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An Analysis of the Severity and Incident Duration of Truck-Involved Freeway Accidents

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ABSTRACT

Data associated with over 9000 accidents involving large trucks and combination vehicles during a two-year period on freeways in the greater Los Angeles area are analyzed relative to collision factors, accident severity, incident duration, and lane closures. Relationships between type of collision and accident characteristics are explored using log-linear models. The results point to significant differences in several immediate consequences of truck-related freeway accidents according to collision type. These differences are associated both with the severity of the accident, in terms of injuries and fatalities, and the impact of the accident on system performance, in terms of incident duration and lane closures. Hit-object and broadside collisions are the most severe types in terms of fatalities and injuries, respectively, and single-vehicle accidents are relatively more severe than two-vehicle accidents. The durations of accident incidents are found to be log-normally distributed for homogeneous groups of truck accidents, categorized according to type of collision and, in some instances, severity. The longest durations are typically associated with overturns.

1.0 OVERVIEW AND SCOPE

This paper documents statistical analyses of certain consequences of truck-related accidents that occurred on freeways in Los Angeles, Orange, and Ventura Counties of California. This research is part of a larger study which is assessing non-recurrent congestion costs associated with truck-related freeway accidents. The analyses are based on data associated with over 9,000 truck-involved accidents that occurred during the two-year period 1983-1984. Data were drawn primarily from the TASAS data base maintained by the California Department of Transportation. Data on incident duration and the number of lanes or ramps closed were obtained from California Highway Patrol dispatch record logs for a random sub-sample of truck accidents contained in the TASAS data base. The data are described in Section 2.

The analyses are organized according to three major categories: type of collision, accident severity, and incident duration and lane closures. In each of these major categories, the analyses seek to identify underlying factors associated with differences in accident characteristics.

In Section 3, accident rates by collision type are analyzed relative to the number of vehicles involved and certain other accident characteristics. Relationships between accident severity (e.g., injuries, fatalities) and types of collision and number of involved vehicles are established in Section 4. Finally, in Section 5, statistical models are developed that relate incident duration to collision type, accident severity, and lane closures.

2.0 THE DATA

The statistical analyses documented in this report are based on data on truck-related accidents that are recorded in the TASAS (Traffic Accident Surveillance and Analysis System) data base maintained by the California Department of Transportation (Caltrans, 1978). This data base purports to contain all accidents on the state highway system that involved police reports. In 1983-1984, there were 9508 such accidents involving trucks larger than pickups or panel trucks on twenty-two freeway routes in Los Angeles, Orange, and Ventura Counties. Highway and ramp characteristics were established for each accident by matching the accident with the current (through 1984) TASAS highway or ramp record at the accident site or closest up-stream postmile.

Data on incident duration and the number of lanes or ramps closed by an accident were obtained from California Highway Patrol (CHP) dispatch record logs. Completed incident logs for 1983 and 1984 were reviewed on microfiche at the Los Angeles CHP Communications Center. Log entries were found for a random sample of truck-involved accidents, identified by CHP beat, date, time of day, and location. The random sample was stratified by collision type, and only accidents located in Los Angeles County, excluding the city of Long Beach, were included (the area covered by the Los Angeles CHP Communications Center).

Incident durations were calculated from the logged time at which obstructions and hazards were cleared and police left the scene. The times during which specific numbers of lanes or ramps were closed were also typically reported on the logs. Biases in these data probably involve the under-reporting of closures that are of short duration.

3.0 GENERAL ACCIDENT CHARACTERISTICS

3.1 Accident and Involved-Vehicle Totals by Collision Types

Seven specific categories of collision type are distinguished in the TASAS data base, but there were low frequencies of occurrence for truck-involved freeway accidents for two of these collision types: head-on collisions (39 accidents) and auto-pedestrian collisions (22 accidents). Consequently, these two types were combined with the residual "other" category in all analyses. The distribution of 1983-1984 truck-involved freeway accidents by type of collisions is shown in the first column of Table 1.

The numbers of total vehicles and trucks involved by collision type are shown in the remainder of Table 1. Non-truck vehicles include passenger cars, motorcycles, pickup and panel trucks, buses, and emergency vehicles. Rear-end accidents generally involve the largest number of vehicles, followed by broadsides and sideswipes. In terms of truck involvement, the six collision types are similar, ranging from 1.08 and 1.11 mean trucks per accident.

3.2 Characteristics by Collision Type

Relationships between type of collision and selected accident characteristics available in the TASAS data base were explored using the method of log-linear modeling (Nelder and Wedderburn, 1972; Bishop, et al., 1975; and Goodman, 1978). Log-linear models are used to decompose cross-tabulation tables into components of a probability process with Poisson-distributed error terms. Logarithmic transformations are used to specify a linear model for the occurrences of events within each cell of the table; and statistical t-tests are conducted to determine whether or not such occurrences are significantly more or less than can be expected

COLLISION TYPE	# OF ACCIDENTS	# VEHICLES INVOLVED 1	2	3	4+	Mean	Std. Dev.	# TRUCKS INVOLVED 1	2	3+	Mean	Std. Dev.
SIDE-SWIPE	4092 (43.0%)	-	80.3%	15.2%	4.5%	2.26	0.62	92.0%	7.7%	0.3%	1.08	0.29
REAR-END	2964 (31.2%)	-	62.7%	25.6%	7.2%	2.54	0.86	90.4%	8.8%	0.8%	1.11	0.34
BROAD-SIDE	456 (4.8%)	-	74.3%	18.4%	7.3%	2.37	0.80	90.4%	8.6%	1.1%	1.11	0.38
HIT OBJECT	1108 (11.7%)	55.6%	31.6%	7.7%	5.1%	1.66	0.97	90.2%	8.4%	1.4%	1.11	0.37
OVER-TURN	272 (2.9%)	88.6%	8.1%	1.5%	1.8%	1.18	0.64	92.3%	6.6%	1.1%	1.09	0.35
OTHER TYPES	616 (6.5%)	21.1%	64.0%	10.9%	4.0%	2.00	0.80	91.6%	8.1%	0.3%	1.09	0.31
ALL TYPES	9508	10.4%	65.7%	17.0%	6.9%	2.24	0.77	91.2%	8.2%	0.7%	1.10	0.32

TABLE 1

BASIC ACCIDENT INVOLVEMENT STATISTICS BY COLLISION TYPE

by chance, based on row and column totals. Log-linear models were also employed by Chira-Chavala and Cleveland (1985) in a study of accident involvement rates.

The first accident characteristic investigated was the fundamental location variable of highway versus ramp. As shown in Table 2, there are substantial

COLLISION TYPE	# OF ACCIDENTS	LOCATION			
		HIGHWAY		RAMP	
SIDESWIPE	4092	3513	(85.9%)+	579	(14.1%)-
REAR-END	2964	2624	(88.5%)+	340	(11.5%)-
BROADSIDE	456	286	(62.7%)-	170	(37.3%)+
HIT OBJECT	1108	801	(72.3%)-	307	(27.7%)+
OVERTURN	272	139	(51.1%)-	133	(48.9%)+
OTHER TYPES	616	526	(85.4%)	90	(14.6%)
ALL TYPES	9508	7889	(83.0%)	1619	(17.0%)

TABLE 2

DISTRIBUTIONS BETWEEN HIGHWAY AND RAMP ACCIDENTS BY COLLISION TYPE WITH SIGNIFICANTLY HIGH (+) OR LOW (-) CELL FREQUENCY IDENTIFIED USING A LOG-LINEAR MODEL differences among collision types in terms of proportional occurrences at highway and ramp locations. The log-linear results documented in this table identify which collision types exhibit locational distributions that are significantly different (at the p = .05 level) from the distributions for all accidents. All collision types except the "other" category have varying highway versus ramp splits, with rear-end and sideswipe collisions located predominately at highway sites, and overturns, broadsides, and hit-objects located at ramp sites.

The relationship between collision type and primary collision factor is shown in Table 3, where factor is specified on the TASAS data base in the nine listed categories (the sample size for the analysis of Table 3 is 9496 due to missing data on 12 accidents). The relationships are largely as expected but do reveal some behavioral traits. For example, rear-end collisions are caused not only by tail-gating driving behavior, but also by alcohol, speeding, and other improper driving. The two collision types, hit object and overturns, have similar primary factor patterns with one exception: both have strong relationships to speeding and not-driver factors, but hit-object collisions are also due to improper turns while overturns are not. All of the other collision types are highly unique in terms of patterns of causal factors.

COLLISION TYPE	PRIMARY ACCIDENT FACTOR								
	INFLUENCE ALCOHOL	TAIL-GATING	FAILURE TO YIELD	IM-PROPER TURN	SPEEDING	OTHER VIOLA-TIONS	OTHER IMPROPER DRIVING	NOT DRIVER	UNKNOWN
SIDESWIPE	100-	7-	22	571+	303-	2881+	56-	74-	75
REAR-END	175+	235+	1-	96-	1746+	546-	80+	54-	26-
BROADSIDE	18	4-	37+	61+	109	191	5	19	11
HIT OBJECT	46	14-	0-	144+	382+	309-	31	170	11
OVERTURN	5	1-	0	14-	143+	57-	6	45+	1
OTHER TYPES	9-	2-	5	17-	103-	292	11	163	12+
Sample Sizes:	353	263	65	903	2786	4276	189	525	136

TABLE 3

COLLISION TYPES BY PRIMARY COLLISIONS FACTOR WITH SIGNIFICANTLY HIGH (+) OR LOW (-) CELL FREQUENCIES IDENTIFIED USING A LOG-LINEAR MODEL

4.0 ACCIDENT SEVERITY

4.1 Relationships to Number of Involved Vehicles

The 9508 truck-involved accidents in 1983 and 1984 on twenty-two freeway routes in Los Angeles, Orange, and Ventura Counties accounted for a total of 4436 recorded injuries and 120 recorded fatalities. This is an overall average of 0.47 injuries and 0.013 fatalities per accident.

Mean fatalities, mean number of injured persons, and mean number of injured persons per vehicle are listed in Table 4 as a function of the number of vehicles involved in the accident. One-vehicle accidents are proportionally more dangerous than multi-vehicle accidents, in terms of both injuries and fatalities. Single-vehicle accidents particularly stand out in the function of mean injuries per vehicle.

However, there is no significant relationship between severity and the number of involved trucks: F-tests of the differences in mean injuries and mean injuries per vehicle indicate that there are no significant differences among accidents involving varying numbers of trucks. It is the total number of vehicles involved, not the number of trucks involved, that partially determines the severity of the accident.

4.2 Collision Types and Factors

The mean values of injuries per accident, injuries per vehicle per accident, and fatalities per accident are listed in Table 5 by collision type. Accident severity is also related to the primary collision factor, as shown in Table 6. The differences among the mean values for all three of the accident-severity variables by both collision type and factor are statistically significant. For collision types, the most severe accidents in terms of fatalities are hit-object collisions, followed by rear-end collisions and "other" types; the least severe are sideswipes. With regard to injuries per accident, broadside collisions have the highest mean of 0.81 injuries per accident, while sideswipes and the collision type "other" have equally low means of 0.31 to 0.32 injuries per accident. With regard to injuries per vehicle per accident, the most dangerous accidents are overturns, followed by broadside and hit-object collisions; the least dangerous accidents on a per-vehicle basis are sideswipes.

NUMBER OF VEHICLES	MEAN FATALITIES	MEAN INJURED	MEAN INJURED/VEHICLE
1	0.015	0.34	0.34
2	0.010	0.36	0.18
3	0.015	0.64	0.21
4	0.020	0.98	0.25
5	0.036*	1.54	0.31
6	--	1.80	0.30
7 or more	--	3.11	0.39

* Mean fatalities for accidents involving five or more vehicles.

TABLE 4

ACCIDENT SEVERITY STATISTICS BY NUMBER OF VEHICLES INVOLVED IN THE ACCIDENT

COLLISION	NUMBER OF ACCIDENTS	INJURIES PER ACCIDENT		INJURIES PER VEHICLE/ACCIDENT		FATALITIES PER ACCIDENT	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SIDE-SWIPE	4092	0.31	0.72	0.13	0.29	0.002	0.049
REAR-END	2964	0.64	1.05	0.25	0.41	0.021	0.164
BROAD-SIDE	456	0.81	1.08	0.33	0.42	0.009	0.093
HIT OBJECT	1108	0.52	0.91	0.32	0.51	0.025	0.202
OVER-TURN	272	0.42	0.63	0.38	0.52	0.015	0.121
OTHER TYPES	616	0.32	0.88	0.17	0.45	0.021	0.144
ALL TYPES	9508	0.47	0.88	0.21	0.38	0.013	0.128

TABLE 5

ACCIDENT SEVERITY STATISTICS BY COLLISION TYPE

PRIMARY COLLISION FACTOR	NUMBER OF ACCIDENTS	INJURIES PER ACCIDENT		INJURIES PER VEHICLE/ACCIDENT		FATALITIES PER ACCIDENT	
		Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
INFLUENCE ALCOHOL	353	0.85	0.97	0.39	0.43	0.074	0.292
FAILURE TO YIELD	65	0.46	0.73	0.23	0.37	0.000	0.000
IMPROPER TURN	903	0.36	0.78	0.17	0.37	0.016	0.124
SPEEDING	2786	0.59	1.06	0.27	0.45	0.012	0.116
OTHER VIOLA-TIONS	4276	0.39	0.80	0.16	0.34	0.008	0.105
OTHER IMPROPER DRIVING	189	0.61	0.88	0.32	0.44	0.011	0.103
NOT DRIVER	525	0.40	0.81	0.22	0.42	0.017	0.200
UNKNOWN	136	0.29	0.74	0.13	0.35	0.022	0.147
ALL FACTORS	9496	0.47	0.88	0.21	0.38	0.013	0.128

TABLE 6

ACCIDENT SEVERITY STATISTICS BY PRIMARY COLLISION FACTOR

Regarding the primary collision factor, the most severe accidents, measured in terms of any of the three variables, are those attributed to alcohol. In terms of fatalities, the next most severe are those attributed to unknown factors, followed by "not driver" accidents and those attributed to improper turns. In terms of both injuries and injuries per vehicle, the next most severe accidents after those that are alcohol-related are those attributed to other improper driving and speeding.

4.3 Involved Vehicle Relationships by Collision Types

Graphs of mean numbers of injured persons by involved vehicle, parameterized by collision type, are given in Figure 1. The differences in mean injuries by involved vehicle are statistically significant for each collision type. Overturns have the highest levels and steepest slopes per involved vehicle, although there are very few overturns that involve more than two vehicles. In the range of two-to-four vehicles, broadsides are the most severe in terms of injuries. For most of the range, other types of collisions and sideswipes are the least severe types of accidents, but rear-end collisions involving five vehicles are also moderate when compared to hit-object collisions involving five vehicles. Finally, the function for the category "other" is unique, being relatively flat in the range of one-to-three involved vehicles and consequently displaying a negatively-sloped relationship of injuries per vehicle to the number of vehicles in this range.

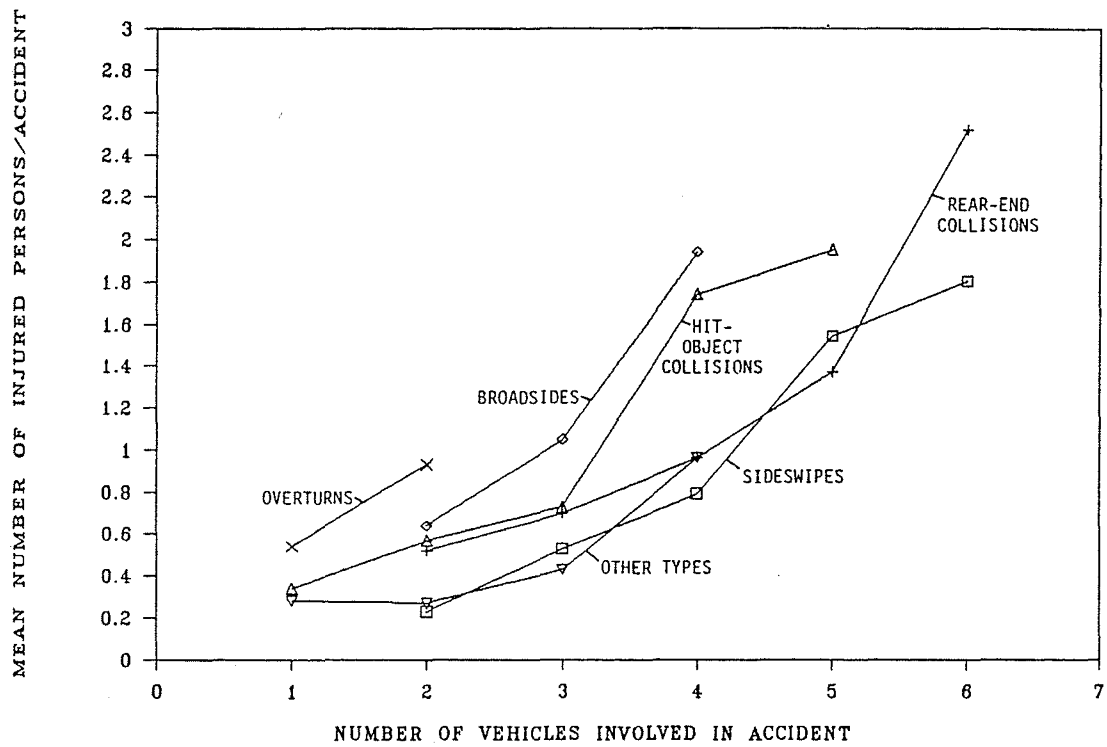

FIGURE 1

INJURIES VERSUS INVOLVED VEHICLES BY COLLISION TYPE

5.0 INCIDENT DURATION AND LANE CLOSURES

5.1 Hypothesized Distributional Properties

The duration of the incident resulting from an accident comprises many different sequential stages, each of which may be influenced by the preceding activity. In broadest terms, each incident may consist of: 1) detection, 2) initial response, 3) injury attention (if required), 4) emergency vehicle response (if required), 5) accident investigation, 6) debris removal, 7) cleanup, and 8) recovery. Each of these broad categories, in turn, typically comprises many activities. It is probable that the amount of time required for completion of any sequence of activities within these categories directly influences that required for activities in subsequent categories. For example, the longer it takes for detection, the greater the resulting congestion, and the greater the difficulty (time) in accessing the incident site. The more serious the injuries, the greater the time required for attention, and the more detailed and time consuming the accident investigation. The longer any such sequence, the greater the time for recovery. The actual relationship between the durations of succeeding incident response activities is, of course, subject to a host of random influences not directly associated with preceding activities. This process suggests a model for the duration of the nth activity in the sequence of incident response that is of the following form:

$$Y_n - Y_{n-1} = Z_n Y_{n-1} \quad , \quad Z_n > 0 \qquad (1)$$

where

Y_n = time at completion of nth response activity, measured from the start of the incident.

Z_n = Random factor (with finite variance) that relates duration of the nth activity to the cumulative time required for preceding activities.

Then

$$Y_n = Y_{n-1} (1 + Z_n) = Y_{n-2} (1 + Z_{n-1}) (1 + Z_n) \ldots$$

$$= Y_0 \prod_{i=1}^{n} (1 + Z_i) \qquad (2)$$

or

$$Y_n = Y_0 \prod_{i=1}^{n} W_i \qquad (3)$$

where

$$W_i = (1 + Z_i), W_i \quad 0 \qquad (4)$$

or

$$\ln Y_n = \ln Y_0 + \ln W_1 + \ln W_2 + \ldots. \qquad (5)$$

From the Central Limit Theorem, the sum of the terms on the right side of Equation (5) will be approximately normally distributed. In that case, $\ln Y_n$ is also normally distributed. This implies that the total incident duration is distributed according to the log normal distribution.

Denoting

Y = total duration of incident

and

$$X = \ln(Y),$$

there are non-linear transformations between the parameters of the probability distribution for the logarithm of duration, μ_X and σ_X, and the parameters μ_Y and σ_Y of the distribution of duration (Devore, 1982, p. 159):

$$\mu_Y = \exp\left(\mu_X + \sigma_X^2 / 2\right) \tag{6}$$

and

$$\sigma_Y = \exp\left(2\mu_X + \sigma_X^2\right) \left[\exp \left(\sigma_X^2\right) - 1\right]. \tag{7}$$

A test of this hypothesis regarding incident duration was made using detailed data for a subset of accidents contained in the TASAS data base. The results are presented in the following section.

5.2 Distributional Properties of Accident Duration

Data from California Highway Patrol dispatch logs on incident duration and number of lanes (ramps and connectors) closed were obtained for 332 highway accidents and 193 ramp accidents. The random sample of accidents for which CHP log entries were sought was stratified by collision type.

A complicating factor in determining statistical distributions of the durations of lane closures was the occurrence of multi-period incidents in which different numbers of lanes were closed for certain durations. Ninety of the 332 highway accidents, or approximately 27 percent, exhibited multi-period incidents. The simplified representation adopted for these multi-period accidents was to compute an equivalent number of lanes closed. This equivalent number was defined as the duration-weighted average number of lanes closed, with fractions of lanes rounded up to the next integer. That is, the equivalent numbers of lanes is the smallest integer number of lanes for which the product of duration times equivalent lanes is greater than or equal to the summation over all periods of the product of duration for each period and the number of lanes closed for that period.

Tests were made of the differences in incident duration and lane closures among the six collision types (sideswipe, rear-end, broadside, hit-object, overturn, and "other" collisions) for the 332 highway accidents. Three principal categories were found: rear-end and sideswipe collisions were mutually indistinguishable, as were hit-objects, broadside, and "other" collisions; overturns were unique. These three major categories are listed in Table 7. (For all categories involving more than one collision type, the stratified sample was weighted so that the statistics are appropriate for the mix of accidents in the larger TASAS data base.)

Within the first two major categories of highway accidents, sub-categories were found with statistically significant differences in either the means or variances of the incident durations (Table 7). (The pair-wise tests of equalities of means and variances were performed using t-tests and F-tests, respectively.) There were similar sub-categories for both the rear-end/sideswipe and hit-object/broadside/other categories: accidents for which there were no lanes closed are subdivided into injury and non-injury accidents. The longer mean duration for injury accidents is particularly accentuated in the case of hit-object/broadside/other collisions.

For both major categories, the variances of duration for incidents with lane closures are related to the number of lanes closed, while the mean durations often are not. There are no significant differences between accidents with and without

INCIDENT TYPE: TRUCK HIGHWAY ACCIDENTS		INCIDENT DURATION		PERCENT OF ALL TRUCK ACCIDENTS
CATEGORY	SUB-CATEGORY	MEAN	STD. DEV.	
Rear-end and Sideswipe Collisions	0 lanes closed/ no injuries	40 min.	26 min.	21.7
	0 lanes closed/ injuries	55 min.	28 min.	9.8
	1 lane closed	58 min.	1 hr. 1 min.	23.3
	2 or more lanes closed	2 hr. 6 min.	2 hr. 31 min.	9.8
Hit-object, Broadside, and "Other" Types of Collisions	0 lanes closed/ no injuries	55 min.	1 hr. 2 min.	4.1
	0 lanes closed/ injuries	1 hr. 50 min.	1 hr. 26 min.	2.2
	1 lane closed	1 hr. 2 min.	38 min.	5.8
	2 lanes closed	1 hr. 51 min.	2 hr. 3 min.	2.5
	3 or more lanes closed	1 hr. 55 min.	1 hr. 1 min.	2.5
Overturns	(All)	2 hr. 22 min	1 hr. 53 min.	1.5

TABLE 7

TRUCK HIGHWAY ACCIDENTS GROUPED ACCORDING TO DIFFERENCES IN INCIDENT DURATION injuries for incidents with lane closures. The highest mean durations are for overturns (2 hours, 22 minutes) and for rear-end/sideswipe collisions with two or more lanes closed (2 hours, 6 minutes); the highest standard deviations are for rear-end/sideswipe collisions with two or more lanes closed (2 hours, 31 minutes) and for hit-object/broadside/other collisions with two lanes closed (2 hours, 3 minutes). Each sub-category's proportional representations of all highway accidents is also shown in Table 7, and these vary from 1.5 percent for overturns to 23.3 percent for rear-end and sideswipe collisions closing one lane.

For all sub-categories, and for the major category of overturn accidents for which no significantly different sub-categories were found, the distributions of incident duration were determined to be log-normal in shape, as predicted by the theory outlined in Section 5.1. That is, the natural logarithm of incident duration was found to be normally distributed for each and every category and sub-category of incident types. Kolmogorov-Smirnov statistical tests, as described in Siegel (1956) and Hajek (1969), were performed to determine whether or not the log-normal distribution could be rejected as representations for the sample distributions for each category or sub-category; they could not. The results of the Kolmogorov-Smirnov tests are listed in Table 8. The tests are based on comparisons of the sample and theoretical cumulative distribution functions: the most extreme difference between the functions has a known distribution that allows testing of the hypothesis that the sample has been drawn from the distribution (Smirnov, 1948). The test is considered to be more powerful than a chi-square test and it avoids the problem of forming arbitrary category groupings for small sample sizes (Siegel, 1956). The Kolmogorov-Smirnov test probabilities are only approximate in situations where the mean and standard deviations of the criterion distribution are estimated from the sample (as is the case here), but all of the results in Table 8 are far from the critical

INCIDENT TYPE: TRUCK HIGHWAY ACCIDENTS			Tests Based on Cumulative Distributions			
CATEGORY	SUB-CATEGORY	Sample Size	Most Extreme Difference	Kolmogorov-Smirnov Z	Probability	Can Log-Normal Distribution be Rejected
Rear-end and Sideswipe Collisions	0 lanes closed/ no injuries	37	-.074	0.451	0.99	NO
	0 lanes closed/ injuries	25	-.189	0.945	0.33	NO
	1 lane closed	47	-.081	0.555	0.92	NO
	2 or more lanes closed	23	0.171	0.820	0.51	NO
Hit-object, Broadside, and "Other" Types of Collisions	0 lanes closed/ no injuries	32	-.154	0.872	0.43	NO
	0 lanes closed/ injuries	20	-.216	0.965	0.31	NO
	1 lane closed	57	-.057	0.428	0.99	NO
	2 lanes closed	24	-.187	0.914	0.37	NO
	3 or more lanes closed	21	-.158	0.722	0.68	NO
Overturns	(All)	46	0.127	0.861	0.45	NO

TABLE 8

TESTS OF HOMOGENEITY BETWEEN INCIDENT DURATION DISTRIBUTIONS AND LOG-NORMAL DISTRIBUTIONS WITH SAMPLE MEANS AND STANDARD DEVIATIONS--HIGHWAY ACCIDENTS values, and the evidence on the extent of the bias (Massey, 1951) indicates that the test conclusions are not affected.

As an alternative hypothesis, it was proposed that the logarithm of duration is distributed uniformly for each category of accident. That is, the cumulative distribution function is linear with the observed maximum duration under this hypothesis. Test results are listed in Table 9: the log-uniform distribution is rejected at the $p = .05$ level for six of the ten accident categories. It can be concluded that the log-normal distribution is preferred to the uniform distribution on both theoretical and empirical grounds, but it is possible that tests of other distributions, such as the gamma distribution, would also result in non-rejection.

The empirical cumulative distribution functions for each of the ten sub-categories of highway accidents are compared against theoretical log-normal cumulative distribution functions in Figure 2. The parameters of each theoretical distribution are based on the observed mean and standard deviation for the sub-category of incidents. The agreements between the empirical and theoretical distributions appear to be very good. As expected, the best fits are generally for the sub-categories with more observations. The parameters of the distributions are listed in Table 10.

The log-normal probability density functions for the four sub-categories of highway rear-end and sideswipe collisions are graphed together for comparison purposes in Figure 3. The graphs show that the most extreme probability distribution functions are for the first (zero lanes closed/no injuries) and last (two or more lanes closed) of the sub-categories.

INCIDENT TYPE: TRUCK HIGHWAY ACCIDENTS			Tests Based on Cumulative Distributions			
CATEGORY	SUB-CATEGORY	Sample Size	Most Extreme Difference	Kolmogorov-Smirnov Z	Probability	Can Log-Uniform Distribution be Rejected
Rear-end and Sideswipe Collisions	0 lanes closed/ no injuries	37	-.245	1.49	0.02	YES
	0 lanes closed/ injuries	25	-.320	1.60	0.01	YES
	1 lane closed	47	-.183	1.25	0.09	NO
	2 or more lanes closed	23	0.187	0.899	0.39	NO
Hit-object, Broadside, and "Other" Types of Collisions	0 lanes closed/ no injuries	32	0.214	1.21	0.11	NO
	0 lanes closed/ injuries	20	-.344	1.54	0.02	YES
	1 lane closed	57	0.243	1.84	0.00	YES
	2 lanes closed	24	-.447	2.19	0.00	YES
	3 or more lanes closed	21	-.498	2.28	0.00	YES
Overturns	(All)	46	-.172	1.17	0.13	NO

TABLE 9

TESTS OF HOMOGENEITY BETWEEN INCIDENT DURATION DISTRIBUTIONS AND LOG-UNIFORM DISTRIBUTIONS WITH MAXIMUMS--HIGHWAY ACCIDENTS

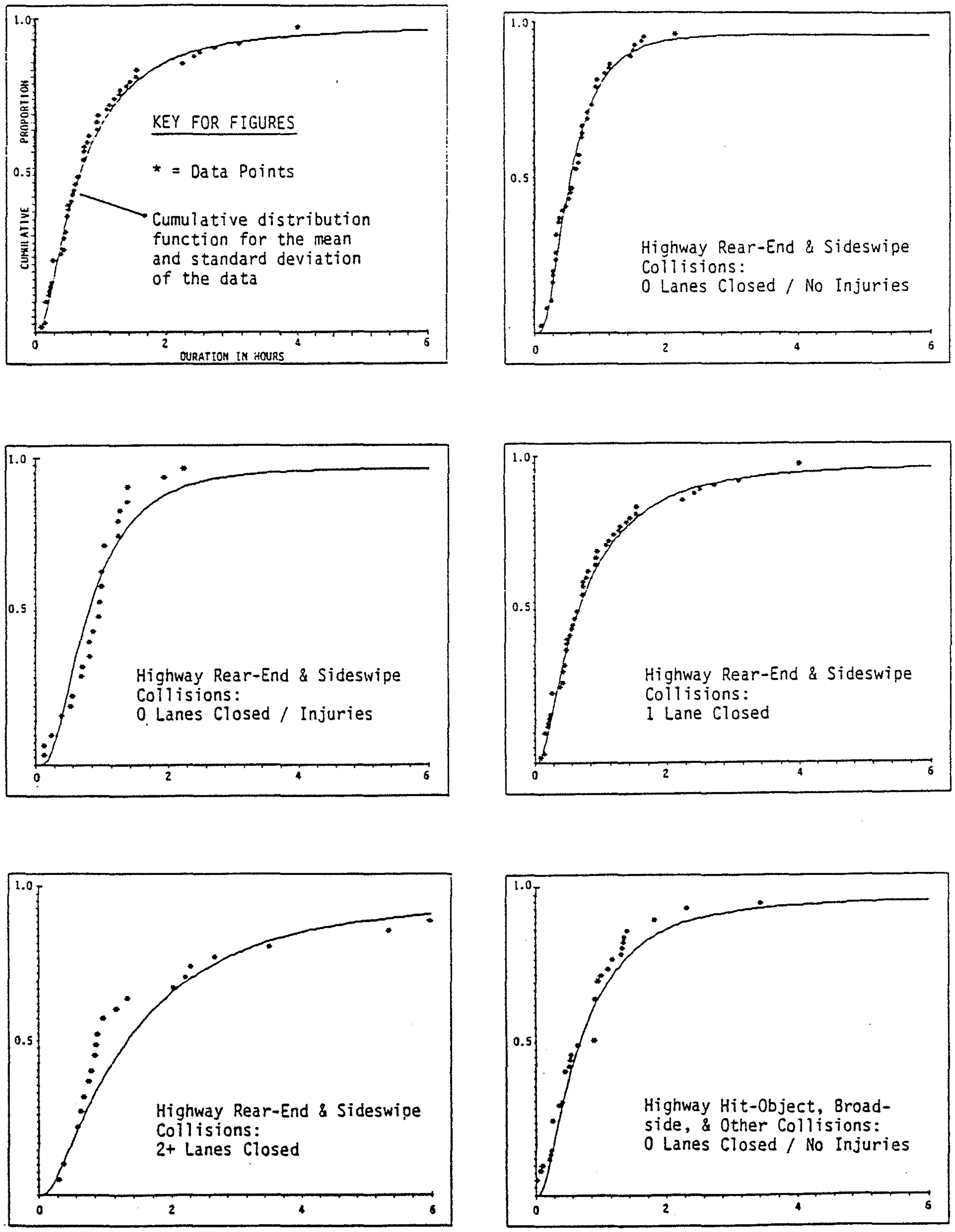

FIGURE 2

FITTED CUMULATIVE DISTRIBUTION FUNCTIONS OF DURATION--HIGHWAY ACCIDENTS

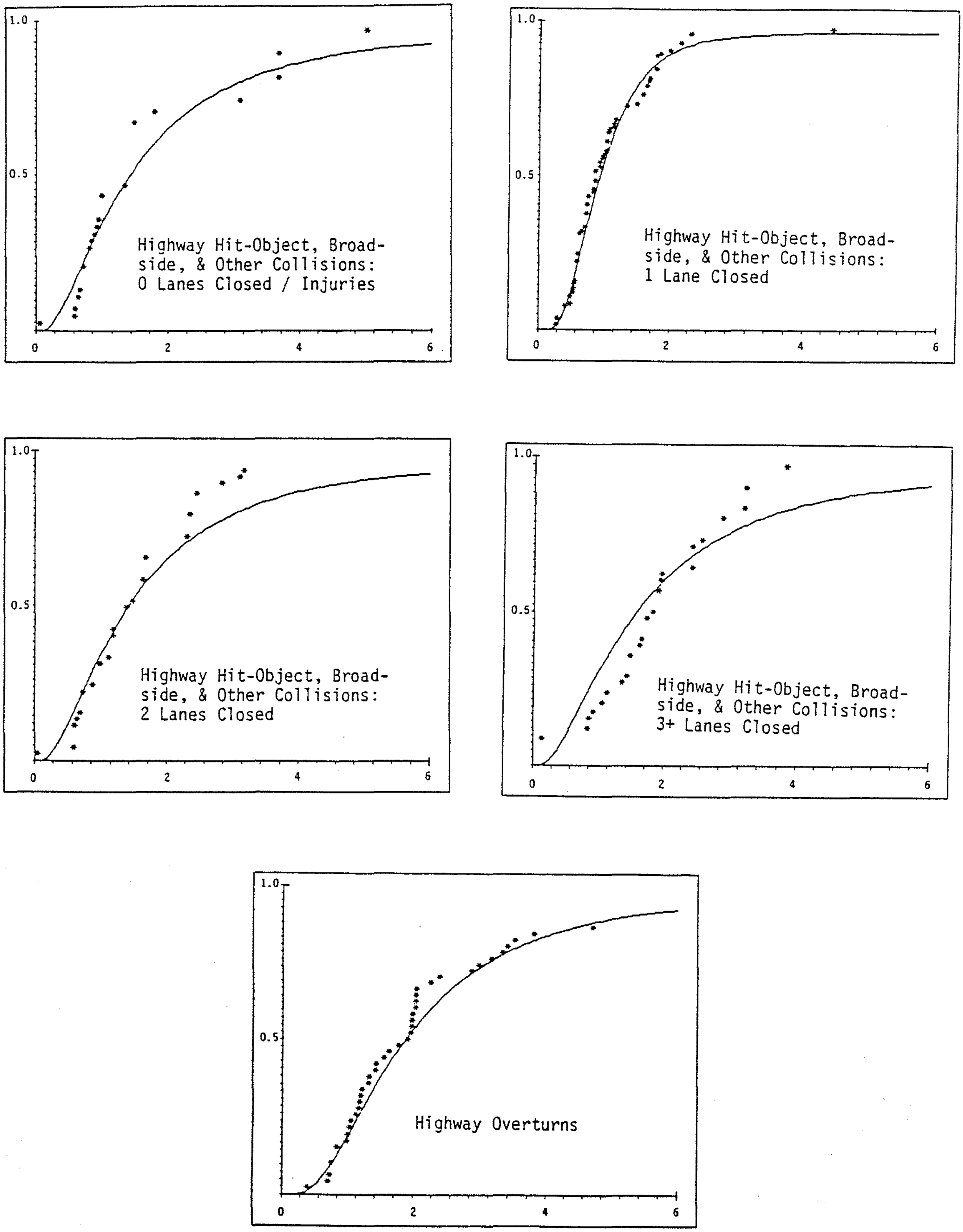

FIGURE 2 (cont'd)

INCIDENT TYPE: TRUCK HIGHWAY ACCIDENTS		PARAMETERS OF LOG-NORMAL DURATION DISTRIBUTION	
CATEGORY	SUB-CATEGORY	MEAN	STD. DEV.
Rear-end and Sideswipe Collisions	0 lanes closed/no injuries	-.62	0.67
	0 lanes closed/injuries	-.26	0.69
	1 lane closed	-.45	0.94
	2 or more lanes closed	0.23	0.99
Hit-object, Broadside, and "Other" Types of Collisions	0 lanes closed/no injuries	-.44	0.91
	0 lanes closed/injuries	0.30	0.87
	1 lane closed	-.10	0.55
	2 lanes closed	0.31	0.86
	3 or more lanes closed	0.41	0.88
Overturns	(All)	0.60	0.70

TABLE 10

LOG-NORMAL DISTRIBUTIONS OF INCIDENT DURATION
FOR TRUCK HIGHWAY ACCIDENTS

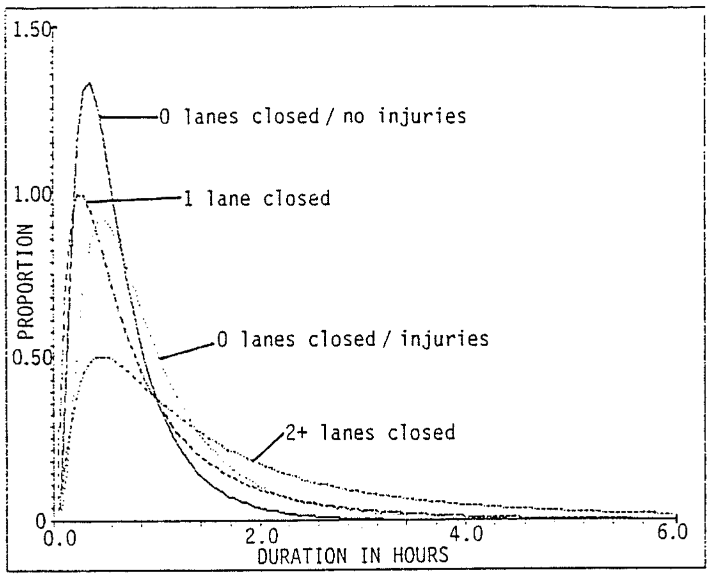

FIGURE 3

PROBABILITY DENSITY FUNCTIONS FOR HIGHWAY REAR-END AND SIDESWIPE COLLISIONS

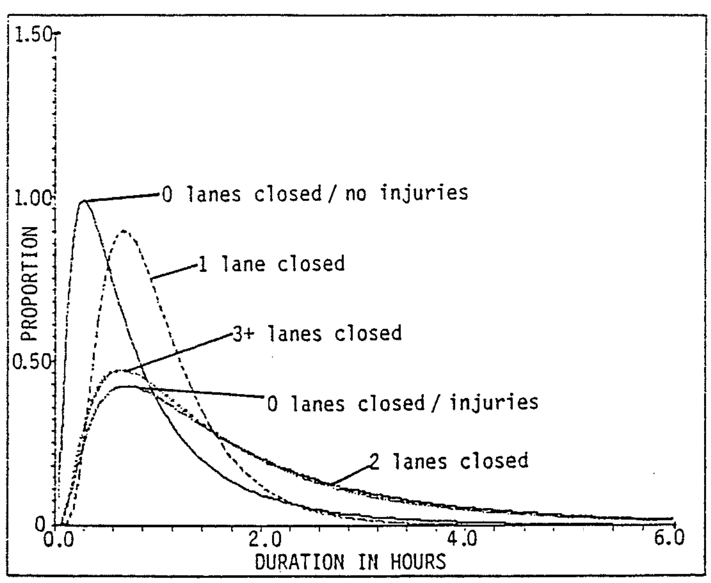

FIGURE 4

PROBABILITY DENSITY FUNCTIONS FOR HIGHWAY HIT-OBJECT, BROADSIDE, AND "OTHER" COLLISIONS

Similarly, the density functions for the five sub-categories of hit-object, broadside, and other types of collisions are graphed in Figure 4. The most distinguished functions are those for zero-lanes-closed/no injuries (the lowest mean) and for one-lane-closed (the lowest standard deviation). The other distributions are similar in shape.

Six types of incidents resulting from ramp truck accidents could be distinguished in terms of incident duration. These are listed in Table 11. Rear-end, sideswipe, and "other" collisions were divided into two sub-categories, injury and

INCIDENT TYPE: TRUCK RAMP ACCIDENTS		INCIDENT DURATION		PERCENT OF ALL TRUCK ACCIDENTS
CATEGORY	SUB-CATEGORY	MEAN	STD. DEV.	
Rear-end, Sideswipe, & "Other" Types of Collisions	No Injuries	52 min.	45 min.	7.5
	Injuries	1 hr. 34 min.	1 hr. 9 min.	3.1
Broadside Collisions	(All)	55 min.	43 min.	1.8
Injuries Hit-object Collisions	No Injuries	1 hr. 21 min.	1 hr. 26 min.	1.8
	Injuries	2 hr. 10 min.	1 hr. 59 min.	1.5
Overturns	(All)	3 hr. 14 min.	2 hr. 16 min.	1.4

TABLE 11

TRUCK RAMP ACCIDENTS GROUP ACCORDING TO DIFFERENCES IN INCIDENT DURATION non-injury collisions on the basis of a significant difference in mean durations. No sub-category differences were found for the second major category, broadside collisions. Non-injury rear-end, sideways, and other collisions and broadside collisions had the shortest incident durations. The next category, hit-object collisions, was also determined to have two sub-categories, injury and non-injury accidents, with significantly different mean durations.

Log-normal probability distributions were also found to be good representations for each sub-category of ramp incident. The tests results for comparisons with log-normal distributions are listed in Table 12, and tests results for alternative comparisons with log-uniform distributions

are listed in Table 13. As in the case of the highway accidents, the log-normal distributions can be rejected for none of the categories while the log-uniform distributions can be rejected for half of the categories. The log-normal distributions are thus preferred on both a theoretical and empirical basis. The relationships between the empirical and theoretical cumulative distributions are shown in Figure 5. The probability density functions are graphed in Figure 6. Parameters for these distributions are listed in Table 14.

Statistics on ramp, mainline lane, and connector (or transition) closures by ramp incident type are shown in Table 15. Rear-end, sideswipe, and other collisions, with injuries, as well as broadside collisions typically close off-ramps when a ramp closure occurs. Overturns affect on-ramps to a greater degree than off-ramps, and hit-object collisions affect either on-ramps and off-ramps. Connectors are also closed in many incidents and this could be related to the relatively long incident durations associated with some accidents. Sample sizes limit further investigations of relationships among closures and incident duration.

INCIDENT TYPE: TRUCK HIGHWAY ACCIDENTS			Tests Based on Cumulative Distributions			
CATEGORY	SUB-CATEGORY	Sample Size	Most Extreme Differ- ence	Kolmogorov- Smirnov Z	Proba- bility	Can Log- Normal Distri- bution be Rejected
Rear-end, Sideswipe, & "Other" Types of Collisions	No injuries	25	0.156	0.779	0.58	NO
	Injuries	12	0.162	0.561	0.91	NO
Broadside Collisions	(All)	50	-.108	0.764	0.60	NO
Hit-object Collisions	No Injuries	38	0.113	0.696	0.72	NO
	Injuries	30	-.112	0.612	0.85	NO
Overturns	(All)	37	-.092	0.558	0.92	NO

TABLE 12

TESTS OF HOMOGENEITY BETWEEN INCIDENT DURATION DISTRIBUTIONS
AND LOG-NORMAL DISTRIBUTIONS WITH SAMPLE MEANS
AND STANDARD DEVIATIONS--RAMP ACCIDENTS

INCIDENT TYPE: TRUCK HIGHWAY ACCIDENTS			Tests Based on Cumulative Distributions			
CATEGORY	SUB-CATEGORY	Sample Size	Most Extreme Difference	Kolmogorov-Smirnov Z	Probability	Can Log-Uniform Distribution be Rejected
Rear-end, Sideswipe, & "Other" Types of Collisions	No injuries	25	0.202	1.01	0.26	NO
	Injuries	12	-.202	0.699	0.71	NO
Broadside Collisions	(All)	50	-.223	1.58	0.01	YES
Hit-object Collisions	No Injuries	38	0.348	2.14	0.00	YES
	Injuries	30	-.162	0.889	0.41	NO
Overturns	(All)	37	-.238	1.45	0.03	YES

TABLE 13

TESTS OF HOMOGENEITY BETWEEN INCIDENT DURATION DISTRIBUTIONS AND LOG-UNIFORM DISTRIBUTIONS WITH MAXIMUMS--RAMP ACCIDENTS

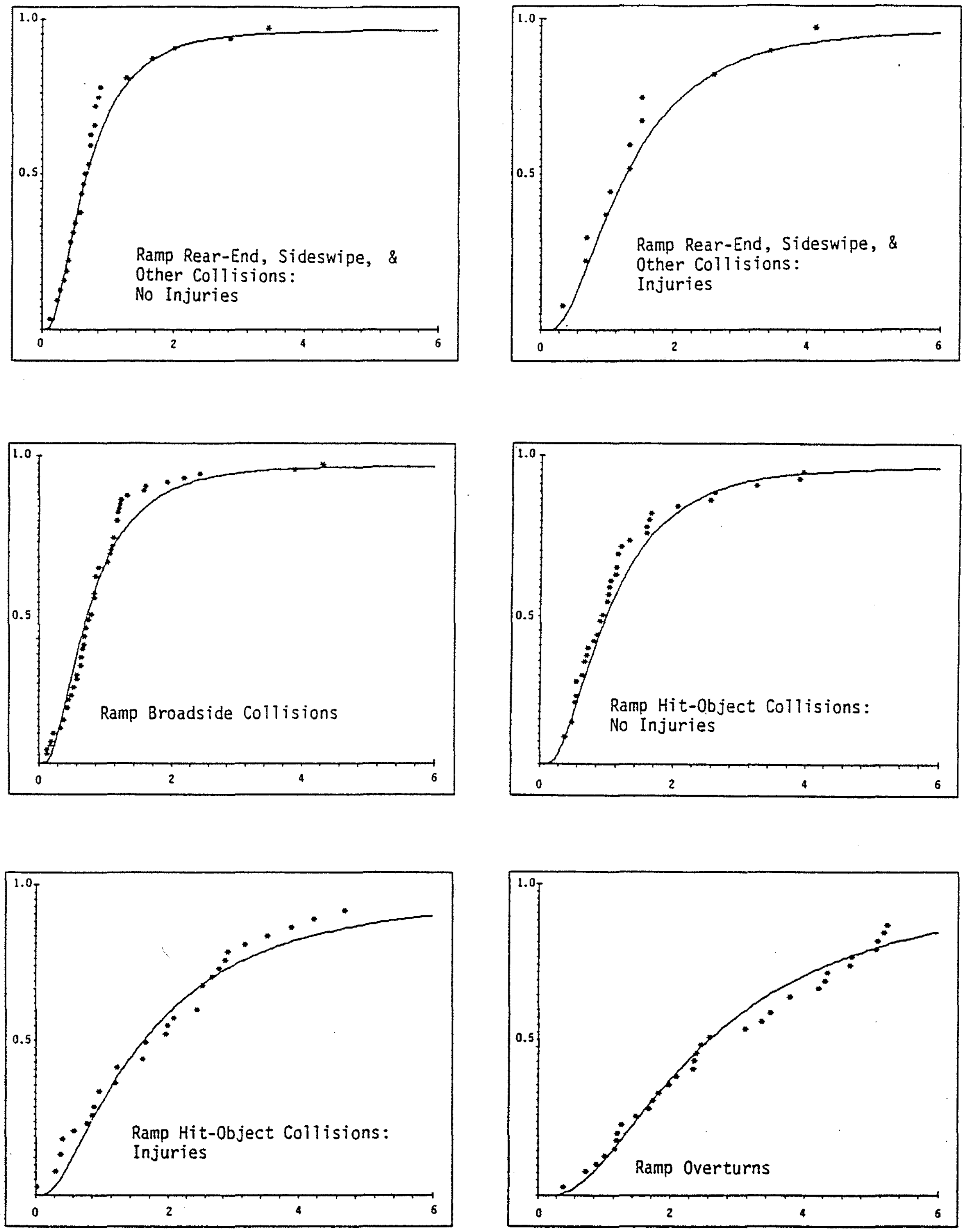

FIGURE 5

FITTED CUMULATIVE DISTRIBUTION FUNCTIONS OF DURATION--RAMP ACCIDENTS

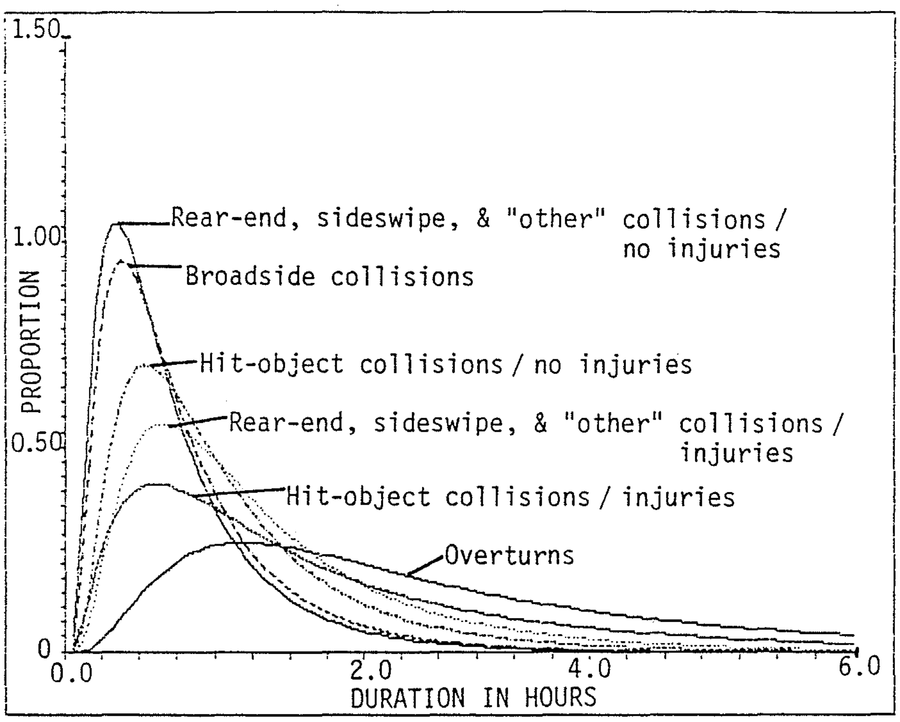

FIGURE 6

PROBABILITY DENSITY FUNCTIONS FOR RAMP ACCIDENTS

INCIDENT TYPE: TRUCK RAMP ACCIDENTS		PARAMETERS OF LOG-NORMAL DURATION DISTRIBUTION	
CATEGORY	SUB-CATEGORY	MEAN	STD. DEV.
Rear-end, Sideswipe, & "Other" Types of Collisions	No injuries	-.42	0.73
	Injuries	0.22	0.71
Broadside Collisions	(All)	-.32	0.72
Hit-object Collision	No injuries	0.00	0.70
	Injuries	0.44	0.90
Overturns	(All)	0.91	0.77

TABLE 14

LOG-NORMAL DISTRIBUTIONS OF INCIDENT DURATION
FOR TRUCK RAMP ACCIDENTS

INCIDENT TYPE: TRUCK RAMP ACCIDENTS		PERCENT OF INCIDENTS CLOSING			PERCENT CLOSING AT LEAST ONE MAINLINE LANE	PERCENT CLOSING AT LEAST ONE CONNECTOR LANE
CATEGORY	SUB-CATEGORY	ON-RAMP	OFF-RAMP	BOTH ON- & OFF-RAMPS		
Rear-end, Sideswipe, and "Other" Types of Collisions	No Injuries	3	3	0	23	13
	Injuries	0	5	0	16	23
Broadside Collisions	(All)	0	10	6	17	3
Hit-object Collisions	No Injuries	9	18	2	11	27
	Injuries	14	8	0	30	19
Overturns	(All)	21	8	5	32	26

TABLE 15

CLOSURE STATISTICS FOR TYPES OF RAMP INCIDENTS

6.0 SUMMARY

The characteristics of truck-involved accidents on the freeway system of three contiguous metropolitan counties in Southern California were found to be functions of type of collision. Interrelated with collision type (in six categories) is the primary accident factor (in nine categories). In particular, the immediate consequences of the accident differ according to collision type. These consequences are measured in the present study in terms of the numbers of injuries and fatalities, the duration of the incident (the elapsed time from accident occurrence to the clearing of hazards and obstacles), and the number of lanes or ramps closed, if any.

The most severe accidents in terms of fatalities were found to be hit-object collisions, followed by rear-end collisions. In terms of injuries only, broadside collisions (often occurring at ramp exits) are the most severe. Regarding the primary causal factor, the most severe accidents in terms of either injuries or fatalities are those attributed to alcohol; the mean fatalities for influence-alcohol accidents is over five times the mean fatality rate for all other accidents, and the mean injury rate for such accidents is approximately twice that of all other accidents.

Injury and fatality rate were also found to be significantly related to the number of involved vehicles, as expected. Single-vehicle (in this case, single-truck) accidents are relatively more severe than two-vehicle accidents in terms of fatalities and are equally severe in terms of injuries. The form of the injuries per involved vehicle relationships varies by collision type: the steepest rate of increases in injuries per vehicle are for overturns in the range of one to two vehicles, for broadsides and hit-object collisions in the range of three to four vehicles, and for rear-end collisions in the range of five to six involved vehicles.

Regarding the duration of the accident incident, it was postulated that durations for homogeneous groups of accidents would be log-normally distributed. For highway accidents, homogeneous groups were found based on three categories of collision type (rear-end and sideswipe collisions/ hit-object, broadside, and other types of collisions/and overturns) and sub-categories within the first two collision type categories. The sub- categories are based on the number of lanes closed, and on whether or not there were injuries for accidents not closing any mainline lanes. For ramp accidents, four collision type categories were found: (1) rear-end, sideswipes and other types of collisions, (2) broadsides, (3) hit-object collisions, and (4) overturns. For the first and third categories, the sub-categories were injuries versus non-injuries.

For each of these sixteen homogeneous groups of freeway truck accidents (ten highway accident groups and six ramp accident groups), the distributions were found to be log-normally distributed. Thus, it is possible to estimate the probability of an accident in any group resulting in a duration greater than a fixed time. This information can serve as input to further research aimed at assessing the total costs of the accidents.

7.0 DIRECTIONS FOR FURTHER RESEARCH

The statistical models developed in this analysis can be used in conjunction with traffic simulation models to estimate congestion delay attributable to truck-involved freeway accidents. In such an analysis, the statistical models may used to generate the frequencies of truck accidents categorized by type, traffic conditions, probable lane closures, and incident durations; the simulation model is used to simulate resulting traffic flow during the incidents. Although the current analysis is integral to such a larger study, the results presented in this paper are judged to reveal independently useful information on truck-related freeway accidents.

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