ANALYSIS OF FATAL ROLLOVER ACCIDENTS IN UTILITY VEHICLES

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I. INTRODUCTION

In recent years, the popularity and use of jeeps and other on/off road utility vehicles has increased, as evidenced by production and registration figures.[1] As the numbers and use increase, however, so do accidents and resulting fatalities. Some of the smaller vehicles have evolved from original military designs, which have documented high incidences of rollover accidents.[2]

The objective of this report is to examine the incidence of fatal rollover accidents for utility vehicles and determine if one type of vehicle is involved more predominantly than others. In addition, occupant fatality rates for utility vehicles identified will be analyzed for an examination of those vehicles which seem more dangerous than others.

II. SOURCES OF DATA

Data used in the analysis of fatal rollover accidents are extracted from the National Highway Traffic Safety Administration's Fatal Accident Reporting System (FARS), which is a census of all police reported accidents involving at least one fatality in the fifty states, District of Columbia, and Puerto Rico. The FARS file contains data from 1975 through 1981, however, the occurrence of rollover as a first event or subsequent event was not recorded until 1978.

One shortcoming of this report is that only fatality accident data are used. Within the National Center for Statistics and Analysis (NCSA) there are two files which contain national estimates of utility vehicle accidents.

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[1] Utility vehicles here refer to a subset of the on/off road type multi-purpose passenger vehicles as opposed to service vehicles.

[2] Office of Richard Snyder, Thomas McDole, William Ladd and Daniel Minihan-- On Road Crash Experience of Utility Vehicles, ESRI, University of Michigan, February 1980.

They are the National Accident Sampling System (NASS) and its precursor the National Crash Severity Study (NCSS). However, because NASS is still in its developing stages the number of accidents and resulting fatalities involving utility vhicles is not large enough to provide reliable national estimates. Similarly in NCSS, which represents an investigation of a sample of accidents over the period April 1976 - March 1979, the number of utility vehicle accidents is too small to yield any meaningful analysis. Therefore, only FARS data are being used, which requires that much care in formulating and interpreting conclusions be exercised. References are made in the concluding remarks, however, to other sources of utility vehicle accident analyses.

Another data source used in the analysis is the R.L. Polk registration data. Since there are no data available on the vehicle miles travelled by each vehicle type, vehicle registrations are used as a partial measure of exposure to the risk of involvement in an accident. This necessitates an assumption that each vehicle type experiences the same average amount of vehicle miles travelled per year.

III. METHODOLOGY

The vehicles examined in this report are listed below by manufacturer:

1) AMC Jeep Wagoneer
2) " " Cherokee
3) " " CJ5
4) " " CJ7
5) " " CJ-Unknown
6) " " Unknown Jeep
7) " " Other Jeep
8) Chevrolet Blazer
9) Ford Bronco
10) Plymouth Trail Duster
11) Dodge Ram Charger
12) VW Thing
13) Toyota Land Cruiser
14) GMC Jimmy

Although Jeepsters were coded separately on the 1980 file, in 1978 and 1979 they were listed as "Other Jeep." Therefore, in this anlysis, all Jeepster models fall under "Other Jeep," or in some cases "Unknown Jeep," and no conclusions specific to Jeepsters can be drawn.

Specific models, for example Blazer and Blazer K-10 or Jeep CJ5 and CJ5A are not distinguishable on the FARS file and are thus all classified under one heading.

As stated earlier, all of the vehicles examined herein are classified as on-road or off-road vehicles and share certain general characteristics. Among these are a relatively short wheelbase, a high center of gravity, stiffer suspension system and typically--four-wheel drive. Accidents in the FARS file reflect only the on-road accident experience of utility vehicles, and, therefore, conclusions may differ somewhat from analyses covering both on-road and off-road experiences.

The data analyzed are single vehicle accident counts for 1978-1980 where rollover occurred versus single vehicle accidents where no rollover occurred. Also included are occupant fatalities for those two categories of accidents, i.e., rollover versus no rollover. (See Appendix A for raw data.) The hypothesis of interest is whether the percentage of rollover accidents (or fatalities) varies significantly by vehicle type.

The first analysis performed was a three-way contingency table analysis to determine the effect of year and vehicle type on accident outcome, i.e., rollover versus no rollover. A contingency table analysis starts with a procedure which fits a set of pre-specified hypotheses to data which are organized into several classifications. Once a model is determined, values for the estimates of interest are predicted. One then computes a statistic which compares the observed data to the predicted values in a test for significance. Contingency table techniques are used on observed data, and since the FARS data are from a census of fatal accidents and not estimates from a sample, it is an appropriate technique. In this analysis, accident outcome (i.e., rollover versus no rollover) was the dependent variable, whereas year and vehicle type were the independent or explanatory variables. For a more complete discussion of the technique used, see Appendix B.

The results of the contingency table analysis showed that the ocurrence of a rollover was independent of year, given vehicle type. Therefore, the variable "year" was removed from the model. Data were collapsed across the three years and the analysis reduced to a two-way table.

The analysis of the two-way table was done using properties of the binomial distribution since an accident involving each vehicle type resulted either in a rollover or no rollover. Postulating the data as sample data from an infinite population, we can calculate the necessary statistics for testing key hypotheses of interest relating to the data.

IV. SINGLE VEHICLE FATAL ROLLOVER ACCIDENTS

As mentioned earlier, the results of the contingency table analysis suggest the following:

1) there is a strong relationship between the type of vehicle and occurrence of rollover in fatal accidents; and

2) there is no significant difference in the pattern of fatal rollover accidents in the three years 1978 - 1980.

Given the second conclusion, it was determined that the data could be summed across years to facilitate the identification of those vehicles with unusually high contributions to fatal rollover accidents.

Collapsing the data across years provides the following two-way table, with vehicle types ordered by descending proportion of rollovers to all fatal accidents:

Table 1. Single Vehicle Fatal Accidents by Descending Ratio of Rollovers/All Fatal Accidents 1978-1980

(1) Vehicle Type Rollover	(2) Number of Fatal Rollover Accidents	(3) Total Number of Fatal Accidents	(4) Ratio = (2)/(3)
Trail Duster	6	7	.86
CJ5	385	479	.80
Land Cruiser	91	116	.78
CJ7	104	151	.69
Unknown Jeep	51	74	.69
Other Jeep	227	335	.68
CJ-Unknown	33	49	.67
Bronco	133	202	.66
Jimmy	35	55	.64
Blazer	221	421	.52
Thing	7	14	.50
Cherokee	16	33	.48
Ram Charger	20	43	.47
Wagoneer	10	35	.28

Each row in the table can be thought of as a binomial distribution with the parameter "p" being the proportion of rollovers in all fatal accidents. Because of problems of reliability associated with small sample sizes, eliminate the two vehicles for which the total number of accidents for the three-year period is less than 25 i.e., the "Trail Duster" and the "Thing." The remaining vehicles will be analyzed to determine which are more likely to involve a rollover in a single vehicle fatal accident.

The question of interest at this point is whether one or more vehicles are more likely than others to be involved in a single vehicle fatal rollover accident. This may be addressed by computing variances and confidence intervals about the means. The binomial distribution provides estimates of the mean and variance by a transformation to the normal distribution with mean zero and standard deviation one. Table C2 in Appendix C shows the results of the above computations, as well as the coefficient of variation for each vehicle type. The confidence limits are shown in Table C3 of Appendix C, and graphically in Figure 1. The difference in the widths of the intervals is attributable to the size of the standard error of the estimate.

Table C5. Confidence Intervals for Estimates of Proportion of Rollover Fatalities to All Fatalities

Vehicle Type	P	$S_{\bar{x}}$ = Standard Error	95% CI
Land Cruiser	.86	.033	(.80, .92)
CJ5	.85	.016	(.82, .88)
Other Jeep	.77	.024	(.72, .82)
CJ7	.76	.036	(.69, .83)
Unknown Jeep	.74	.051	(.64, .84)
CJ Unknown	.74	.064	(.61, .87)
Bronco	.74	.032	(.68, .80)
Ram Charger	.73	.077	(.58, .88)
Jimmy	.71	.063	(.59, .83)
Blazer	.66	.025	(.61, .71)
Cherokee	.61	.092	(.43, .79)

RESULTS

Once vehicle types with too small a sample size are eliminated, the data in Table 1 show all of the Jeeps and the Land Cruiser as being most likely to have a rollover in a fatal accident. Consideration of the design and structural similarity of the Land Cruiser to the Jeep offers some explanation as to why this vehicle (Land Cruiser) has the second highest proportion of rollovers per fatal accident. Among the Jeeps, the CJ5 has the highest proportion of fatal rollover accidents.

In addition, the data show the Bronco, Jimmy, Blazer, Cherokee and Ram Charger as falling below the Jeeps in terms of the ordering by proportions. The likelihood of having a rollover in a fatal accident for those vehicles varies from 0.47 to 0.66. Finally, the Wagoneer has the smallest proportion over all vehicle types of rollover for fatal accidents.

An hypothesis of interest is at what point do the means become significantly different from the highest ones. A test on the difference between the mean of the CJ5 with all other vehicle types is performed. At the 95% confidence level the test results show no significant difference in the mean for the CJ5 when compared to the Land Cruiser.

However, there is a significant difference when compared to all other vehicles on the list. Table 2 summarizes these data. Further verification of the findings is evident in two-way chi-square analyses of the CJ5 versus the other vehicle types. For the test of no significant difference between the means of the CJ5 and Land Cruiser, the computed chi-square value is 0.217, which clearly falls within the acceptance region. Thus we can conclude there is no significant difference between the CJ5 and Toyota Land Cruiser. However, the two-way analyses with all other vehicles and the CJ5 show a significant difference between the two means. (See Appendix C for chi-square values.)

Table 2. Value of z-Statistic in Significance Tests for Difference Between Means for Rollover Accidents (at $\alpha = .05$, $z = 1.96$)

Comparison of CJ5 Mean with...	z
Land Cruiser	0.47
CJ7	2.96
Unknown Jeep	2.24
Other Jeep	4.10
CJ-Unknown	2.14
Bronco	4.06
Jimmy	2.87
Blazer	8.89
Cherokee	4.30
Ram Charger	5.10
Wagoneer	7.01

Data are not available for the categories Other Jeep, CJ-Unknown and Unknown Jeep.

When the number of rollover accidents for 1978-80 are divided by the appropriate registration figures, we get the following ordering of vehicles by decreasing fatal rollover rate:

Table 4. Fatal Rollover Accident Rates (In Descending Order, 1978-80)

Vehicle Type	# of Fatal Rollover Accidents	Vehicle Years of Registration	Fatal Rollover Accident Rate (per 100,000 regis vehicle-years)
CJ5	385	734,432	52
Land Cruiser	91	194,584	47
CJ7	104	293,992	35
Blazer	221	1,283,744	17
Bronco	133	832,168	16
Jimmy	35	227,856	15
Thing	7	63,183	11
Ram Charger	20	184,581	11
Trail Duster	6	75,642	8
Cherokee	16	329,116	5
Wagoneer	10	320,154	3

Consistent with previous tables, the Jeeps (CJ5, CJ7) and Land Cruiser lead the list. The rates for the other vehicles are less striking with five of the remaining seven (Thing, Ram Charger, Trail Duster, Cherokee and Wagoneer) having fewer than 25 rollover accidents for the three year period. Again we run into small sample estimation problems, and must be careful about the interpretation of the results.

Additional significance tests can be performed to determine the difference between fatal rollover rates associated-with each vehicle type. Each fatal rollover accident rate can be thought of as a Poisson distribution where the parameter λ equals the square root of the number of fatal rollover accidents divided by the vehicle years of registration (per 100,000 registered vehicle years). This gives us the variance and standard deviation of the distribution, which allows one to compute confidence intervals in the usual way. Table 5 shows the results of the above computations.

Table 5. Fatal Rollover Accident Rates
(Poisson parameters, 95% Confidence Intervals)

Vehicle Type	Fatal Rollover Accidents	Rate*	Variance	Standard Deviation	95% CI
CJ5	385	52	2.67	1.63	(48.8, 55.2)
Land Cruiser	91	47	4.90	2.21	(42.7, 51.3)
CJ7	104	35	3.47	1.86	(31.4, 38.6)
Blazer	221	17	1.16	1.08	(14.8, 19.1)
Bronco	133	16	1.38	1.18	(13.7, 18.3)
Jimmy	35	15	2.60	1.61	(11.8, 18.2)
Thing	7	11	4.19	2.05	(6.9, 15.0)
Ram Charger	20	11	2.42	1.56	(7.9, 14.1)
Trail Duster	6	8	3.24	1.80	(4.5, 11.5)
Cherokee	16	5	1.21	1.10	(2.8, 7.2)
Wagoneer	10	3	.98	.99	(1.1, 4.9)

The comparison of Poisson observations assumes that the accident rates $X_1, X_2, \ldots, X_k$ are independently distributed with parameters $\lambda_1, \lambda_2, \ldots, \lambda_k$. Under the null hypothesis X_1 and X_2 will both be approximately normally distributed independently with expectation λ and variance λ, so $X_1 - X_2$ will be approximately normally distributed with with expectation zero and variance 2λ. We can estimate 2λ as $X_1 + X_2$. Thus under the null hypothesis, the distribution

$$\frac{(X_1 - X_2)}{\sqrt{X_1 + X_2}}$$

is approximately normal with mean zero and variance one. This approximation is improved by introducing corrections for continuity. Therefore, for a test against an alternative hypothesis $\lambda_1 > \lambda_2$, the null hypothesis is rejected if

$$\frac{(X_1 - 1/2) - (X_2 + 1/2)}{\sqrt{X_1 + X_2}} > \mu_{1-\alpha},$$

where $\mu_{1-\alpha}$ is the value of the unit normal deviate at the appropriate α level.

The results of this test on data from Table 5 shows that in comparing the rate for CJ5 with all other vehicle types, the null hypothesis is not rejected for the Land Cruiser and for the CJ7. This means that there is no statistically significant difference in the fatal rollover accident rate for the CJ5, Land Cruiser and CJ7. However, there is a significant difference between the rates for CJ5 and all other vehicle types. A similar comparison between Land Cruiser and all other vehicle types shows no significant difference in the rates for Land Cruiser and CJ7, but significant differences between Land Cruiser and all other vehicle types.

*Per 100,000 registered vehicle-years

OCCUPANT FATALITIES IN FATAL ROLLOVER ACCIDENTS

As with the analyses of single vehicle accidents, a contingency table analysis of occupant fatalities by year, vehicle type and occurrence of rollover adds no additional information when analyzed by year. Thus the data are summed across years and displayed in Table 6 by descending ratio of rollover fatalities to all fatalities involving utility vehicles.

Table 6. Occupant Fatalities in Single Vehicle Fatal Utility Accidents by Descending Ratio of Rollover Fatalities/All Fatalities, 1978-80

(1) Vehicle Type	(2) Rollover Fatalities	(3) Total Fatalities	(4) Ratio = (2)/(3)
Land Cruiser	96	112	.86
Trail Duster	6	7	.86
CJ5	412	487	.85
Other Jeep	243	315	.77
CJ7	110	144	.76
Unknown Jeep	54	73	.74
CJ-Unknown	35	47	.74
Bronco	142	191	.74
Ram Charger	24	33	.73
Jimmy	37	52	.71
Blazer	234	353	.66
Cherokee	17	28	.61
Thing	6	11	.55
Wagoneer	10	23	.43

RESULTS

Eliminating those vehicle types with less than 25 fatalities for the three year period (Trail Duster, Thing, Wagoneer) leaves an ordering very similar to that describing accident occurence. The Land Cruiser and Jeeps have the highest percentage of fatalities per fatal rollover accident, with the Ram Charger, Jimmy, Blazer and Cherokee having slightly smaller percentages. When testing the difference between the means, we find that there is no significant difference between the means of the CJ5 vs Land Cruiser, CJ5 vs CJ-Unknown and CJ5 vs Ram Charger. There is a significant difference between the mean of the CJ5 with all other vehicle types.

Upon examining the data in Table C4, the first conclusion above becomes somewhat obvious, that is, the means of the CJ5 and Land Cruiser only differ by one percentage point. The other two comparisons are not as obvious but the main factor involved is the relatively large standard errors on the estimate of the mean for CJ-Unknown and Ram Charger, resulting from the small sample sizes. This implies that there is not a lot of precision associated with these estimates. Hence, the test of comparison with the mean of the CJ5 results in the unexpected conclusion.

Additional tests of the difference between the mean of the Land Cruiser and other vehicle types show no significant difference between Land Cruiser as compared to the CJ7, CJ-Unknown, Other Jeep and Ram Charger. The values for the test statistic are summarized in Table 7. The test of the Land Cruiser with Unknown Jeep is marginal. We conclude that this further supports the hypothesis of the Land Cruiser and Jeeps being in a particular class as relates to rollover accidents and the resulting occupant fatalities.

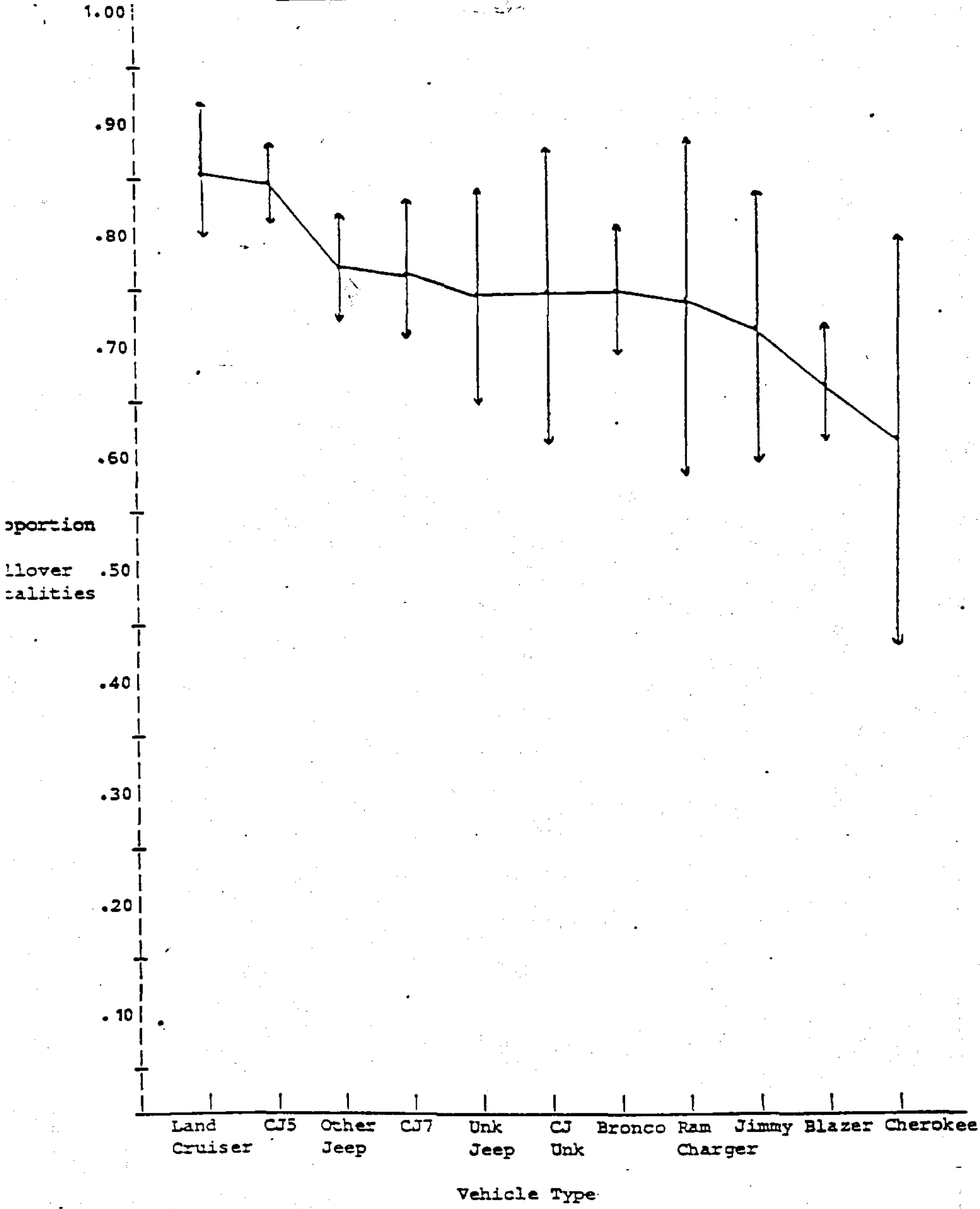
Table 7. Value of z-Statistic in Significance Tests for Difference Between Means (at α = .05, z = 1.96)

Comparison of CJ5 Mean with...	z
Land Cruiser	-0.296
Other Jeep	2.66
CJ7	2.29
Unknown Jeep	2.26
CJ-Unknown	1.79
Bronco	3.11
Ram Charger	1.79
Jimmy	2.47
Blazer	6.20
Cherokee	3.29

Cruiser of Land Cruiser Mean with...	z
CJ5	0.296
Other Jeep	1.93
CJ7	1.87
Unknown Jeep	1.99
CJ-Unknown	1.70
Bronco	2.33
Ram Charger	1.74
Jimmy	2.22
Blazer	3.95
Cherokee	2.99

As with the estimates of accident counts, confidence intervals for rollover fatalities were computed and displayed in Figure 2. This figure shows much less variation in the proportions for fatalities than observed for rollover accidents, (a difference of 25 percentage points as opposed to 52 for rollover accidents).

Figure 2.
Confidence Intervals on the Proportion of
Rollover Fatalities (α = .05)



Registration Data

As with accident counts, the number of registered vehicles can be used as the denominator for calculating occupant fatality rates for the different vehicle types. The following table shows the fatality rates in descending order:

Table 8. Occupant Rollover Fatality Rates (In Descending Order, 1978-80)

Vehicle Type	# of Rollover Fatalities	Vehicle-Years of Registration	Rollover Fatality Rate (per 100,000 registered vehicle-years)
CJ5	412	734,432	56
Land Cruiser	96	194,584	49
CJ7	110	293,992	37
Blazer	234	1,283,744	18
Bronco	142	832,168	17
Jimmy	37	227,856	16
Ram Charger	24	184,581	13
Thing	6	63,183	9
Trail Duster	6	75,642	8
Cherokee	17	329,116	5
Wagoneer	10	320,154	3

This ordering of vehicle type by fatality rate is identical to the ordering for accident rate, if the position of Thing and Ram Charger in Table 4 is interchanged. As noted before, the vehicles with the smallest number of rollover fatalities also have the lowest rollover fatality rates.

As in the case of fatal rollover accidents, tests can be performed to determine the significance of the differences between occupant rollover fatality rates. Considering each rate as being Poisson distributed, one can obtain the variance, and hence the 95 percent confidence limits. Table 9 contains the results.

Table 9. Occupant Rollover Fatality Rates
(Poisson Parameters, 95% Confidence Intervals)

Vehicle Type	Rollover Fatalities	Rate*	Variance	Standard Deviation	95% CI
CJ5	412	56	2.76	1.66	(52.7, 59.3)
Land Cruiser	96	49	5.04	2.24	(44.6, 53.4)
CJ7	110	37	3.57	1.89	(33.3, 40.7)
Blazer	234	18	1.19	1.09	(15.9, 20.1)
Bronco	142	17	1.43	1.20	(14.6, 19.4)
Jimmy	37	16	2.67	1.63	(12.8, 19.2)
Ram Charger	24	13	2.65	1.63	(9.8, 16.2)
Thing	6	9	3.88	1.97	(5.1, 12.9)
Trail Duster	6	8	3.24	1.80	(4.5, 11.5)
Cherokee	17	5	1.25	1.12	(2.8, 7.2)
Wagoneer	10	3	.98	.99	(1.1, 4.9)

The comparison of any two Poisson observations via the transformation $\frac{(X_1 - 1/2) - X_2 + 1/2)}{\sqrt{X_1 + X_2}}$ yields identical results as the comparisons on fatal rollover accident rates. There is no significant difference at the $\alpha = .05$ level between the occupant rollover fatality rate for the CJ5 and Land Cruiser, CJ5 and CJ7, and Land Cruiser and CJ7. There is a significant difference between the rates for CJ5 and all other vehicle types, the Land Cruiser and all other vehicle types as well as the CJ7 and all other vehicle

*per 100,000 registered vehicle-years

types. Thus the first three vehicle types have significantly higher occupant rollover fatality rates than all other vehicles in the table.

Fatality Rates Per Occupancy

Utilizing available data on occupancy per vehicle, one is able to compute a different measure for rollover occupant fatality rate. Since the count of number of occupants is available for all vehicle types, the entire list of vehicle types can be ordered by descending occupant fatality rate for the three-year period 1978-80. (See Table 10.)

Table 10. Rollover Occupant Fatalities/Occupancy (1978-80)

Vehicle Type	Total Fatalities	Total Occupants	Fatality Rate*
CJ Unknown	35	62	56.4
Land Cruiser	96	184	52.2
Unknown Jeep	54	104	51.9
Other Jeep	243	472	51.5
CJ7	110	214	51.4
CJ5	412	812	50.7
Bronco	142	282	50.3
Thing	6	12	50.0
Wagoneer	10	20	50.0
Blazer	234	482	48.5
Ram Charger	24	57	42.1
Jimmy	37	92	40.2
Cherokee	17	46	36.9
Trail Duster	6	17	35.3

*Per 100 occupants.

As with fatality rates using registration data as a base, the vehicles with the highest rates are Jeeps (excluding the Wagoneer and Cherokee), and the Land Cruiser. In this ordering of fatality rates the Land Cruiser has a higher rate than the Jeeps with a known model (CJ5 and CJ7). However, if we perform the test to compare fatality rates per every 100 occupants, for example, we would find that the only significant difference lies between the highest and the lowest rates (CJ-Unknown and Trail Duster). All other comparisons do not reject the null hypothesis; therefore, there is no statistically significant difference. Obviously the use of fatalities/occupancy allows very little discrimination to be made among the fourteen vehicle types.

CONCLUSIONS

This report presents an analysis of utility vehicle fatal accidents which involved a rollover, and the resulting fatalities on the FARS file. Overall, the following conclusions may be drawn from the data presented:

Vehicles With Lowest Rates

1. The Jeep Wagoneer and Jeep Cherokee have strikingly lower proportions of rollover accidents and rollover occupant fatalities than other Jeep vehicles. Given their involvement in a fatal accident, there is less than a 50 percent chance that the accident involved a rollover as compared to fatal nonrollover accident, and less than 62 percent of the occupants killed in fatal accidents were killed in rollover accidents.
2. The Wagoneer and Cherokee rank fourth and fifth in descending order of registered vehicles (after Blazer, Bronco and CJ5), but have the first and third lowest percentage of fatal rollover accidents.
3. The Thing, Ram Charger, Trail Duster, Cherokee and Wagoneer have the lowest fatal rollover accident rates (per 100,000 registered vehicle years), as well as the lowest rollover occupant fatality rates (per 100,000 registered vehicle years).

Vehicles with Highest Rates

4. Given a fatal accident involving a utility vehicle, the Jeep CJ5 and Toyota Land Cruiser are more likely to have rolled over than any other vehicle type.
5. Occupant fatalities resulting from utility vehicle fatal accidents which involve a rollover occur more frequently in Jeeps (excluding the Wagoneer and Cherokee) and the Land Cruiser as opposed to the other vehicle types.

6. There is no statistically significant difference between the rollover accident rates and occupant fatality rates (using vehicle years of registration as the base) for the CJ5, Land Cruiser and CJ7 given that a fatal accident has occurred.

<u>Others</u>

7. There is no significant difference in the mean for occupant fatalities involving the CJ5 when compared to the Land Cruiser, CJ-Unknown and Ram Charger. However, the primary contributing factor in the case of the CJ-Unknown and Ram Charger is the large variance associated with small sample sizes.
8. There is no significant difference in the occupant fatality rates for all but two vehicle types (CJ-Unknown and Trail Duster) when the denominator is total number of occupants as opposed to registration data.

These conclusions are based wholly on the data presented in this report, which is somewhat biased because it considers only fatal accidents. A better picture may be obtained by analyzing all accidents involving utility vehicles, on-road and off-road. Comparisons may also be made against passenger cars as opposed to limiting an analysis to utility vehicles.

For a comprehensive analysis of all on-road accidents involving utility vehicles for selected states, the reader is referred to a publication by the Highway Safety Research Institute of the University of Michigan. The report is entitled "On-Road Crash Experience of Utility Vehicles" and the authors are Richard G. Snyder, Thomas L. McDole, William M. Ladd and Daniel J. Minahan. This technical report, along with an accompanying "Overview of the On-Road Crash Experience of Utility Vehicles," may be obtained from the National

Technical Information Service, 5285 Fort Royal Road, Springfield, VA 22161. Refer to the main report by the code PB-80 160 468, and the summary by PB-80 160 476. The price for the publications is $20.00 and $5.00 respectively.

Some of the major findings of the study were:

1. Utility vehicles experience rollover at a rate that is at least 5 times higher than that experienced by the average passenger car.
2. The Jeep and pre-1978 Bronco overturned at least twice as often as the Blazer.
3. Both the death rate and the rate of disabling injury per accident are about twice as high in utility vehicles and both rates are approximately twice as high in Jeeps as in Blazers.

Another publication which presents a different type of result in analyzing utility vehicle accidents is entitled "Injury Claim Frequency Results by Size of Claim for Vans, Pickups, and Utility Vehicles 1977-1980 Models," (HLDI V80-2). This report is published by the Highway Loss Data Institute (HLDI), Watergate 600, Washington, D.C. 20037 and was printed in September 1981. The following conclusions were drawn from the analysis of the utility vehicles:

1. For all 1977-1980 model year utility vehicles for which insurance claims for injuries to occupants were made, the Jeep CJ5 and CJ7 had the highest frequencies.
2. The Jeep CJ5 had the worst results of all vehicles, with its overall claim frequency being 122 percent worse than the average for all 1977-1980 vans, pickups and utility vehicles.
3. The frequency of claims exceeding $250, $500 and $1,000 for the CJ5 were all higher than those for any other vehicle reported for the same model years.

The Toyota Land Cruiser is not included in this analysis. When asked why, one of the authors explained that the number of Land Cruisers on the road did not meet their threshold for inclusion as a separate category. Instead it was added into the category "other utility vehicles."

Finally, one other report which analyzed the crash experience of utility vehicles was conducted by the Highway Safety Research Center and the Insurance Institute for Highway Safety and released in September 1981. Accident data were obtained from the states of Maryland and North Carolina. The report is entitled "A Comparison of the Crash Experience of Utility Vehicles, Pickup Trucks and Passenger Cars" and focused primarily on the three leading utility vehicles—the Jeep CJ5, Ford Bronco and Chevrolet Blazer. In addition, the analysis was restricted to model years 1972 to 1978 for the CJ5; 1973 to 1978 for the Blazer; and 1972 to 1977 for the Bronco. The restriction in model years was undertaken to isolate as much as possible effects due to design and structural changes in the vehicles. They concluded that for single vehicle crashes, the Jeep CJ5 had the highest crash rate of all utility vehicles in both Maryland and North Carolina. This report may be obtained from the Insurance Institute for Highway Safety, Watergate 600, Washington, D.C. 20037.

APPENDIX A - DATA

SINGLE VEHICLE ACCIDENTS

Vehicle Type	1978 Rollover	1978 No Rollover	1979 Rollover	1979 No Rollover	1980 Rollover	1980 No Rollover	1978 - 1980 TOTAL	1978 - 1980 Rollover	1978 - 1980 No Rollover	r= Roll[illegible]/Tot[illegible]
Wagoneer	2	9	4	13	4	3	35	10	25	.28
Cherokee	6	7	4	4	6	6	33	16	17	.48
CJ5	118	30	158	39	109	25	479	385	94	.80
CJ7	28	11	47	19	29	17	151	104	47	.69
CJ-Unknown	13	4	14	8	6	4	49	33	16	.67
Unknown Jeep	21	9	14	7	16	7	74	51	23	.6[illegible]
Other Jeep	43	19	41	27	143	62	335	227	108	.6[illegible]
Blazer	64	80	77	56	80	64	421	221	200	.52
Bronco	29	20	47	22	57	27	202	133	69	.6[illegible]
Trail Duster	4	1	0	0	2	0	7	6	1	.8[illegible]
Ram Charger	3	4	10	10	7	9	43	20	23	.4[illegible]
VW Thing	4	4	3	3	0	0	14	7	7	.5
Land Cruiser	22	9	31	9	38	7	116	91	25	.7[illegible]
Jimmy	8	7	6	4	21	9	55	35	20	.6[illegible]
	365	214	456	221	518	240	2014	1339	675	

579 + 677 + 758 = 2014

OCCUPANT FATAILTIES--SINGLE VEHICLE ACCIDENTS

Vehicle Type	1978 Rollover	1978 No Rollover	1979 Rollover	1979 No Rollover	1980 Rollover	1980 No Rollover	1978 - 1980 Rollover	1978 - 1980 No Rollover	Total	P
Wagoneer	2	7	4	6	4	0	10	13	23	.43
Cherokee	6	5	5	3	6	3	17	11	28	.61
CJ5	131	29	166	26	115	20	412	75	487	.85
CJ7	28	4	52	16	30	14	110	34	144	.76
CJ-Unknown	14	2	14	7	7	3	35	12	47	.74
Unknown Jeep	21	6	15	7	18	6	54	19	73	.74
Other Jeep	48	9	43	16	152	47	243	72	315	.77
Blazer	67	45	84	32	83	42	234	119	353	.66
Bronco	29	14	51	13	62	22	142	49	191	.74
Trail Duster	4	1	0	0	2	0	6	1	7	.8[illegible]
Ram Charger	5	1	11	5	8	3	24	9	33	.7[illegible]
VW Thing	4	1	2	4	0	0	6	5	11	.5[illegible]
Land Cruiser	23	6	34	6	39	4	96	16	112	.8[illegible]
Jimmy	8	5	8	3	21	7	37	15	52	.7
	390	135	489	144	547	171	1426	450	1876	

525 + 633 + 718 = 1876

APPENDIX B - METHOD OF ANALYSIS

METHOD OF ANALYSIS

Contingency table analysis is a method used in analyzing cross-classified categorical or count data. The data are grouped into categories and presented in a multi-dimensional contingency table. Actual counts of observations are recorded as opposed to sample estimates of some characteristic. The computer program used in the present study is CONTAB, which was developed at George Washington University under the direction of Dr. Solomon Kullback.

Contingency table techniques are appropriate for data that have been cross-classified by several variables of interest. The number of cells in a contingency table is equal to the product of the number of categories or levels in each variable or factor of interest. In the utility vehicle rollover problem studied, there were three factors, with 3, 14 and 2 categories, respectively. Therefore, the 3-way classification described by them has 3 . 14 . 2 = 84 cells.

The aim of contingency table analysis is to fit a model to the observed data using the simplest possible structure. In accordance with the data collection design, the data are assumed to obey an underlying multinomial distribution over all cells. A complete description of the multinomial distributions would require information on all probabilities in all cells. However, this is not parsimonious; therefore, a description employing fewer parameters is desirable. The analysis thus provides, for a nested set of hypothesis (if so specified) a measure of the goodness of fit to the data for each hypothesis or model as well as an analysis of the interactions present in the model. The test statistics used are minimum discrimination information

(MDI) statistics which are asymptotically (for large samples) distributed as chi-square with appropriate degrees of freedom.

The model associated with the contingency table analysis is log-linear, where the logarithms of the cell probabilities are expressed as linear functions of the main effects and interactions. This structure is not imposed on the analysis but arises naturally given the principle of minimum discrimination information estimation. For example, consider a data set with three factors, i, j, k with categories 2, 3, 2 respectively. The number of cells is 2 . 3 . 2 = 12. If we let p(i,j,k) represent the underlying probability that a data point selected at random lies in cell (i,j,k) then the log linear model representing each p(i,j,k) is of the form

$$\ln p(i,j,k) = L + \tau_i^I + \tau_j^J + \tau_k^K + \tau_{ij}^{IJ} + \tau_{ik}^{IK} + \tau_{jk}^{JK} + \tau_{ijk}^{IJK}$$, where L is

a normalizing value and the subscripts take on values i=1, j=2, k=i and parameters with i=2 and/or j=3 and/or k=2 are set equal to zero by convention to attain linear independence. Furthermore τ_i^I, τ_j^J, τ_k^K are the one-factor terms, with 1, 2, and 1 linearly independent parameters, respectively; τ_{ij}^{IJ}, τ_{ik}^{IK}, τ_{jk}^{JK} are two-factor interaction terms, with 2, 1 and 2 linearly independent parameters, respectively; and τ_{ijk}^{IJK} is a three-factor interaction term, with 2 linearly independent parameters. Thus, a complete description of all probabilities would require 12 linearly independent parameters. Since the data contain 12 cells the system would be completely determined. The goal of contingency table analysis is to find a model using fewer than 12 parameters but which still gives a good fit to the data.

The test statistic or information statistic (IS) is computed as

$$2I(x:x^*) = \quad x(\omega) \ \ln \frac{x(\omega)}{x^*(\omega)}$$

where $x(\omega)$ = observed distribution over the cells ω and $x^*(\omega)$ = predicted distribution or MDI estimate for the observed distribution.

The IS is used to measure the fit of the predicted distribution x^* to the observed distribution x. Under the null hypothesis that the model is correct, this statistic has a distribution which is asymptotically chi-square with degrees of freedom equal to the number of cells minus the number of linearly independent parameters specified by the model.

The IS can also be used to test a nested ordering of models. If x_1^* and x_2^* are distributions predicted from two models, and all the parameters used in the model for x_1^* are also used in the model for x_2^*, then the statistic $2I(x_2^*:x_1^*)$ satisfies the following pythagorean type relationship:

$$2I(x:x_1^*) = 2I(x:x_2^*) + 2I(x_2^*:x_1^*)$$

which can be proved using properties of MDI estimation. The distribution of of $2I(x_2^*:x_1^*)$ is also asymptotically chi-square, with degress of freedom equal to the number of linearly independent parameters specified by x_2^* which are not specified by x_1^*. This statistic is used to test whether the effect of constraints specified by x_2^* but not by x_1^* are significant.

APPENDIX C - DATA ANALYSIS

D the data is CONTAB acquired

e classified into a 3-way

s

c

CJ7, CJ-Unknown, Unknow Jeep,

co, Trail Duster, Ram Charger,

Jimmy (14 levels)

er (2 levels)

2 = 84 cells for the 2014 observations

Th tcome. The hypotheses tested were:

or the 42 combinations of year and

outcome; and

2

3

A s ng information statistic (I.S.) degrees

of value (significance level) are shown in

Tab nested order to facilitate the test

of it is added. They are numbered according

to odness-of-fit of the model. The effect

test f-fit numbers for the appropriate models.

In a als since there were no accident outcome

obse ter and 1980 x Thing.