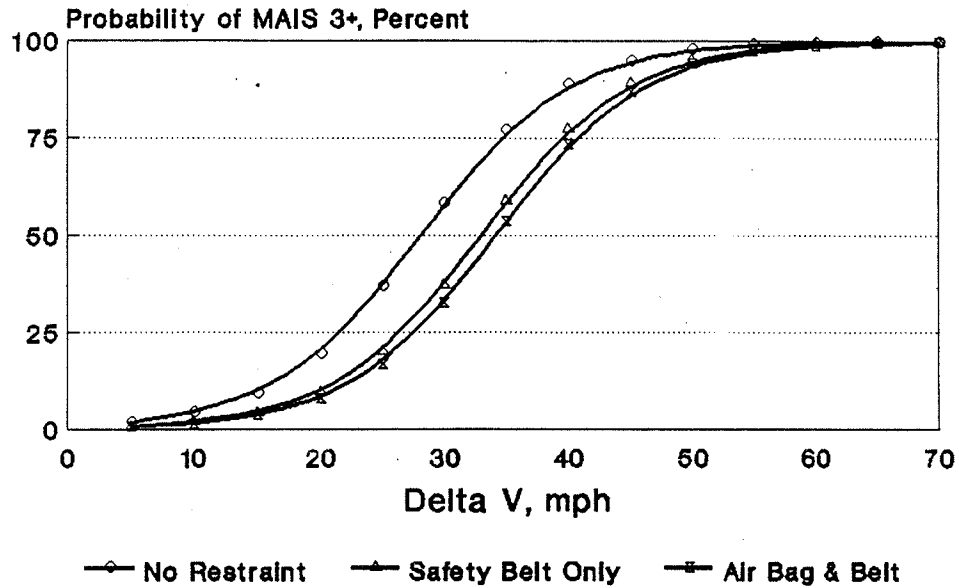
The NASS/CDS 1988-1995

Fig. 2. Sensitivity of Max AIS 3+
to the Direction of Force,
as a Function of Car Crash Severity



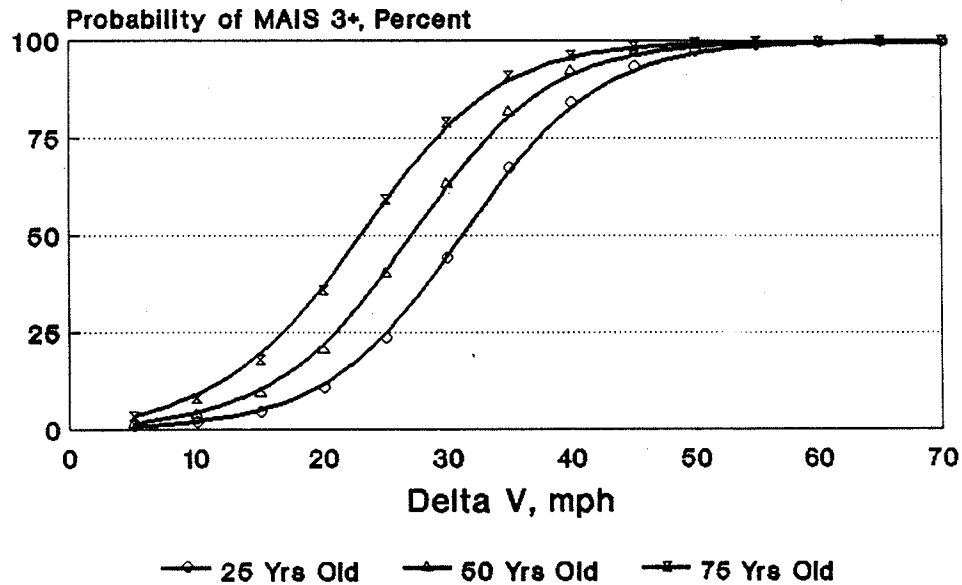
The NASS/CDS 1988-1995

Fig. 3. Sensitivity of Max AIS 3+
to an Occupant's Restraint Use and Type,
as a Function of Car Crash Severity



The NASS/CDS 1988-1995

Fig. 4. Sensitivity of Max AIS 3+
to an Occupant's Age,
as a Function of Car Crash Severity



The NASS/CDS 1988-1995

Fig. 5. Sensitivity of Casualty Probability to Shown Values of a Logistic Regression Coefficient

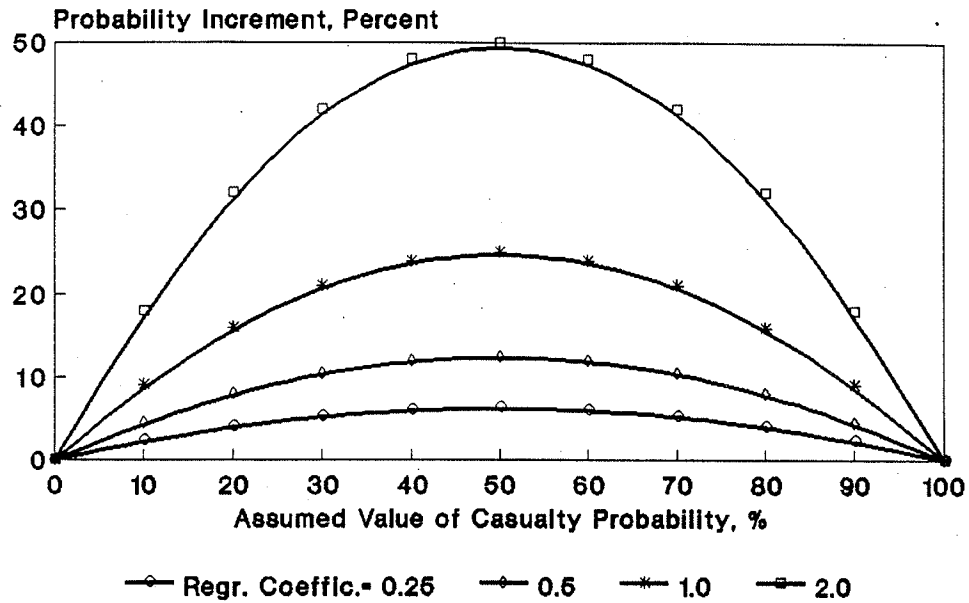


Fig. 6. Increase of MAIS 3+ Probability over Shown Base, Due to Shown Influences

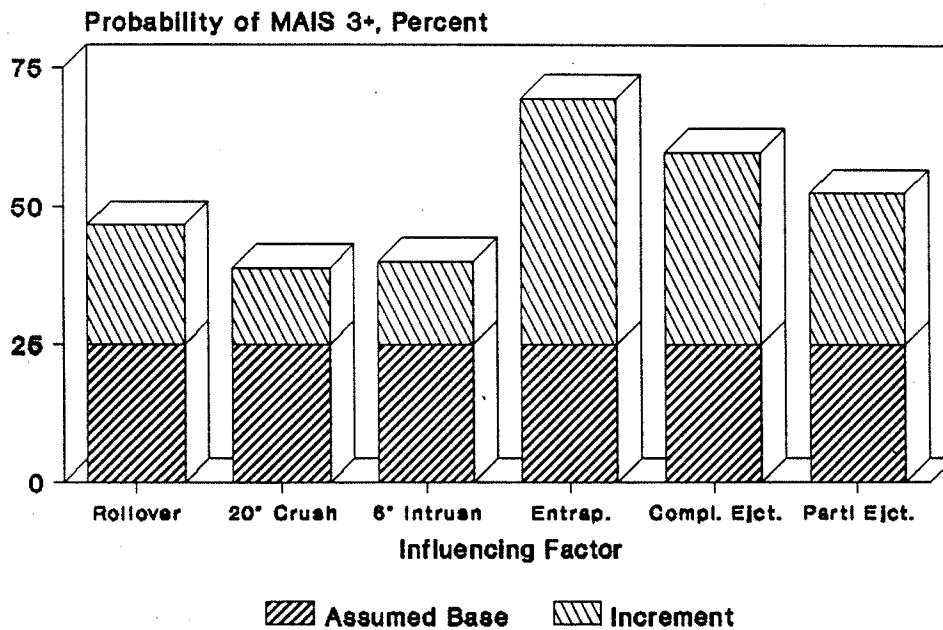


Table I(E), & Relation (11)

INCIDENCE AND OUTCOMES OF INJURY MULTIPLICITY OF CRASH INVOLVED CAR OCCUPANTS

INTRODUCTION

Because of human impact multiplicity, people injured in highway crashes sustain injuries with a multiplicity much higher than that observed in other classes of injured people. For occupants injured in towaway car crashes, the number of injuries per occupant is often five, ten, twenty, or higher. This is especially true when the most severe injury is serious, severe, critical, or fatal.

It is the purpose of the work presented in this paper to address the incidence of multiple injuries and to evaluate the likelihood of outcomes such as: fatality, hospitalization, and emergency transport, as a function of injury multiplicity, injury severity, and the injured person's age.

SOURCES OF DATA

The data compiled in the eight years, 1988-1995, of NASS/CDS are the basic data used. The sample volumes in the NASS 1988-1995 are generally sufficient for addressing the issues of this investigation with adequate resolution. However, in certain cases of small samples, supplemental and compatible data are used from the NASS/CSS 1982-1986. The total sample of car occupants exceeds 120,000 over the years of the cited NASS files

The NASS weights are used as weighing factors in any data processing procedure. This provides estimates of counts and rates of casualties projected nationally.

ERROR ESTIMATION

All results in this paper are accompanied by a standard error. When dealing with analyses of data from the NASS, it must be taken into account that this file contains a sample as opposed to a census of national data. In order to deal with this when error estimation is performed, the applicable statistical procedures are those prescribed in "Survey Data Analysis" (SUDAAN) software, Research Triangle Institute, Research Triangle Park, North Carolina, 1992. Such procedures are applicable in the analysis of data from multi-stage sample designs, like that of the NASS.

POPULATIONS AT ISSUE

The populations at issue in this investigation are injured occupants involved in towaway car crashes. Specifically we address: (a) all injured irrespective of outcome; (b) injured survivors that were hospitalized for at least one night; and (c) injured survivors that were transported to an emergency facility without subsequent hospitalization.

A perspective of the populations and subpopulations at issue is presented in Table I. Here the cited subpopulations of injured occupants are shown as a function of maximum injury severity (MAIS). Estimated annual incidence in the U.S. is given, both via the number per year and the percentage, of a total of about 1,595,000 injured occupants per year. This plus about 1,769,000 of uninjured occupants results in the total of about 3,364,000 occupants involved in towaway car crashes each year in the U.S.

INJURY MULTIPLICITY

A summary of injury multiplicity for car occupants is presented in Fig. 1. This summary displays the frequency of injured occupants as a function of the number of injuries per occupant, for shown maximum injury severity. It is evident in this figure that, when MAIS=1, the frequency of occupants declines sharply as the number of injuries increases beyond one or a few. The same holds true for all injured irrespective of severity, given that this population is dominated by the subpopulation of MAIS=1.

However for higher MAIS values, starting at MAIS=2, injured occupants are spread over a much broader spectrum of higher numbers of injuries per occupant. It is this multiplicity that leads to higher probabilities of fatality, hospitalization, and emergency transport.

MORTALITY AS A FUNCTION OF INJURY MULTIPLICITY

The sharp rise of fatality rates as the maximum injury severity (MAIS) increases is well known. However, at any given MAIS, mortality increases also sharply as an occupant's number of injuries increases. This is evident in Figs 2b, 3b, and 4b. In each of these figures the MAIS is constant at values: MAIS=5, 4, and 3, respectively.

The importance of sharply rising mortality, as injury multiplicity rises, may be appreciated by reviewing the paired results shown in Figs 2a & 2b; 3a & 3b; and 4a & 4b. In each of these pairs, incidence of occupants with multiple injuries is shown in parallel with mortality.

Table II presents summary results concerning frequency of occupants and mortality as a function of injury multiplicity, for five cases of MAIS=5, 4, 3, 2, and 1. Shown also in this table is the mortality irrespective of injury multiplicity. This is designated as "any" and corresponds to a 100% frequency.

The rise of mortality with rising injury multiplicity is also quite sensitive to an injured occupant's age, as is evident in Fig. 5. Results for three age groups are shown here: 0 to 35, 36 to 55, and over 55 years old.

INFLUENCE OF THE THREE MOST SEVERE INJURIES

The severity of the first, most severe, injury has been addressed so far as a strong determinant of mortality. It is intuitively evident that mortality may be influenced by the severity of adjunct injuries. This is shown in Fig. 6 and, with more specificity, in Figs 7 to 9.

An injured occupant's age has a further resolving effect as is evident in Fig. 10, where three age groups are shown: 0 to 35, 36 to 55, and over 55 years old.

EFFECTS OF INJURY MULTIPLICITY ON NONFATAL OUTCOMES

In addition to strongly affecting mortality, injury multiplicity also affects nonfatal outcomes. First, hospitalization is addressed here for survivors. The incidence and hospitalization of injured car occupant survivors are summarized in Table III, and illustrated in Figs 11, 12a, and 12b, for fixed survivor's MAIS=3, 2 and 1, respectively.

Next, emergency transport is addressed, for nonhospitalized surviving car occupants. These results are summarized in Table IV and illustrated in Figs 13a and 13b, for MAIS=2 and 1, respectively.

Table I. Perspective of Towaway Crash
Involved Car Occupants

Population	MAIS	U.S. Incidence	
		Injured per Yr	Percent
Killed	1	852	0.0534
Killed	2	1919	0.1203
Killed	3	3083	0.1933
Killed	4	3880	0.2433
Killed	5	3904	0.2448
Killed	6	3236	0.2029
Killed	7	2370	0.1486
HospSurv	1	40691	2.5512
HospSurv	2	60933	3.8204
HospSurv	3	43947	2.7554
HospSurv	4	7465	0.4680
HospSurv	5	3167	0.1985
HospSurv	7	4704	0.2949
XportSurv	1	635622	39.8524
XportSurv	2	94298	5.9123
XportSurv	3	8532	0.5349
XportSurv	4	137	0.0086
XportSurv	5	26	0.0016
XportSurv	7	29814	1.8693
Other	1	476142	29.8533
Other	2	18299	1.1473
Other	3	810	0.0508
Other	4	6	0.0004
Other	5	30	0.0019
Other	7	151075	9.4721
All Injured		1595000	100.0000
Uninjured		1769000	
All Crash Involved		3364000	

Table II. Incidence and Mortality of Injured Car Occupants, as a Function of the Number of Injuries

@ MAIS=5 & 6; about 11,751 per Year

Num. of Injuries	Mortality Percent		Frequency Percent	
01	9.94	+/- 6.42	2.55	+/- 0.89
02-03	40.78	7.70	9.95	1.50
04-10	48.95	4.41	43.65	2.96
11-20	58.09	5.90	35.44	2.99
21+	91.48	2.80	8.41	1.09
Any	53.96	2.94	100.00	0.00

@ MAIS=4; about 13,026 per Year

01	30.80	+/- 11.19	1.89	+/- 0.52
02-03	40.62	18.02	14.15	3.93
04-10	22.11	2.47	52.61	3.47
11-20	45.43	5.93	26.30	2.89
21+	82.48	5.21	5.06	0.90
Any	34.08	3.49	100.00	0.00

@ MAIS=3; about 63,923 per Year

01	2.10	+/- 1.10	8.10	+/- 2.38
02-03	3.31	0.69	19.70	1.67
04-10	4.60	0.72	61.22	2.42
11-20	13.13	2.35	10.31	0.83
21+	49.56	12.45	0.68	0.17
Any	5.33	0.57	100.00	0.00

@ MAIS=2; about 198,951 per Year

01	1.13	+/- 0.37	10.13	+/- 3.14
02-03	0.80	0.16	25.56	4.52
04-10	0.81	0.13	38.76	5.30
11-20	5.84	1.95	20.29	5.83
21+	85.48	8.97	5.26	2.84
Any	1.09	0.13	100.00	0.00

@ MAIS=1; about 1,307,795 per Year

01	0.03	+/- 0.01	13.85	+/- 3.93
02-03	0.08	0.02	45.27	7.75
04-10	0.13	0.03	34.91	7.07
11-20	1.20	0.70	5.30	2.78
21+	23.34	22.31	0.68	0.69
Any	0.07	0.01	100.00	0.00

Table III. Incidence and Hospitalization of Injured Car Occupant Survivors, as a Function of the Number of Injuries

@ MAIS=3; about 45,300 per Year

Num. of Injuries	Hospitalization Percent		Frequency Percent	
01	73.69	+/-10.25	7.48	+/- 2.96
02-03	61.43	5.22	14.98	1.19
04-10	88.59	3.20	66.23	2.64
11-20	94.96	2.00	10.88	0.94
21+	100.00	0.00	0.44	0.14
Any	82.52	2.44	100.00	0.00

@ MAIS=2; about 62,800 per Year

01	25.11	+/- 3.09	6.97	+/- 0.92
02-03	29.96	2.13	29.50	1.91
04-10	38.87	1.62	57.55	1.93
11-20	58.37	4.83	5.96	0.72
21+	100.00	0.00	0.03	0.01
Any	35.15	1.17	100.00	0.00

@ MAIS=1; about 41,900 per Year

01	1.80	+/- 0.30	19.42	+/- 2.92
02-03	3.38	0.50	39.44	3.95
04-10	7.14	0.48	39.74	3.10
11-20	15.29	5.85	1.37	0.49
21+	66.51	31.50	0.03	0.03
Any	3.55	0.25	100.00	0.00

Table IV. Incidence and Emergency Xport of Injured
Nonhospitalized Car Occupant Survivors,
as a Function of the Number of Injuries

@ MAIS=2; about 98,300 per Year

Num. of Injuries	Emergency Xport		Frequency	
	Percent		Percent	
01	76.29	+/- 3.60	10.25	+/- 1.05
02-03	78.09	2.80	34.79	1.77
04-10	89.59	1.93	52.39	1.82
11-20	93.45	5.66	2.57	0.39
21+	.	.	0.00	0.00
Any	83.88	1.48	100.00	0.00

@ MAIS=1; about 662,600 per Year

01	40.87	+/- 1.29	27.89	+/- 0.78
02-03	63.07	1.18	45.79	0.83
04-10	77.70	1.88	25.83	0.73
11-20	99.50	0.39	0.49	0.14
21+	100.00	0.00	0.00	0.00
Any	57.28	0.83	100.00	0.00

Fig. 1. Frequency of Car Occupants
v. Number of Injuries, in Each Shown
Category of Maximum Injury Severity

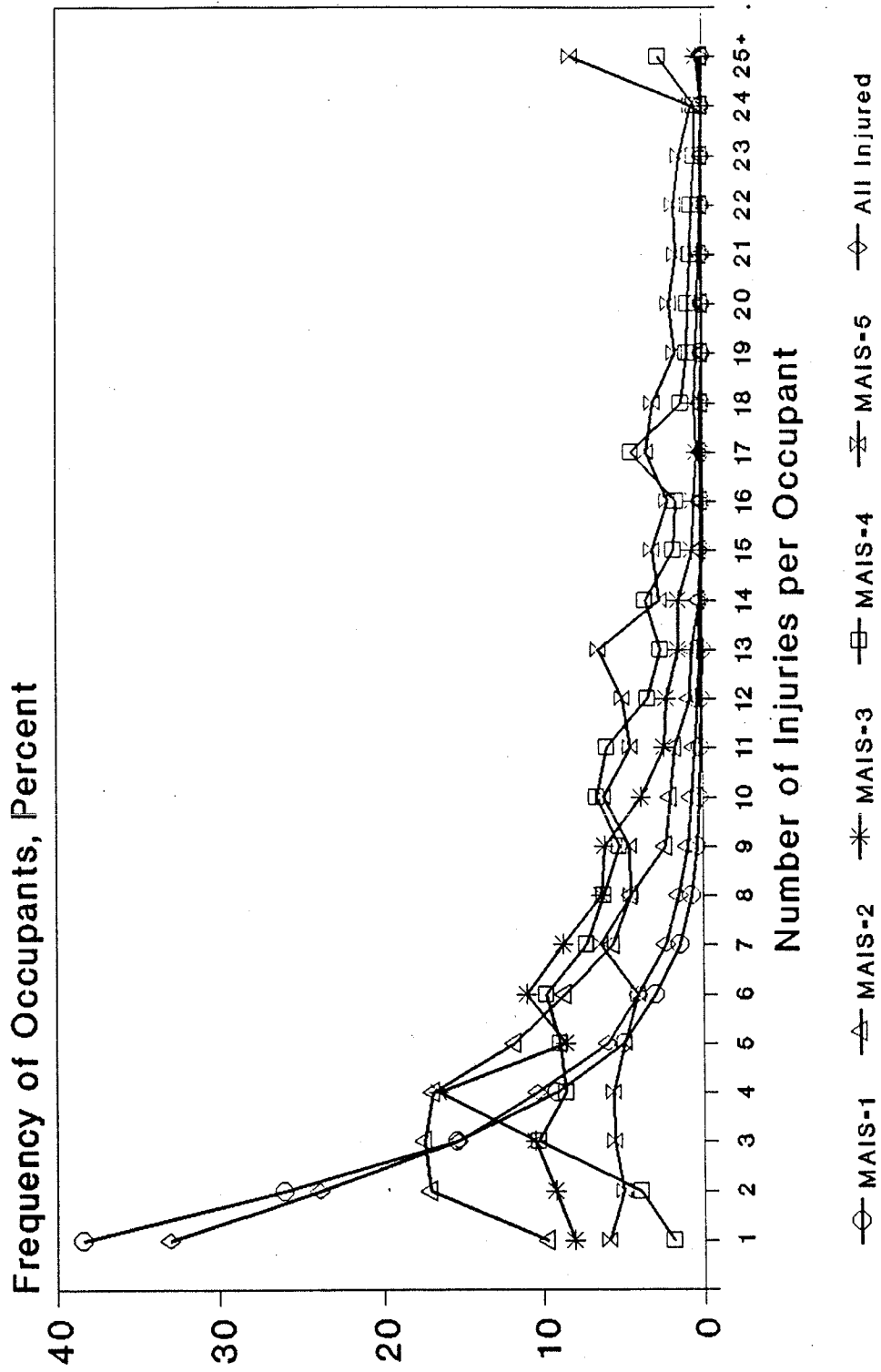
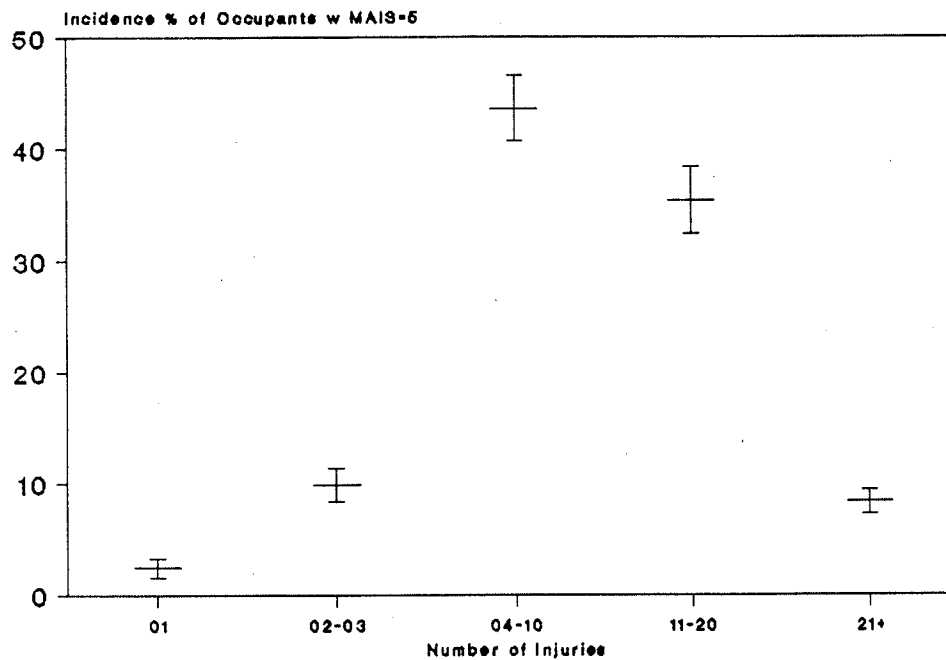
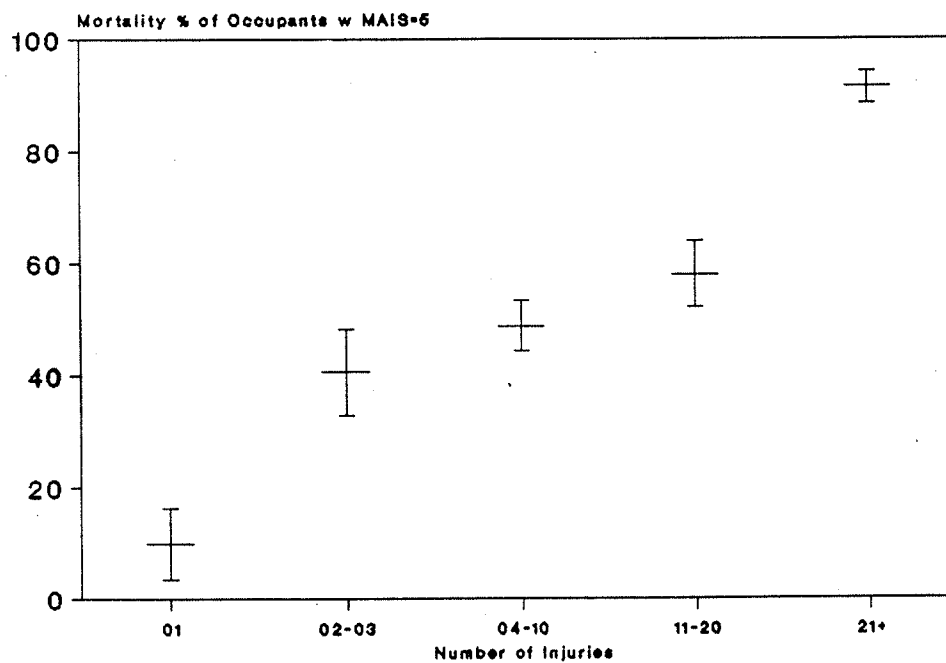


Fig. 2a. Incidence of Car Occupants with Multiple Injuries, When MAIS-5



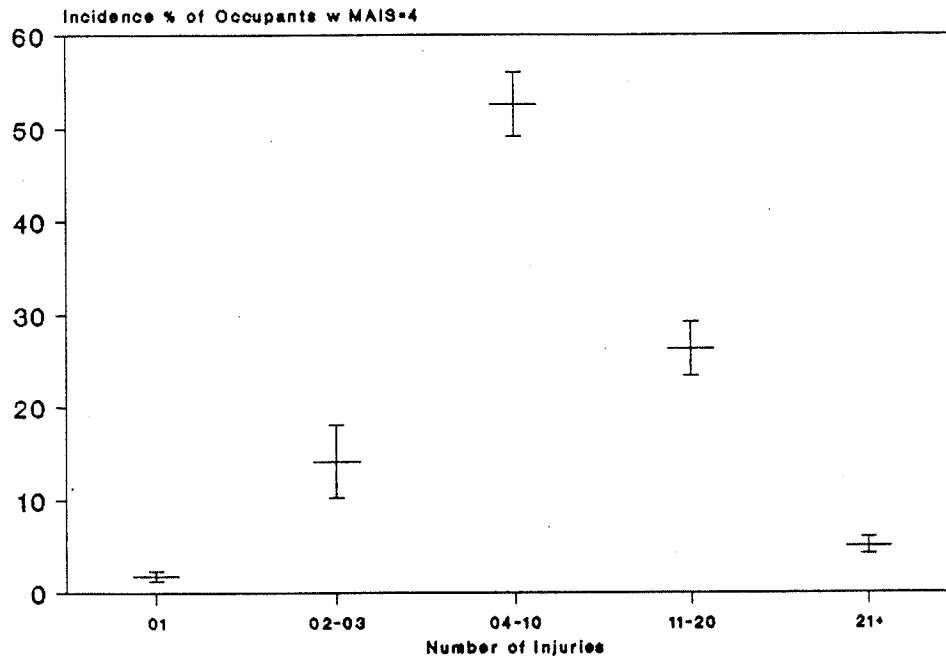
The NASS 1988-1995

Fig. 2b. Mortality of Car Occupants with Multiple Injuries, When MAIS-5



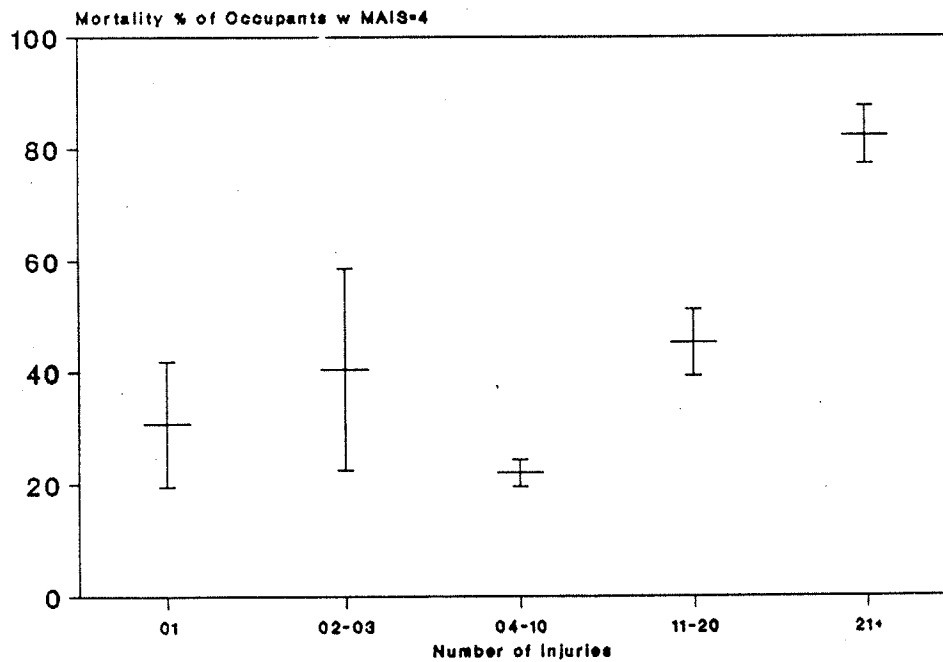
The NASS 1988-1995

Fig. 3a. Incidence of Car Occupants with Multiple Injuries, When MAIS=4



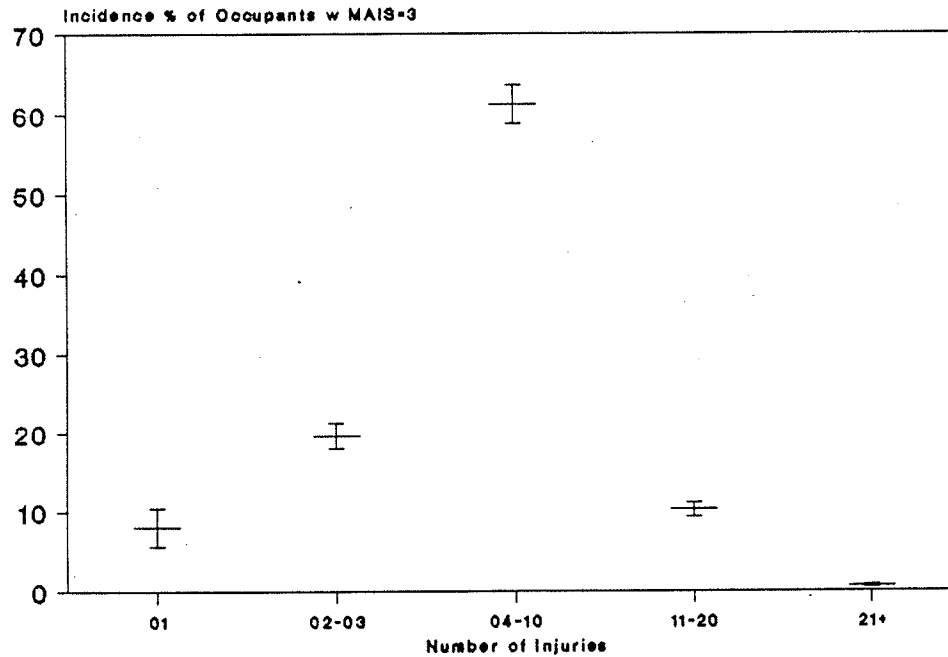
The NASS 1988-1995

Fig. 3b. Mortality of Car Occupants with Multiple Injuries, When MAIS=4



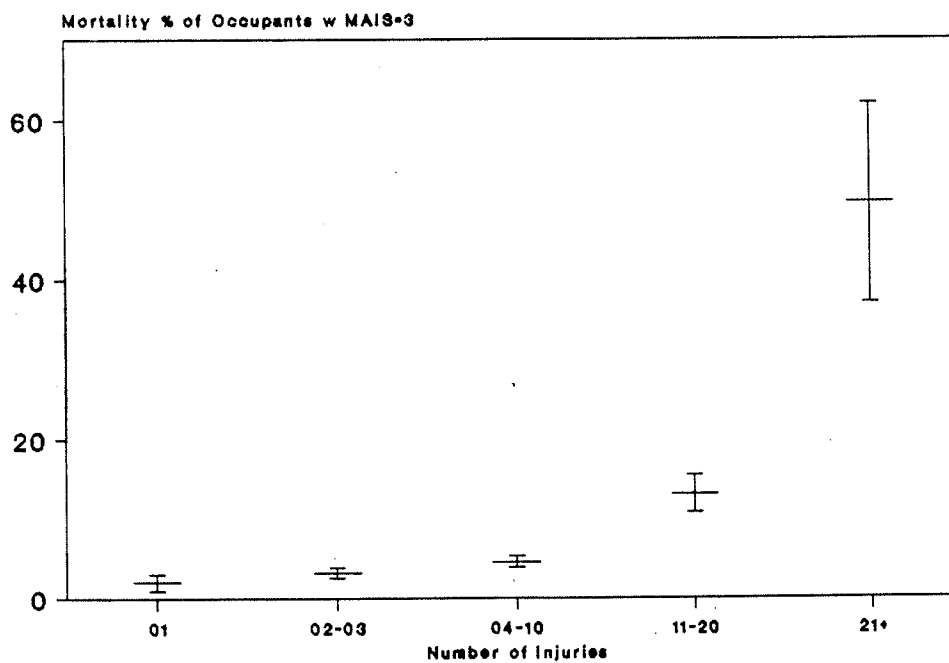
The NASS 1988-1995

Fig. 4a. Incidence of Car Occupants with Multiple Injuries, When MAIS-3



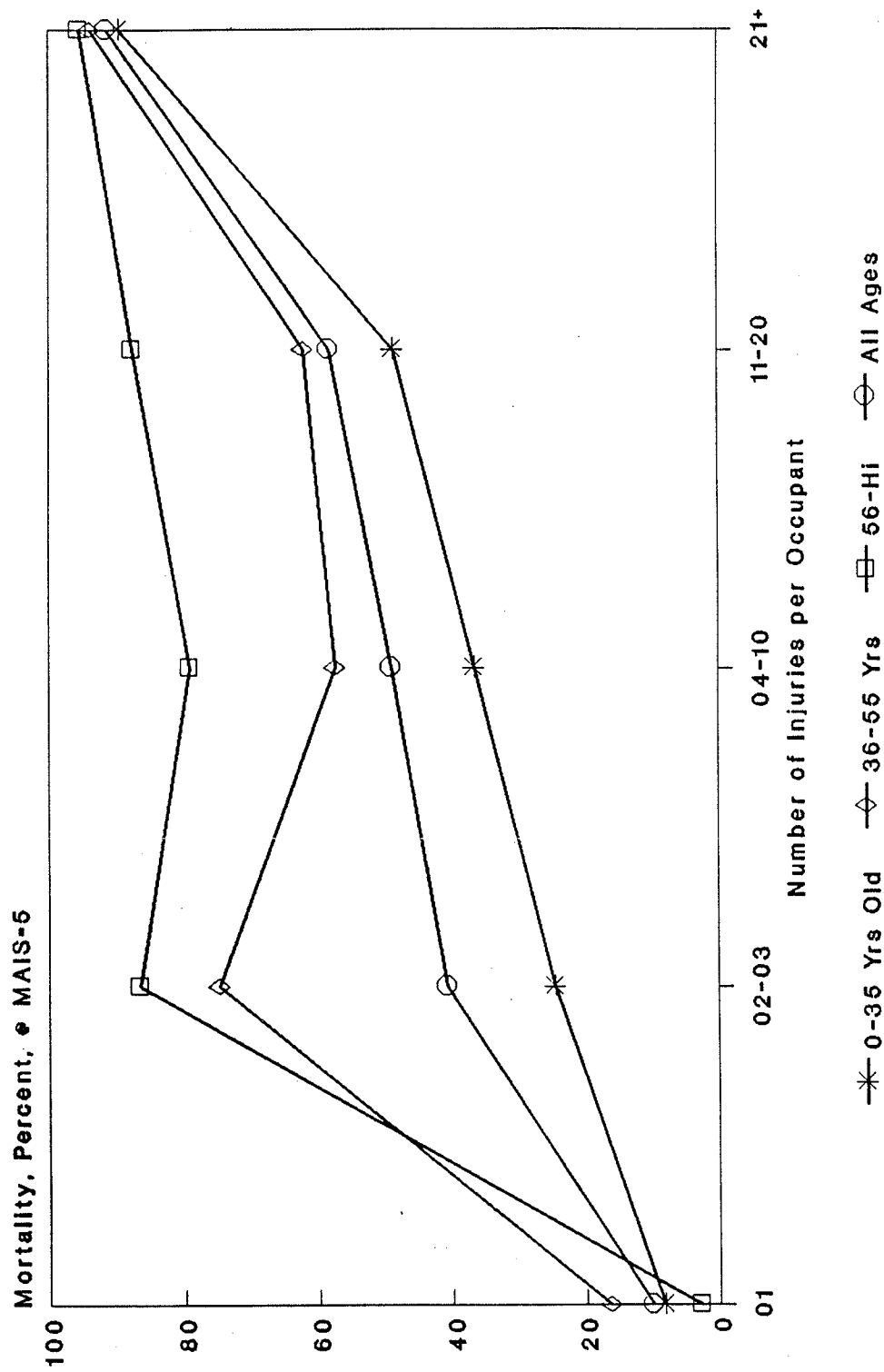
The NASS 1988-1995

Fig. 4b. Mortality of Car Occupants with Multiple Injuries, When MAIS-3



The NASS 1988-1995

Fig. 5. Mortality of Car Occupants at MAIS-5, as a Function of Number of Injuries, for Shown Age Brackets



The NASS 1988-1995

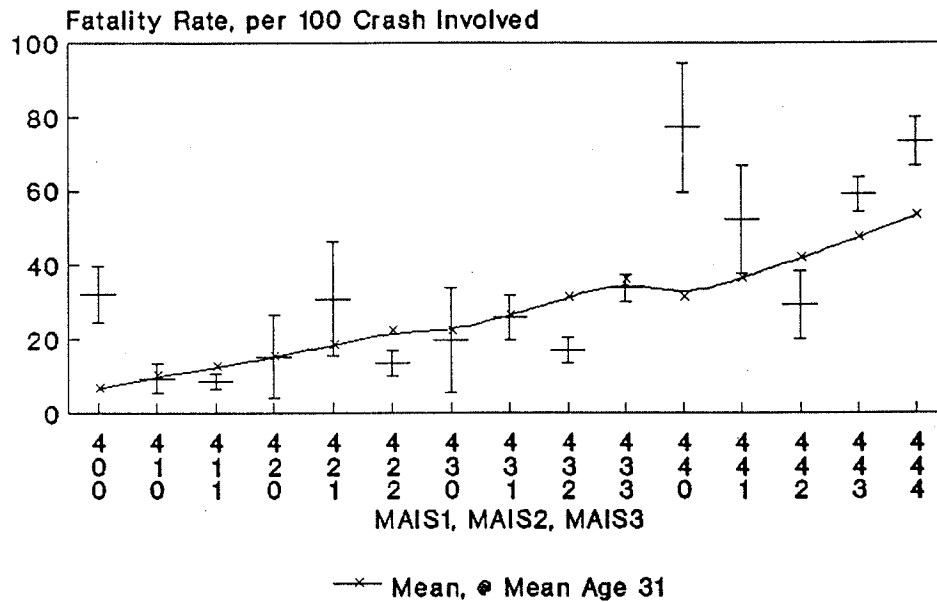
Fatality Rate per 100 Crash Involved

MAIS1	MAIS2	MAIS3	Fatality Rate (approx.)
3	0	0	5
3	0	1	2
3	0	2	2
3	0	3	2
3	1	0	2
3	1	1	2
3	1	2	2
3	1	3	5
3	2	0	2
3	2	1	12
3	2	2	32
3	2	3	10
3	3	0	10
3	3	1	8
4	0	0	15
4	0	1	10
4	0	2	10
4	1	0	30
4	1	1	15
4	1	2	20
4	1	3	25
4	2	0	15
4	2	1	18
4	2	2	35
4	2	3	25
4	3	0	35
4	3	1	75
4	3	2	52
4	3	3	30
4	4	0	60
4	4	1	65
4	4	2	55
4	4	3	75
5	0	0	28
5	0	1	20
5	0	2	15
5	1	0	35
5	1	1	20
5	1	2	25
5	1	3	18
5	2	0	38
5	2	1	35
5	2	2	52
5	2	3	30
5	3	0	40
5	3	1	35
5	3	2	42
5	3	3	62
5	4	0	58
5	4	1	55
5	4	2	48
5	4	3	60
5	5	0	75
5	5	1	75
5	5	2	75
5	5	3	75
5	5	4	75
5	5	5	75

Fig. 7. Fatality Rate as a Function of an Occupant's Three Most Severe Injuries, Starting @ MAIS1-5

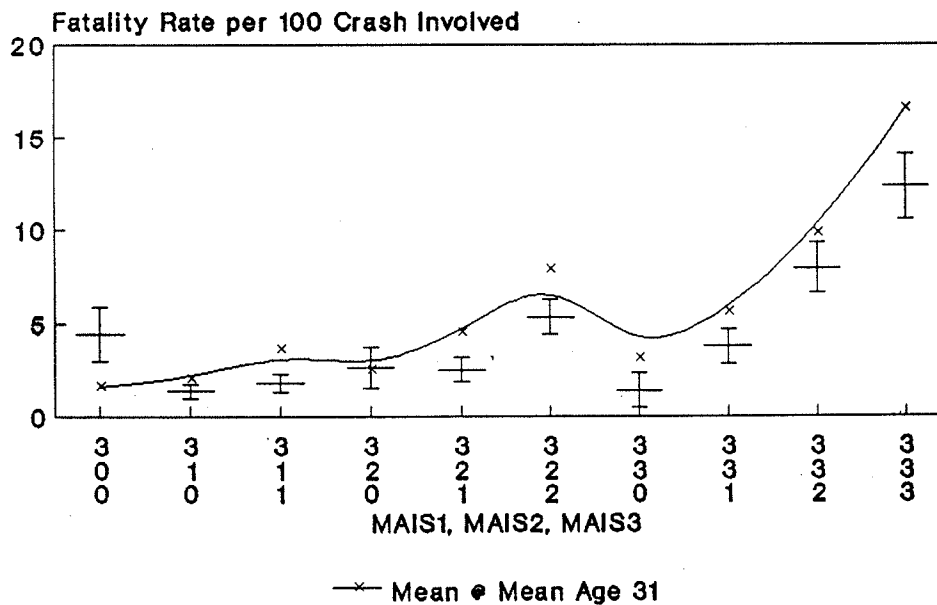


Fig. 8. Fatality Rate, as a
Function of an Occupant's Three Most
Severe Injuries, Starting • MAIS1-4



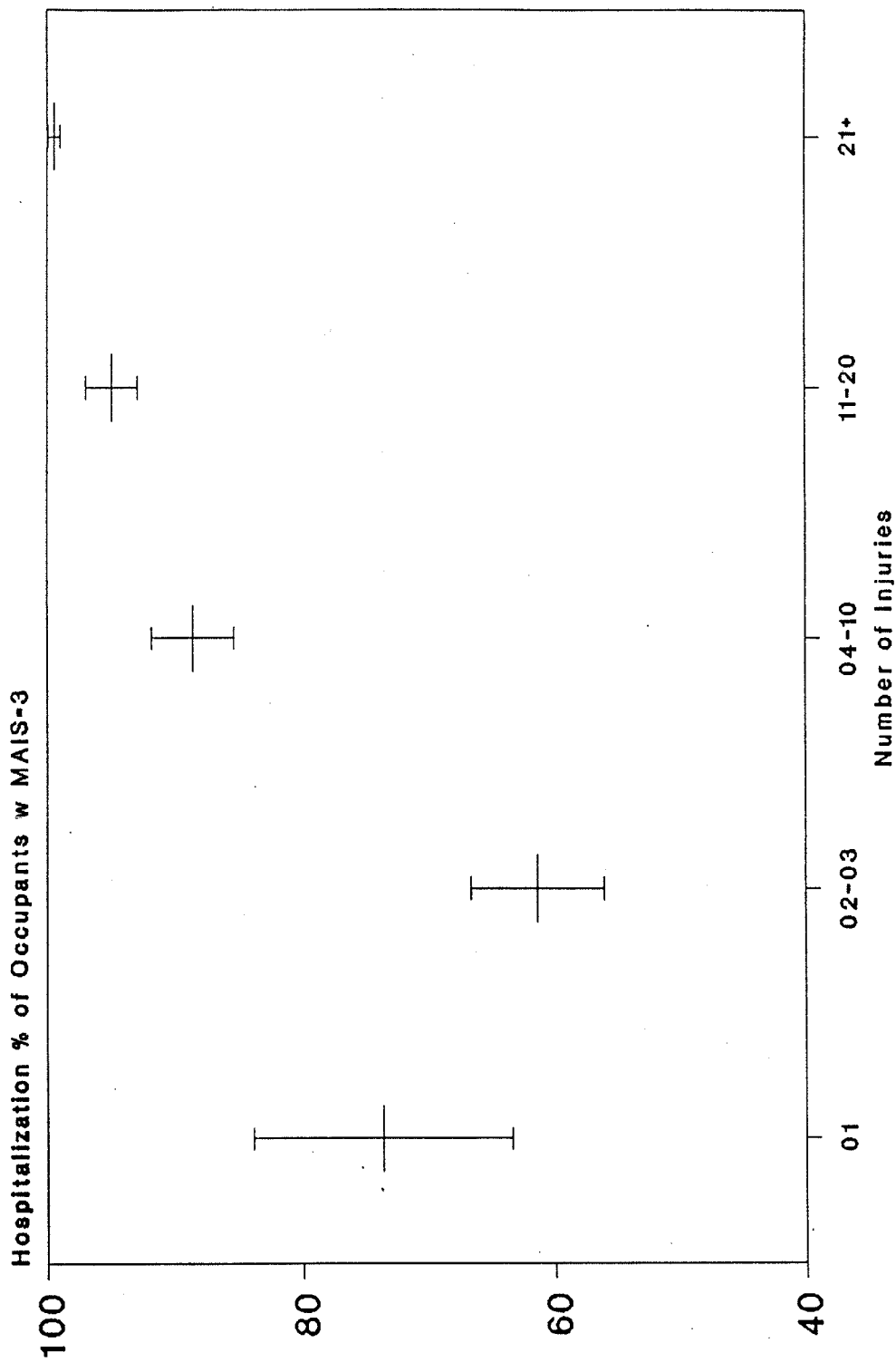
The NASS 1982-1995

Fig. 9. Fatality Rate as a
Function of an Occupant's Three Most
Severe Injuries, Starting • MAIS1-3



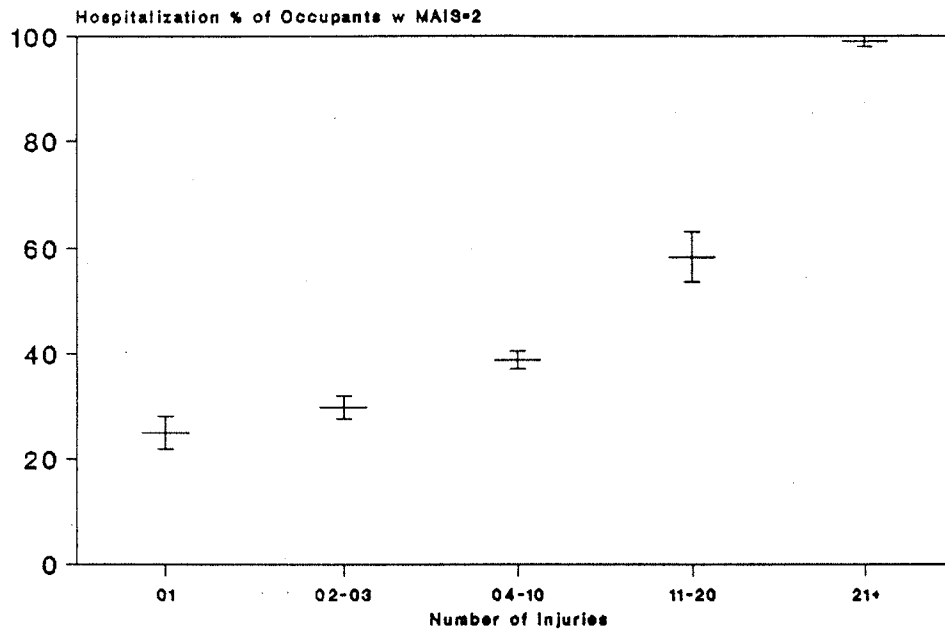
The NASS 1982-1995

Fig. 11. Hospitalization of Car Crash Survivors with Multiple Injuries, when MAIS-3, versus Number of Injuries



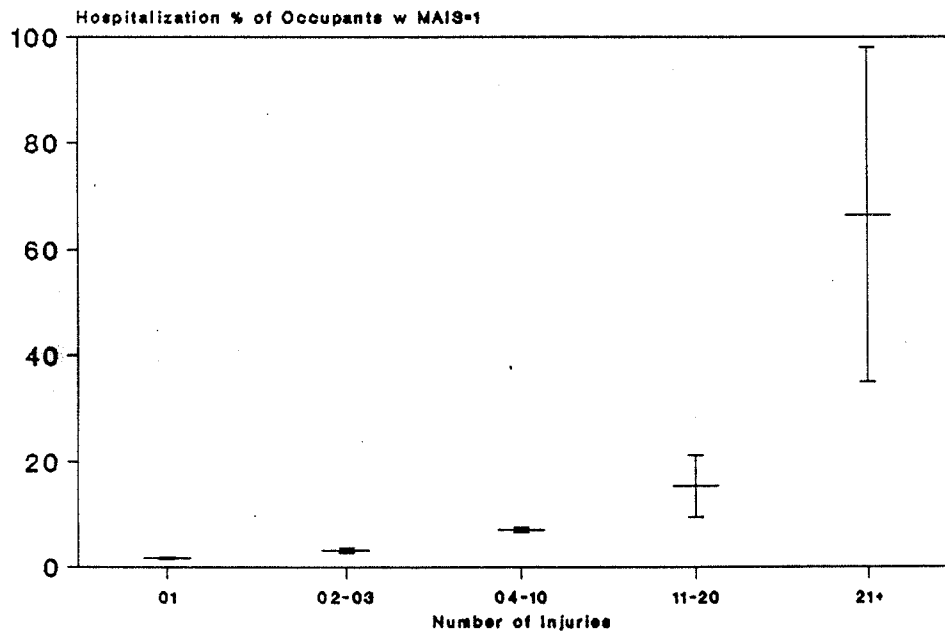
The NASS 1988-1995

Fig. 12a. Hospitalization of Car Crash Survivors with Multiple Injuries, when MAIS=2, versus Number of Injuries



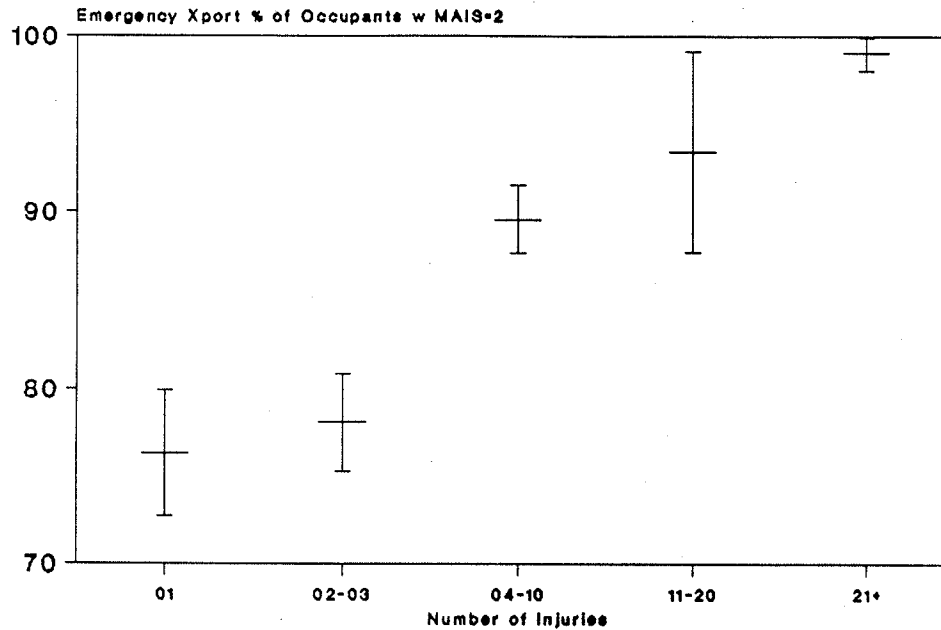
The NASS 1988-1995

Fig. 12b. Hospitalization of Car Crash Survivors with Multiple Injuries, when MAIS=1, versus Number of Injuries



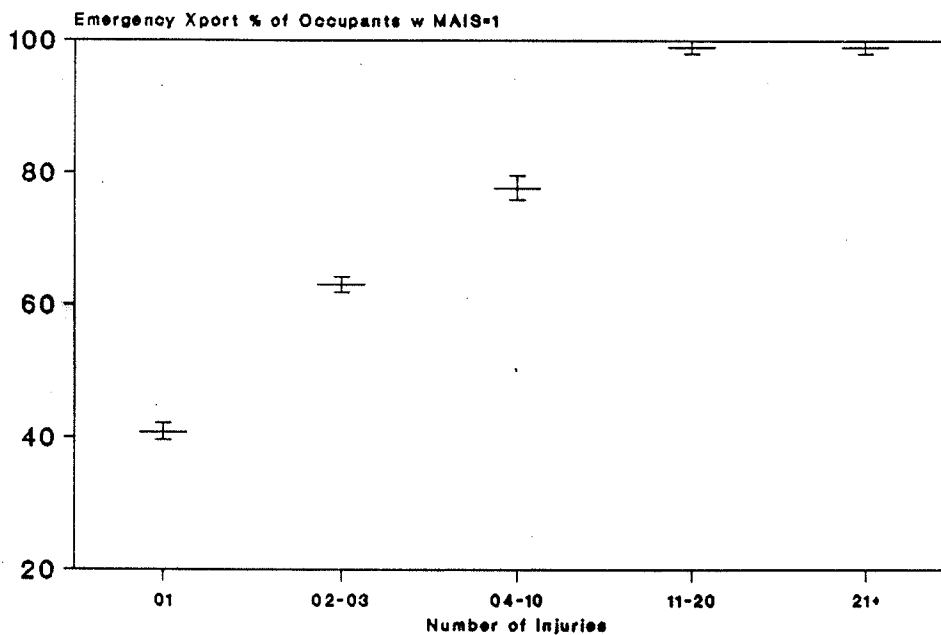
The NASS 1988-1995

**Fig. 13a. Emergency Xport of Car Crash
Nonhospitalized Survivors with Multiple
Injuries, @ MAIS=2, v Number of Injuries**



The NASS 1988-1995

**Fig. 13b. Emergency Xport of Car Crash
Nonhospitalized Survivors with Multiple
Injuries, @ MAIS=1, v Number of Injuries**



The NASS 1988-1995

