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Injury Severity and Measured Response for Pedestrian Head Impacts

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16. Abstract

Reconstructions of pedestrian accidents were previously performed. The analysis of the data was presented in the form of functional relationships between measured/computed HIC responses and the probability of death. The probability of death was estimated from the three highest AIS values according to an approach presented by Ulman, et al.

A potential for error exists in that the Ulman study was based upon injuries to all body regions, whereas the pedestrian accident reconstructions were based upon only head injuries. This study addresses the probability of death based upon the 2 or 3 highest AIS levels to the head. The differences were found to be relatively small.

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TECHNICAL SUMMARY

Report Title:	
Injury Severity and Measured Response for Pedestrian Head Impacts	March 1989
Report Author(s):	
Michael W. Monk	

The pedestrian protection program of the National Highway Traffic Safety Administration is attempting to reduce the number of deaths and injuries which occur in pedestrian accidents. This study relates to the use and interpretation of accident data to derive relationships between measured responses in the laboratory and injury severity.

An earlier study provided an analysis of a number of pedestrian accidents. Reconstructions were performed using a mechanical headform. The Head Injury Criterion (HIC) was also correlated to the probability of death (POD) as determined by Ulman et al., based upon the three highest recorded AIS levels. This was an apparent inconsistency since in the Ulman study, injuries to all body regions were used, whereas in the VRTC study, only head injuries were considered.

This study derived the POD based upon the two or three highest AIS levels to the head. Two separate methods of POD derivation were used. The effect that the newly derived POD's had on the earlier derived HIC-POD relationships was then explored.

INJURY SEVERITY AND MEASURED RESPONSE FOR PEDESTRIAN HEAD IMPACTS

1.0 BACKGROUND

The Pedestrian Protection Program at VRTC has explored various methods of correlating measured responses with body injuries. For head protection work, a mechanical headform is used to represent a human head. The acceleration response is measured for each impact simulation and the Head Injury Criteria (HIC) value is calculated. Although other criteria have been used at various times, HIC is being used currently, since it is the most widely accepted criterion for automotive safety testing.

A threshold HIC value of 1000 has been established for use in other federal safety standards. Thus, test responses which result in calculated HIC values of less than 1000 are considered successful, and those with HIC values exceeding 1000 are considered unsuccessful.

A recent study of pedestrian accident reconstructions (1) supported this threshold value of HIC. One portion of the study focused on the results of 14 adult pedestrian reconstructions. The headform speed and mass were adjusted until the dent in the vehicle was successfully reproduced. Once a reasonable combination of headform mass and velocity was established, the acceleration response of the headform was used to compute a HIC from the impact.

Attempts were then made to correlate the measured HIC responses with the observed injuries which occurred to the pedestrians. This was done using the highest AIS, and the probability of death (POD) [for this report, the terms probability of death, fatality rate and mortality rate have the same meaning] based upon the three highest AIS values(2). Figure 1.1 contains the highest AIS plotted against the reconstruction HIC values. Figure 1.2 contains a presentation of HIC and POD. It is observed that the HIC-POD plot resulted in a better correlation. It is believed that this is because the highest AIS is a less accurate indicator of overall injury level.

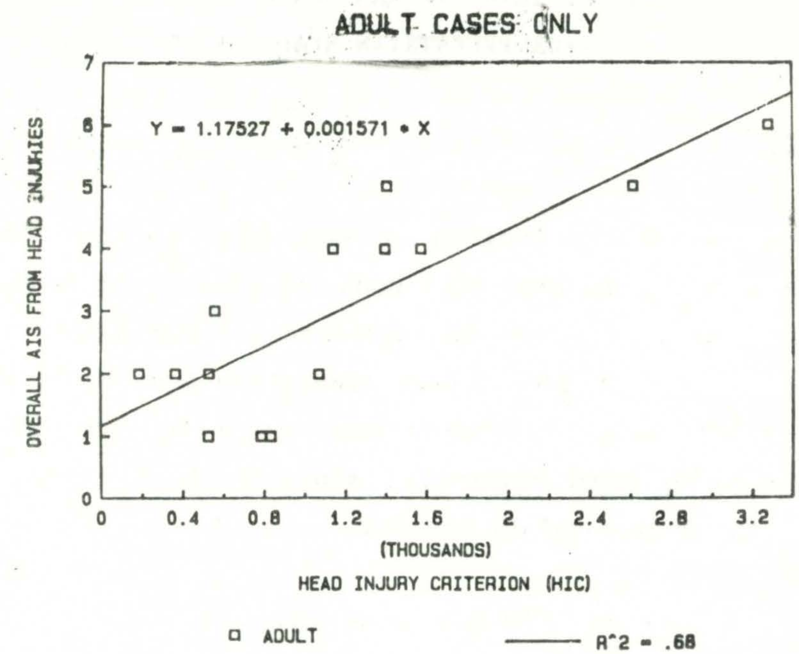


FIGURE 1.1 HIC Versus Overall Head AIS (See Reference 1)

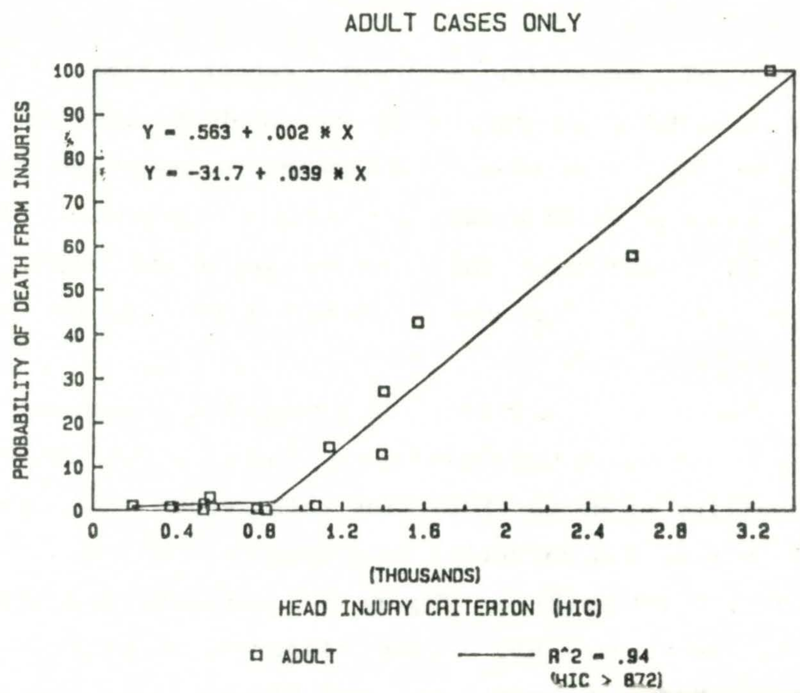


FIGURE 1.2 HIC Versus Probability of Death (See Reference 1)

The Ulman study of Reference 2 established correlation between the 3 highest AIS levels to all body regions and the probability of death. All of the injuries used in the pedestrian reconstruction study, however, were to the head and face. It would be more appropriate for the pedestrian program, to have a relationship between the highest AIS levels to the head/face region and the probability of death.

2.0 OBJECTIVE

The objective of this study is to determine the functional relationship between the 2 or 3 highest AIS levels to the head and the probability of death (POD) .

3.0 HEAD INJURY BASED POD DERIVATION

Two separate methods of correlating POD with AIS levels were found in literature, either of which could be used for the analysis of head injury. The first method was documented by Ulman et. al. in Reference 2. This method involved the use of statistical regression lines fitted to the 3 highest AIS levels from accident data. This will be referred to as the "regression method". The second method was presented by Eppinger (3). This method is based upon the assumption that the survival rate for two separate injuries is the product of the survival rates of each single injury. The individual survival rates were derived using an optimization technique. This will be referred to as the "optimization method".

These two methods were explored in an attempt to derive a relationship between the highest head AIS levels and POD. The approach, results, and analysis of each will be given in the following sections.

3.1 Regression Method

The data used in the Ulman all-body study were from the unweighted NASS accident file. Data from 1979-1983 were rank ordered according to the 3 highest AIS levels coded. Table 3.1 contains the 55 combinations of AIS in the assumed rank order. It is noted that this is a key assumption for this approach, which is

TABLE 3.1 3-Highest AIS Rankings and Mortality Rate
(See Reference 2)

Index	Ranking	Injured	Dead	Mortality Rate	Index	Ranking	Injured	Dead	Mortality Rate
1	1 0 0	7917	4	0.0505	29	4 3 3	109	31	28.4404
2	1 1 0	5031	1	0.0199	30	4 4 0	0	0	---
3	1 1 1	8858	24	0.2713	31	4 4 1	4	3	75.0000
4	2 0 0	387	6	1.5504	32	4 4 2	14	5	35.7143
5	2 1 0	527	5	0.9488	33	4 4 3	47	21	44.6809
6	2 1 1	2359	19	0.8054	34	4 4 4	24	17	70.8333
7	2 2 0	84	3	3.5714	35	5 0 0	11	4	36.3636
8	2 2 1	653	9	1.3783	36	5 1 0	3	1	33.3333
9	2 2 2	250	14	5.6000	37	5 1 1	38	8	21.0526
10	3 0 0	91	2	2.1978	38	5 2 0	2	1	50.0000
11	3 1 0	123	0	0.0000	39	5 2 1	13	3	23.0769
12	3 1 1	585	8	1.3675	40	5 2 2	7	1	14.2857
13	3 2 0	47	0	0.0000	41	5 3 0	4	2	50.0000
14	3 2 1	344	12	3.4884	42	5 3 1	14	4	28.5714
15	3 2 2	254	18	7.0866	43	5 3 2	30	6	20.0000
16	3 3 0	30	3	10.0000	44	5 3 3	50	23	46.0000
17	3 3 1	147	1	0.6803	45	5 4 0	0	0	---
18	3 3 2	229	11	4.8035	46	5 4 1	7	4	57.1429
19	3 3 3	198	23	11.6162	47	5 4 2	11	4	36.3636
20	4 0 0	16	5	31.2500	48	5 4 3	42	24	57.1429
21	4 1 0	13	1	7.6923	49	5 4 4	38	28	73.6842
22	4 1 1	51	6	11.7647	50	5 5 0	1	0	0.0000
23	4 2 0	6	1	16.6667	51	5 5 1	0	0	---
24	4 2 1	34	4	11.7647	52	5 5 2	2	0	0.0000
25	4 2 2	27	2	7.4074	53	5 5 3	14	7	50.0000
26	4 3 0	6	0	0.0000	54	5 5 4	32	24	75.0000
27	4 3 1	29	2	6.8966	55	5 5 5	22	19	86.3636
28	4 3 2	49	9	18.3673	56	6 - -	192	192	100.0000

not readily proven. An injury combination of 3,3,0 is assumed to be worse than 3,2,2 and so on. With this assumption in place, the approach is quite straightforward.

The number of fatalities within each injury combination was divided by the total number injured to obtain the probability of death associated with each injury combination. The data pairs (sequence number and POD) were plotted as a scatter plot, and regression lines were fit within each highest AIS group. The results of the analysis are shown in Figure 3.1. It is noted that the regression lines are a reasonable representation of the overall trends of the data, with reported correlation coefficients (CC) ranging from .4 to better than .63. The equations for the lines and actual CC's were not given in the paper.

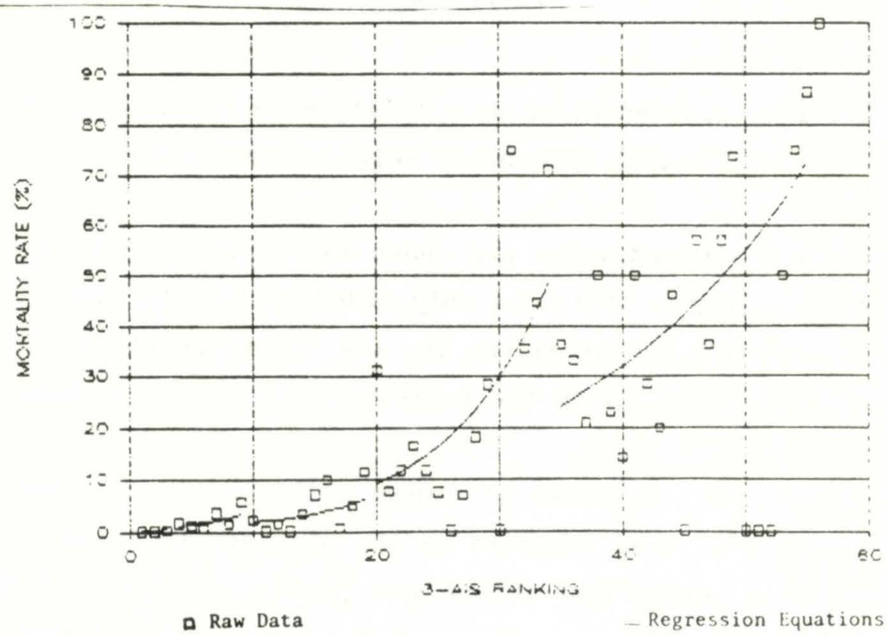


FIGURE 3.1 -- Regression Lines and Raw Data (Reference 1)

Three more years of compatible data have been added to the NASS files since the Ulman study was performed. The first step of this analysis was to repeat the regression approach, using NASS data from 1979-1986. This all-body update was performed using weighted data rather than unweighted. The data sample contains approximately 64,000 injured persons (unweighted) of which approximately 6800 were AIS 3-5. The results are contained in Figure 3.2. Power functions were fit to the data points within each category of highest AIS. The equation for

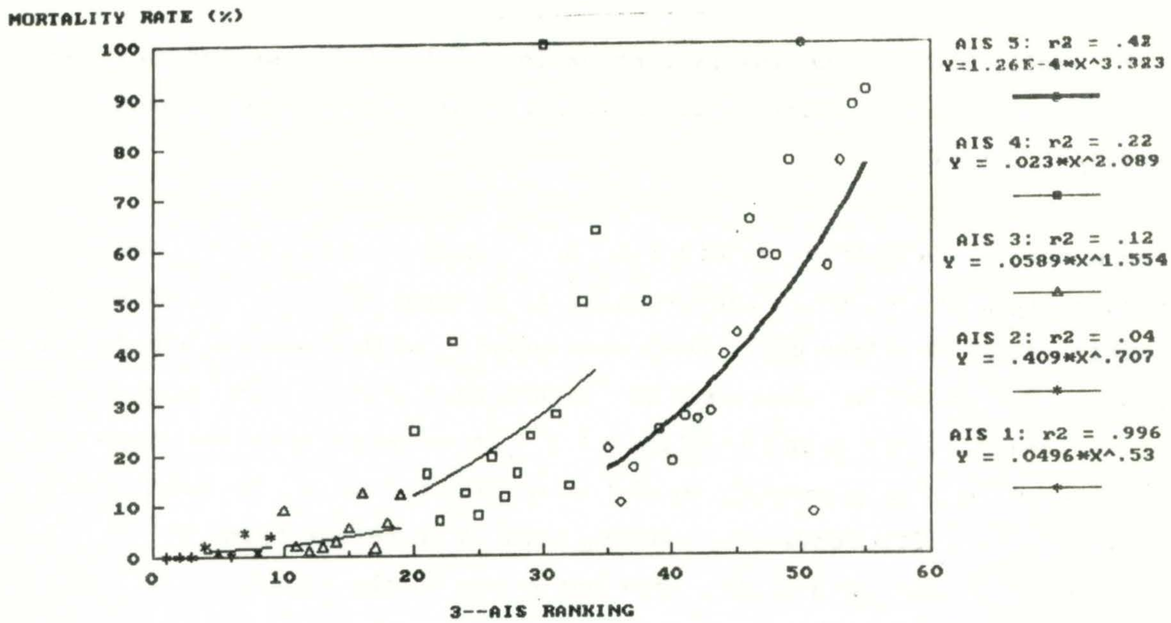


FIGURE 3.2 -- Updated All-Body Fatality Rate Regressions for the 1979-1986 Nationally Weighted NASS Data

each line and the R-squared value are shown in the legend to the right of the scatter plots. The degree of fit is only moderate for the AIS 3-5 range, near zero for the AIS 2 data and excellent for the 3 data points comprising AIS 1. The lines agree fairly well with the regression lines in the Ulman study.

Next, the NASS data were screened to remove all injuries to other body areas, leaving only cases with head injuries as the most severe injuries in the set. These data were then categorized in the same manner according to the 3 highest AIS values to the head. The data were much more sparse with approximately 2800 injured persons (unweighted) of which 121 were AIS 3-5. These 121 injured persons are divided into the 46 categories of AIS 3-5. Many of the cells did not have any data. In other cells, the sparsity of data resulted in erratic results...all of the persons were fatalities or none were fatalities. Applying the weighting factors to these sparse data is likely not valid, but was done in order to observe the trends of results with head injury.

The results are contained in Figure 3.3. Once again, the equations for the lines and the R-squared values are shown in the legend. It may or may not be significant, but the R-squared values for AIS 2,3 and 5 ranges were better than those based upon all body regions. More significant is the consistent trend of higher probability of death for the head injuries. This is especially true for the AIS 3 range, with the POD based upon 3 head injuries averaging around 50% higher than that for all body regions. It is noted, however, that the slope of the line for the AIS 3 injuries is largely driven by the single data point with 100% mortality rate. This illustrates much of the uncertainty of using such small numbers of data for an analysis of this type. In the AIS 4 and 5 ranges, the POD based upon head injuries is also 15-40% higher than that based upon injuries to all body regions.

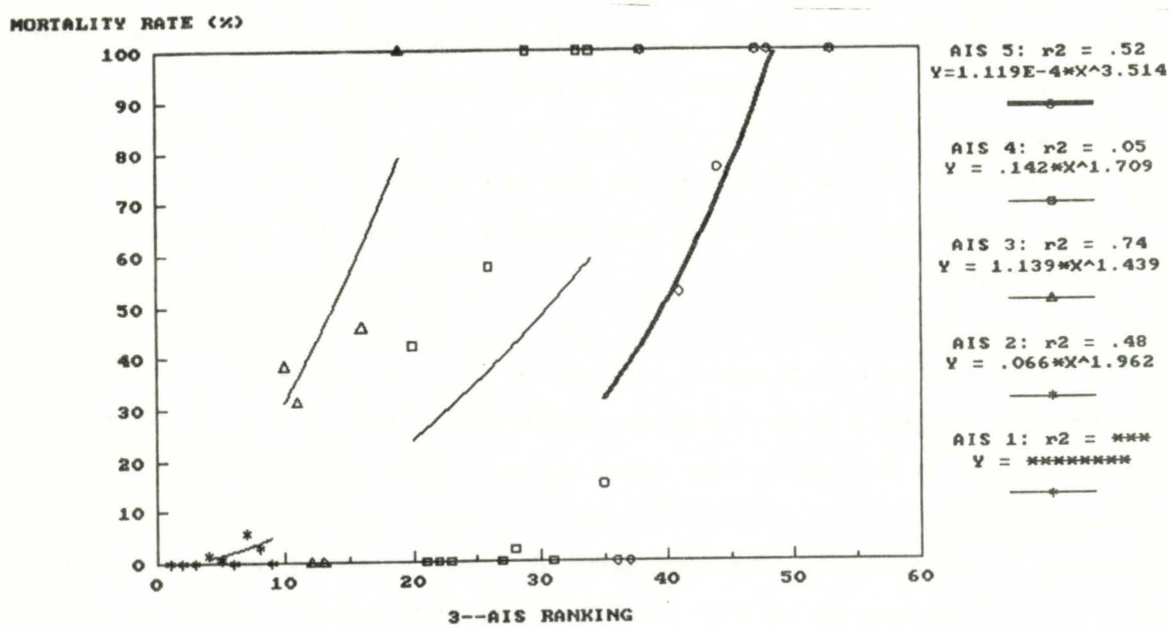


FIGURE 3.3 -- Fatality Rate Regressions Based on Head Injuries
NASS 1979-1986 Weighted Data

The POD values for the 55 combinations of the 3 highest AIS values for head injury, using the regression method, have been derived. They are based upon weighted, sparse data, but it appears that the POD is higher for head AIS levels than for all body regions combined. The significance of this to the Pedestrian Research Program will be discussed in a later section of this report. The POD by the optimization method will be derived in the next section.

3.2 Optimization Method

The optimization method was used by Eppinger (3) in a study of biases in the AIS scheme. This study was also based upon accident data from the NASS, using 1982-85. The method is somewhat more complex than the regression method, and is basically as follows:

> NASS cases were selected in which the 2 highest level injuries occurred to the head, chest or abdomen with AIS levels of 3, 4 or 5. Cases with less than 2 injuries were not selected. Cases with more than 2 injuries were selected if the third injury was equal in severity to the second and to the same body region, or if the third injury was of lesser severity than the second.
>
> The survival rate for each combination of injuries was computed as the number of subjects with the injury combination who survived divided by the total number with the injury combination.
>
> A model of survival rate was assumed...the survival rate of an injury combination (such as an AIS 3 head injury and an AIS 5 abdominal injury) was assumed to be the product of the two individual survival rates.
>
> The search for individual survival rates for injuries to each of the 3 body regions at each of the 3 AIS levels was accomplished with an optimization routine. The optimum survival rates were those which when multiplied together for each of the paired occurrences best matched the overall set of accident data.

Table 3.2 contains the actual and model predicted survival rates for each combination of injury pairs. It is noted that there are 45 paired combinations. Table 3.3 contains the calculated optimum survival rates for individual body regions and AIS level. Both tables are from the report of Reference 3.

For purposes of this study, the same years ('82-'85) from the NASS file were used and the same methodology applied. Instead of limiting the AIS levels to the 3-5 range, all levels from AIS 1-5, including single injuries, were accepted. The number of paired combinations was then 135 instead of 45. A complete listing of the AIS combinations, the actual survival rates and the optimization model predicted survival rates is contained in Appendix A.

Table 3.4 contains the optimum individual survival rates. The POD's for each of the 20 combinations of the 2 highest AIS levels were then calculated from the optimum survival rates. The calculation is:

$$POD = 1 - (SR1 * SR2)$$

Note that the survival rates were derived from a model of the 2 highest AIS levels, and that the 3rd AIS value was not used in computing the POD as it was in the previous two models. Table 3.5 contains the 55 combinations of the 3 highest AIS levels, the POD from the Ulman model (3 most severe injuries from all body regions), the POD from the regression model (3 most severe head injuries), and the POD from the optimization model (2 most severe head injuries). The 3 models (NASS '79-'86 all body regions, NASS '79-'86 head injuries-regression method, and NASS '82-'85 head injuries-optimization method) are shown in Figure 3.4. It is noted that the two models based upon head injuries show higher POD's than the model based upon injuries to all body regions. The POD's based upon the optimization method are generally closer to those from all body regions than are those based upon the regression method. It is again emphasized that the data for head injuries are much more sparse than the data set which includes injuries to all body regions. Even though both methods have indicated that the POD is higher when based upon head injuries, it is a judgement as to whether or how to use this information.

TABLE 3.2 Actual and Predicted Survival Rates (Reference 3)

PRIMARY (HIGHEST) INJURY

SECONDARY INJURY	C5	C4	H5	A5	H4	H3	A4	A3	C3
C5	0								
	0.127								
C4	0.37	0.5							
	0.161	0.205							
H5	0	0.13	0.54						
	0.232	0.295	0.424						
A5	0.14	0.09	0	0.51					
	0.246	0.313	0.45	0.48					
H4	1	0.1	0.38	NO DATA	0.45				
	0.26	0.333	0.48	0.51	0.54				
H3	0.24	0.76	0.59	0	0.75	0.62			
	0.301	0.383	0.55	0.585	0.62	0.72			
A4	0.1	0.18	0.58	0.76	0.77	0.84	0.71		
	0.315	0.48	0.58	0.61	0.65	0.75	0.78		
A3	0	0.18	0.68	0.86	NO DATA	0.87	1	1	
	0.349	0.443	0.64	0.68	0.72	0.86	0.86	0.96	
C3	0.81	0.8	0.81	1	0.8	0.83	1	0.78	0.95
	0.35	0.45	0.65	0.686	0.73	0.88	0.87	0.97	0.98

TABLE 3.3 -- Optimum Survival Rates (Reference 3)

(Body Region/AIS Rank)

Head 5 = 0.65	Chest 5 = 0.36	Abdomen 5 = 0.69
Head 4 = 0.74	Chest 4 = 0.45	Abdomen 4 = 0.88
Head 3 = 0.84	Chest 3 = 0.99	Abdomen 3 = 0.98

TABLE 3.4 -- Calculated Optimum Survival Rates Using 5 AIS Levels

	BODY REGION		
AIS Level	Head	Chest	Abdomen
1	.999	1.00	1.00
2	1.00	1.00	.985
3	.894	.982	.976
4	.739	.505	.894
5	.670	.351	.720

TABLE 3.5 -- Fatality Rates From Various Models

	AIS Combination	Original Ulman Model All Regions	Updated Ulman Model 1979-1986 All Regions	Regression Method 1979-1986 Head Injury	Optimization Method 1982-1985 Head Injury
1	1 0 0	.15	0.05	*	0.10
2	1 1 0	.35	0.07	*	0.20
3	1 1 1	.81	0.09	*	
4	2 0 0	.94	1.09	1.00	0.00
5	2 1 0	1.21	1.28	1.55	0.10
6	2 1 1	1.57	1.45	2.22	
7	2 2 0	2.03	1.62	3.00	0.00
8	2 2 1	2.63	1.78	3.90	
9	2 2 2	3.41	1.93	4.92	
10	3 0 0	1.82	2.11	31.28	10.60
11	3 1 0	2.08	2.45	35.88	10.69
12	3 1 1	2.38	2.80	40.67	
13	3 2 0	2.71	3.17	45.63	10.60
14	3 2 1	3.10	3.56	50.76	
15	3 2 2	3.54	3.96	56.06	
16	3 3 0	4.05	4.38	61.52	20.08
17	3 3 1	4.62	4.81	67.12	
18	3 3 2	5.28	5.26	72.87	
19	3 3 3	6.03	5.72	78.77	
20	4 0 0	9.15	12.01	23.81	26.10
21	4 1 0	10.30	13.30	25.88	26.17
22	4 1 1	11.61	14.66	28.02	
23	4 2 0	13.07	16.08	30.23	26.10
24	4 2 1	14.73	17.58	32.52	
25	4 2 2	16.59	19.14	34.87	
26	4 3 0	18.69	20.78	37.28	33.93
27	4 3 1	21.05	22.48	39.77	
28	4 3 2	23.71	24.26	42.32	

TABLE 3.5 -- Fatality Rates From Various Models (Continued)

	AIS Combination	Original Ulman Model All Regions	Updated Ulman Model 1979-1986 All Regions	Regression Method 1979-1986 Head Injury	Optimization Method 1982-1985 Head Injury
29	4 3 3	26.71	26.10	44.93	
30	4 4 0	30.09	28.02	47.61	45.39
31	4 4 1	33.89	30.00	50.36	
32	4 4 2	38.18	32.06	53.17	
33	4 4 3	43.00	34.19	56.04	
34	4 4 4	48.44	36.39	58.97	
35	5 0 0	24.52	17.03	31.73	33.00
36	5 1 0	25.88	18.71	35.04	33.07
37	5 1 1	27.32	20.49	38.58	
38	5 2 0	28.84	22.39	42.37	33.00
39	5 2 1	30.45	24.40	46.42	
40	5 2 2	32.14	26.55	50.74	
41	5 3 0	33.93	28.82	55.33	40.10
42	5 3 1	35.82	31.22	60.22	
43	5 3 2	37.81	33.76	65.42	
44	5 3 3	39.91	36.44	70.92	
45	5 4 0	42.13	39.26	76.75	50.49
46	5 4 1	44.48	42.24	82.91	
47	5 4 2	46.95	45.37	89.42	
48	5 4 3	49.56	48.66	96.29	
49	5 4 4	52.32	52.11	100.00	
50	5 5 0	55.23	55.72	100.00	55.11
51	5 5 1	58.02	59.51	100.00	
52	5 5 2	61.55	63.48	100.00	
53	5 5 3	64.97	67.63	100.00	
54	5 5 4	68.58	71.96	100.00	
55	5 5 5	72.40	76.49	100.00	
56	6 - -		100.00	100.00	100.00

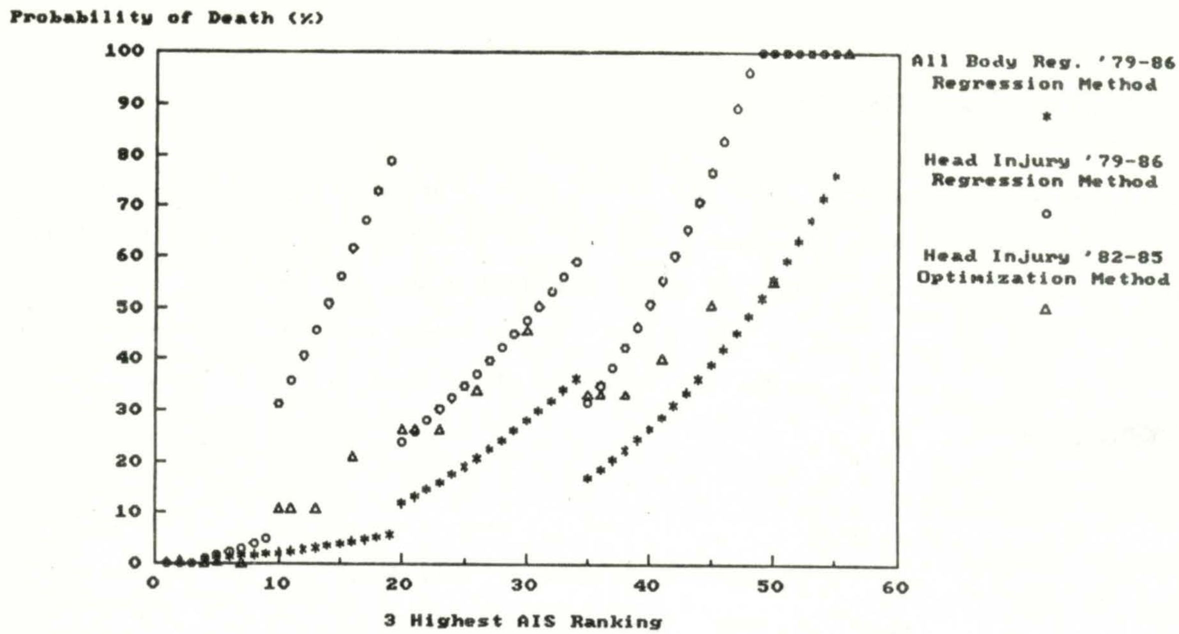


FIGURE 3.4 -- Probability of Death Comparisons - All Body Regions Versus Head Injury Derived

The POD based upon the 3 highest or 2 highest AIS levels to the head has now been derived by two separate methods. It was found that POD is higher for head injuries than for that derived from injuries to all body regions. The utility of either of these POD relationships is limited because of the sparse data from which they were derived. Nevertheless, to illustrate how significant this might be to the pedestrian program, the next section will explore the HIC-POD relationships and some vehicle response calculations based upon these 3 possible POD-AIS relationships.

4.0 ANALYSIS OF SIGNIFICANCE OF POD FUNCTIONS

In the previous section of the report, it was shown that the POD for head injuries was higher than that derived from all body regions in the Ulman study of Reference 2. This section will explore how significant this increase would be to the Pedestrian Protection Program. The 14 adult reconstruction cases upon which the original HIC-POD relationship were based will be re-examined with the new data sets.

4.1 HIC-POD Relationships

In the study of Reference 1, 14 adult pedestrian accidents were reconstructed using the pedestrian head impact simulation device. The speed was obtained by impacting at incremental speeds until the damage was matched. The HIC value for the impact was computed from the acceleration response. The POD for each impact was based upon the values in the Ulman study...derived from the 3 highest AIS levels to all body regions.

Table 4.1 contains the 14 reconstruction cases, the HIC values, calculated for each, the 3 highest recorded AIS levels to the head of the pedestrian, the original fatality rate from the Ulman study (all body regions), the fatality rate based upon head injuries by the regression method, and the fatality rate based upon head injuries by the optimization method.

The data of Table 4.1 were used for regression modeling. Each of the 3 data sets were partitioned into two ranges, that with HIC less than 1000 and that with HIC greater than 1000. It was noted that the data in the low HIC range for each data set was modeled fairly well with a straight line. The data in the higher HIC range was fit better with a logarithmic curve. One of the data points was dropped in the regression modeling. Reconstruction #S86254 with an AIS combination of 3,2,1 resulted in a POD of 50.8% using head injury data and the regression method of derivation. This point drastically different from the other 6 points in the HIC range. All other data were used in the regression modeling.

The results of the regression modeling of the 14 reconstruction cases is shown in Figure 4.1. It is noted that all three data sets result in low POD for HIC values less than 900. The two methods derived on head injuries begin to indicate a sharp increase in injury beyond a HIC value of 900. The function derived from injuries to all body regions does not indicate a rise in injury level until a HIC of 1000 is exceeded. All of the methods support an injury threshold value of HIC in the 900-1000 range. Individual scatter plots for the 3 data sets of Figure 4.1 are contained in Appendix B.

TABLE 4.1 -- Reconstruction Cases From Reference 1
HIC and POD Values by Three Methods

Test Number	Three High Head AIS	REPORT HIC	POD Original ULMAN	POD NASS 1979-1986 Head Injury Regression	POD NASS 1982-1985 Optimization
S86240	4,4,3	1571	43.0	56.0	45.4
S86242	2,0,0	365	0.9	1.0	0.0
S86243	1,0,0	527	0.2	0.0	0.1
S86245	2,1,1	531	1.6	2.2	0.1
S86252	4,2,0	1394	13.1	30.2	26.1
S86254	3,2,1	559	3.1	50.8	10.6
S39015	5,5,1	2613	58.0	100.0	55.1
S10RRE	6,5,2	3281	100.0	100.0	100.0
S39013	4,2,1	1137	14.7	32.5	26.1
S39056	5,1,1	1403	27.3	38.6	33.1
S39109	1,1,0	785	0.4	0.0	0.2
S39135	2,1,0	1071	1.2	1.6	0.1
S39090	2,1,0	187	1.2	1.6	0.1
S39145	1,0,0	832	0.2	0.0	0.1

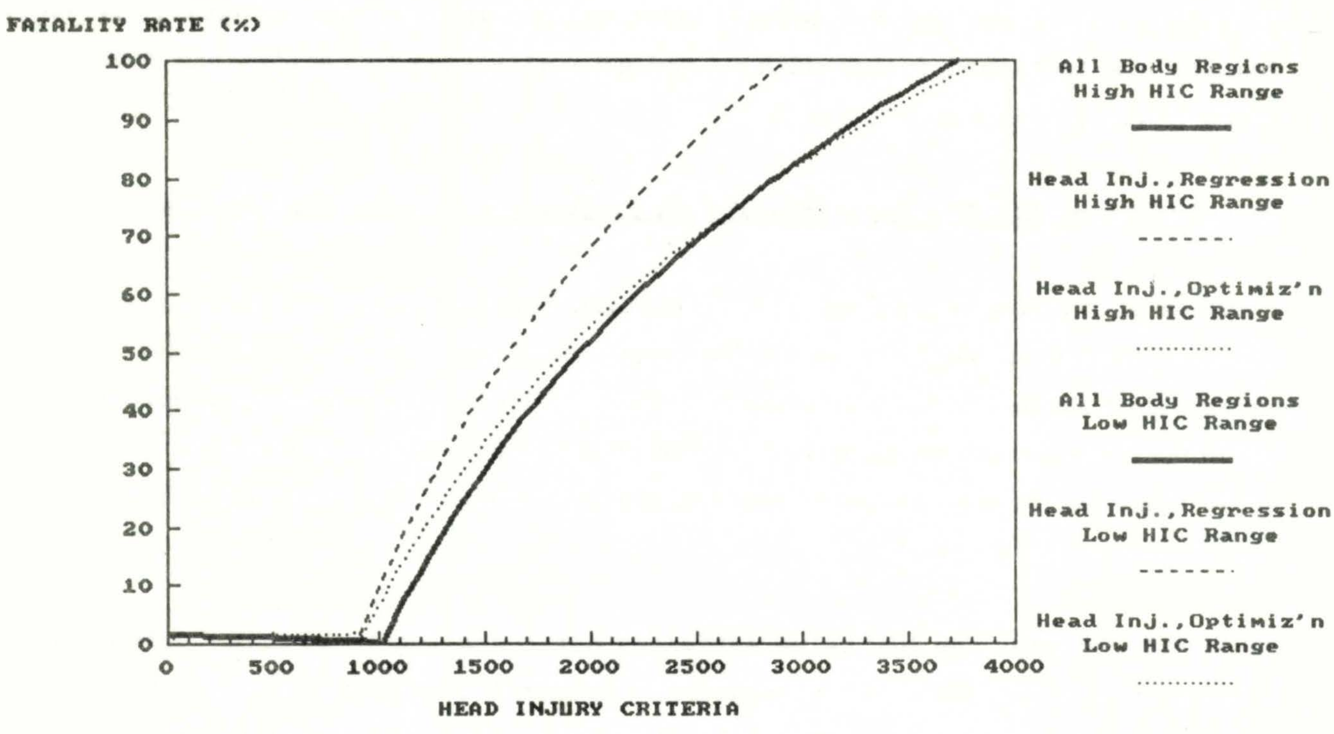


FIGURE 4.1 -- Fatality Rate Comparisons Derived From the 14 Reconstruction Cases (Ref 1) Using Ulman POD and Alternate, Head Injury Derived POD's

The difference in the POD for a given HIC in the upper range of the curve ranges from 10-20%. This is probably within the range of uncertainty of the curve, based on the number of reconstruction tests. How useful the differing curves are will depend on the degree of confidence one has in the sparse accident data from which the head AIS-POD relationships were derived and on the need to know detailed information such as whether a HIC of 2900 equates to a POD of 80% or 100%. Section 4.3 will investigate the differences in injury values predicted in production vehicle testing using these possible POD-HIC relationships.

4.2 Weibull Fatality Rate Analysis

In the preceding section, the AIS information from each of the 14 cases was used to estimate the fatality rate based upon the NASS file data. Another method, perhaps useful as a "second opinion" is the use of the fatality information from the 14 cases directly. A review of the cases reveals that 10 pedestrians survived and four were fatally injured. The 14 HIC values and the fatality outcomes were input to the Weibull statistical distribution program. These results are contained in Appendix C, and generally tend to confirm the fatality rates shown in Figures 1.1 and 4.1.

4.3 Effect of HIC-POD Relationships on Production Vehicle Test Results

A series of tests were performed on production vehicles using the pedestrian head impact simulation device (4). The test speed was 27 mph. A later study established a scaling relationship to estimate the HIC responses at lower speeds based upon the 27 mph responses (5). The production vehicle response data scaled to 23 mph will be used here to examine the difference that the various HIC-POD relationships will cause.

Table 4.2 contains the HIC value estimates after scaling to 23 mph. Columns 1-3 contain test and vehicle information. Column 4 contains the HIC values for each test. The 4 columns to the right of the HIC values represent the POD values obtained by each of 4 functional relationships between HIC and POD. The first,

TABLE 4.2 -- Production Vehicle Test Results Using

Ulman and Alternate POD-HIC Functions

IMPACT TYPE	TEST NO.	VEHICLE TYPE	HIC 23 (mph)	POD by Standard and Alt Methods: All Body Ref. 1	All Body Log Fit	Head Inj Rgsn Mtd	Head Inj Opt Mtd
HOOD/OA	295	1985 Ciera	518	1.6	1.1	0.9	1.6
HOOD/OA	308	1983 Thunderbird	667	1.9	0.9	0.5	1.7
HOOD/OA	320	1985 Escort	728	2.0	0.8	0.3	1.7
HOOD/OA	290	1983 Saab 900	766	2.1	0.8	0.2	1.8
HOOD/OA	288	1985 LeBaron GTS	815	2.2	0.7	0.1	1.8
HOOD/OA	323	1983 Saab 900	847	2.2	0.7	0.0	1.8
HOOD/OA	322	1985 LeBaron GTS	903	3.1	0.6	1.0	1.9
HOOD/OA	298	1985 Grand AM	973	5.8	0.5	7.3	4.7
HOOD/OA	361	1984 Celebrity	1042	8.5	1.8	13.0	9.4
HOOD/OA	292	1985 Sunbird	1073	9.7	4.1	15.5	11.4
HOOD/OA	312	1983 Caprice	1093	10.4	5.5	17.0	12.7
HOOD/OA	304	1985 Mustang SVO	1145	12.5	9.1	21.0	15.9
HOOD/OA	324	1983 Chevette	1333	19.7	20.8	33.8	26.5
HOOD/OA	321	1985 Mustang SVO	1362	20.8	22.4	35.5	27.9
HOOD/SS	327	1983 Chevette	854	2.2	0.7	0.0	1.8
HOOD/SS	313	1983 Caprice	1021	7.7	0.3	11.4	8.0
HOOD/SS	319	1985 Sunbird	1223	15.5	14.1	26.5	20.5
HOOD/SS	291	1983 Saab 900	1304	18.6	19.1	31.9	24.9
HOOD/SS	302	1985 Escort	1394	22.1	24.2	37.5	29.5
HOOD/SS	299	1985 Grand Am	1479	25.3	28.8	42.5	33.6
HOOD/SS	318	1982 Cavalier	1492	25.8	29.4	43.2	34.2
HOOD/SS	309	1983 Thunderbird	1533	27.4	31.5	45.5	36.1
HOOD/SS	301	1985 Escort	1552	28.2	32.5	46.6	37.0
HOOD/SS	325	1983 Chevette	1575	29.0	33.6	47.8	38.0
HOOD/SS	315	1982 Cavalier	1750	35.8	41.7	56.7	45.3
HOOD/SS	286	1985 LeBaron GTS	2273	55.9	61.8	78.7	63.4
HOOD/SS	293	1985 Sunbird	2975	83.0	82.5	100.0	82.0
HOOD/SS	307	1985 Mustang SVO	2979	83.2	82.6	100.0	82.1
HOOD/SS	358	1985 Fiero	3281	94.8	90.1	100.0	88.8
HOOD/SS	296	1985 Ciera	3301	95.6	90.5	100.0	89.2
HOOD/SS	311	1983 Thunderbird	3414	99.9	93.1	100.0	91.5
HOOD/SS	316	1982 Cavalier	3474	100.0	94.4	100.0	92.7
HOOD/SS	305	1985 Mustang SVO	3583	100.0	96.8	100.0	94.9
HOOD/SS	362	1984 Celebrity	4390	100.0	100.0	100.0	100.0
HOOD/SS	360	1985 Fiero	6626	100.0	100.0	100.0	100.0
HOOD/FENDER	289	1983 Saab 900	2092	49.0	55.4	71.7	57.6
HOOD/FENDER	326	1983 Chevette	2927	81.2	81.3	100.0	80.9
HOOD/FENDER	314	1983 CAPRICE	3004	84.1	83.3	100.0	82.7
HOOD/FENDER	310	1983 Thunderbird	3114	88.4	86.0	100.0	85.1
HOOD/FENDER	303	1985 ESCORT	3196	91.5	88.0	100.0	86.9
HOOD/FENDER	300	1985 GRAND AM	3240	93.2	89.1	100.0	87.9
HOOD/FENDER	287	1985 LeBaron GTS	3244	93.4	89.2	100.0	88.0
HOOD/FENDER	363	1984 Celebrity	3353	97.6	91.7	100.0	90.3
HOOD/FENDER	294	1985 Sunbird	3419	100.2	93.2	100.0	91.6
HOOD/FENDER	297	1985 CIERA	3472	100.0	94.4	100.0	92.7
HOOD/FENDER	306	1985 SVO MUSTANG	3485	100.0	94.7	100.0	92.9
HOOD/FENDER	317	1982 Cavalier	4270	100.0	100.0	100.0	100.0
HOOD/FENDER	359	1985 FIERO	6715	100.0	100.0	100.0	100.0
COWL	101	1985 Ciera	835	2.2	0.7	0.1	1.8
COWL	389	1985 Ciera	943	4.6	0.6	4.6	2.4
COWL	395	1985 Escort	1128	11.8	7.9	19.7	14.9
COWL	390	1985 Ciera	1200	14.6	12.6	24.9	19.1
COWL	100	1985 Ciera	1611	30.4	35.3	49.7	39.5
COWL	103	1985 Escort	1661	32.3	37.7	52.3	41.6
COWL	102	1985 Escort	2155	51.4	57.7	74.2	59.7
	OA= open area						
	SS= substructure		<10 -	25%	31%	20%	24%
			<20 -	38%	36%	29%	33%
			<50 -	58%	56%	53%	56%

column 5, is from the report of Reference 1 and uses the linear HIC-POD relationship based upon the Ulman study, using all body regions. The next 3 columns are based upon the functions shown in Figure 4.1. Column 6 is derived from the same data (all body regions, NASS '79-'83) but a logarithmic, rather than a linear curve was fit through the higher HIC range. Columns 7 and 8 represent the two functions based upon only head injuries. Column 7 is from the regression method and column 8 is from the optimization method.

These columns indicate the degree of effect of the various methods of POD estimation. It is noted again that all of the methods support a threshold HIC value of about 1000. The functions derived from head injuries result in higher POD's for HIC values just over 1000. The regression method, derived from head injury data, (column 7) results in the highest POD predictions. The summaries at the bottom of the columns indicate the percentage of the vehicles tested which had POD's below the 3 arbitrarily chosen levels. It is noted that using the Ulman derived function, 25% of the vehicles have POD's below 10%, 38% have POD's below 20% and 58% have POD's below 50%. In the worst case, using the regression-head injuries derived function, these are reduced to 20%, 29% and 53% of the vehicles below the arbitrary response levels. Given the inherent uncertainty of the whole process, these differences are probably not very significant. Estimates based upon the Ulman functional relationship, using injuries to all body regions, are probably sufficient for the pedestrian head impact program.

5.0 CONCLUSIONS

The following conclusions are offered as a result of this study:

> The probability of death (POD) based upon two or three head injuries of any given severity level appears to be higher than that based upon injuries to all body areas. Functional relationships based upon two separate methods each resulted in higher POD's than that indicated by the Ulman study, which was derived from injuries to all body areas.

The head injury relationship derived using an optimization approach predicted only marginally higher POD's than the Ulman relationship. The head injury relationship derived from the regression approach resulted in even higher POD predictions.

The degree of confidence for the HIC-POD functions based upon head injuries is lower because of the sparsity of the data. In one example, the regression method, 121 unweighted data points were partitioned into 46 categories in the AIS 3-5 range.

The apparent differences in percentages of the vehicle fleet being less than given levels of POD based upon the alternate HIC-POD approaches were not judged to be very significant. The worst cases noted on Table 4.2 were on the order of 10% of the fleet. This was small in light of the uncertainty of the data.

REFERENCES

1. Hoyt, T.A., MacLaughlin, T.F., and Kessler, J.W., "Experimental Pedestrian Accident Reconstructions--Head Impacts", DOT Report No. DOT-HS-807 288, June, 1988.

2. Ulman, M.S., Stalnaker, R.L., "Evaluation of the AIS as a Measure of Probability of Death", Proceedings of the 1986 International IRCOBI Conference on the Biomechanics of Impacts, Zurich, Switzerland, June 2-4, 1986.

3. Eppinger, R., "On the Examination of Biases in the Abbreviated Injury Scale", Proceedings of the Eleventh International Technical Conference on Experimental Safety Vehicles, Washington, D.C., May, 1987.

4. Kessler, J.W., Hoyt, T.A., and Monk, M.W., "Pedestrian Head Injury Reduction Concepts", DOT Report No. DOT-HS-807-432, June, 1988.

5. Kessler, J.W. and Monk, M.W., "Scaling Pedestrian Head Injury Estimates for Changes in Impact Velocity", Event Report for Project No. VRTC-86-0019, December, 1988

APPENDIX A

DEATH RATES FOR INJURY COMBINATIONS

The data of NASS 1982-1985 were queried and categorized according to the two highest AIS levels to the head, chest and abdomen. In the following computer table, the first column is a sequential numbering of the injury categories. The second column describes the injury location and severity (1A2C = AIS level 1 injury to Abdomen, AIS level 2 injury to Chest). The next two columns contain the optimization model predicted survival rates and fatalities. Reference 3 contains a description of the optimization modeling approach. The last two columns contain the NASS data counts of each injury category. For example, category 7, 1C1H, contained 18,201 weighted cases, of which 176 were fatalities.

		---PREDICTED---		----RECORDED-----	
	Injury	SR	#Dead	#Dead	Sample
1	1A	1.000	11.169	0.000	59408.600
2	1A1A	1.000	6.340	0.000	16862.800
3	1A1C	1.000	3.931	0.000	8996.410
4	1A1H	0.999	6.708	0.000	5164.560
5	1C	1.000	14.482	0.000	58155.900
6	1C1C	1.000	6.444	0.000	12940.100
7	1C1H	0.999	24.748	175.865	18201.270
8	1H	0.999	110.916	410.831	99837.220
9	1H1H	0.998	88.185	0.000	39710.800
10	2A	0.985	31.111	0.000	2024.940
11	2A1A	0.984	3.491	0.000	224.489
12	2A1C	0.984	1.814	0.000	116.240
13	2A1H	0.984	4.198	0.000	255.099
14	2A2A	0.970	28.246	0.000	926.342
15	2A2C	0.985	44.382	0.000	2869.970
16	2A2H	0.984	24.113	0.000	1541.900
17	2C	1.000	2.481	0.000	24324.100
18	2C1A	1.000	0.000	0.000	0.000
19	2C1C	1.000	1.968	0.000	5607.950
20	2C1H	0.999	3.944	0.000	3169.610
21	2C2C	1.000	1.532	88.714	7509.064
22	2C2H	1.000	5.130	0.000	13465.000
23	2H	1.000	3.864	130.284	13850.490
24	2H1A	1.000	0.739	0.000	1583.350
25	2H1C	0.999	1.753	0.000	3320.770
26	2H1H	0.999	15.980	0.000	11499.100
27	2H2H	0.999	5.020	84.986	8997.936
28	3A	0.976	52.770	0.000	2201.390
29	3A1A	0.976	7.762	0.000	321.363
30	3A1C	0.976	22.252	0.000	918.975
31	3A1H	0.975	3.937	0.000	157.117
32	3A2A	0.961	23.476	301.922	602.453
33	3A2C	0.976	55.476	0.000	2304.720
34	3A2H	0.976	167.110	0.000	6893.040
35	3A3A	0.953	84.435	0.000	1782.550
36	3A3C	0.959	141.662	763.990	3445.030
37	3A3H	0.873	154.784	42.287	1218.907
38	3C	0.982	47.952	0.000	2729.050
39	3C1A	0.982	0.000	0.000	0.000
40	3C1C	0.982	9.640	65.703	541.097
41	3C1H	0.981	13.574	0.000	727.358
42	3C2A	0.967	4.642	0.000	142.110
43	3C2C	0.982	154.425	181.896	8738.785
44	3C2H	0.982	83.857	113.285	4699.185
45	3C3C	0.965	179.424	241.512	5150.943
46	3C3H	0.879	245.428	335.881	2023.961
47	3H	0.894	110.174	149.633	1043.860
48	3H1A	0.894	0.000	0.000	0.000
49	3H1C	0.894	31.239	0.000	295.352
50	3H1H	0.893	52.761	191.331	495.228
51	3H2A	0.881	11.077	0.000	92.860
52	3H2C	0.894	298.489	90.740	2825.630
53	3H2H	0.894	345.564	0.000	3266.370
54	3H3H	0.800	605.633	1164.990	3028.920

55	4A	0.894	93.995	0.000	875.742
56	4A1A	0.894	0.000	0.000	0.000
57	4A1C	0.894	0.000	0.000	0.000
58	4A1H	0.893	0.000	0.000	0.000
59	4A2A	0.880	0.000	0.000	0.000
60	4A2C	0.894	0.000	0.000	0.000
61	4A2H	0.894	69.868	0.000	656.415
62	4A3A	0.872	271.991	0.000	2131.330
63	4A3C	0.878	115.500	0.000	947.534
64	4A3H	0.799	121.688	82.064	606.841
65	4A4A	0.799	433.786	634.226	2157.026
66	4A4C	0.451	1347.189	2023.040	2455.225
67	4A4H	0.661	373.571	248.443	1101.170
68	4C	0.505	279.179	387.760	563.899
69	4C1A	0.505	35.548	0.000	71.787
70	4C1C	0.505	48.918	0.000	98.781
71	4C1H	0.504	0.000	0.000	0.000
72	4C2A	0.497	0.000	0.000	0.000
73	4C2C	0.505	124.995	34.407	252.445
74	4C2H	0.505	31.060	0.000	62.719
75	4C3A	0.493	130.815	211.500	257.921
76	4C3C	0.496	1170.235	453.239	2322.089
77	4C3H	0.452	175.725	77.669	320.446
78	4C4C	0.255	740.048	492.875	593.270
79	4C4H	0.373	662.447	955.557	1056.970
80	4H	0.739	292.201	845.153	1120.625
81	4H1A	0.739	0.000	0.000	0.000
82	4H1C	0.739	86.366	0.000	330.990
83	4H1H	0.738	205.611	0.000	786.067
84	4H2A	0.728	22.833	0.000	83.912
85	4H2C	0.739	118.562	0.000	454.568
86	4H2H	0.739	298.521	99.559	1143.959
87	4H3A	0.722	0.000	0.000	0.000
88	4H3C	0.726	92.871	67.474	339.272
89	4H3H	0.661	2369.693	1716.510	6994.941
90	4H4H	0.546	1303.518	1590.470	2874.310
91	5A	0.720	0.000	0.000	0.000
92	5A1A	0.719	0.000	0.000	0.000
93	5A1C	0.719	0.000	0.000	0.000
94	5A1H	0.719	0.000	0.000	0.000
95	5A2A	0.708	0.000	0.000	0.000
96	5A2C	0.719	0.000	0.000	0.000
97	5A2H	0.719	0.000	0.000	0.000
98	5A3A	0.702	177.651	85.160	596.699
99	5A3C	0.707	47.851	0.000	163.250
100	5A3H	0.644	44.062	123.626	123.626
101	5A4A	0.643	752.077	462.019	2107.359
102	5A4C	0.363	508.011	726.401	797.879
103	5A4H	0.532	0.000	0.000	0.000
104	5A5A	0.518	1053.380	1063.480	2184.150
105	5A5C	0.253	1991.214	2291.090	2664.254
106	5A5H	0.482	113.177	218.621	218.621
107	5C	0.351	0.000	0.000	0.000
108	5C1A	0.351	0.000	0.000	0.000
109	5C1C	0.351	0.000	0.000	0.000
110	5C1H	0.351	0.000	0.000	0.000
111	5C2A	0.346	0.000	0.000	0.000

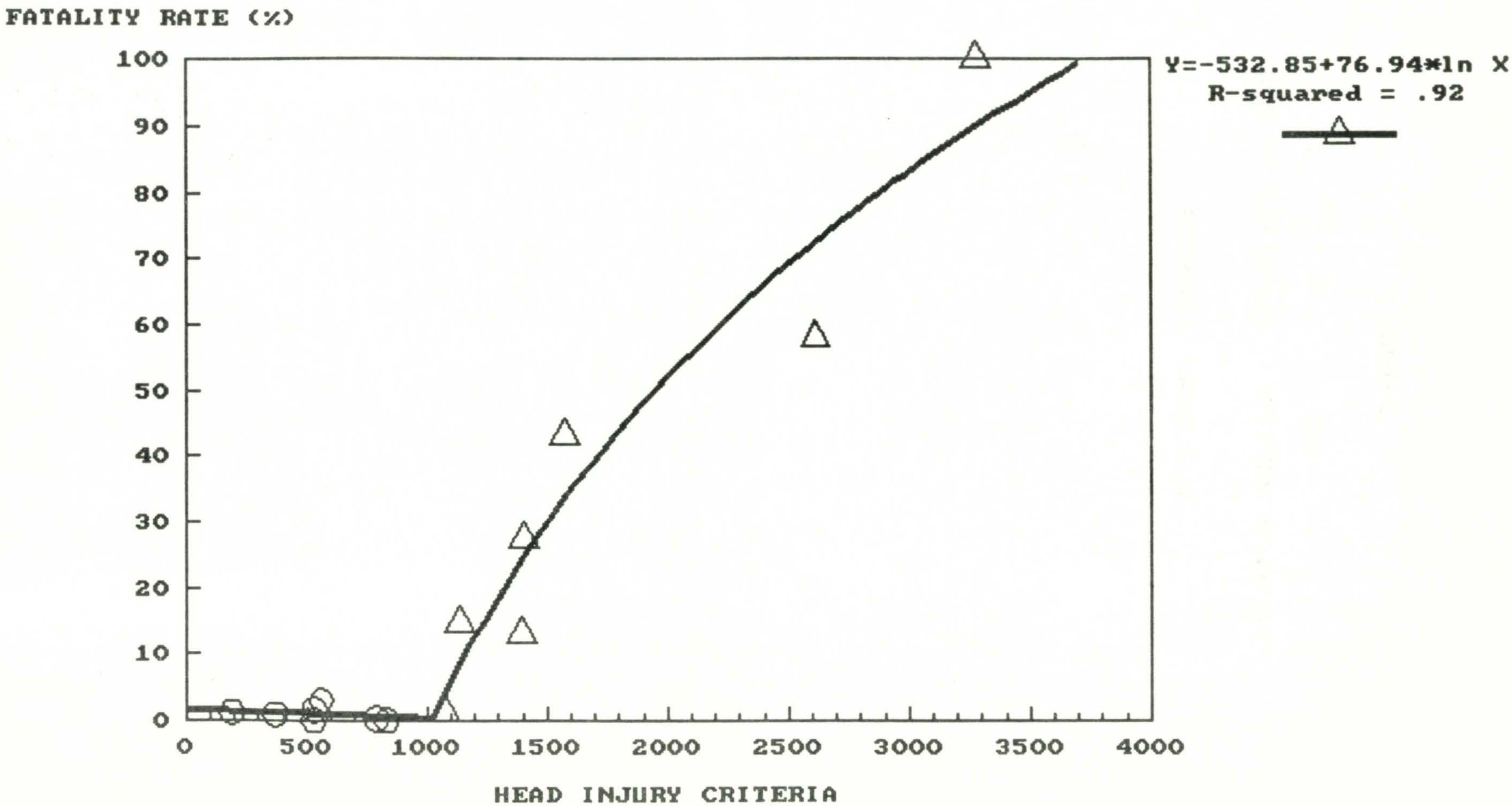
112	5C2C	0.351	27.442	42.287	42.287
113	5C2H	0.351	77.199	0.000	118.950
114	5C3A	0.343	173.212	263.510	263.510
115	5C3C	0.345	669.496	198.594	1022.010
116	5C3H	0.314	230.750	254.888	336.388
117	5C4A	0.314	724.054	944.343	1055.178
118	5C4C	0.177	1255.618	956.787	1526.162
119	5C4H	0.260	29.107	0.000	39.309
120	5C5C	0.123	1708.169	1948.330	1948.330
121	5C5H	0.235	29.928	39.139	39.139
122	5H	0.670	193.441	197.559	586.760
123	5H1A	0.670	55.496	168.270	168.270
124	5H1C	0.670	0.000	0.000	0.000
125	5H1H	0.670	87.738	0.000	265.535
126	5H2A	0.660	0.000	0.000	0.000
127	5H2C	0.670	35.552	0.000	107.818
128	5H2H	0.670	250.162	116.986	758.382
129	5H3A	0.654	130.443	119.009	377.281
130	5H3C	0.659	350.997	200.489	1027.948
131	5H3H	0.600	627.446	641.598	1566.949
132	5H4A	0.599	361.462	326.723	901.721
133	5H4C	0.338	975.331	1276.690	1474.325
134	5H4H	0.496	714.312	871.242	1415.988
135	5H5H	0.449	258.828	215.098	470.027

APPENDIX B

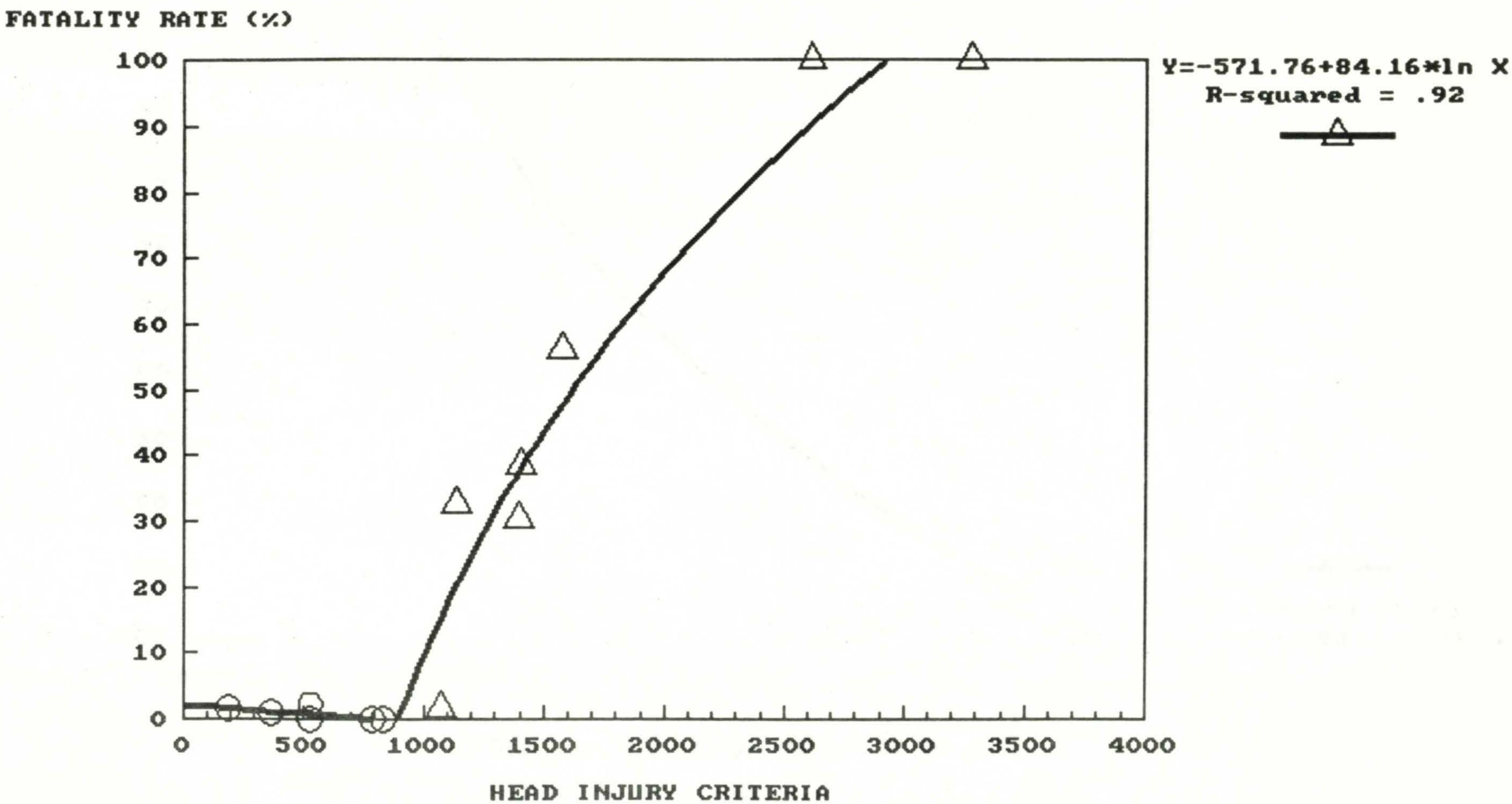
REGRESSION PLOTS FOR 14 RECONSTRUCTION CASES

BY 3 INJURY APPROACHES

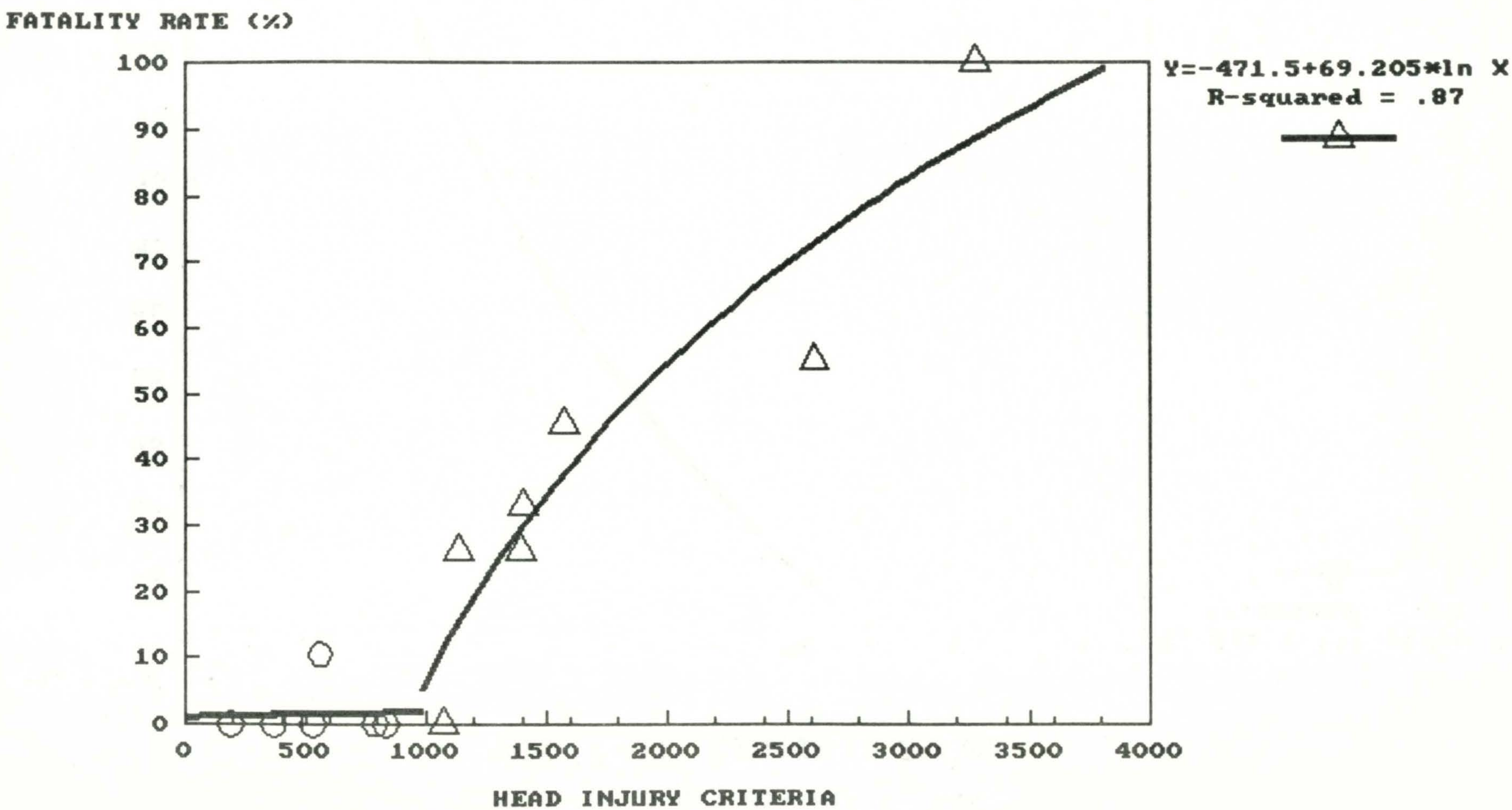
FATALITY RATE vs. HIC, 14 RECONSTRUCTION CASES
Based on 3 Highest Ais to Any Body Region
NASS '79-83 Ulman Regression Model



FATALITY RATE vs. HIC, 14 RECONSTRUCTION CASES
Based on 3 Highest AIS to Head
NASS '79-86 Regression Method



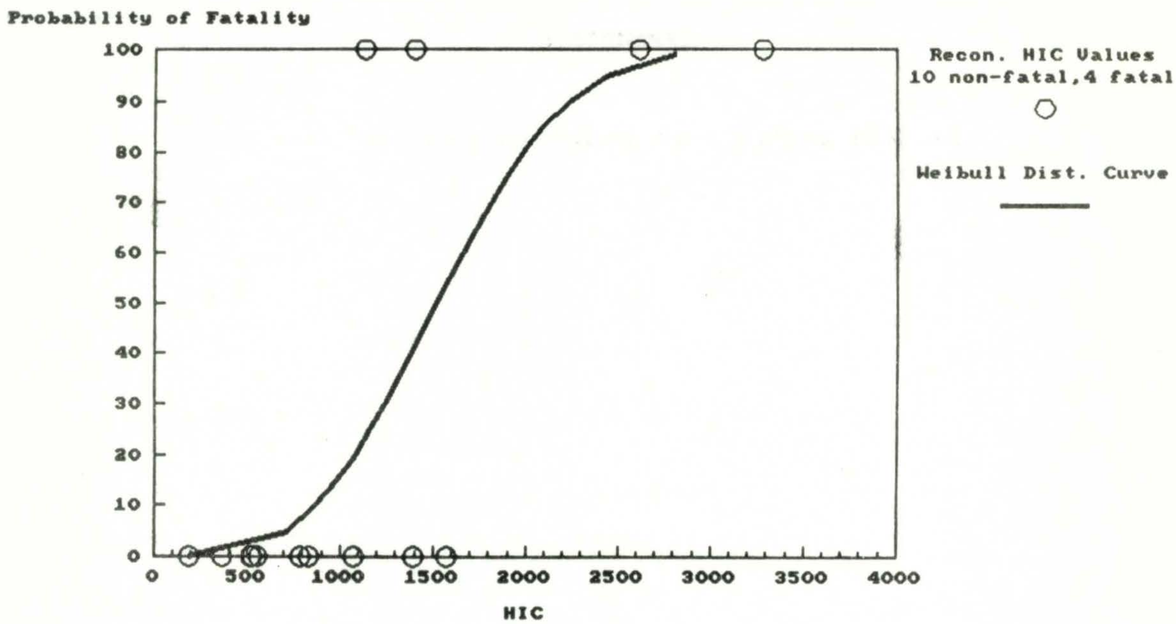
FATALITY RATE vs. HIC, 14 RECONSTRUCTION CASES
Based on 2 Highest AIS to Head
NASS '82-85 Optimization Method



APPENDIX C

Weibull Analysis of 14 Reconstruction Cases

HIC VS. PROBABILITY OF FATALITY
Weibull Analysis of 14 Reconstruction Cases



WEIBULL REPORT ON hicfatl.de

WEIBULL PARAMETERS - ALPHA =1519.398, BETA = 2.809, GAMMA = 187.000

WEIBULL SOLUTIONS

PROBABILITY AND DISTRIBUTION

F(x)	LOAD	f(x)
0.0	187.000	0.00000
5.0	714.814	0.00259
1C.0	868.971	0.00391
15.0	982.739	0.00488
20.0	1077.803	0.00563
25.0	1162.116	0.00622
30.0	1239.665	0.00666
35.0	1312.837	0.00699
40.0	1383.252	0.00720
45.0	1452.143	0.00730
50.0	1520.548	0.00730
55.0	1589.442	0.00720
60.0	1659.842	0.00699
65.0	1732.924	0.00668
70.0	1810.189	0.00625
75.0	1893.745	0.00570
80.0	1986.877	0.00502
85.0	2095.389	0.00419
90.0	2231.618	0.00316
95.0	2432.411	0.00187
99.0	2803.810	0.00049

DATA POINTS ENTERED

	10 NON-RESPONDING	4 RESPONDING
1	1571.00	2613.00
2	365.00	3281.00
3	527.00	1137.00
4	521.00	1403.00
5	1394.00	
6	559.00	
7	785.00	
8	1071.00	
9	187.00	
10	832.00	