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16. Abstract

This report is concerned with the characteristics and consequences of over 9,000 truck-involved freeway accidents and non-accident incidents in a three-county case study region in Southern California. The research was conducted in two major phases: (1) identification of the number and type of truck-involved accidents occurring on freeways in the region, together with statistical analyses of the influence of a wide range of conditions on the frequency and severity of these accidents; and (2) estimation of the impact of these accidents on the freeway system in terms of congestion and delay, and estimation of the total annual economic costs of these accidents.

Chapter Two reports the results of statistical analyses of the salient characteristics of over 9,000 truck-involved freeway accidents that occurred in the region during 1983-84. Chapter Three focuses on the immediate consequences of these accidents: accident severity (i.e. injuries and fatalities), incident duration, and lane closure. Chapter Four is an analysis of 424 major incidents involving large trucks on freeways in the region during 1983-85. Chapter Five focuses on the impacts of truck-involved mainline collisions on freeway congestion and delay; simulation models are used to estimate total delay attributable to such collisions for the 1987-88 period. Chapter Six focuses on the total economic costs of these accidents. We conclude that over 10 million vehicle hours, and $154.6 million dollars, may be lost each year due to truck-involved freeway accidents in the region.

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FINANCIAL DISCLOSURE STATEMENT

This research was funded jointly by the State of California, Department of Transportation, and by the U.S. Federal Highway Administration. The total ceiling amount for this contract (Contract No. RTA 13945-55D281) was $75,000. The research is reported in the final report: An Analysis of the Characteristics and Congestion Impacts of Truck-Involved Freeway Accidents.

IMPLEMENTATION STATEMENT

Copies of this report will be distributed to certain districts of the California Department of Transportation and to selected individuals at the Sacramento office of that Department. The procedures and results described in this report may be used to evaluate the policies designated to lessen the impact of truck-related accident congestion on urban freeways.

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CHAPTER ONE

INTRODUCTION

The impact of large trucks on urban freeways has been a subject of increasing concern among traffic engineers and transportation agencies. Major truck incidents, including vehicular collisions, overturns, spilled loads, and fires, can block much or all of a freeway and result in congestion which lasts for several hours. On a heavily traveled urban freeway, thousands of hours of vehicle delay can result from a single major truck incident. Various proposals have been advanced for alleviating the problem, including such radical strategies as banning trucks from some or all freeways during peak periods.

While there is a widespread perception that truck incidents are a major problem for urban freeway operations, there has been little quantitative analysis of the salient characteristics of truck-related freeway incidents, or the impact of these incidents on freeway congestion and delay. This is the purpose of the present study.

The study uses a three-county region in Southern California as a case study site. The region was selected as a setting due to its size (over 11.5 million people in an area of 6,693 square miles), the highly developed nature of its freeway system (5,504 lane miles), and heavy truck volumes on many of the region's most congested freeway segments.

Truck-related incidents are a significant and growing problem in the region. During 1983, 1984, and 1985, 424 major incidents -- defined as an incident which closes at least two lanes and is predicted to last at least two hours -- involving large trucks occurred on the freeway system. In other words, a major truck related-incident occurred nearly three out of five days of the work week. Truck-related incidents are also a major contributor to non-recurrent freeway congestion and motorist delay. In 1987, for example, the California Highway Patrol reported 5,203 truck-involved collisions on the region's freeway mainline. Over 90 percent of these collisions occurred on weekdays; 95 percent of these weekday collisions occurred during the period of heavy freeway usage (6:00 a.m. to 6:00 p.m.); and 56 percent occurred during the morning and evening peak periods. Within our case study region, over 10 million additional vehicle hours of delay per year may have been incurred by motorists as a result.

REVIEW OF THE LITERATURE

Typical problems associated with the involvement of trucks in road accidents have been discussed in the literature. Eck (1980) analyzed some 600 accidents related to runaway trucks, and presented several contributing factors, among which were driver error, equipment failure, and lack of experience with mountain driving. A study by McGee et al (1982) of accident types and contributing factors indicated that truck accident rates varied inversely with truck weight. Among the elements surveyed were the effects of roadway geometrics, roadside features, and wide load influence. A review of research involving truck size and weight by Freitas (1982) concluded that the available research on large truck safety is not always consistent. One reason is that truck data are not consistent in some studies, particularly when they mix large combination trucks, which tend to travel on rural freeways, and smaller single-unit trucks, which tend to travel on urban streets. Another reason is that the quality of the data is sometimes questionable because of the difficulty in devising accident rates.

Lohman and Waller (1975) analyzed accident characteristics by vehicle weight.

Their study revealed that larger trucks were more likely to be involved in single-vehicle crashes than were cars or smaller trucks. The study also suggested that some truck drivers appeared to encounter difficulties in stopping and maneuvering their vehicles. This point was also discussed in a British study of accidents involving heavy goods vehicles (Neilson et al, 1979). This study further demonstrated that trucks take a considerably longer distance to maneuver than do cars, particularly when laden.

The literature contains conflicting evaluations of the safety of double trailers versus singles. Winfrey et al (1968) and Scott and O'Day (1971) found that doubles have a relatively lower accident rate than do singles. Vallette et al (1981) offered the opposite conclusion: the accident rate per 100 million vehicle miles of travel is higher for double trucks than for singles. Alternatively, McGee et al (1982) found that the accident rates of the two truck types did not show a clear difference. By contrast, the accident rate per 100 million ton-miles of travel was higher for single trailers than for doubles (14.7 versus 11.0). Vallette et al (1981) also found that the accident rate decreases with increasing truck weight. This tendency occurs both for single unit trucks and for doubles. Vallette et al (1981) also reported that 16 percent of truck accidents take place near interchanges. The high risk of truck accidents at intersections and interchanges stems from long stopping distances, difficulty in maneuvering in small radii, and inability to accelerate rapidly.

The characteristics of trucks also expose them to certain types of accidents. One of the most common types of accidents in which high truck involvement may be expected is the rear-end collision. Trucks are exposed to rear-end collisions both at interchanges and in highly congested traffic. At interchanges, the problem stems from stopping difficulties; in congested traffic, trucks are prone to being rear-ended due to visibility problems (e.g. splashing), and may rear-end other vehicles due to the inadequate responsiveness of large trucks in stop-and-go traffic. There is also a high involvement of trucks in side-to-side collisions, caused primarily by the dimensions of trucks and their special difficulties both on curves and during lane changes.

ORGANIZATION OF THE REPORT

This report is concerned with the characteristics and consequences of truck-involved freeway accidents and non-accident incidents in a three-county case study region in Southern California. For the purposes of this study, trucks are defined as tractor-trailers and single vehicles larger than twin-axle (four wheel pickups or vans). Accidents are all multi-vehicle collisions and single-vehicle collisions or overturns investigated by a police officer in the field. [It is generally believed that such investigated accidents cover over 90 percent of all freeway injury accidents and about one-half of all freeway property-damage-only (PDO) accidents.] Non-acccident incidents are occurrences such as vehicle breakdowns and stalls, spilled loads, and fires.

The research was conducted in two major phases:

(1) Identification of the number and type of truck-involved accidents occurring on freeways in our case study area, together with analysis of the influence of a wide range of conditions on the relative frequency and severity of various types of such accidents; and

(2) Estimation of the impact of truck-involved accidents on the operation of the freeway system in our case study area in terms of total congestion and delay, and estimation of the overall economic costs of these accidents.

Chapter Two reports the results of statistical analyses of the *salient characteristics* of over 9,000 truck-involved accidents that occurred over a two-year time period (1983-84) on freeways in the case study area. The analyses are divided into two categories: (a) accident characteristics by type of collision and (b) accident characteristics by freeway route segment. In each case, the objective was to identify underlying patterns of accident characteristics. First, accidents by collision type are analyzed in terms of characteristics such as primary collision factor, accident location, time of day, road conditions, and weather. Next, statistical models are applied to identify differences among freeway segments in terms of accident characteristics. Thirty-eight specific freeway segments are analyzed to identify roadways with varying accident characteristics.

Chapter Three focuses on the immediate *consequences* of these accidents: accident severity (e.g. injuries and fatalities), incident duration, and lane closure. For each of these consequences, analyses are conducted to identify underlying factors associated with differences in accident characteristics, and to establish relationships between accident severity, type of collision, and number of involved vehicles. Then, statistical models are developed to relate incident duration to collision type, accident severity, and lane closures.

Chapter Four is an analysis of selected *major incidents* involving large trucks on freeways in the case study area. These incidents were each of sufficient magnitude to require the response of the California Department of Transportation (Caltrans) Major Incident Response (MIR) Team. These responses are typically based on an evaluation of whether or not the incident is likely to result in the closure of at least two lanes for two or more hours. Data for 424 such incidents that occurred during 1983-85 are analyzed to identify relationships between the types of incidents to which the MIR team responds, and the characteristics of these incidents, and to explain resultant delay in terms of incident type and other characteristics.

Chapter Five focuses on the impact of mainline truck-involved collisions on freeway operation in our case study area in terms of *total delay*. A simulation procedure is used to develop estimates of motorist delay attributable to these collisions. The simulation procedure is conducted in two phases. In the first phase, the INTRAS (INtegrated TRaffic Simulation) model is used to simulate the added delay associated with a randomly selected subset of 332 truck-involved collisions occurring in our case study area in 1983-84. In the second phase, we generate incident durations and lane closures for the population of truck-involved freeway collisions that occurred in our case study region in 1987-88. These estimates are summed to provide an estimate of total additional annual delay attributable to truck-involved collisions in the region.

In Chapter Six, we estimate the total annual *economic costs* of truck-involved accidents in our case study area. Estimates are made for: delay costs (the monetary value of time lost to occupants of personal and commercial vehicles due to delays imposed by truck-related accidents); operating costs (additional fuel consumption costs attributable to reduction in vehicle speed); and accident costs (vehicle damage, personal injury, and fatality costs). A simulation procedure is applied to data on 10,805 truck-involved freeway accidents in our case study area to estimate additional annual economic costs which may result.

Appendix A describes the log-linear modeling procedure used in this study to identify structural relationships between categorical variables. Appendix B reports results of the Kolmogorov-Smirnov tests used for validation of our statistical analyses. Appendix C is a description of the INTRAS model used in our simulations of vehicle delay.

CHAPTER TWO

ACCIDENT CHARACTERISTICS

The first stage of our research involved statistical analyses of characteristics of over 9,000 truck-involved accidents that occurred over a two-year period (1983-84) on freeways in three metropolitan counties in Southern California.The analyses were divided into two categories: (a) accident characteristics by type of collision and (b) accident characteristics by freeway route segment. In each case, the objective was to identify underlying patterns of accident characteristics. First, accidents by collision type were analyzed in terms of characteristics such as primary collision factor, accident location, time of day, road conditions, and weather. Next, statistical models were developed to identify differences among freeway segments in terms of accident characteristics. Thirty-eight specific freeway segments in Southern California were analyzed to identify roadways with varying accident characteristics.

DATA

Data for this analysis were drawn from the TASAS data base maintained by the California Department of Transportation (Caltrans) (California Department of Transportation, 1978). This data base theoretically records information on all accidents on the state highway system that require on-site police investigations. In 1983-84, there were 9,508 such accidents involving trucks larger than pickups or panel trucks on 22 freeway routes in the three adjacent metropolitan Southern California counties of Los Angeles, Orange, and Ventura.

Our analysis focused on the variables listed in Table 2-1. All variables are categorical (i.e., there is no preconceived ordering). Category frequencies for each variable are also included in this table. The overall sample size of 9,508 truck-involved accidents over two years was sufficient to satisfy minimum cell size requirements in the cross-classifications of most variable pairs. [A general rule for the accuracy of the statistical measures used is that all cells (category pairs) in a cross-classification must have at least one observation, and 80% of the cells must have at least five observations (Cochran, 1954; Haberman, 1978, Vol. I.] These conditions were satisfied in all but a few cases; these are indicated in the description of our results.

Freeway geometrics, traffic volume and many other factors broadly defined as "freeway conditions" were expected to influence the characteristics of truck-involved accidents in our sample. Therefore, freeway routes in our case study region were divided into segments, with conditions *within* each segment being relatively homogeneous compared to differences in conditions *between* the segments. Of the 22 freeway routes in the region, 16 had sufficient numbers of accidents for reliable statistical analysis. With the help of Caltrans, 38 freeway segments were defined on these 16 routes. These 38 segments are identified in Table 2-2, and mapped in Figure 2-1.

TABLE 2-1

LIST OF VARIABLES USED IN THE ANALYSIS, WITH FREQUENCY OF OCCURRENCE

VARIABLE	CATEGORIES	FREQUENCY (n = 9,508)
Collision Type	1. Sideswipe	4,092
	2. Rear-end	2,964
	3. Broadside	456
	4. Hit Object	1,108
	5. Overturn	272
	6. All Other Types	616
Primary Collision Factor	1. Influence Alcohol	353
	2. Tailgating	263
	3. Failure to Yield	65
	4. Improper Turn	903
	5. Speeding	2,786
	6. Other Violations (hazardous)	4,276
	7. Other Improper Driving	189
	8. Not Driver	525
	9. Unknown	136
Generic Location	1. Mainline	7,889
	2. Ramp (includes connectors)	1,619
Time Period	1. 00:00 - 05:59	669
	2. 06:00 - 08:59	1,613
	3. 09:00 - 11:59	2,039
	4. 12:00 - 14:59	2,127
	5. 15:00 - 17:59	1,871
	6. 18:00 - 20:59	728
	7. 21:00 - 23:59	438
Terrain	1. Flat	8,057
	2. Rolling	904
	3. Mountainous	547
Road Conditions	1. No Unusual Conditions	9,030
	2. Holes or Loose Material	76
	3. Construction	253
	4. Other Unusual Conditions	111
Weather	1. Clear	7,415
	2. Cloudy	1,327
	3. Rain or Fog	749
Road Surface Condition	1. Dry	8,423
	2. Wet	987
	3. Icy or Otherwise Slippery	63
Ramp Direction (Ramp accidents only)	1. On-ramp	581
	2. Off-ramp	991
	3. Other (scales, etc.)	47
Ramp Location (Ramp accidents only)	1. Ramp Intersection (exit)	451
	2. Ramp	520
	3. Ramp Entry	229
	4. Intersecting Street	419

TABLE 2-2

DESCRIPTION OF FREEWAY SEGMENTS

CODE	DESCRIPTION OF FREEWAY SEGMENT
5.1	Santa Ana (I-5): Orange-San Diego Co. line to Jct. 55 (Costa Mesa Fwy.)
5.2	Santa Ana (I-5): Jct. 55 to Jct. 10/60 (Pomona Fwy.)
5.3	Santa Ana-Golden State (I-5) Jct. 10/60 to Jct. 170 (Hollywood Fwy.)
5.4	Golden State-Hollywood (SR 170) (I-5): Jct. 101/134 to Jct. 170/5 to Los Angeles-Kern Co. line
10.1	Santa Monica (I-10): Jct. 405 (San Diego Fwy.) to Jct. 110 (Harbor Fwy.)
10.2	Santa Monica (I-10)-Pomona (SR 60): Jct. 110 to Jct. 710 (Long Beach Fwy.)
10.3	San Bernardino (I-10): Jct. 101 to Jct. 710 (Long Beach Fwy.)
10.4	San Bernardino (I-10): Jct. 710 to Jct. 605 (San Gabriel R. Fwy.)
10.5	San Bernardino (I-10): Jct. 605 to Los Angeles-San Bernardino Co. line
14.0	Antelope Valley (SR 14): Begin Jct. 5 (Golden State Fwy.) to Los Angeles-Kern Co. line
22.0	Garden Grove (SR 22): Jct. 405 (San Diego Fwy.) to end, Jct. 55 (Costa Mesa Fwy.)
55.0	Costa Mesa (SR 55): Begin Fwy. southwest of 73 to end, Jct. 91 (Riverside Fwy.)
57.1	Orange (SR 57: Begin Jct. 5/22 to Orange-Los Angeles Co. line
57.2	Orange (SR 57)-Pomona (SR-60)-Foothill (I-210): Co. line to Jct. 30
60.1	Pomona (SR 60): Jct. 710 (Long Beach Fwy.) to Jct. 605 (San Gabriel R. Fwy.)
60.2	Pomona (SR 60): Jct. 605 to L.A.-San Bernardino Co. line (excluding overlap with Rte. 60)
91.1	Artesia-Redondo Beach-Riverside (SR 91): Begin Fwy. near Jct. 110 (Harbor Fwy.) to Jct. 55
91.2	Riverside (SR 91): Jct. 55 to Orange San Bernardino Co. line
101.1	Santa Ana-Hollywood (US 101): Begin, Jct. 5 (Golden State Fwy.) to Jct. 134/170
101.2	Ventura (US 101): Jct. 134/170 to Jct. 405 (San Diego Fwy.)
101.3	Ventura (US 101): Jct. 405 to Los Angeles-Ventura Co. line
101.4	Ventura (US 101): Los Angeles-Ventura Co. line to Ventura-Santa Barbara Co. line
110.1	Harbor (I-110): Begin Fwy. near Jct. 47 to Jct. 405 (San Diego Fwy.)
110.2	Harbor (I-110): Jct. 405 to Jct. 10 (Santa Monica Fwy.)
110.3	Harbor (I-110): Jct. 10 to Jct. 101 (Hollywood Fwy.)
118.0	Simi Valley-San Fernando Valley (SR 118): Begin Fwy. in Ventura Co. to Jct. Rte. 210
134.0	Ventura (SR 134): Jct. 101/170 (Hollywood Fwy.) to Jct. 210 Foothill Fwy.)
210.1	Foothill (I-210): Begin Jct. 5 (Golden State Fwy.) to Jct. 134 (Ventura Fwy.)
210.2	Foothill (I-210): Jct. 134 to end, Jct. 30
405.1	San Diego (I-405): Begin Jct. 5 (Santa Ana Fwy.) to Jct. 22 (Garden Grove Fwy.)
405.2	San Diego (I-405): Jct. 22 to Jct. 10 (Santa Monica Fwy.)
405.3	San Diego (I-405): Jct. 10 to Jct. 101 (Ventura Fwy.)
405.4	San Diego (I-405): Jct. 101 to end, Jct. 5 (Golden State Fwy.)
605.1	San Gabriel River (I-605): Begin Jct. 22 to Jct. 91 (Artesia Fwy.)
605.2	San Gabriel River (I-605): Jct. 91 to Jct. 60 (Pomona Fwy.)
605.3	San Gabriel River (I-605): Jct. 60 to end, Jct. 40 (Foothill Fwy.)
710.1	Long Beach (I-710): Begin Jct. 1 to Jct. 5 (Santa Ana Fwy.)
710.2	Long Beach (I-710): Jct. 5 to break in route, Valley Blvd., north of 10

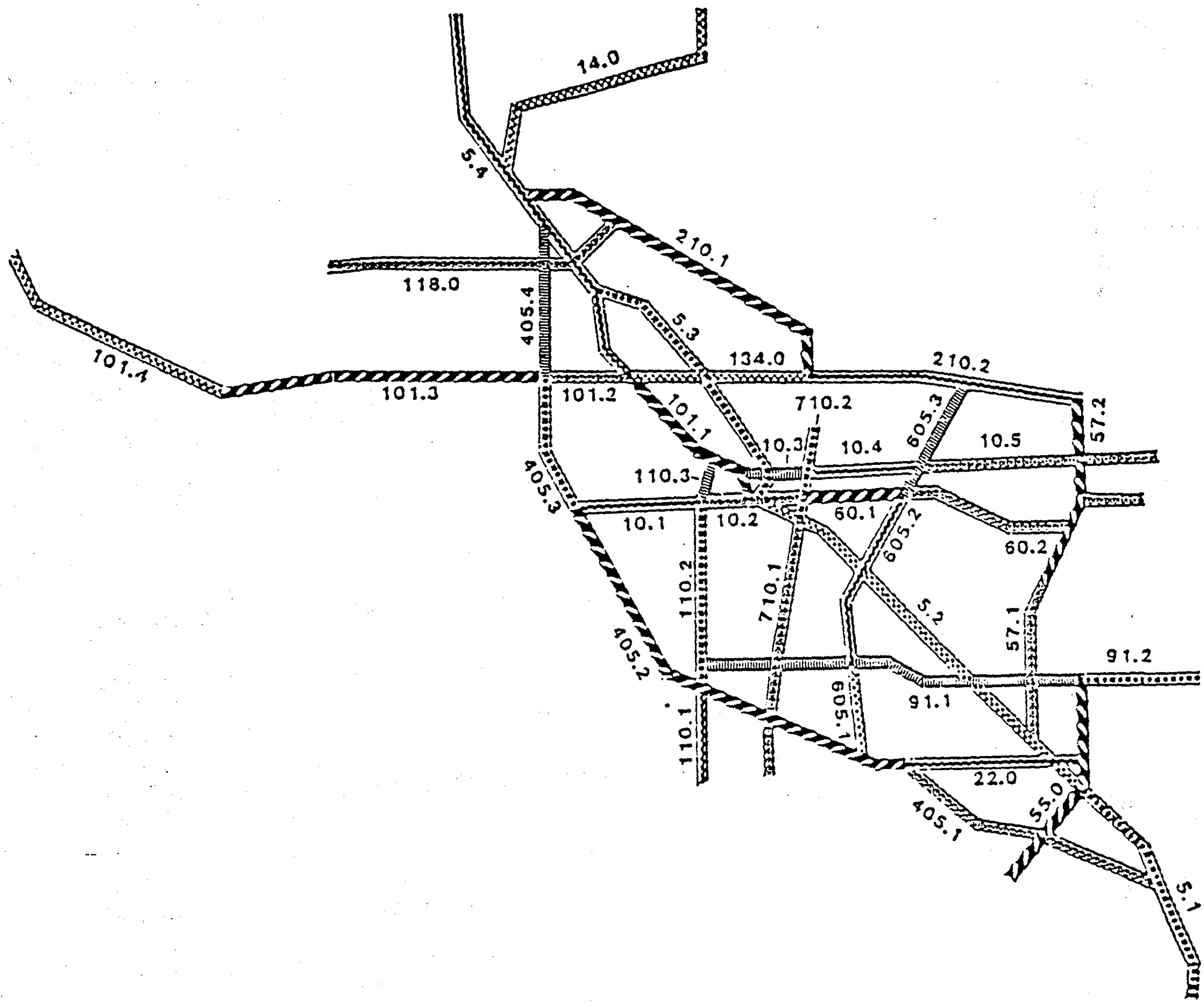

FIGURE 2-1

MAP OF FREEWAY SEGMENTS

METHODOLOGY

Log-linear models were used to determine relationships between the characteristics and locations of truck-involved freeway accidents. [For a discussion of log-linear modeling and its use in this study, see Appendix A.] The variables analyzed included type of collision, primary collision factor, eight other accident characteristic variables [see Table 2-1], and route segment. Results are described below.

RESULTS

Accident Characteristics by Collision Type

The first stage of our analysis focused on accident characteristics by type of collision. Results of this analysis are described below.

Primary collision factor. The relationship between collision type and primary collision factor was analyzed using a log-linear model. There was a very strong relationship between the variables, as shown in Table 2-3. [In Tables 2-3 through 2-10, data are shown only for cells with significant model coefficients; all other cells are left blank.]

The values in Table 2-3 indicate relationships that are largely as expected. However, they do reveal some associations that can be useful in explaining accident cause. For instance, rear-end collisions had a strong relationship not only with tailgating driving behavior, but also with alcohol, speeding, and other improper driving. The strongest associations were for speeding (positively associated with rear-end collisions,

TABLE 2-3

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY PRIMARY COLLISION FACTOR

	PRIMARY COLLISION FACTOR								
COLLISION TYPE	INFLUENCE OF ALCOHOL	TAIL-GATING	FAILURE TO YIELD	IMPROPER TURN	SPEEDING	OTHER VIOLA-TIONS	OTHER IMPROPER DRIVING	NOT DRIVER	UNKNOWN
SIDESWIPE	- 4.2	- 10.0		+9.2	- 25.9	+24.2	- 2.8	- 10.1	
REAR-END	+6.2	+16.9	- 4.3	- 11.1	+29.8	- 21.5	+2.8	- 8.6	- 2.5
BROADSIDE		- 2.4	+19.2	+2.7					
HIT OBJECT		- 3.0	- 2.8	+3.8	+3.2	- 8.5		+13.9	
OVERTURN		- 2.4		- 2.3	+7.1	- 5.9		+7.7	
OTHER TYPES	- 2.9	- 3.6		- 5.4	- 5.7			+22.2	
Sample Sizes:	**353**	**263**	**65**	**903**	**2,786**	**4,276**	**189**	**525**	**136**

negatively associated with sideswipes); "other" violations (positively associated with sideswipes, negatively associated with rear-end collisions); and the "not-driver" factor (positively associated with "other" types of collisions).

Accident location. There were significant differences between collision types at mainline versus ramp locations. Rear-end and sideswipe collisions occurred more frequently at mainline sites; overturns, broadsides, and hit-objects occurred more frequently on ramps.

TABLE 2-4

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY LOCATION: HIGHWAY VERSUS RAMP

COLLISION TYPE	ACCIDENT LOCATION	
	MAINLINE	RAMP
SIDESWIPE		-4.5
REAR-END		-7.3
BROADSIDE		+10.5
HIT OBJECT		+8.6
OVERTURN		+12.7
OTHER TYPES		
Sample Sizes:	**7,889**	**1,619**

The strongest associations between collision type and site were for overturns and broadside collisions at ramp locations (Table 2-4).

TABLE 2-5

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY TIME OF DAY

COLLISION TYPE	TIME OF DAY						
	MIDNIGHT to 5:59 AM	6:00 AM to 8:59 AM	9:00 AM to 11:59 AM	NOON to 2:59 PM	3:00 PM to 5:59 PM	6:00 PM to 8:59 PM	9:00 PM to 11:59 PM
SIDESWIPE	-5.5						
REAR-END		+3.5					
BROADSIDE						-2.2	
HIT OBJECT	+7.3	-3.8				-3.5	
OVERTURN							+2.7
OTHER TYPES							
Sample Sizes:	669	1,631	2,039	2,127	1,871	728	438

Time of day. Collision type and time of day were strongly related, as shown in Table 2-5. Hit-object collisions tended to occur from midnight to 6:00 a.m., whereas sideswipes did not. Rear-end collisions appeared to be particularly a morning rush hour phenomenon, and overturns occurred more frequently than expected during the 9:00 p.m. to midnight period. The strongest association involved the occurrence of hit-object collisions during the midnight to 6:00 a.m. period. There were no significant differences among the collision types in terms of their occurrences over days of the week.

Roadway terrain. The relationships between collision types and roadway terrain are shown in Table 2-6. Only mountainous terrain exhibited differences in the distribution of collision types, with relatively more rear-end and overturn collisions and relatively fewer sideswipes occurring on mountainous sections.

TABLE 2-6

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY TERRAIN

COLLISION TYPE	TERRAIN		
	FLAT	ROLLING	MOUNTAINOUS
SIDESWIPE			- 6.5
REAR-END			+4.8
BROADSIDE			
HIT OBJECT			
OVERTURN			+4.1
OTHER TYPES			
Sample Sizes:	**8,057**	**904**	**547**

Road conditions. There was also a significant relationship between collision type and road conditions. As shown in Table 2-7, hit-object collisions were more prevalent in areas of construction or other unusual conditions. Collisions in the "other" category occurred in areas classified as having holes or loose material; this is the strongest association in the table.

TABLE 2-7

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY ROAD CONDITIONS

	ROAD CONDITIONS			
COLLISION TYPE	NO UNUSUAL CONDITIONS	HOLES OR LOOSE MATERIAL	CONSTRUCTION	OTHER UNUSUAL CONDITIONS
SIDESWIPE		- 2.2	- 3.1	
REAR-END				
BROADSIDE				
HIT OBJECT			+3.2	+3.6
OVERTURN				
OTHER TYPES		+4.1		
Sample Sizes:	**9,030**	**76**	**253**	**111**

Weather conditions. As shown in Table 2-8, broadside, hit-object, and "other" types of collisions occurred relatively more frequently in conditions of rain or fog; these were the strongest associations in the table. Conversely, sideswipe collisions were less likely to occur during rainy or foggy conditions. The overall relationship between collision type and weather was, again, highly significant.

TABLE 2-8

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY WEATHER CONDITION

COLLISION TYPE	WEATHER		
	CLEAR	CLOUDY	RAIN OR FOG
SIDESWIPE			- 6.2
REAR-END		-2.8	
BROADSIDE			+7.2
HIT OBJECT	-3.1		+7.6
OVERTURN			
OTHER TYPES			+3.8
Sample Sizes:	**7,415**	**1,327**	**749**

Surface conditions. Table 2-9 shows a significant relationship between collision type and surface condition. Hit-object and "other" collisions occurred relatively more often under both wet and icy or slippery road surface conditions. However, broadsides were related to wet roads only, and overturns were related to icy or slippery conditions. The largest deviations from expected frequencies were associated with the occurrences of truck-involved hit-object and broadside collisions on wet freeways.

TABLE 2-9

COLLISION TYPES WITH SIGNIFICANTLY HIGH (+) OR LOW (-) FREQUENCIES BY ROAD SURFACE CONDITIONS

COLLISION TYPE	ROAD SURFACE CONDITION		
	DRY	WET	ICY OR OTHERWISE SLIPPERY
SIDESWIPE		- 6.4	- 3.1
REAR-END			
BROADSIDE		+7.7	
HIT OBJECT	- 3.2	+8.2	+4.3
OVERTURN			+3.1
OTHER TYPES		+2.7	+2.4
Sample Sizes:	**8,423**	**987**	**63**

Accident Characteristics by Freeway Segment

The second stage of our analysis focused on accident characteristics (e.g., collision type, relative concentration of ramp involvement, entry vs. exit incidents, and time of occurrence) by freeway segment. This analysis highlighted freeway segments that tended to have either a particularly severe or a light association with the various accident characteristics. The relationship between freeway segment and collision type was significant in 34 cases. These relationships are shown in Table 2-10 and described below.

Sideswipe collisions. Freeway segments with relatively high concentrations of sideswipe collisions were segments 10.2 and 5.3 (Table 2-10). These two adjacent segments serve downtown Los Angeles and are highly congested. Segments with relatively low concentrations of sideswipes were 5.4, 14.0, 605.7, and 57.1. Congestion levels on all four of these segments were substantially lower than the average for all segments.

The positive relationship between sideswipe accidents and traffic congestion was further confirmed through correlation analyses of maximum annual average daily traffic (AADT) per lane at locations along each of the 38 freeway segments. The median maximum AADT per lane for all 38 segments was approximately 54,300. The maximum AADT per lane for the two segments with *high* sideswipe incidences was 105,500 and 91,500, respectively. The maximum AADT per lane for each of the three segments with *low* incidence of sideswipes was 18,000; 42,700; and 49,000, respectively.

TABLE 2-10

FREEWAY-SEGMENT/COLLISION TYPE COMBINATIONS WITH SIGNIFICANT CELL EFFECTS IN THE LOG-LINEAR MODEL

	COLLISION TYPE					
ROUTE	SIDESWIPE	REAR-END	BROADSIDE	HIT OBJECT	OVERTURN	OTHER
5.1				+2.3		
5.2					- 2.8	
5.3	+2.6					
5.4	- 5.8			+3.9	+4.5	
10.1						
10.2	+2.8			- 2.2		
10.3					+2.2	
10.4						- 2.4
10.5						
14.0	- 4.5				+4.4	+4.2
22.0						
55.0						
57.1	- 2.2		+2.1			
57.2						
60.1						
60.2						
91.1						+2.2
91.2						
101.1				- 2.5		- 3.5
101.2		+2.5				
101.3						
101.4		- 2.3		+2.5		+3.0
110.1						
110.2				- 2.6		
110.3		+2.8				
118.0			+2.6			
134.0						
210.1						
210.2						
405.1						
405.2			- 2.5	- 2.4		
405.3		+3.4	- 2.3			
405.4.						
605.1	- 2.3					
605.2						
605.3				+2.3		
710.1			- 2.2	+4.5		
710.2		- 2.2				

Rear-end collisions. Rear-end collisions represented a relatively high percentage of all truck-involved accidents on segment 110.3 and intersecting segments 405.3 and 101.2 (Table 2-10). These are three of the heaviest traveled freeway segments in the area. In contrast, rear-end collisions represented a relatively low percentage of accidents on less heavily traveled segments 101.4 and 710.2.

The percentage of rear-end collisions was significantly related to the mean AADT at all locations along a freeway segment. Two of the three freeway segments with high incidences of rear-end collisions had the highest levels of mean AADT among all segments (206,300 for segment 405.3 and 198,200 for segment 101.2); the third segment (110.3) also had a high mean AADT level of 163,800. Correlations with maximum AADT and maximum AADT per lane were not significant. Thus, relatively high percentages of rear-end collisions were associated with higher levels of *overall* traffic, whereas high percentages of sideswipe collisions were associated with high levels of traffic *per lane* at key locations.

Broadside collisions. Two freeway segments had significantly high concentrations and three segments had significantly low concentrations of broadside collisions. Segments 118.0 and 57.1 were high; and two adjacent segments of Route 405, 405.2 and 405.3, and segment 710.1 were low (Table 2-10).

Such collisions frequently occurred on ramps, confirming the relationship reported in Table 2-4. Investigation of the characteristics of the ramps for each freeway segment revealed that the percentage of broadside collisions was directly related to the percentage of ramps that were associated with diamond interchanges. Approximately 38 percent of all ramps in the study area on which truck-involved accidents occurred were diamond-interchange ramps, but 77 percent of the ramps on segment 118.0 and 64 percent of the ramps on segment 57.1 were diamond-interchange ramps. Conversely, only 6 percent, 10 percent, and 16 percent of the ramps on the three freeway segments with significantly low proportions of broadside collisions were diamond-interchange ramps.

Hit-object collisions. High concentrations of hit-object collisions were found on segments 710.1, 5.4, 101.4, 605.3, and 5.1 (Table 2-10). Low concentrations were found on intersecting segments 405.2, 110.2, 10.2, and 101.1. In contrast to sideswipe and rear-end collisions which were a direct function of high levels of congestion, hit-object collisions were *inversely* related to traffic volume.

Overturn accidents. Segments with significant concentrations of overturn accidents are shown in Table 2-10. Segments 14.0, 5.4, and 10.3 had a high concentration, and segment 5.2 had a significantly lower concentration. Two of the three segments with high percentages of overturns, segments 14.0 and 5.4, are located in mountainous and rolling terrain. The third segment, segment 10.3, is adjacent to downtown Los Angeles and is built primarily with roadways on separate structures with relatively steep ramps.

"Other" collisions. Finally, high percentages of "other" types of collisions were found on segments 14.0, 101.4, and 91.1, and low percentages were found on segments 10.5 and 101.1 (Table 2-10). As in the case of hit-object collisions, there was generally an inverse relationship between the percentage of "other" types of collisions and average

traffic volume on a segment. However, the high incidence of "other" types of collisions on segment 91.1, which has a greater than median level of AADT, demonstrates that other factors may be involved as well.

Ramp vs. mainline accidents. Freeway segments with significantly higher or lower proportions of ramp accidents are shown in Table 2-11. Segments with relatively *high* concentrations of ramp accidents were intersecting segments 10.3 and 710.2, 605.3 and 10.5, 22.0 and 405.1, and segments 10.1 and 57.1, the majority of which are east and south of downtown Los Angeles. Segments with relatively *low* concentrations of ramp accidents (or high concentrations of mainline accidents) were 101.1 and 101.3, 60.1, 5.3 and 5.4, 110.2, and 405.3, all of which are west or north of downtown Los Angeles.

TABLE 2-11

FREEWAY SEGMENTS WITH PROPORTIONS OF TRUCK ACCIDENTS SIGNIFICANTLY DIFFERENT FROM EXPECTED: RAMP ACCIDENTS

SIGNIFICANTLY HIGH CONCENTRATIONS		SIGNIFICANTLY LOW CONCENTRATIONS	
Segment	Percent of All Collisions	Segment	Percent of All Collisions
10.3	41.2	101.3	9.2
710.2	34.4	60.1	9.3
22.0	31.0	405.3	9.6
605.3	29.0	5.4	9.7
57.1	26.3	110.2	10.8
10.1	25.9	101.1	8.4
405.1	23.5	5.3	12.2
10.5	22.6		

(OVERALL AVERAGE = 16.8 PERCENT)

On-ramp vs. off-ramp accidents. Three freeway segments were found to have relatively high concentrations of on-ramp (e.g., freeway entrance ramp) versus off-ramp (e.g., freeway exit ramp) accidents (Table 2-12). The overall split in the study area was 36 percent on-ramp, 61 percent off-ramp, and 3 percent "other" (such as truck scales and rest areas). However, these three segments, 605.2, 5.3, and 405.2, had from 50 percent to 63 percent on-ramp accidents. In contrast, segment 101.3 had fewer than 10 percent on-ramp (over 90 percent off-ramp) accidents.

TABLE 2-12

FREEWAY SEGMENTS WITH PROPORTIONS OF TRUCK ACCIDENTS SIGNIFICANTLY DIFFERENT FROM EXPECTED: ON-RAMP VS. OFF-RAMP ACCIDENTS

HIGH CONCENTRATIONS OF ON-RAMP ACCIDENTS		HIGH CONCENTRATIONS OF OFF-RAMP ACCIDENTS	
Segment	Percent of All Collisions	Segment	Percent of All Collisions
605.2	63.1	101.3	90.9
5.3	51.2		
405.2	50.0		

(OVERALL SPLIT = 36.0 PERCENT ON RAMP /
61.0 PERCENT OFF RAMP / 3.0 PERCENT OTHER)

Locations of ramp accidents. Three locations of ramp accidents were analyzed: ramp entry, ramp itself, and intersecting street (Table 2-13). Relatively high percentages of accidents at ramp entries occurred on two segments, 10.4 and 10.2, both of which serve the immediate downtown Los Angeles area. One segment, 710.1, had a high percentage of accidents on the ramp itself. Finally, four segments had high concentrations of accidents on intersecting streets; these were 91.2 and 91.1, 5.1, and 57.1, all of which are at least partially in Orange County in the southern portion of the metropolitan area.

TABLE 2-13

FREEWAY SEGMENTS WITH PROPORTIONS OF TRUCK ACCIDENTS SIGNIFICANTLY DIFFERENT FROM EXPECTED: BY RAMP LOCATIONS

AT RAMP ENTRIES		ON RAMPS THEMSELVES		ON INTERSECTING STREETS	
Segment	Percent of all Collisions	Segment	Percent of all Collisions	Segment	Percent of all Collisions
10.4	37.5	710.1	54.3	91.2	70.0
10.2	28.3	5.1	53.3		
				57.1	42.9
				91.1	40.8
OVERALL AVERAGE: 14.4		**OVERALL AVERAGE: 32.0**		**OVERALL AVERAGE: 25.7**	

Time of day. The final accident characteristic investigated by freeway segment was the time of day during which an accident occurred. Seven time periods were analyzed; there were significant differences in accident concentration during five of these periods on some freeway segments (Table 2-14). Three adjacent segments northwest of downtown Los Angeles had relatively high concentrations of accidents in the early morning hours (midnight to 6:00 a.m.) These were segments 101.1, 5.4, and 14.0, all of which are major truck routes north from Los Angeles. Segment 5.4 also exhibited a high percentage of accidents in the 9:00 p.m. to midnight period. Two segments, 57.1 and 10.5, had high percentages of accidents during the morning peak hours. Two

TABLE 2-14

FREEWAY SEGMENTS WITH PROPORTIONS OF TRUCK ACCIDENTS SIGNIFICANTLY DIFFERENT FROM EXPECTED: TIME OF DAY

Midnight- 5:59 AM		**6:00 AM- 8:59 AM**		**9:00 AM- 11:59 AM**		**NOON- 2:59 PM**		**9:00 PM- 11:59 PM**	
Segment	Percent	Segment	Percent	Segment	Percent	Segment	Percent	Segment	Percent
14.0	26.5	57.1	25.8	405.3	30.9	110.1	42.4	5.4	14.4
5.4	19.4	10.5	22.6	5.2	25.0	110.2	31.2		
101.1	10.8					110.3	32.7		
OVERALL AVERAGE: 7.0		OVERALL AVERAGE: 17.2		OVERALL AVERAGE: 21.4		OVERALL AVERAGE: 22.4		OVERALL AVERAGE: 4.6	

segments, 405.3 and 5.2, had high percentages in the 9:00 a.m. to noon period. Finally, the three segments making up the entire length of Route 110 -- the major harbor access route -- (segments 110.1, 110.2, and 110.3) exhibited high concentrations of accidents in the noon to 3:00 p.m. period. No segments had significantly high or low concentrations of accidents during the afternoon peak hours or during the 6:00 p.m. to 9:00 p.m. period.

SUMMARY

In this chapter, log linear models were used to associate accident characteristics with type of collision and to identify freeway segments on which various accident categories were more prevalent than expected. The results indicated substantial differences between the types of collisions that tend to occur at ramp locations and those that occurred along the mainline. The analysis was also able to uncover significant differences among the factors associated with the types of collision and to associate other characteristics, such as weather and road conditions, with particular collision types. Some roadway characteristics, particularly overall traffic levels, were also found to explain the pattern of freeway-segment results. In the analysis of accident characteristics by freeway segment, the analysis revealed several freeway segments that were particularly susceptible to certain types of accidents.

CHAPTER THREE

ACCIDENT SEVERITY AND INCIDENT DURATION

In the preceding chapter, we described the salient characteristics of over 9,000 truck-involved accidents that occurred on the Los Angeles freeway system in 1983 and 1984.

This chapter focuses on the immediate *consequences* of these accidents: accident severity (i.e., injuries and fatalities), incident duration, and lane closures. For each of these consequences, we sought to identify underlying factors associated with differences in accident characteristics, and establish relationships between accident severity, type of collision, and number of involved vehicles. Then, statistical models were developed to relate incident duration to collision type, accident severity, and lane closures.

INJURIES AND FATALITIES

Relationships to Number of Involved Vehicles

The 9,508 truck-involved accidents described in Chapter Two resulted in 4,436 recorded injuries and 120 recorded fatalities: an 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 as a function of the number of vehicles involved in the accident are shown in Table 3-1. Single-vehicle accidents were proportionally more dangerous than multi-vehicle accidents, (exclusive of accidents involving 7 or more vehicles) in terms of mean injuries *per vehicle.*

TABLE 3-1

ACCIDENT SEVERITY BY NUMBER OF VEHICLES INVOLVED IN THE ACCIDENT

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.

However, there was no significant relationship between severity and the number of involved trucks: It is the total number of *vehicles* involved, not the number of *trucks* involved that, in part, determines the severity of the accident.

Collision Types and Factors

The mean values of injuries per accident, injuries per vehicle per accident, and fatalities per accident by collision type are shown in Table 3-2. Accident severity was also

TABLE 3-2

ACCIDENT SEVERITY BY COLLISION TYPE

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

related to the primary collision factor, as shown in Table 3-3. The differences among the mean values for all three of the accident-severity variables by both collision type and factor were statistically significant. For collision types, the most severe accidents in terms of fatalities were hit-object collisions, followed by rear-end collisions and "other" types; the least severe were sideswipes. In terms of injuries per accident, broadside collisions had the highest mean (0.81 injuries per accident), while sideswipes and the collision type "other" had equally low means of 0.31 and 0.32 injuries per accident. In terms of injuries per vehicle per accident, the most dangerous accidents were overturns, followed by broadside and hit-object collisions; the least dangerous accidents on a per-vehicle basis were sideswipes.

Table 3-3 shows accident severity by primary collision factor. The most severe accidents, measured in terms of any of the three variables, were those attributed to alcohol. In terms of fatalities, the next most severe were 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 were alcohol-related were those attributed to "other improper driving" and speeding.

Involved Vehicles and Collision Types

Mean numbers of injured persons by involved vehicle, parameterized by collision type, are shown in Figure 3-1. The differences in mean injuries by involved vehicle were statistically significant for each collision type. Overturns had the highest levels and steepest slopes per involved vehicle, although there were very few overturns that involved more than two vehicles. In the range of two-to-four vehicles, broadsides were the most severe in terms of injuries. For most of the range, "other" types of collisions and sideswipes were the least severe types of accidents, but rear-end collisions involving five vehicles were also moderate when compared to hit-object collisions involving five vehicles. Finally, the function for the category "other" was 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.

TABLE 3-3

ACCIDENT SEVERITY BY PRIMARY COLLISION FACTOR

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 VIOLATIONS	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

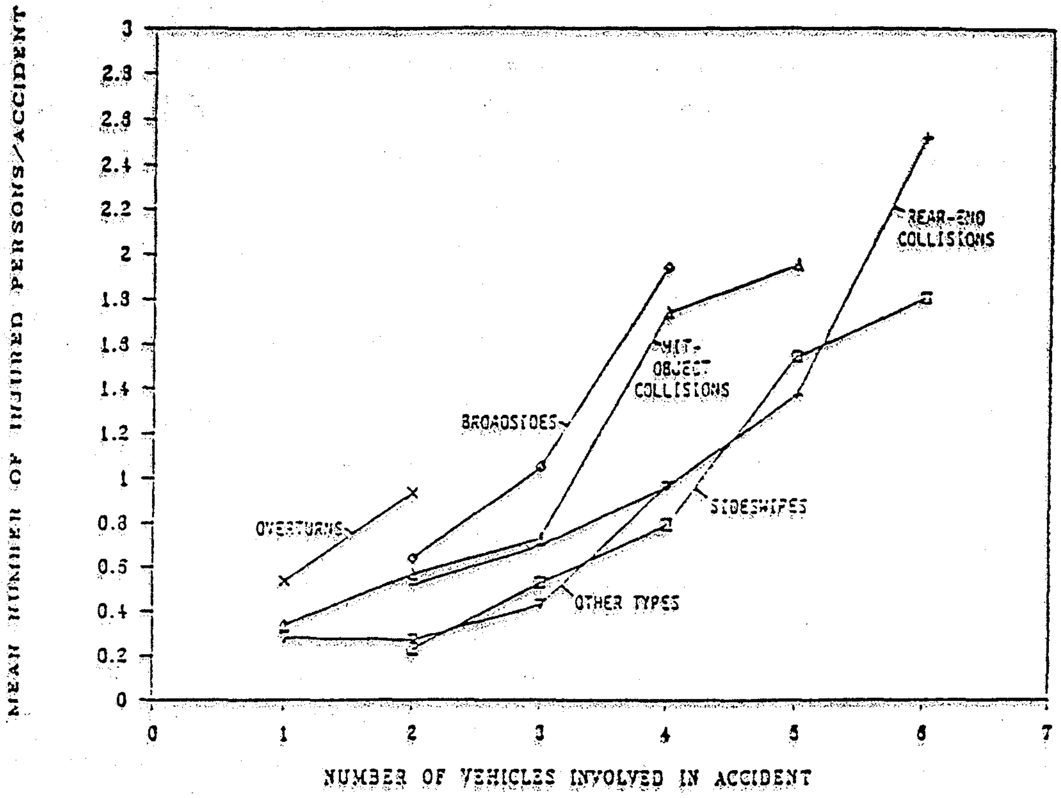

FIGURE 3-1

INJURIES VERSUS INVOLVED VEHICLES BY COLLISION TYPE

INCIDENT DURATION AND LANE CLOSURE

Theoretical Distributions

Incident duration is composed of a sequence of activities. In broad terms, each incident may consist of: (a) detection; (b) initial response; (c) injury attention (if required); (d) emergency vehicle response (if required); (e) accident investigation; (f) debris removal; (g) cleanup; and (h) recovery. The nature of these categories (and the activities within them) and the amount of time required for the completion of any activity directly influences the duration of subsequent activities. 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:

$$Y_n - Y_{n-1} = Z_n Y_{n-1} \ , \ Z_n > 0 \qquad (3\text{-}1)$$

listed in Table 3-5.

where

Y_n = time at completion of n^{th} 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

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

$$= Y_0 \quad \overset{n}{\underset{i=1}{}} (1 + Z_i) \tag{3-2}$$

or

$$Y_n = Y_0 \quad \overset{n}{\underset{i=1}{}} W_i \tag{3-3}$$

where

$$W_i = (1 + Z_i),\ W_i \quad 0 \tag{3-4}$$

or

$$\ln Y_n = \ln Y_0 + \ln W_1 + \ln W_2 + \ldots . \tag{3-5}$$

From the Central Limit Theorem, the sum of the terms on the right side of Equation (3-5) 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, $_X$ and $_X$, and the parameters . $_Y$ and $_Y$ of the distribution of duration (Devore, 1982, p. 159):

$$_Y = \exp \quad _X + \quad _X^2 / 2 \tag{3-6}$$

and

$$_Y = \exp \; 2 \; _X + \quad _X^2 \quad \exp \quad _X \; ' - 1 \; . \tag{3-7}$$

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.

Distributional Properties

To test our model of incident duration, data from California Highway Patrol (CHP) dispatch logs on incident duration and number of lanes (ramps and connectors) closed were obtained for a random sample of 332 mainline accidents and 193 ramp accidents. This sample was then stratified by collision type.

A complicating factor in determining statistical distributions of the duration of lane closures within our sample was the occurrence of multi-period incidents in which different numbers of lanes were closed for certain durations. Ninety of the 332 mainline 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 for six collision types (sideswipe, rear-end, broadside, hit-object, overturn, and "other" collisions) for the 332 mainline accidents. Three principal categories were found. Rear-end and sideswipe collisions were virtually identical; as were hit-object, broadside, and "other" collisions; overturns were unique. These three major categories are listed in Table 3-4. [For all categories involving more than one collision type, the stratified sample was weighted so that the statistics were 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 3-4). [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 pronounced in the case of hit-object/broadside/other collisions.

TABLE 3-4

TRUCK ACCIDENTS GROUPED ACCORDING TO DIFFERENCES IN INCIDENT DURATION: MAINLINE ACCIDENTS

INCIDENT TYPE: TRUCK MAINLINE ACCIDENTS		INCIDENT DURATION		PERCENT OF ALL MAINLINE ACCIDENTS
CATEGORY:	SUB-CATEGORY	MEAN	STD. DEV.	
Rear-end and Sideswipe Collisions	0 lanes closed/ no injuries	40 min.	26 min.	26.1
	0 lanes closed/ injuries	55 min.	28 min.	11.8
	1 lane closed	58 min.	1 hr. 1 min.	28.0
	2 or more lanes closed	2 hr. 6 min.	2 hr. 31 min.	11.8
Hit-object, Broadside, and "Other" Types of Collisions	0 lanes closed/ no injuries	55 min.	1 hr. 2 min.	4.9
	0 lanes closed/ injuries	1 hr. 50 min.	1 hr. 26 min.	2.6
	1 lane closed	1 hr. 2 min.	38 min.	7.0
	2 lanes closed	1 hr. 51 min.	2 hr. 3 min.	3.0
	3 or more lanes closed	1 hr. 55 min.	1 hr. 1 min.	3.0
Overturns	(All)	2 hr. 22 min	1 hr. 53 min.	1.8

For both major categories, the variances of duration for incidents with lane closures were related to the number of lanes closed, while the mean durations often were not. There were no significant differences between accidents with and without injuries for incidents with lane closures. The highest mean durations were 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 were 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 representation of all mainline accidents is also shown in Table 3-4. These varied 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 previously in this chapter. 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 presented in Appendix B.]

Six types of incidents resulting from truck accidents on ramps could also be distinguished in terms of incident duration. These are shown in Table 3-5.

TABLE 3-5

TRUCK ACCIDENTS GROUPED ACCORDING TO DIFFERENCES IN INCIDENT DURATION: RAMP ACCIDENTS

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

Statistics on ramp, mainline lane, and connector (or transition) closures by ramp incident type are shown in Table 3-6. Rear-end, sideswipe, and "other" collisions, with injuries, as well as broadside collisions typically closed off-ramps when a ramp closure occurred. Overturns affected on-ramps to a greater degree than off-ramps, and hit-object collisions affected either on-ramps and off-ramps. Connectors were also closed in many incidents; this could be related to the relatively long incident durations associated with

TABLE 3-6

CLOSURE STATISTICS FOR TYPES OF RAMP INCIDENTS

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

some accidents. Sample sizes limited further investigations of relationships among closures and incident duration.

CONCLUSIONS

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) was the primary accident factor (in nine categories.) In particular, the immediate consequences of the accident differed according to collision type. These consequences were measured 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) were the most severe. In terms of the primary causal factor, the most severe accidents in terms of either injuries or fatalities were those attributed to alcohol; the mean fatalities for influence-alcohol accidents was over five times the mean fatality rate for all other accidents, and the mean injury rate for such accidents was approximately twice that of all other accidents.

Injury and fatality rates were also found to be significantly related to the number of involved vehicles. Single-vehicle (in this case, single-truck) accidents were more severe than two-vehicle accidents in terms of fatalities, and were equally as severe in terms of injuries. The form of the injuries per involved vehicle relationships varied by collision type: the steepest rate of increases in injuries per vehicle were 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.

In terms of the duration of the accident incident, it was postulated that durations for homogeneous groups of accidents would be log-normally distributed. For mainline 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 for subcategories within the first two collision type categories. The sub-categories were 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 (rear-end, sideswipes and "other" types of collisions; broadside collisions; hit-object collisions; and overturns) For the first and third categories of ramp accidents, 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 an a duration greater than a fixed time.

CHAPTER FOUR

ANALYSIS OF MAJOR INCIDENTS

In Chapters Two and Three, we analyzed over 9,000 truck-involved freeway incidents which occurred in the Los Angeles region over a two-year period. This chapter is an analysis of selected *major* freeway incidents involving large trucks. Data from Caltrans were available for 424 such incidents that occurred in the Los Angeles region during 1983-85. Each of these incidents was of sufficient magnitude to require the response of a Caltrans Major Incident Response (MIR) Team. These responses are typically based on an evaluation of whether or not the incident is likely to result in the closure of at least two lanes for two or more hours. Variables used for to analyze these major incidents are listed in Table 4-1. Selected incident characteristics, with frequency of occurrence, are summarized in Table 4-2.

The objectives of this analysis were: first, to identify relationships between the types of incidents to which the Caltrans Major Incident Response Team responds and the characteristics of these incidents; and, second, to explain resultant delay in terms of all of the other variables. The estimated delays were reported by the Major Incident Response Teams at the lane blockage points; they do not generally include delays incurred by motorists who switch to alternate routes well in advance of the incident site.

To assess the statistical significance of variable relationships, all tests were conducted at the $p = .05$, or 95 percent confidence level. That is, if a specific relationship was found to be significant, there is less than a 5 percent chance that the relationship could be due to chance alone, under normal statistical assumptions.

DESCRIPTION OF THE INCIDENTS

Incident Type

Table 4-3 shows the frequency and percentage of the seven major incident types for the three-year period analyzed in this chapter. The relatively small sample sizes for some categories limited the depth of the analysis. However, the total sample size of 424 incidents was sufficient to support the statistical analyses reported here.

The distribution of the seven incident types over the three years is shown in Table 4-4. The major incident teams responded to more overturns with spilled loads after 1983, and to fewer jackknifed trucks after 1984.

Incident Characteristics

Incident Location

Incident locations were categorized according to three criteria: mainline, connector, and ramp. The distribution across incident location types by year is shown in Table 4-5. There was no statistically significant variation in the distribution of incidents over the three years between the two major location categories: mainline versus connector.

TABLE 4-1

LIST OF VARIABLES USED TO ANALYZE MAJOR INCIDENTS

VARIABLE	CATEGORIES
Incident Type	1. Overturned Truck 2. Jackknifed Truck 3. Spilled or Shifted Load 4. Overturn & Spill 5. Collision 6. Breakdown 7. Other Types or Unknown
Incident Characteristics	1. Incident Location a. Mainline b. Connector c. Ramp 2. Time of Day 3. Incident Duration 4. Number of Lanes Available at Site of Incident 5. Number of Lanes Closed 6. Number of Connectors 7. Number of Ramps Closed
Resultant Delay (In Vehicle Hours)	

TABLE 4-2

SELECTED MAJOR INCIDENT CHARACTERISTICS, WITH FREQUENCY OF OCCURRENCE

VARIABLE	CATEGORIES	FREQUENCY (n = 424)
Incident Type	1. Overturned Truck	137
	2. Jackknifed Truck	30
	3. Spilled or Shifted Load	59
	4. Overturn & Spill	88
	5. Collision	71
	6. Breakdown	14
	7. Other Types or Unknown	25
Incident Location	1. Mainline	257
	2. Connector	127
	3. Ramp	5
	4. Mainline and Connector	16
	5. Mainline and Ramp	19
Time of Day	1. 00:00-5:59	71
	2. 06:00-8:59	63
	3. 09:00-11:59	104
	4. 12:00-14:59	116
	5. 15:00-17:59	31
	6. 18:00-23:59	36
Number of Lanes Closed for Incident	1. 0	1
	2. 1	29
	3. 2	97
	4. 3	78
	5. 4	60
	6. 5	12
	7. 6	3
	8. 7	1
	9. 8	6
	10. 9	1
Number of Connectors Closed for Incident	1. 0	307
	2. 1	109
	3. 2	6
	4. 3	1
	5. 4	1
Number of Ramps Closed for Incident	1. 0	335
	2. 1	72
	3. 2	11
	4. 3	5
	5. 4	1

TABLE 4-3

MAJOR INCIDENT TYPE (THREE YEARS COMBINED)

TYPE	FREQUENCY	PERCENT
OVERTURNED TRUCK	137	32.3
JACKKNIFED TRUCK	30	7.1
SPILLED OR SHIFTED LOAD	59	13.9
OVERTURN & SPILL	88	20.8
COLLISION	71	16.7
BREAKDOWN	14	3.3
OTHER TYPES OR UNKNOWN	25	5.9
TOTAL:	**424**	**100.0**

TABLE 4-4

MAJOR INCIDENT TYPE BY YEAR

	1983	1984	1985	Total
OVERTURNED TRUCK	49 42.2%	49 29.5%	39 27.5%	137 32.3%
JACKKNIFED TRUCK	12 10.3%	15 9.0%	3 2.1%	30 7.1%
SPILLED OR SHIFTED LOAD	13 11.2%	16 9.6%	30 21.1%	59 13.9%
OVERTURN & SPILL	10 8.6%	44 26.5%	34 23.9%	88 20.8%
COLLISION	23 19.8%	22 13.3%	26 18.3%	71 16.7%
BREAKDOWN	5 4.3%	5 3.0%	4 2.8%	14 3.3%
OTHER TYPES OR UNKNOWN	4 3.4%	15 9.0%	6 4.2%	25 5.9%
TOTAL:	**116**	**166**	**142**	**424**

TABLE 4-5

MAJOR INCIDENT LOCATION TYPE BY YEAR

	1983	1984	1985	TOTAL
MAINLINE	74 63.8%	102 59.6%	81 57.0%	257 60.6%
CONNECTOR	34 29.3%	53 31.9%	40 28.2%	127 30.0%
RAMP	2 1.7%	3 1.8%	0 -	5 1.2%
MAINLINE AND CONNECTOR	0 7.0%	6 3.8%	10 -	16 3.8%
MAINLINE AND RAMP	6 5.2%	2 1.2%	11 7.7%	19 4.5%

Time of Day

The time of incident occurrence were grouped into six categories, as shown in Table 4-6. The rates of major incident response were highest in the two 3-hour periods of 9:00 - 11:59 and 12:00 - 14:59. There was no statistically significant difference among the three years in terms of distribution of responses over these time periods.

TABLE 4-6

TIME OF MAJOR INCIDENT (CATEGORIZED)

Time Period	Frequency	Percent
0:00 - 5:59	71	16.9
6:00 - 8:59	63	15.0
9:00 - 11:59	104	24.7
12:00 - 14:59	116	27.6
15:00 - 17:59	31	7.4
18:00 - 23:59	36	8.6

Incident Duration

The mean major incident duration was 3 hours and 39 minutes, with a standard deviation of 2 hours and 20 minutes. An hourly histogram of duration is shown in Figure 4-1. The distribution of duration was highly skewed, with an extreme value of 22 hours and 35 minutes for an incident that occurred on December 28, 1984, involving an overturn and spill. An analysis-of-variance test of duration as a function of year revealed no statistically significant differences between mean incident duration over the three year period (3 hours, 38 minutes for 1983; 3 hours, 39 minutes for 1984; and 3 hours, 41 minutes for 1985, respectively).

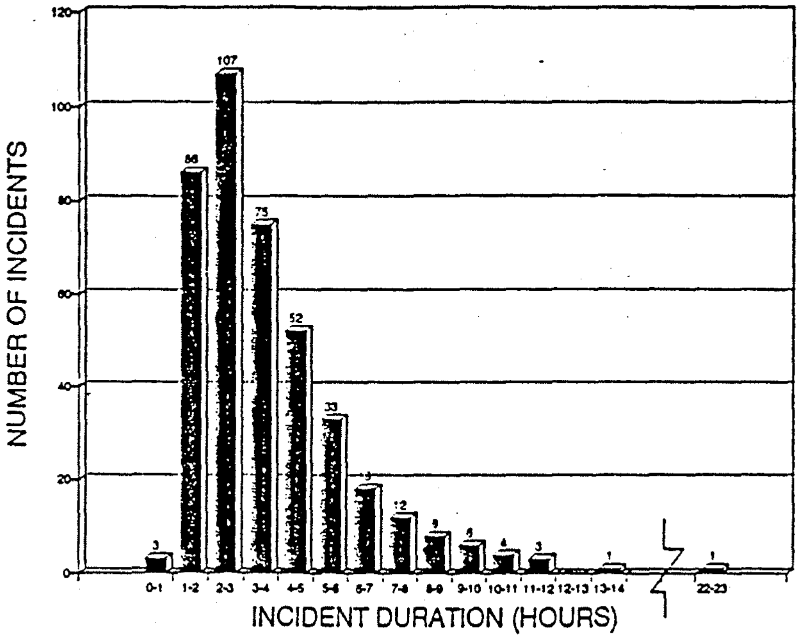

FIGURE 4-1

DURATION OF MAJOR INCIDENTS (IN HOURS)

Number of Lanes Available at the Site

The distribution of mainline incidents by the number of lanes available at the site of the incident is shown in Table 4-7; the mean number of lanes available was 4.4.

TABLE 4-7

NUMBER OF LANES AVAILABLE AT SITE FOR MAJOR MAINLINE INCIDENTS

Number of Lanes	Frequency	Percent
2	6	2.1
3	45	15.4
4	152	52.1
5	44	15.1
6	17	5.8
7	1	0.3
8	18	6.2
9	2	0.7
10	2	0.7
11	1	0.3
TOTAL:	**288**	**100.0**

Number of Lanes Closed

The distribution of the number of lanes closed by the incident is shown in Table 4-8; the mean was 2.9. A cross tabulation of incidents by lanes available versus lanes closed is shown in Table 4-9.

TABLE 4-8

NUMBER OF LANES CLOSED FOR MAJOR MAINLINE INCIDENTS

Number	Frequency	Percent
0	1	0.3
1	29	10.1
2	97	33.7
3	78	27.1
4	60	20.8
5	12	4.2
6	3	1.0
7	1	0.3
8	6	2.1
9	1	0.3
TOTAL:	**288**	**100.0**

TABLE 4-9

LANES AVAILABLE VERSUS LANES CLOSED FOR MAJOR MAINLINE INCIDENTS*

					Lanes Closed						Row
	0	1	2	3	4	5	6	7	8	9	Total
Lanes Available	2		2 (0.7)	4 (1.4)							6 (2.1)
	3		12 (4.2)	21 (7.3)	12 (4.2)						45 (15.4)
	4	1 (0.3)	13 (4.5)	56 (19.4)	41 (14.2)	41 (14.2)					152 (52.1)
	5		1 (0.3)	15 (5.2)	15 (3.1)	9	4 (1.4)				44 (15.1)
	6		1 (0.3)		6 (2.1)	5 (1.7)	3 (1.0)	2 (0.7)			17 (5.8)
	7						1 (0.3)				1 (0.3)
	8			1 (0.3)	2 (0.7)	4 (1.4)	3 (1.0)	1 (0.3)	1 (0.3)	6 (2.1)	18 (6.2)
	9	1			(0.3)		1	2	(0.3)	(0.7)	
	10	1		1	(0.3)	(0.3)		2			(0.7)
	11	1			(0.3)			1			(0.3)
	Column Total	1 (0.3)	29 (10.1)	97 (33.7)	78 (27.1)	60 (20.8)	12 (4.2)	3 (1.0)	1 (0.3)	6 (2.1)	1 (0.3)

* Numbers in parentheses indicate percents of all incidents.

The distribution by percent of lanes closed for mainline incidents is shown in categorized form in Table 4-10. Nearly 24 percent of all the mainline incidents resulted in a closure of 100 percent of the lanes; 83 percent resulted in a closure of at least 50 percent of the lanes. The mean percent of lanes closed was 66.4.

TABLE 4-10

PERCENT OF LANES CLOSED FOR MAJOR MAINLINE INCIDENTS

Range	Frequency	Percent
0 - 25%	17	5.9
26 - 49%	32	11.1
50%	69	24.0
60 - 74%	45	15.6
75 - 99%	55	19.1
100%	70	23.3
TOTAL:	**288**	**100.0**

In addition to these variables measuring lanes available, lanes closed, and percentage of lanes closed, in certain analyses it was useful to capture measures of traffic by-pass. Thus, a difference variable measuring lanes remaining open (lanes available minus lanes closed) was computed. The frequency distribution for this variable for all mainline incidents is shown in Table 4-11.

TABLE 4-11

LANES REMAINING OPEN FOR MAJOR MAINLINE INCIDENTS

Number	Frequency	Percent
0	70	24.3
1	77	26.7
2	90	31.3
3	37	12.8
4	6	2.1
5	5	1.7
6	1	0.3
7	1	0.3
8	1	0.3
TOTAL:	**288**	**100.0**

Number of Connectors and Ramps Closed

Numbers of connectors and ramps closed by major incidents are shown in Tables 4-12 and 4-13, respectively.

TABLE 4-12

NUMBER OF CONNECTORS CLOSED FOR ALL MAJOR INCIDENTS

Number	Frequency	Percent
0	307	72.4
1	109	25.7
2	6	1.4
3	1	0.2
4	1	0.2
TOTAL:	**424**	**100.0**

TABLE 4-13

NUMBER OF RAMPS CLOSED FOR ALL MAJOR INCIDENTS

Number	Frequency	Percent
0	335	79.0
1	72	17.0
2	11	2.6
3	5	1.2
4	1	0.2
TOTAL:	424	**100.0**

At least one connector was closed by almost 28 percent of the incidents; while at least one ramp was closed by about 21 percent of the incidents. A cross classification of incidents by numbers of lanes, connectors and ramps closed is shown in Table 4-14. More than one-half of the incidents resulted in the closure of mainline lanes only. The next most frequent event was the closure of both mainline lanes and ramps (about 18 percent of the incidents), followed by events involving the closure of both mainline lanes and connectors (about 13 percent of the incidents).

TABLE 4-14

TYPES OF FACILITIES CLOSED FOR ALL MAJOR INCIDENTS

CLOSURES				
Lanes	Connectors	Ramps	Number of Incidents	Percent of All Incidents
0	0	0	1	0.2
1+	0	0	227	56.2
0	1+	0	39	9.7
0	0	1+	1	0.2
1+	1+	0	52	12.9
1+	0	1+	72	17.8
0	1+	1+	0	-
1+	1+	1+	12	3.0

Resultant Delay

Finally, the descriptive statistics for the resultant estimated delay in vehicle hours yielded a mean delay of 2,070 vehicle hours, with a high standard deviation of 3,502 vehicle hours and a maximum value of 31,740. The highly skewed distribution is shown in Figure 4-2. There was no statistically significant difference between the mean delays for 1983 (mean = 1,988.5), 1984 (mean = 2,019.3), and 1985 (mean = 2,196.4).

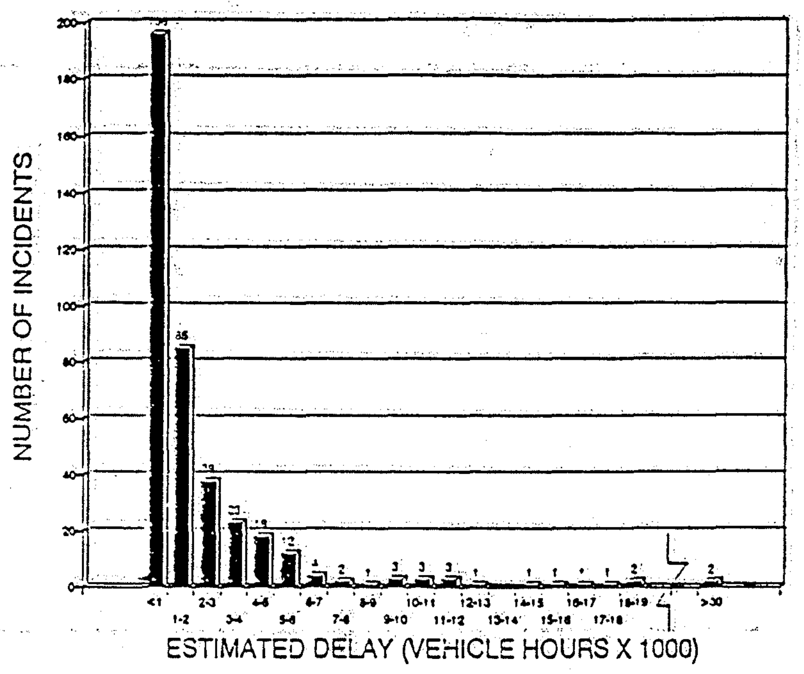

FIGURE 4-2

ESTIMATED DELAY IN VEHICLE HOURS

MAJOR INCIDENT CHARACTERISTICS AS A FUNCTION OF INCIDENT TYPE

The next question addressed was whether or not specific types of incidents (such as overturned trucks) occured more frequently in certain locations, at certain times, and with certain patterns of consequences (such as incident durations and numbers of lanes closed).

Incident location was the first characteristic investigated. There was a statistically significant relationship between type of incident, broken down into the five categories for which there were a sufficient number of incidents, and primary location, broken down into three categories. The cross tabulation of the two variables is shown in Table 4-15. The chi-square statistic computed for Table 4-15 is 38.2 with 8 degrees-of-freedom, which indicates a statistically significant relationship between the type of incident and its location. Incidents requiring Major Incident Response Teams which involved jackknifed trucks and vehicle collisions tended to occur at mainline locations, while spilled loads and overturns with spilled loads were relatively more likely to be located on connectors and ramps.

The distribution of incident types across five time periods is shown in Table 4-16. The primary differences were during the morning peak hours (relatively more overturns with spills and spilled or shifted loads) and during the noon to 3:00 p.m. period (more jackknifed trucks).

The statistics for incident duration by type are shown in Table 4-17, together with the results of a test that the mean durations were the same across all types. The hypothesis of equal mean durations was rejected: overturns involving spilled loads had

TABLE 4-15

MAJOR INCIDENT LOCATION BY INCIDENT TYPE*

	PRIMARY LOCATION		
Type	Mainline Only	Connector or Mainline and Connector	Ramp or Mainline and Ramp
OVERTURNED TRUCK	79 (57.7)	54 (39.4)	4 (2.9)
JACKKNIFED TRUCK	24 (80.0)	5 (16.7)	1 (3.3)
SPILLED OR SHIFTED LOAD	30 (43.2)	22 (37.3)	7 (11.9)
OVERTURN & SPILL	38 (43.2)	43 (48.9)	7 (8.0)
COLLISION	58 (81.7)	9 (12.7)	4 (5.6)
TOTALS:	**229** **(59.5)**	**133** **(34.5)**	**23** **(6.0)**

* Numbers in parentheses indicate row percentages.

TABLE 4-16

TIME OF MAJOR INCIDENT BY INCIDENT TYPE*

TYPE	0:00-5:59	6:00-8:59	9:00-11:59	12:00-14:59	15:00-17:59	18:00-23:59
OVERTURNED TRUCK	20 (14.8)	14 (10.4)	36 (26.7)	41 (30.8)	91 (6.7)	5 (11.1)
JACKKNIFED TRUCK	2 (6.7)	3 (10.0)	5 (16.7)	14 (46.7)	3 (10.0)	3 (10.0)
SPILLED OR SHIFTED LOAD	11 (18.6)	12 (20.7)	10 (16.9)	18 (30.5)	5 (8.5)	3 (5.1)
OVERTURN & SPILL	19 (21.8)	18 (20.7)	18 (20.7)	22 (25.3)	3 (3.4)	7 (8.0)
COLLISION	14 (19.7)	10 (14.1)	23 (32.4)	14 (19.7)	5 (7.0)	5 (7.0)
COLUMN TOTAL:	**66** **(17.3)**	**57** **(14.9)**	**92** **(24.1)**	**109** **(28.5)**	**25** **(6.5)**	**33** **(8.6)**

* Numbers in parentheses indicate row percentages.

TABLE 4-17

INCIDENT DURATION BY INCIDENT TYPE FOR ALL MAJOR INCIDENTS

Incident Type	Cases	Mean (Hours)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	132	3.49	1.96		
JACKKNIFED TRUCK	27	2.04	1.14	5.98	
SPILLED OR SHIFTED LOAD	57	3.30	2.06	(4,365)	YES
OVERTURN & SPILL	86	4.33	2.89		
COLLISION	68	3.84	2.39		

the longest mean duration (over four and a quarter hours), while the shortest mean duration was for jackknifed trucks (less than two hours).

Similar breakdowns of the mean numbers of lanes closed, the mean numbers of lanes remaining available, the mean numbers of connectors closed, and the mean numbers of ramps closed are shown in Tables 4-18 through 4-21, respectively. All of these characteristics, with the exception of numbers of ramps closed, were statistically related to incident type. However, the relationship with number of connectors closed

TABLE 4-18

NUMBER OF MAINLINE LANES CLOSED BY INCIDENT TYPE FOR ALL MAJOR INCIDENTS

Type	Cases	Mean (Lanes)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	129	2.35	1.54		
JACKKNIFED TRUCK	30	2.60	1.61	2.80	
SPILLED OR SHIFTED LOAD	59	2.34	1.46	(4,362)	YES
OVERTURN & SPILL	81	2.07	1.55		
COLLISION	69	2.86	1.24		

simply reflects the previously established finding (Table 4-15) that incidents involving overturns and load spills were proportionally more prevalent on connectors.

TABLE 4-19

NUMBER OF MAINLINE LANES REMAINING AVAILABLE AT SITE BY INCIDENT TYPE FOR ALL MAJOR INCIDENTS

Incident Type	Cases	Mean (Lanes)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	116	3.78	1.63		
JACKKNIFED TRUCK	28	4.11	1.45	3.19	
SPILLED OR SHIFTED LOAD	51	3.63	1.39	(4,324)	YES
OVERTURN & SPILL	66	3.61	1.57		
COLLISION	68	4.40	1.34		

Finally, the breakdown of mean estimated vehicle delay by incident type is shown in Table 4-22. There was no statistically significant difference among the five incident types, primarily due to the high incident-to-incident variations in delay for each type (with the exception of jackknifed trucks). The breakdown of delay by incident type

TABLE 4-20

NUMBER OF CONNECTORS CLOSED BY INCIDENT TYPE FOR ALL MAJOR INCIDENTS

Incident Type	Cases	Mean (Lanes)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	137	0.31	0.49		
JACKKNIFED TRUCK	30	0.10	0.31	5.36	
SPILLED OR SHIFTED LOAD	59	0.32	0.47	(4,380)	YES
OVERTURN & SPILL	88	0.51	0.63		
COLLISION	71	0.18	0.59		

for only mainline incidents is shown in Table 4-23. Again, there was no significant difference among the incident types. Similar results are given in Table 4-24 for connector incidents only. Consequently, we determined that it was necessary to focus on the incident characteristics (location, time of day, etc.), rather than the type of incident, for explanations of total delay.

TABLE 4-21

NUMBER OF RAMPS CLOSED BY INCIDENT TYPE FOR ALL MAJOR INCIDENTS

Incident Type	Cases	Mean (Lanes)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	137	0.20	0.47		
JACKKNIFED TRUCK	30	0.30	0.49	1.18	
SPILLED OR SHIFTED LOAD	59	0.24	0.50	(4,380)	NO
OVERTURN & SPILL	88	0.23	0.54		
COLLISION	71	0.38	0.76		

GROUPING OF INCIDENT TYPES

The results described in the preceding section indicate that certain types of major incidents can be distinguished from one another on the basis of incident characteristics, while other types of major incidents cannot. The overall characteristic uniqueness of each type of incident can be assessed using the technique of multivariate discriminant analysis. This technique is used to find the linear combinations (i.e., weighted averages) of incident characteristics which do the best job of distinguishing

TABLE 4-22

ESTIMATED DELAY BY INCIDENT TYPE FOR ALL MAJOR INCIDENTS

Incident Type	Cases	Mean (Vehicle Hours)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	126	1942	4149		
JACKKNIFED TRUCK	27	1705	1287	0.45	
SPILLED OR SHIFTED LOAD	54	2570	4051	(4,354)	NO
OVERTURN & SPILL	85	1857	3025		
COLLISION	67	1978	2735		

the types of incidents (i.e., the five incident categories). Once these linear combinations are found, statistical measures of the degree of difference between each pair of incident categories are calculated.

Only three variables were found to have statistically significant coefficients in the discriminant functions. These were, in order of power of discrimination: duration of the incident, number of connectors closed, and a dichotomous variable measuring whether or not the incident occurred in the 9:00 a.m. to 12:00 noon time period.

TABLE 4-23

ESTIMATED DELAY BY INCIDENT TYPE FOR MAJOR MAINLINE INCIDENTS

Incident Type	Cases	Mean (Vehicle Hours)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	76	2574	5160		
JACKKNIFED TRUCK	21	1744	1370	1.16	
SPILLED OR SHIFTED LOAD	26	4060	5213	(4,207)	NO
OVERTURN & SPILL	35	2840	3912		
COLLISION	54	2162	2980		

On the basis of these three-variable discriminant functions, the mean values for each type of major incident were calculated and tests of equality were performed. The test results are shown in Table 4-25, where the cells with asterisks denote pairs of incident types which were statistically different. Incidents involving jackknifed trucks were distinguished from all other types. Incidents involving vehicle collisions were distinguished from all other types except overturned trucks. Overturns were not distinguished from either spilled loads or collisions, and overturns with spills were not distinguished from spilled or shifted loads.

TABLE 4-24

ESTIMATED DELAY BY INCIDENT TYPE FOR MAJOR CONNECTOR INCIDENTS

Incident Type	Cases	Mean (Vehicle Hours)	Standard Deviation	F-Statistic (degrees of freedom)	Significant Difference Among Means?
OVERTURNED TRUCK	47	1045	1279		
JACKKNIFED TRUCK	5	1437	1076	0.12	
SPILLED OR SHIFTED LOAD	21	1082	1733	(4,120)	NO
OVERTURN & SPILL	43	1232	2107		
COLLISION	9	1075	1072		

Differences among incident types with respect to location, facilities closed, time of day of occurrence, and duration can thus be summarized as follows. Incidents selected for response by the Major Incident Response Team involving jackknifed trucks had relatively short duration, and, with overturned trucks, were less likely to occur during the morning peak. Like collisions, they were also less likely to involve the closure of connectors. Overturns with load spills that invoked a response from the MIR Team tended to be of relatively long duration, often resulted in the closure of connectors, and occured

TABLE 4-25

F-STATISTICS BETWEEN PAIRS OF INCIDENT TYPES FOR DISCRIMINANT FUNCTIONS BASED ON DURATION OF INCIDENT, NUMBER OF CONNECTORS CLOSED, AND WHETHER OR NOT INCIDENT IS IN 9:00 A.M. - 12:00 NOON TIME PERIOD

	Overturned Truck	Jackknifed Truck	Spilled Load	Overturn & Spill	Vehicle Collision
OVERTURNED TRUCK	---				
JACKKNIFED TRUCK	4.02*	---			
SPILLED OR SHIFTED LOAD	1.50	4.29*	---		
OVERTURN & SPILL	5.50*	10.31*	1.97	---	
VEHICLE COLLISION	2.24	4.53*	2.67*	5.98*	---

* Difference between types significant at p = .05 confidence level (degrees of freedom = 3,327).

primarily during the morning rush hour (and during the early morning hours). Collisions were less likely than spilled loads and overturned trucks to lead to the closure of connectors.

EXPLANATIONS OF TOTAL DELAY

Certain key explanators of total vehicle delay were unavailable for the present analyses. Critical among these was average traffic volume on the specific freeway for the specific time period of the incident. Nevertheless, an attempt was made to explain the total vehicle delay, as estimated on the major incident reports, in terms of the available data concerning the characteristics of the incidents. For incidents in which mainline lanes were closed, these available data included the number of lanes closed, the number of lanes available at the site, duration of the incident, and time period of occurrence.

It was expected that there would be a multiplicative relationship between the number of lanes closed and incident duration in explaining delay:

$$V = a\,L^{b}\ D^{c} \tag{4-1}$$

where V denotes estimated delay in vehicle hours, D is duration in hours, L is the number of lanes closed, and a, b, and c are parameters to be estimated. Taking natural logarithms of both sides of equation (4-1), the parameters can be estimated using linear regression:

$$\ln (V) = \ln (a) + b \ln (L) + c \ln (D) \tag{4-2}$$

The influences on delay of other variables, such as the number of lanes remaining open, can be assessed by adding additional terms to the regression equation. Also, differences in parameter values across the time periods or for different types of incidents or types of location can be tested by performing separate regression analyses (e.g., one analysis for each of the six time periods).

The parameter estimates for the regression expressed in equation (4-2) are given in Table 4-26. The adjusted proportion of variance accounted for (coefficient of determination, or R^2) was 0.19, and all parameters were significantly different from zero. These results imply the following estimate of equation (4-1):

$$V = 322\ L^{0.960}\ D^{0.455} \tag{4-3}$$

This equation is plotted in Figure 4-3, with predicted delay as a function of incident duration parameterized by number of lanes closed.

TABLE 4-26

RESULTS OF THE LOG-LOG REGRESSION OF DELAY VERSUS LANES CLOSED, AND DURATION FOR ALL MAJOR INCIDENTS WITH MAINLINE LANE CLOSURES (N = 291)

Variable	Coefficient	T-statistic
Number of lanes closed	0.960	7.22
Duration of incident	0.455	3.87
Constant	5.78	31.4

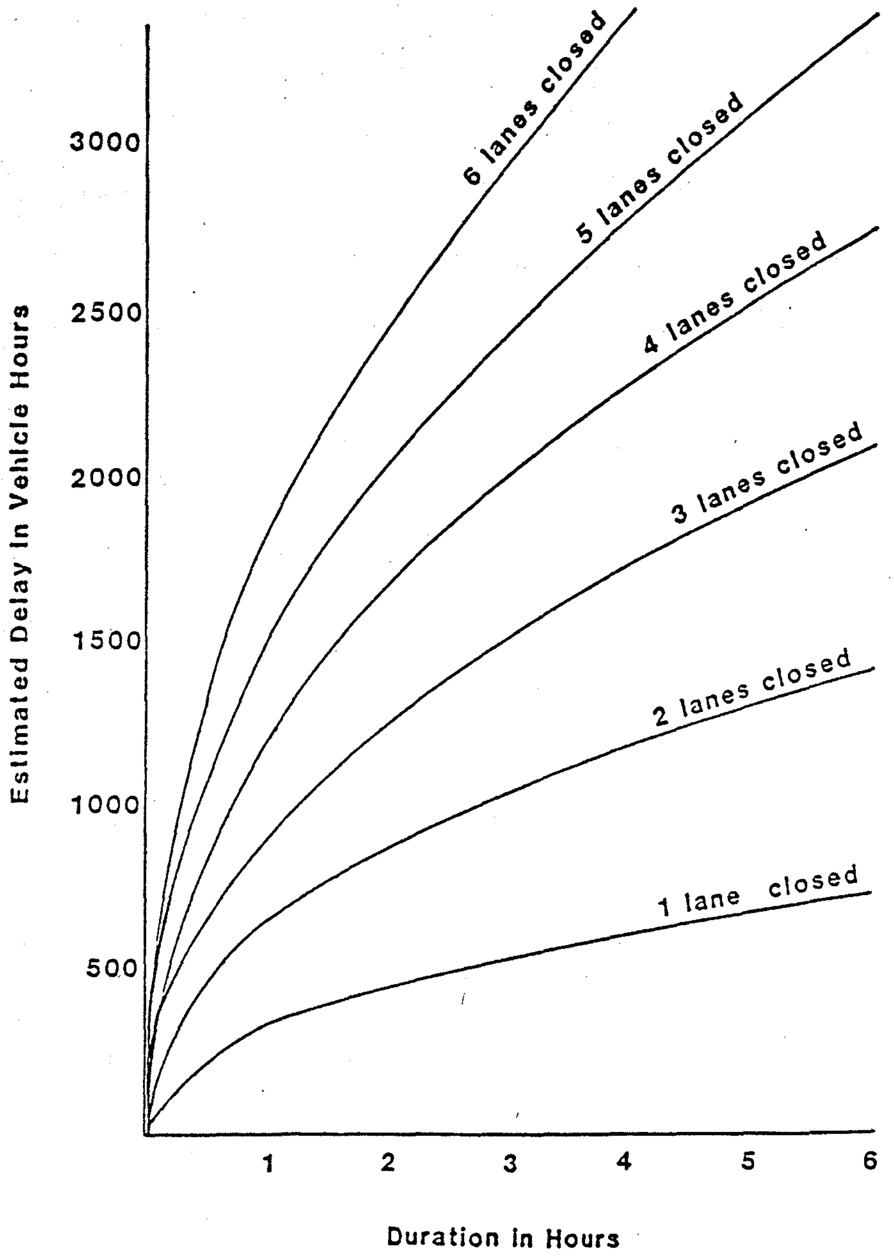

FIGURE 4-3

ESTIMATED DELAY AS A FUNCTION OF INCIDENT DURATION AND NUMBER OF LANES CLOSED FOR MAJOR INCIDENTS WITH MAINLINE LANE CLOSURES

No other variable was found to be significant, either as an additional variable in the logarithmic form of equation (4-2) or in a straight linear regression form. One of the variables with insignificant explanatory power was percent of lanes closed. The effects of a closure of one lane out of two available were similar to the effects of the closure of one lane out of eight; the effects of the closure of one out of two (50 percent) were *not* similar to the effects of the closure of four out of eight (50 percent). However, focusing on the "percent of lanes closed" variable in the sense of 100 percent versus anything less than 100 percent did lead to different results, as described in the remainder of this section.

The parameter estimates for equation (4-1) for incidents in which *all* mainline lanes were closed are shown in Table 4-27, and the estimates for incidents in which only some mainline lanes were closed are shown in Table 4-28. The adjusted proportions of

TABLE 4-27

RESULTS OF THE LOG-LOG REGRESSION OF DELAY VERSUS LANES CLOSED, AND DURATION FOR MAJOR INCIDENTS CLOSING ALL MAINLINE LANES
(N = 113)

Variable	Coefficient	T-statistic
Number of lanes closed	1.51	7.73
Duration of incident	0.300	1.57
Constant	5.11	15.3

TABLE 4-28

RESULTS OF THE LOG-LOG REGRESSION OF DELAY VERSUS LANES CLOSED, AND DURATION FOR MAJOR INCIDENTS CLOSING LESS THAN ALL MAINLINE LANES (N = 178)

Variable	Coefficient	T-statistic
Number of lanes closed	0.543	3.29
Duration of incident	0.897	6.15
Constant	5.90	27.9

variance accounted for were 0.35 for complete-closure incidents and 0.21 for partial-closure incidents (indicating correlations between predicted and reported estimated vehicle delays of 0.60 and 0.47, respectively). A comparison of Tables 4-24 through 4-26 shows that the functional form for all incidents (Table 4-26) was a compromise between two substantially different functional forms for complete-closure incidents (Table 4-27) and partial-closure incidents (Table 4-28).

The families of delay functions for the two types of incidents, represented by the parameters of Tables 4-27 and 4-28, are graphed in Figures 4-4 and 4-5, respectively.

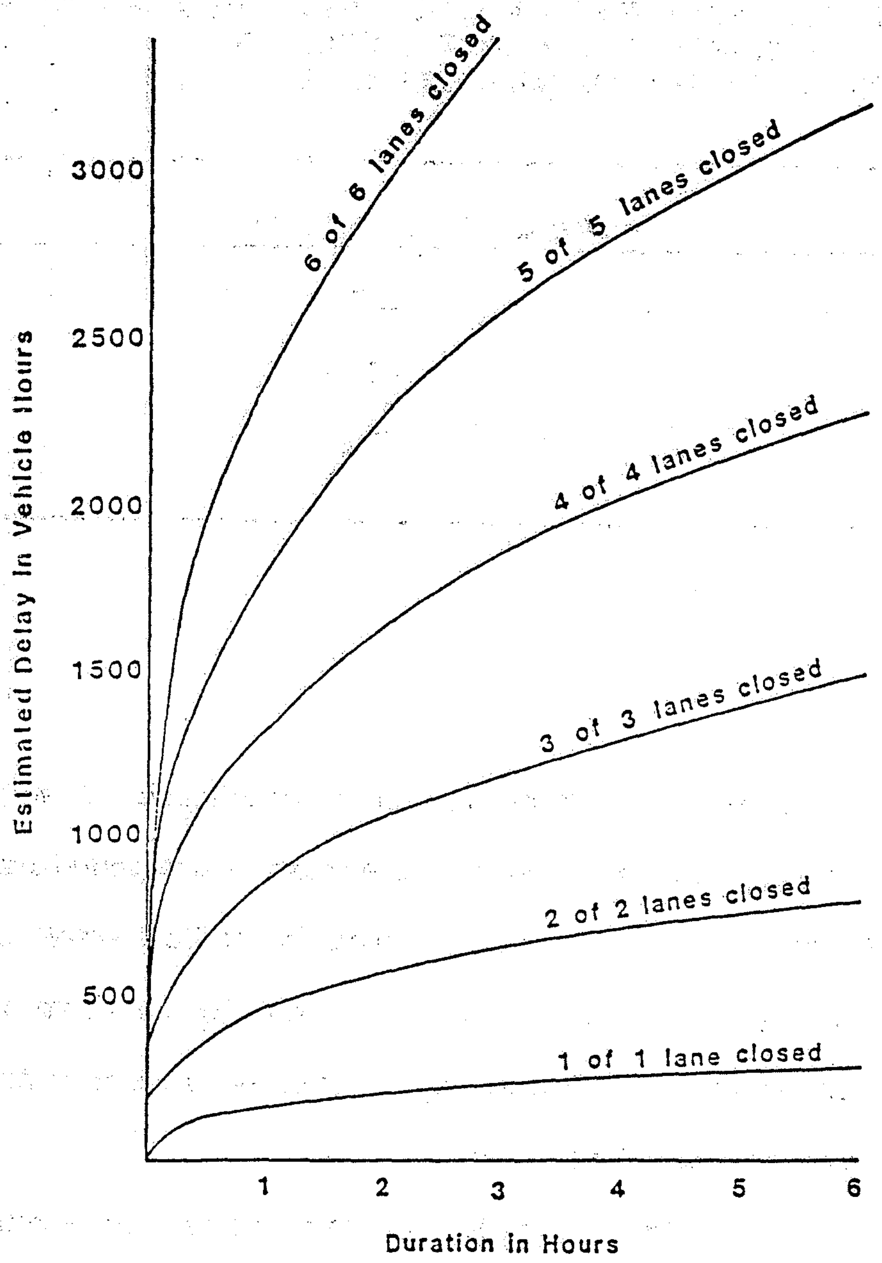

FIGURE 4-4

ESTIMATED DELAY AS A FUNCTION OF INCIDENT DURATION AND NUMBER OF LANES CLOSED FOR MAJOR INCIDENTS CLOSING ALL MAINLINE LANES

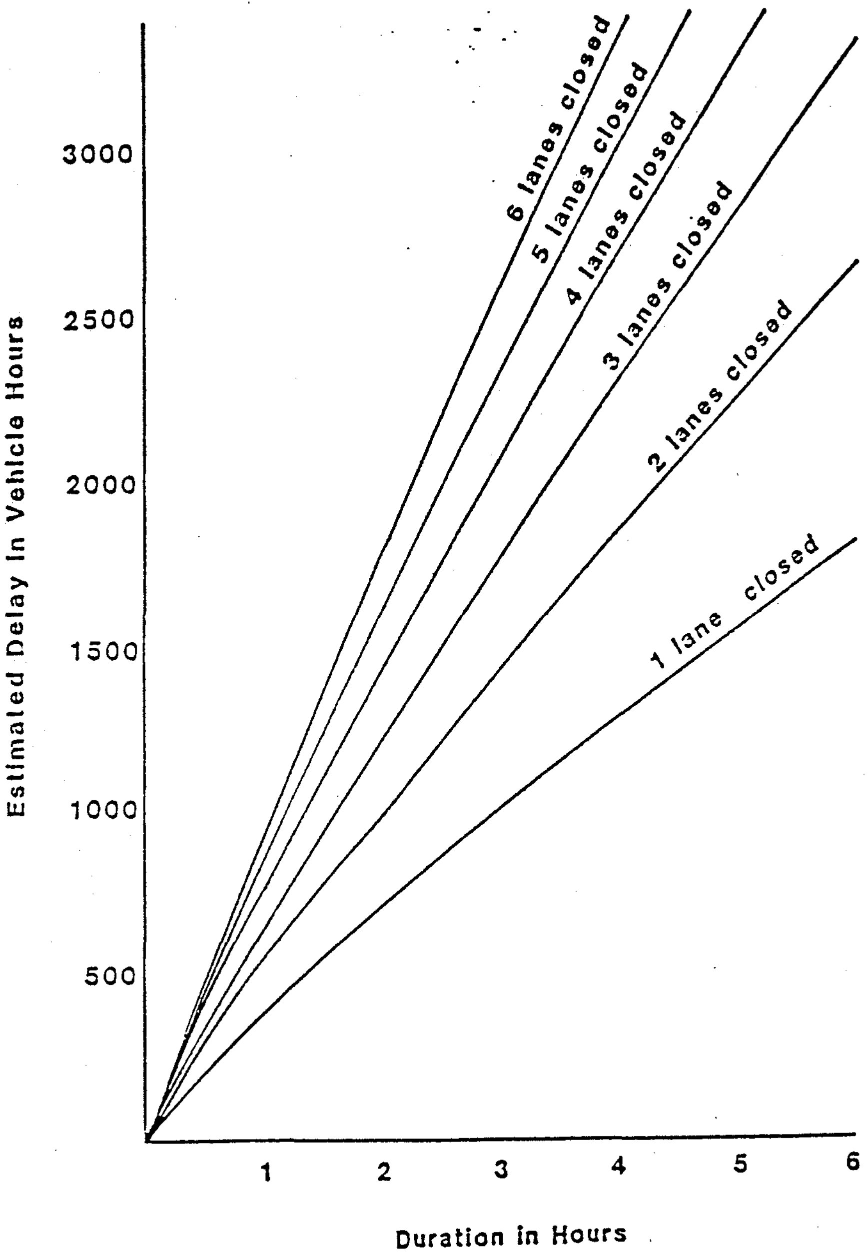

FIGURE 4-5

ESTIMATED DELAY AS A FUNCTION OF INCIDENT DURATION AND NUMBER OF LANES CLOSED FOR MAJOR INCIDENTS CLOSING LESS THAN ALL MAINLINE LANES

The functions for complete-closure incidents (Figure 4-4) exhibited a substantial degree of diminishing marginal delay. These functional forms dictated that fully one-half of the total delay after six hours of incident duration was accumulated after only the first 36 minutes, independent of the number of lanes closed. Similarly, one-half of the total delay after three hours of incident duration was accumulated in the first 18 minutes. This implies that closure of a complete freeway section leads to rapid fundamental adjustments in traffic patterns (route-avoidance behavior) after the initial blockage period. This analysis is limited, of course, to the estimation of delay to vehicles at the scene of the closure.

The functions for partial-closure incidents (Figure 4-5) exhibited non-linearity in terms of number of lanes closed, but the curves were approximately linear in terms of incident duration. Thus, the accumulation of vehicle delay was almost linear over duration (with one-half of the total expected delay in six hours duration being realized in the first two hours and 46 minutes, independent of the number of lanes closed). The non-linearity in terms of numbers of lanes closed implies that fundamental traffic adjustments increase with the number of lanes closed.

Finally, the delay equation (4-1) was estimated for both complete-closure and partial-closure incidents that occurred in each of three time periods: evening through early morning (18:00 - 05:59), peak periods (06:00 - 08:59 and 15:00 - 17:59), and mid-day (09:00 - 14:59). The results for the complete-closure incidents are shown in Table 4-29. For these incidents, the effect of the number of lanes closed was greatest in the peak period and least at night. The effect of duration was similar in the peak period to its overall average effect (where a summary of Table 4-27 is shown for "all periods" in Table 4-29). That is, for peak periods the effect of duration was highly non-linear,

TABLE 4-29

RESULTS OF LOG-LOG REGRESSIONS OF DELAY VERSUS LANES CLOSED, AND DURATION FOR MAJOR INCIDENTS CLOSING ALL MAINLINE LANES, BY TIME PERIOD

Time Period	Sample Size	Proportion of Variance Accounted For	Constant	Exponent of Lanes Closed	Exponent of Duration
18:00 - 05:59	33	0.37	4.96*	1.56*	0.00
06:00 - 08:59 and 15:00 - 17:59	22	0.42	4.98*	1.77*	0.29
09:00 - 14:59	58	0.45	4.76*	1.61*	0.72*
All Periods:	113	0.35	5.11*	1.51*	0.30*

* Coefficient significantly different from zero at the p = .05 confidence level.

implying rapid developments of traffic avoidance. The effect of duration was absolutely zero during the 18:00 - 05:59 period, and was more linear in the 09:00 - 14:59 period. All three time periods displayed relatively good fits for the regression models, particularly in light of the relatively small sample sizes.

The results for partial-closure incidents are shown in Table 4-30. The pattern of these results was quite different from that of the complete-closure incidents. The influence of the number of lanes closed was greatest, and approximately linear, for the mid-day period. However, this influence was quite small for peak periods. With regard

TABLE 4-30

RESULTS OF LOG-LOG REGRESSIONS OF DELAY VERSUS LANES CLOSED, AND DURATION FOR MAJOR INCIDENTS CLOSING LESS THAN ALL MAINLINE LANES, BY TIME PERIOD

Exponent of Time Period	Exponent of Size	Sample Accounted For	Variance Constant	Closed	Proportion of Lanes Duration
18:00 - 05:59	33	0.30	4.95*	0.67	1.22*
06:00 - 08:59 and 15:00 - 17:59	45	0.15	6.47*	0.21	0.82*
09:00 - 14:59	99	0.25	5.67*	0.87*	0.87*
All Periods:	178	0.21	5.90*	0.54*	0.90*

* Coefficient significantly different from zero at the p = .05 confidence level.

to duration, the contrast was between the 18:00 - 05:59 (night) period and the entire 06:00 -17:59 (day) period: there was a slightly increasing marginal rate of delay as a function of duration in the nighttime period, and a slightly decreasing marginal rate in the daytime period.

The regression fits were poorer for partial-closure incidents than for complete-closure incidents for all time periods, particularly the peak periods. This indicates considerable incident-to-incident variations for partial-closure incidents. Consequently, the results for peak-period partial-closure incidents should be considered as representing only crude approximations. The results for the other time periods and for complete-closure incidents are more statistically secure.

CHAPTER FIVE

CONGESTION EFFECTS

This chapter focuses on the impact of mainline truck-involved collisions on the operation of the freeway system in terms of total delay. [Non-collision incidents, such as stalls and spilled loads, are not included in this analysis. All analyses are for mainline accidents only].

DATA

The primary data source for our analysis of the congestion effects of truck-related collisions was the TASAS (Traffic Accident Surveillance and Analysis System) data base maintained by the California Department of Transportation (California Department of Transportation, 1978). This data base theoretically contains records on all collisions on the state highway system that involve police investigations at the scene. For 1987-88, there were 10,805 such collisions involving trucks larger than pickups or panel trucks on 22 freeway routes in Los Angeles, Orange, and Ventura Counties.

Because the TASAS data base does not contain any information on incident duration or number of lanes closed, data on incident duration and the number of lanes or ramps closed by an incident 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 collisions, identified by CHP beat, date, time of day, and location obtained from the TASAS data file. The random sample was stratified by collision type, and only collisions 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 underreporting of closures that are of short duration.

OVERVIEW OF APPROACH

A simulation procedure was used to develop estimates of motorist delay attributable to truck-involved freeway collisions. The simulation was conducted in two phases. First, INTRAS, a microscopic traffic flow model (Federal Highway Administration, 1980a,b) was used to simulate the added delay associated with a randomly selected subset of collisions taken from California Highway Patrol logs. [For a description of the INTRAS model, see Appendix C]. These incidents were selected in a manner that ensured adequate representation of collisions in each of ten categories found to have significantly different characteristics. The actual duration of each incident and the pattern of lane closures (if any) detailed in the CHP logs were merged with the corresponding TASAS record to create a data set for simulation of the traffic conditions associated with each incident. Base cases corresponding to "no incident" conditions were also simulated to calculate added delay attributable to the collision. From the results of these simulations, regression models of simulated additional delay were estimated using the information contained in the accident and highway records together with incident duration and lane closure information as explanatory variables.

The second phase of the simulation involved the generation of incident durations and lane closures for the population of truck-involved freeway collisions that occurred on freeways located in the study area of Los Angeles, Orange, and Ventura Counties in California during the two-year period 1987 through 1988. This was required since such information is not contained in the state-maintained accident records. The duration and lane closure information corresponding to each incident was simulated using distributions obtained from the subsample of collisions drawn from the CHP logs for each of the various incident categories. These simulations were repeated a large number of times and the data generated combined with the corresponding collision information. These data were then used as values for the explanatory variables in the regression models of delay, producing estimates of the mean expected delay and corresponding level of confidence of this estimate for each incident. Finally, these individual estimates were summed to provide an estimate of total delay.

DISTRIBUTIONS OF INCIDENT DURATION AND SIMULATION SUBSAMPLING

The subsample of truck-involved freeway collisions used in the INTRAS simulation of delay was drawn from California Highway Patrol records for Los Angeles County for the two-year period 1983-1984. This subsample was created from a random selection of collisions involving at least one truck. A total of 332 mainline collisions were drawn and matched against the state-maintained accident records by comparing time, date, and location of the incidents.

In Chapter Three, we reported results of our analysis of the differences in incident duration and lane closures among six collision types (sideswipe, rear-end, broadside, hit-object, overturn, and "other" collisions) for the same 332 truck-involved mainline collisions (Table 3-4). Based on differences in either means or standard deviations, rear-end and sideswipe collisions were found to be mutually indistinguishable; as were hit-object, broadside, and "other" collisions; while overturns were unique. Within these first two major categories of incidents, sub-categories were found with statistically significant differences in either the means or variances of the incident durations, and there were similar sub-categories for both major categories. The subcategories were defined by incidents for which there were no lanes closed, subdivided into injury and non-injury collisions, collisions for which there was one lane closed, those for which there were two lanes closed, and those for which there were three or more lanes closed (second major category only). For both of the major categories of incidents in Table 5-1, the variances, rather than the means, of duration for incidents with lane closures were related to the number of lanes closed. For each of the ten types of truck-involved freeway collisions in Table 3-4, the distributions of incident duration were determined through Kolmogorov-Smirnov tests to be log-normal. [See Apppendix B] The best-fitting log-normal probability density functions for the ten collision categories are graphed in Figures 5-1 and 5-2. The differences among the incident durations for collision categories are clearly demonstrated in these graphs.

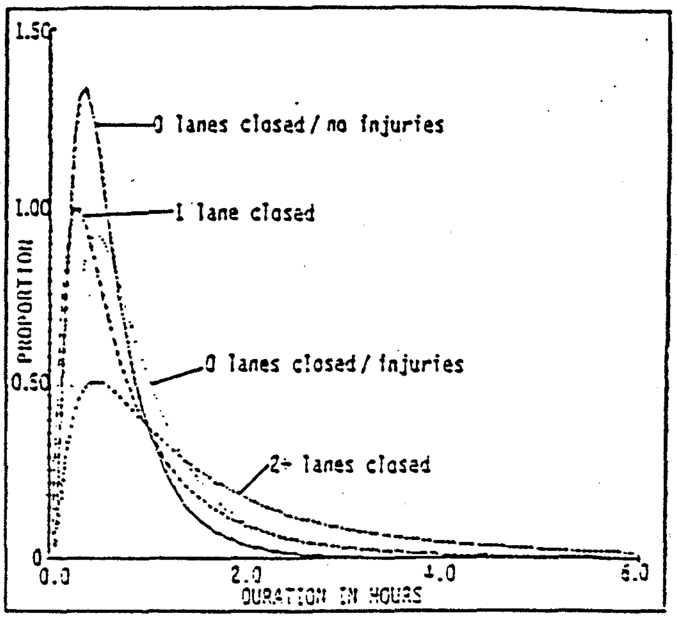

FIGURE 5-1
PROBABILITY DENSITY FUNCTIONS FOR MAINLINE REAR-END AND SIDESWIPE COLLISIONS

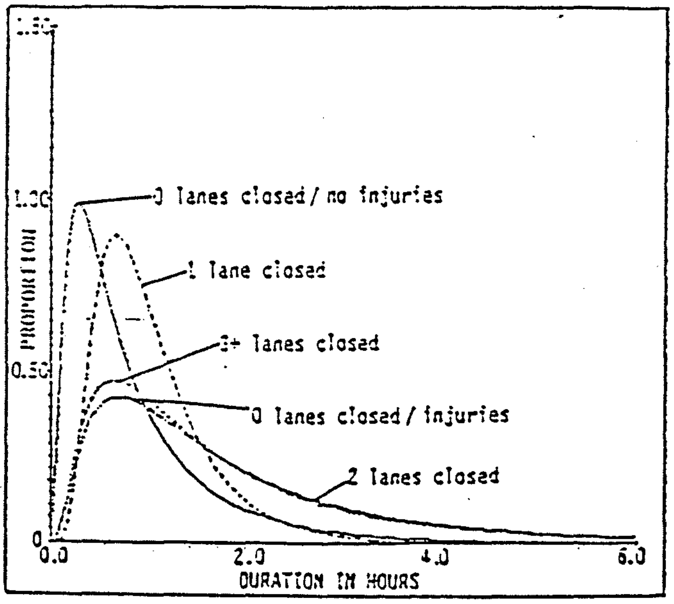

FIGURE 5-2
PROBABILITY DENSITY FUNCTIONS FOR MAINLINE HIT-OBJECT, BROADSIDE, AND "OTHER" COLLISIONS

The ten collision categories provided the typology for a quota sampling of incidents for INTRAS simulation. Several of the randomly selected incidents in the quota sample involved parameters that were beyond the practical limits of INTRAS (e.g., incidents with the combination of multiple-lane closures and long durations during periods of peak congestion); these were discarded and the subsample replenished with a random sample of incidents selected independent of category.

Simulation of Delay by INTRAS

Ninety-two (92) collisions were selected for incident simulation using the INTRAS microscopic traffic simulation model. The freeway network coded for each case study comprised a one-mile section of the mainline freeway immediately downstream of the collision, a section of the mainline freeway immediately upstream of the collision location of sufficient length to encompass any disruptive impact of the incident (subject to certain limitations), and all ramps and connectors associated with the mainline segment. The length of the upstream segment was limited by the restriction in INTRAS of having a total of fewer than 100 links comprising the freeway network. Typical upstream sections ranged between five and ten miles, depending on the density of on-/off-ramps, traffic conditions, and incident characteristics. Where possible, the upstream length was selected such that the entire mainline extent of the effect of the incident was encompassed by the network coded; in the few cases in which this was not possible, procedures were established to estimate the extent and impact of the incident beyond the boundaries of the network modeled. Practical considerations and INTRAS limitations prohibited simulation of any effects of the incident on adjacent surface streets or on connecting freeways. This feature of the simulation is expected to underestimate the delay associated with a collision.

Traffic volumes loaded onto the network for each simulation were derived from Caltrans' published average annual daily traffic (AADT) counts, using data both for the freeway mainline and for all associated ramps. A growth factor of 6 percent per year was assumed and applied to all non-current mainline AADT counts; non-current ramp AADT counts were adjusted using a combination of growth factors (for data less than four years old) and continuity (based on mainline freeway counts at appropriate stations). Estimates of traffic volumes (in vehicles per hour) for each 15-minute period of the day were obtained by applying continuous count (loop data) temporal volume distributions taken from stations on the Santa Monica (Route I-10) and Harbor (Route I-110) Freeways in Los Angeles in July 1984, together with directional factors obtained from Caltrans for each freeway segment. Changes in traffic volumes resulting from congestion effects due to the incident (i.e., diversion to alternate routes) were not considered in the simulations; the effect of this simplification is expected to overestimate delay by an unknown amount. However, this overestimation is counterbalanced somewhat by the additional travel time spent by vehicles diverted to less favorable routes.

Although any effects of lane closures on traffic conditions are treated internally through the car-following and lane-changing modules in INTRAS, the effects of spectator slowing are subject to an input "rubbernecking factor" that represents the percentage decrease in ambient speed associated with this behavior. In the collision simulations, a "rubbernecking factor" of 40 percent was assumed for all lanes within 250 feet downstream of the collision; a factor of 20 percent was assumed for all lanes between 250 and 500 feet downstream of the collision. Rubbernecking occurring on the opposite side of the freeway was not considered, and this contributed to an underestimation of the total delay due to the incident.

For each collision simulated, a base situation corresponding to conditions exclusive of the incident was also simulated. The simulation time frame for each incident was extended beyond the actual incident duration until such time that freeway conditions had returned to that predicted by the corresponding base simulation; i.e., to a time at which the performance characteristics (on a link-by-link basis) of the freeway for both the "base" and "incident" cases were virtually indistinguishable. Collision simulations therefore included not only the incident, but also the recovery period. In all simulations, traffic volumes and lane closure information were updated every 15 minutes; output from the simulation model was produced for each 15-minute interval simulated.

Regression Models of Nonrecurrent Delay

Because of the obvious impracticalities of using INTRAS to simulate the delay associated with all truck-involved mainline freeway collisions that occurred during the 1987-1988 period, regression models were developed to extrapolate case study results to the entire population of incidents. From simulations of the 92 collisions, three resultant variables were extracted as delay indicators:

1. TOTAL DELAY: The additional delay (in vehicle hours) attributed to any particular incident. This value is defined as the difference between the incident case and base case simulations in delay experienced by all vehicles affected by the incident.

2. LANE MILE HOURS < "SPEED": The total additional lane mile hours for which travel speed is less than a specified value as a result of incident-related congestion. This value is defined as the total lane miles on which the average vehicle speed is less than the criterion speed during the incident case, but greater than the criterion speed during the base case, times the duration that such a condition exists for any particular link. Three criterion speeds were used: 35 MPH, 20 MPH, and 10 MPH.

3. VEHICLE HOURS < "SPEED": The total additional vehicle hours spent traveling at a speed less than a specified value as a result of incident-related congestion. This value is defined as the difference between the incident case and base case in vehicle hours spent traveling at a speed that is less than the criterion speed. Three criterion speeds were used: 35 MPH, 20 MPH, and 10 MPH.

Candidate explanatory variables in the regressions of these three variables were drawn from aspects likely to affect traffic conditions following a collision, such as volumes and capacities, incident duration, and lane closures. Consideration was also given to the availability of reasonable estimates of the values of these variables for the population of truck-involved freeway collisions under consideration. Due to the limited sample size, the stratified sampling procedure, and limitations of the INTRAS simulations for certain types of conditions (most notably multiple lane closures for extended periods during heavy demand), models developed from the sample data are necessarily limited by the range of conditions represented. Table 5-1 presents a summary of the range of types of incidents included in the simulation sample categorized by lane closures, duration of incident, and nominal volume-to-capacity ratio (V/C), and corresponding information regarding simulated additional delays due to the incidents.

A preliminary exploratory analysis revealed that the relationships between the indicator and explanatory variables were nonlinear, and it was found that log-linear forms were most effective in capturing nonlinearities. However, such a nonlinear transformation greatly compresses the wide range of delay values represented by the 92 data points used in the estimation of the models. Relatively small errors in the estimates of the logarithms of large delays are magnified greatly upon inversion. This problem is exacerbated by the skewedness of the sample toward incidents resulting in smaller delays. To counteract this problem, the data points in the regression estimation were weighted by the logarithm of the respective outcome variable.

The model functional form found to give the best results was:

$$y = D^{\gamma} \exp\left[\alpha + \beta_1 L + \beta_2 (V/C)\right] \tag{1}$$

where

y = Delay indicator.

L = Maximum number of lanes closed by the incident; 0, 1, 2 (or more).

V = Traffic volume in VPH at the time and location of the incident.

C = Nominal freeway capacity at the location of the incident, taken as the number of freeway lanes in the direction of travel x 2000 VPH.

D = Duration of the incident in hours (measured as the time from the initial reporting of the incident until the incident is cleared).

α, β_1, β_2, γ = Regression parameters.

TABLE 5-1

SAMPLE CHARACTERISTICS:
DELAY BY V/C, DURATION, AND LANE CLOSURE

Lanes Closed	Duration Hours	V/C	Cases	Mean Delay (Veh.-Min.)	Std. Dev. (Veh.-Min.)
0	< .05	< 0.4	5	286.4	510.1
		0.4 - 0.8	6	745.2	527.2
		> 0.8	3	13,172.7	10,941.1
	0.5 - 1.0	< 0.4	2	162.0	227.7
		0.4 - 0.8	17	18,844.3	41,277.9
	1.0 - 2.0	< 0.4	2	107.3	107.5
		0.4 - 0.8	6	13,197.0	29,829.8
	> 2.0	< 0.4	2	81.1	84.3
1 or more	< 0.5	< 0.4	3	225.4	131.8
		0.4 - 0.8	7	27,009.9	37,619.4
	0.5 - 1.0	< 0.4	5	12,932.1	16,209.4
		0.4 - 0.8	13	57,579.5	65,328.8
		vol > 0.8	1	219,313.0	0.0
	1.0 - 2.0	< 0.4	5	86,780.6	108,751.0
		0.4 - 0.8	8	92,465.0	95,987.9
	> 2.0	< 0.4	4	350,440.2	287,403.4
		0.4 - 0.8	3	423,148.0	40,980.6
TOTAL SAMPLE:			**92**	**59,921.1**	**122,426.0**

Table 5-2 summarizes the results of the regression analyses, where the dependent delay-indicator variables are:

$\frac{\text{ADDED DELAY}}{\text{VOLUME}}$ = Total additional delay resulting from the incident divided by the total hourly demand present during the incident; an indicator of the average additional delay per vehicle per hour of duration.

LMH <35, LMH <20, LMH <10 = Total additional lane mile hours at speeds less than 35 MPH, 20 MPH and 10 MPH, respectively, resulting from the incident.

VH <35, VH <20, VH <10 = Total additional vehicle hours spent at speeds less than 35 MPH, 20 MPH, and 10 MPH, respectively, resulting from the incident.

The regression results indicated a relatively good explanation of all seven indicator variables, with R^2 values ranging from 0.58 to 0.65. All parameters were significant at the $p = .01$ level in every regression, with the exception of the intercept term of the exponent (α in equation (1)) for the indicators of additional lane mile hours spent at less than 35 mph. These models provided a basis for estimating the total delay associated with the nearly 11,000 truck-involved freeway collisions under consideration.

TABLE 5-2

MODELS OF DELAY

Dependent Delay Indicator	Estimated Parameters (t-statistics)				
	α	β_1	β_2	γ	R^2
Added Delay / Volume	1.71 (3.9)	.39 (4.5)	1.53 (2.6)	1.57 (11.1)	0.58
LMH <35	0.39 (1.11)	0.58 (7.8)	4.90 (9.7)	1.51 (12.6)	0.57
LMH <20	0.82 (2.26)	0.45 (5.8)	4.19 (8.4)	1.57 (12.9)	0.58
LMH <10	1.35 (3.3)	0.33 (3.7)	3.10 (5.9)	1.66 (13.5)	0.63
VH <35	3.16 (11.9)	0.87 (14.7)	6.96 (17.4)	1.85 (20.2)	0.65
VH <20	3.62 (12.7)	0.75 (11.6)	6.33 (15.2)	1.88 (19.0)	0.62
VH <10	4.12 (12.0)	0.64 (8.4)	5.58 (12.3)	1.81 (15.9)	0.51

APPLICATION OF DELAY MODELS

The TASAS records provided information on the route, postmile, lane number, and time of each incident; simulation procedures were developed to estimate the duration of the incident and the number of lanes closed. First, in the generation of lane closure information, each incident was categorized according to the classifications of Table 3-4. Lane closure values were then randomly assigned to each case according to the probabilities represented by the category frequencies listed in Table 3-4 and more detailed TASAS data. Table 5-3 provides a summary of the resulting breakdowns of simulated lane closures for each collision type.

Incident duration was then assigned to each case based on the log-normal distributions of delay depicted in Figures 5-1 and 5-2. For each case, the duration was obtained from a log normally-distributed random number generator. Table 5-4 summarizes the simulated incident durations by collision type resulting from this procedure.

Traffic volume data for the models were derived from AADT information at the collision location and the time of the occurrence of the collision. For non-peak hours, volume was estimated directly from AADT information and the hourly factors described previously. For peak hour conditions, this information was used together with Caltrans data and freeway congestion diagrams to produce a simplified table of sectional peak-hour directional flow.

The collision case records were augmented by these estimated data to produce data files that were complete with respect to information required by the statistical models of delay. The various indicators of delay were then calculated using the models developed in the previous section. These calculations were performed for each incident

TABLE 5-3

SIMULATED DISTRIBUTION OF LANE CLOSURES

Collision Type	Lanes Closed	Percent of Cases in each Type
1. Rear-end, Sideswipe, & No Injury	0 lanes closed	62.5
	1 lane closed	23.6
	2 lanes closed	8.8
	≥ 3 lanes closed	5.1
2. Rear-end, Sideswipe, & with Injury	0 lanes closed	50.2
	1 lane closed	30.9
	2 lanes closed	10.1
	≥ 3 lanes closed	8.8
3. Hit-Object, Broadside, & Other & No Injury	0 lanes closed	61.5
	1 lane closed	18.9
	2 lanes closed	16.1
	≥ 3 lanes closed	3.5
4. Hit-Object, Broadside, & Other & with Injury	0 lanes closed	39.7
	1 lane closed	14.1
	2 lanes closed	17.0
	≥ 3 lanes closed	29.2
5. Overturns	0 lanes closed	11.3
	1 lane closed	16.9
	2 lanes closed	39.6
	≥ 3 lanes closed	32.1

TOTAL PERCENTAGE FOR EACH COLLISION TYPE: 100%

to produce mean estimates (and associated statistics) of the delay indicators for each case.

TABLE 5-4

SIMULATED DURATIONS

Incident Type	Description	Duration Mean (Min.)	Duration Std.Dev. (Min.)	Parameters μ	Parameters σ
1	RE & SS--0 lanes closed, no injuries	54.4	17.3	-.1417	.3067
2	RE & SS--0 lanes closed, injuries	60.8	16.5	-.0212	.2608
3	RE & SS--1 lane closed	61.5	16.9	.0199	.2751
4	RE & SS--2 or more lanes closed	69.4	20.2	.1003	.2841
5	HO, BS, & Other --0 lanes closed, no injuries	59.0	15.0	-.0460	.2585
6	HO, BS, & Other --0 lanes closed, injuries	71.9	17.7	.1304	.2509
7	HO, BS, & Other --1 lane closed	74.0	34.0	.1074	.4180
8	HO, BS, & Other --2 lanes closed	70.6	18.3	.1469	.2511
9	HO, BS, & Other --3 or more lanes closed	77.2	17.8	.2223	.2402
10	Overturns	85.6	25.8	.2987	.2937

KEY:
RE = Rear-End Collision
SS = Sideswipe Collision
HO = Hit Object
BS = Broadside Collision

RESULTS

Models are limited in application to the ranges of conditions for the sample used to estimate the model. For the 1987-88 truck sample, 349 incidents (approximately 3 percent of the entire sample) had combinations of conditions (e.g., multiple lane closures, long durations, and/or high volume to capacity ratios) that exceeded these limits. The delays estimated by the model for these incidents are probably unreliable; in the following analyses, results attributable to these incidents are depicted separately and identified as "out-of-range."

The total *additional expected delay* attributable to truck-involved freeway collisions in the study area for the two-year period 1987 through 1988 was found to be approximately 20.6 million vehicle hours, or 10.3 million vehicle hours of delay per year. The average total additional delay per incident was found to be 1,911 vehicle hours, and the average additional delay per vehicle affected by an incident was estimated to be 20.5 minutes. A breakdown of these results by year, showing the relative contributions of "in-range" and "out-of-range" cases, is given in Table 5-5. The actual distribution of delays is shown in Figure 5-3, and the corresponding cumulative distribution is shown in Figure 5-4.

These figures show that the majority (approximately two-thirds) of truck-involved incidents caused delays below the mean. The relatively small number of accidents that contributed disproportionately to delay typically were accidents of high V/C, longer duration, with multiple lane closures. ["Out of Range" cases account for 9 percent of these incidents].

Although overturned vehicles and broadside collisions resulted in the greatest vehicle hours of delay per incident (Figure 5-5), their relatively small number (accounting for 1.5 percent and 2.5 percent of all truck-involved freeway collisions, respectively) led to a correspondingly small contribution to total delay (Figure 5-6). Conversely, the relatively small amount of delay per incident associated with sideswipes and rear-end collisions was counterbalanced by their high frequencies of occurrence, leading to significant contribution to the overall delay situation.

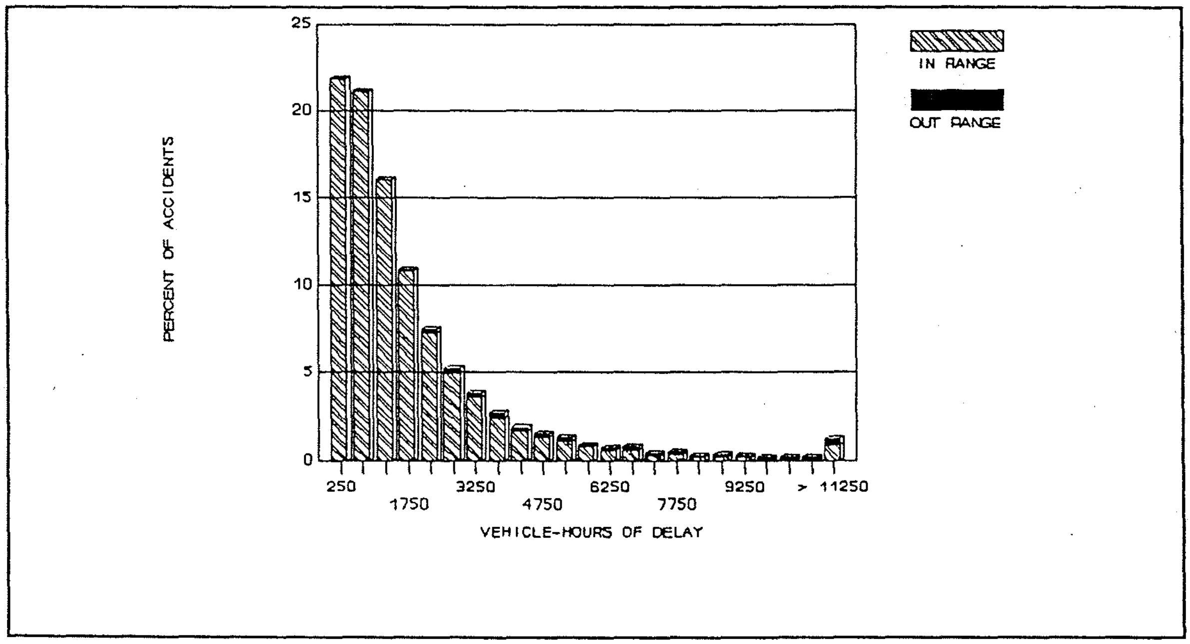

FIGURE 5-3
DISTRIBUTION OF TOTAL DELAY

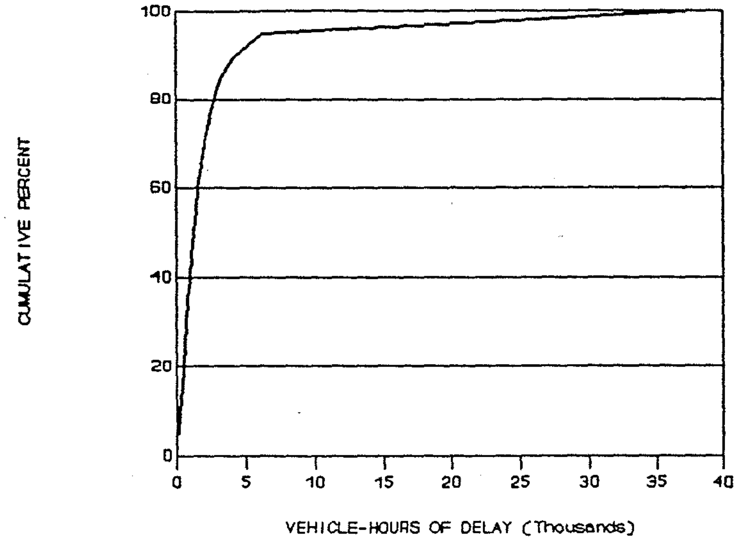

FIGURE 5-4
CUMULATIVE DISTRIBUTION OF DELAY

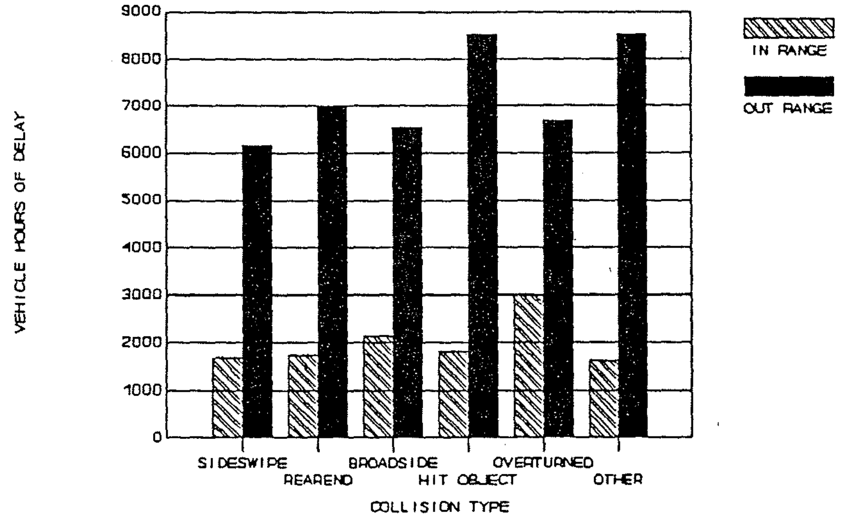

FIGURE 5-5
VEHICLE HOURS OF DELAY PER INCIDENT
BY COLLISION TYPE

TABLE 5-5
SUMMARY OF ADDITIONAL DELAY FOR TRUCK-INVOLVED FREEWAY COLLISIONS

	1987			1988		
DELAY MEASURE	IN-RANGE (N=5097)	OUT-OF RANGE (N=106)	TOTAL (N=5203)	IN-RANGE (N=5359)	OUT-OF RANGE (N=243)	TOTAL (N=5602)
Total Additional Delay (Vehicle Hours)	8.8×10^6	$.73 \times 10^6$	9.5×10^6	9.5×10^6	1.65×10^6	11.15×10^6
Average Additional Delay per Incident (Vehicle Hours)	103,134	411,268	109,411	106,535	405,769	119,515
Average Additional Delay Per Vehicle (Minutes)	19.31	48.03	19.90	19.75	48.46	21.00

Figures 5-7 and 5-8 provide an indication of congestion levels resulting from incidents of various types. Figure 5-7 presents the average additional lane mile hours per incident at speeds less than a specified level (i.e., 10, 20, and 35 MPH) attributable to truck-involved collisions of various types. For example, a figure of 30 lane mile hours at a speed less than 35 MPH per incident might just as logically be associated with such average speed conditions existing for a six-mile section of a five-lane freeway for a period of one hour, as with the same conditions on a five-mile section of a four-lane freeway for 1.5 hours. The average relative severity of incidents involving overturned vehicles is evident in Figure 5-7. This pattern is repeated in Figure 5-8 which shows the breakdown of average vehicle hours per incident spent traveling at speeds less than a specified speed. As was the case with total additional delay, the effect of the relatively high congestion impacts associated with incidents involving overturned vehicles, broadside collisions, and hit objects, was mitigated by the relatively low frequency of occurrence of these types of incidents (Figures 5-9 and 5-10). The large number of typically relatively minor rear-end and sideswipe collisions accounted for approximately 80 percent of the congestion effects (as defined by speed) associated with truck-involved collisions; the next largest category involved hit objects, accounting for approximately 8.7 percent.

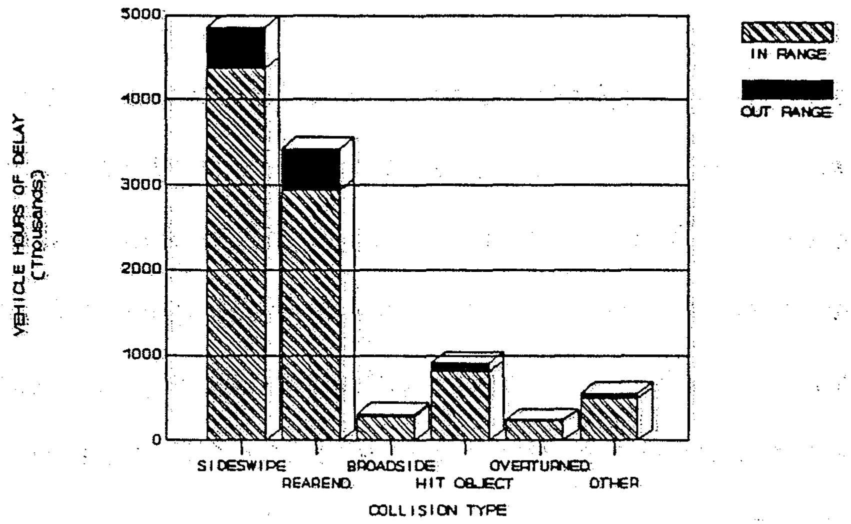

FIGURE 5-6
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY COLLISION TYPE

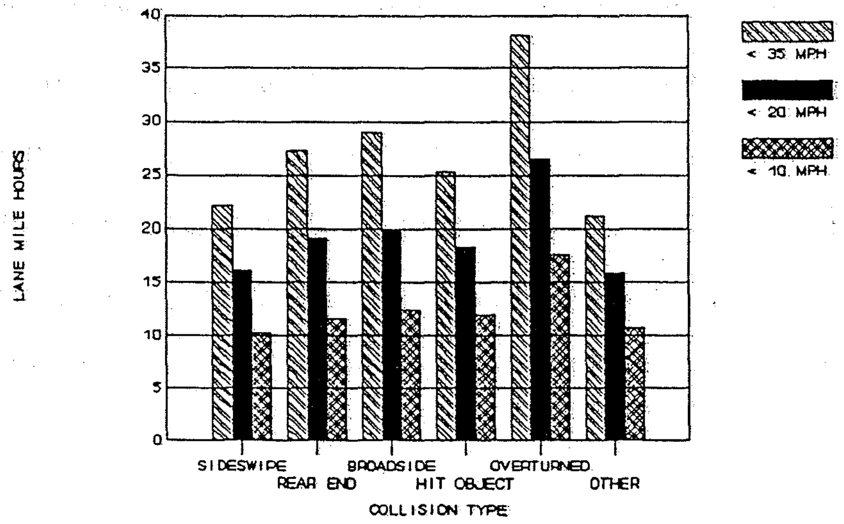

FIGURE 5-7
LANE MILE HOURS PER INCIDENT BY SPEED
BY COLLISION TYPE

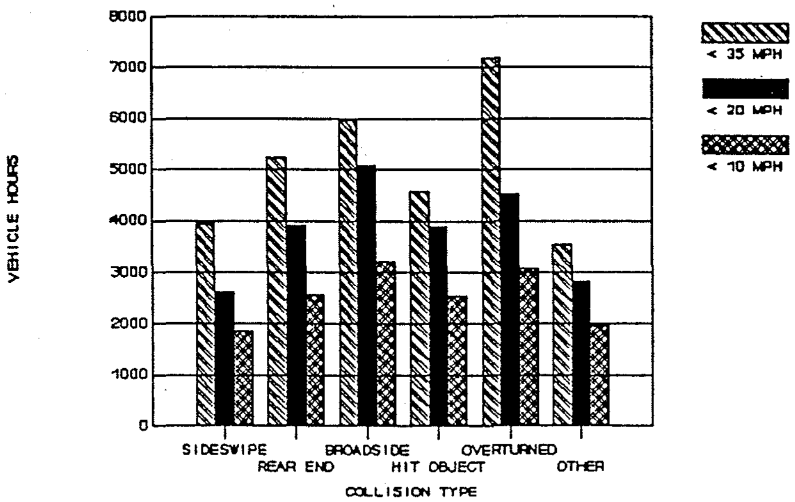

FIGURE 5-8
VEHICLE HOURS PER INCIDENT BY SPEED
BY COLLISION TYPE

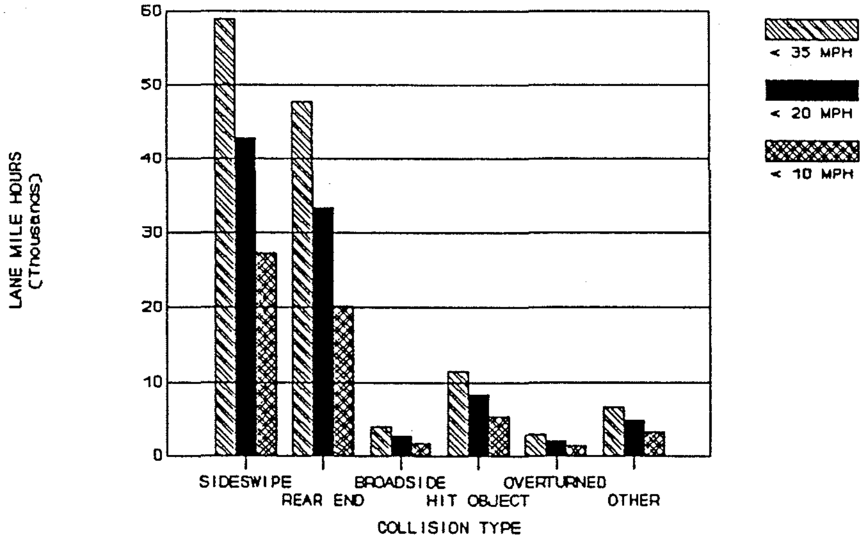

FIGURE 5-9
TOTAL LANE MILE HOURS PER YEAR BY SPEED
BY COLLISION TYPE

Figures 5-11 and 5-12 summarize the influences of primary collision factor on resultant delay. For "in-range" incidents, the resultant delay per incident was relatively invariant with respect to the primary collision factor, except for alcohol-related incidents. The relatively small value for this latter category may be due to the occurrence of most alcohol-related incidents during periods of very light traffic (e.g., late at night, or very early in the morning). Conversely, tailgating (which shows the greatest delay per incident for the "in-range" cases) was typically associated with heavy traffic conditions. Although the average delay per incident for most of the factors was similar, the frequency of these factors was not.

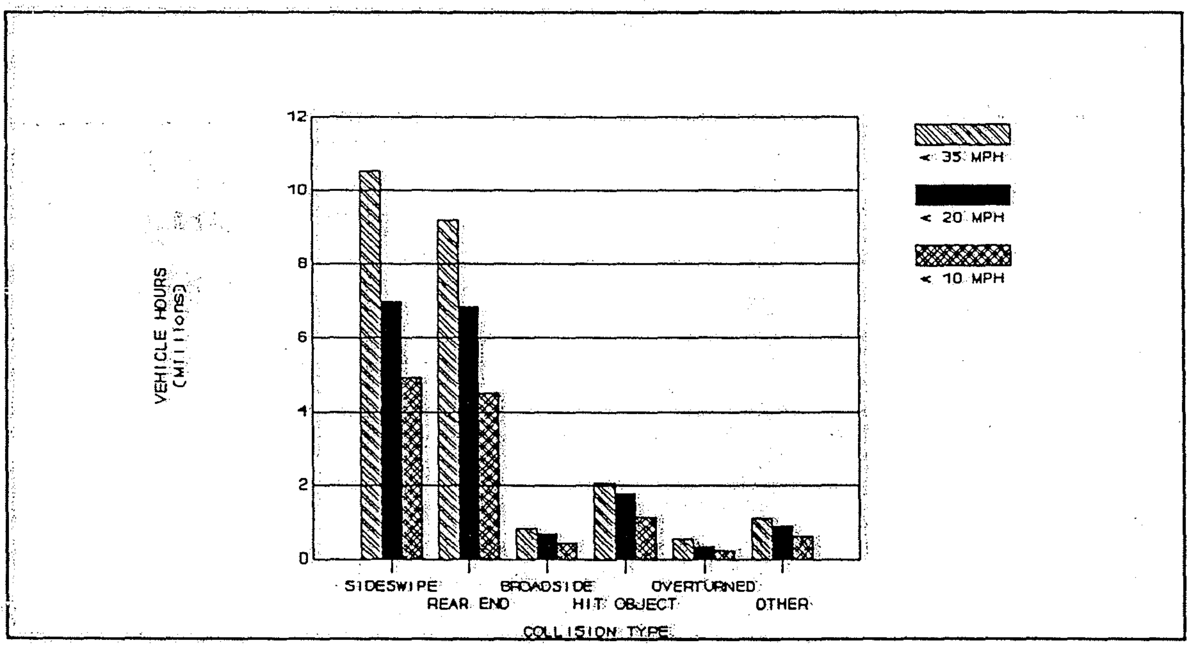

FIGURE 5-10
TOTAL VEHICLE HOURS PER YEAR BY SPEED
BY COLLISION TYPE

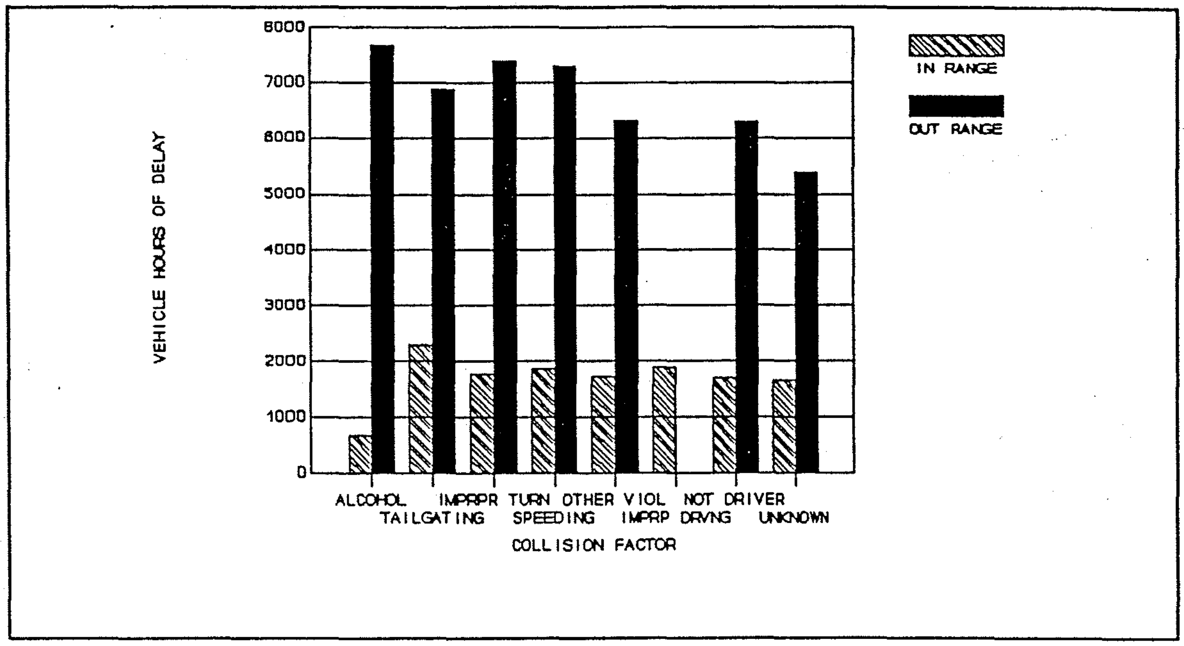

FIGURE 5-11
VEHICLE HOURS OF DELAY PER INCIDENT
BY PRIMARY COLLISION FACTOR

"Other" violations accounted for approximately 50 percent of total delay caused by truck-involved incidents, followed by speeding with 30 percent. While these two factors contributed the bulk of delay, it was not disproportional to their frequency in the population. The other incident factors were less frequent; combined, they accounted for approximately 20 percent of total added delay.

Figures 5-13 and 5-14 provide a summary of the influence of the number of involved vehicles on traffic delays resulting from truck-involved freeway collisions. The results showed a slight trend toward increasing delay associated with an incident as vehicle involvement increased (Figure 5-13). The relatively high frequency of collisions involving two vehicles (approximately 66 percent of the total number of collisions recorded) resulted in the greatest share of total delay in this category (Figure 5-14).

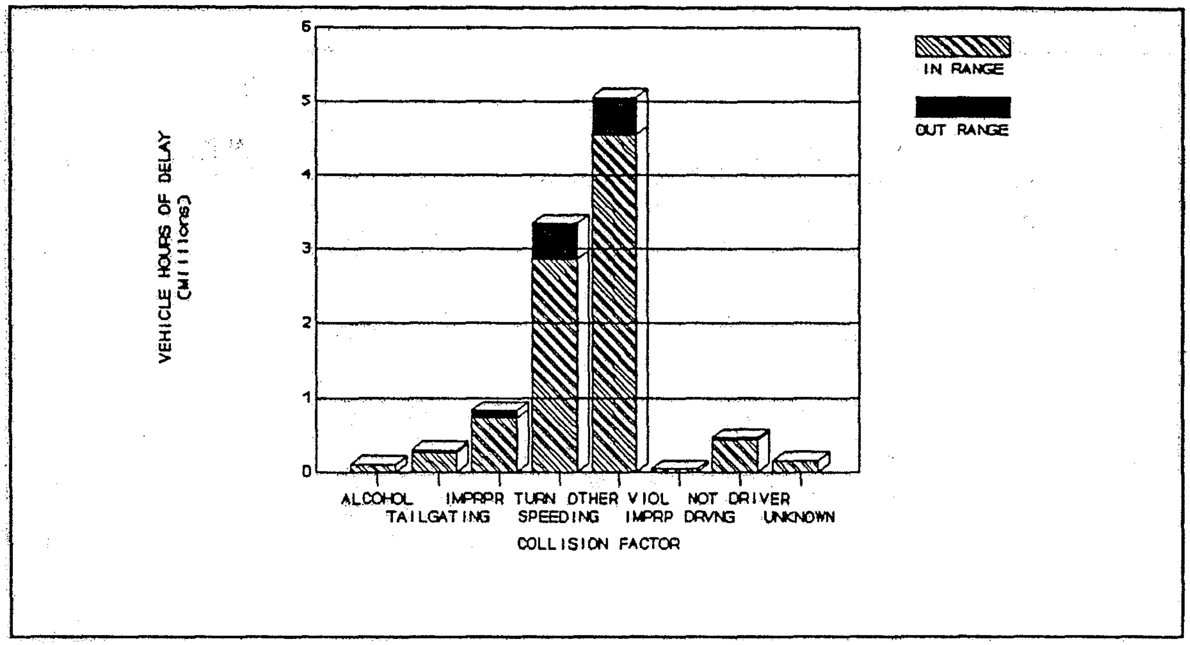

FIGURE 5-12
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY PRIMARY COLLISION FACTOR

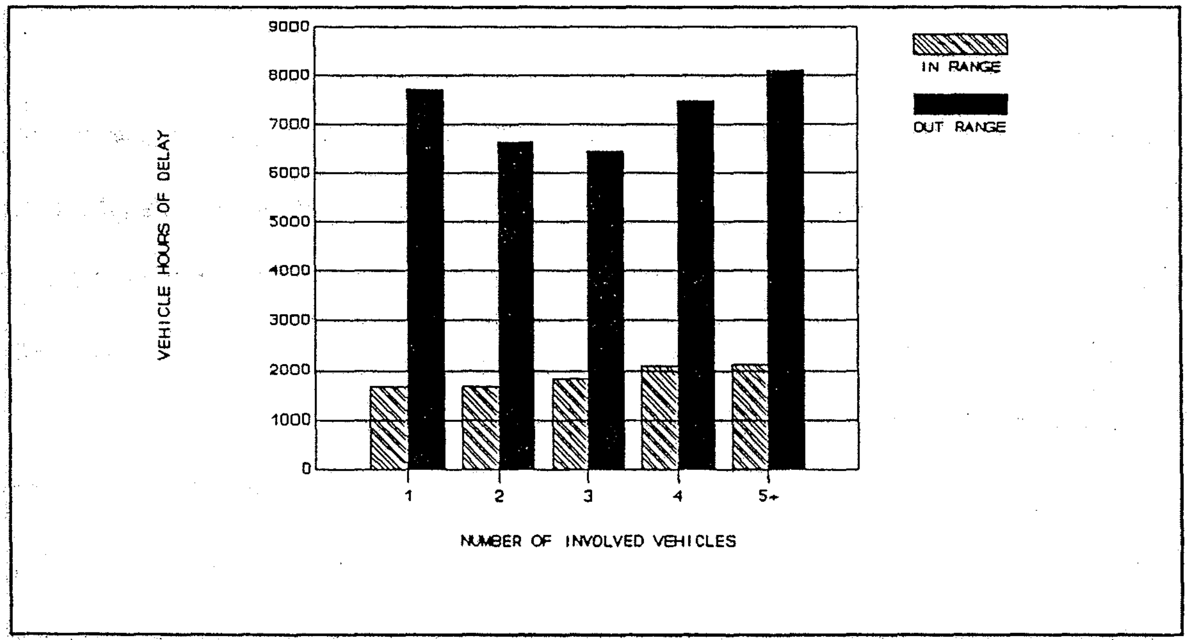

FIGURE 5-13
VEHICLE HOURS OF DELAY PER INCIDENT
BY NUMBER OF INVOLVED VEHICLES

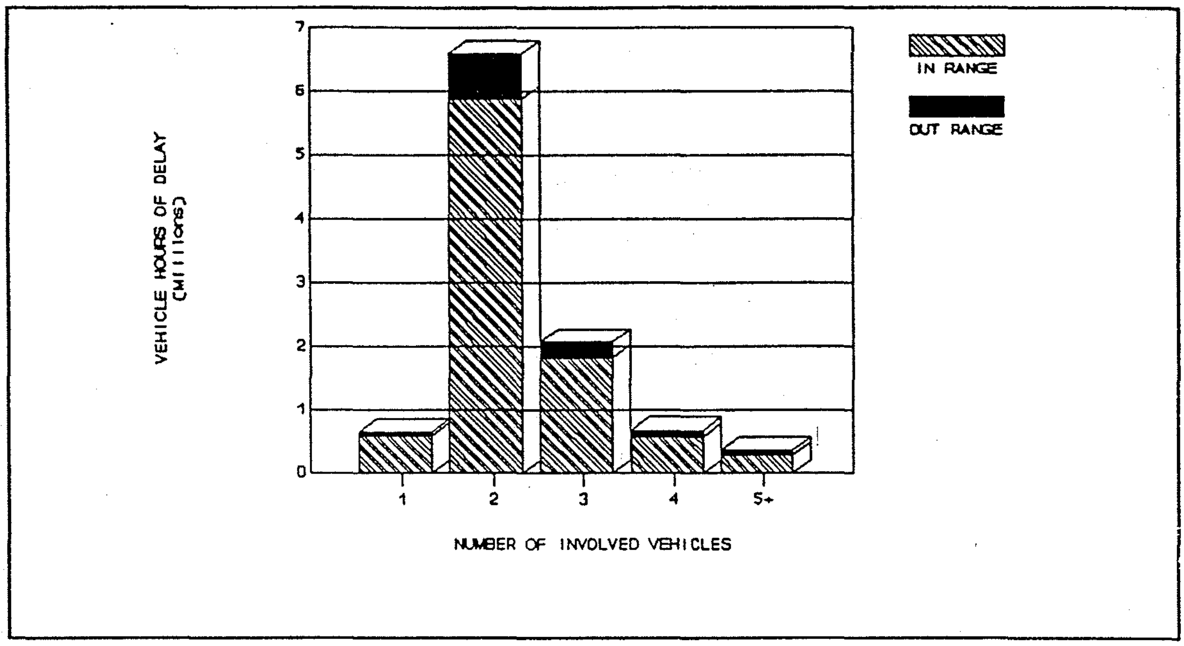

FIGURE 5-14
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY NUMBER OF INVOLVED VEHICLES

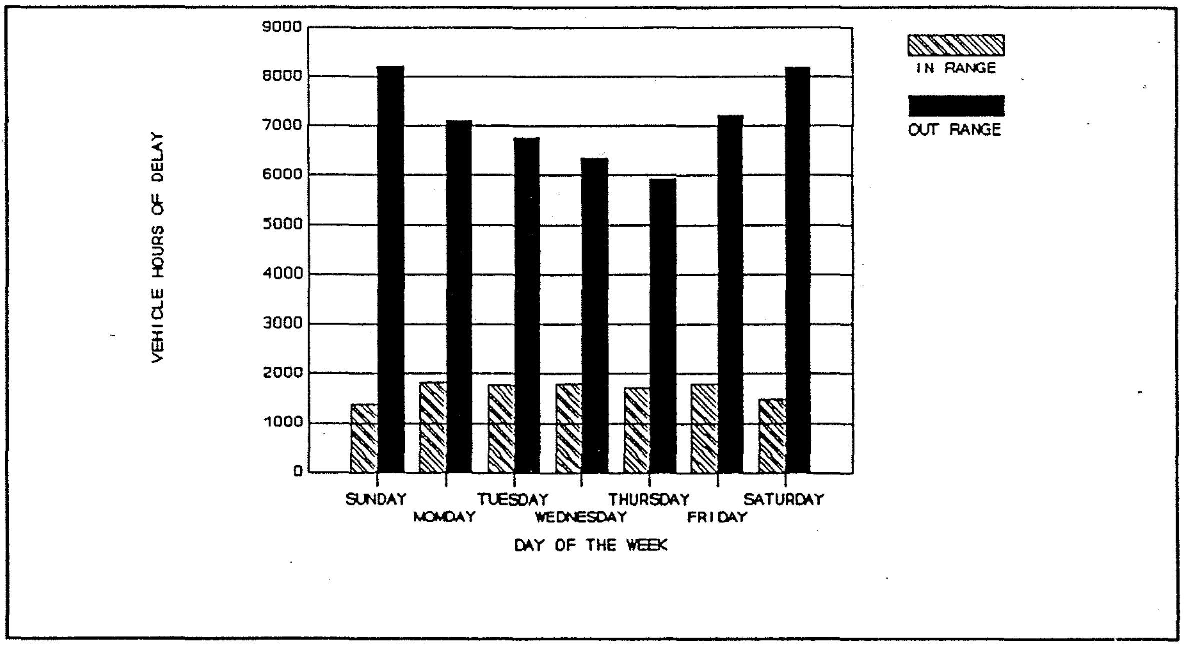

FIGURE 5-15
VEHICLE HOURS OF DELAY PER INCIDENT BY
DAY OF WEEK

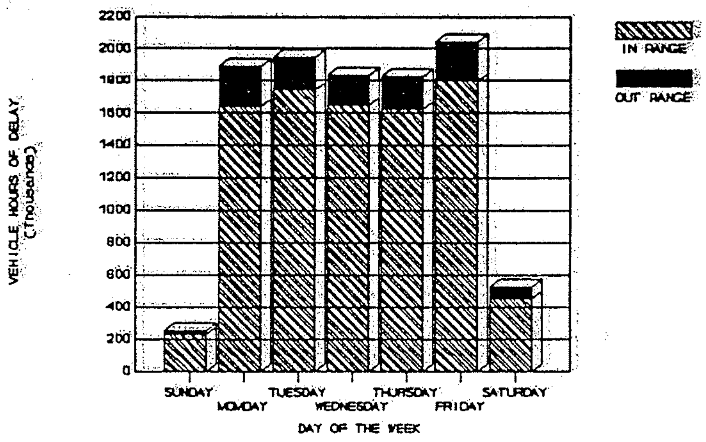

FIGURE 5-16
TOTAL VEHICLE HOURS OF DELAY PER YEAR BY DAY OF WEEK

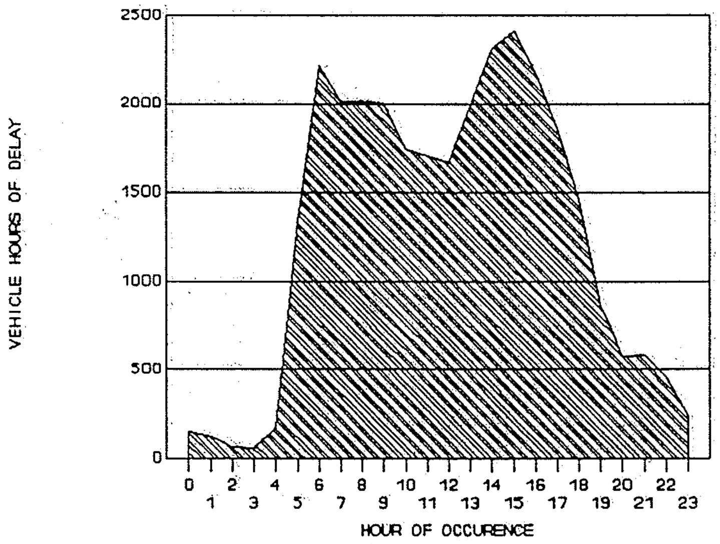

FIGURE 5-17
VEHICLE HOURS OF DELAY PER INCIDENT BY HOUR OF THE INCIDENT (IN-RANGE CASES)

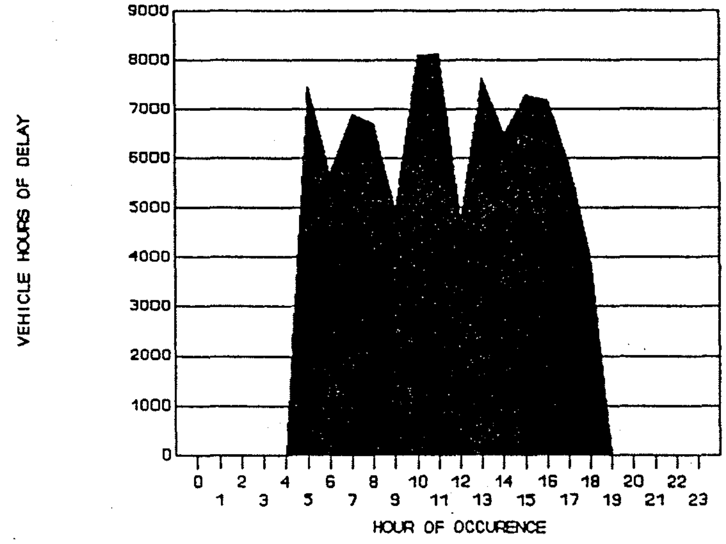

FIGURE 5-18
VEHICLE HOURS OF DELAY PER INCIDENT
BY HOUR OF THE INCIDENT
(OUT-OF-RANGE CASES)

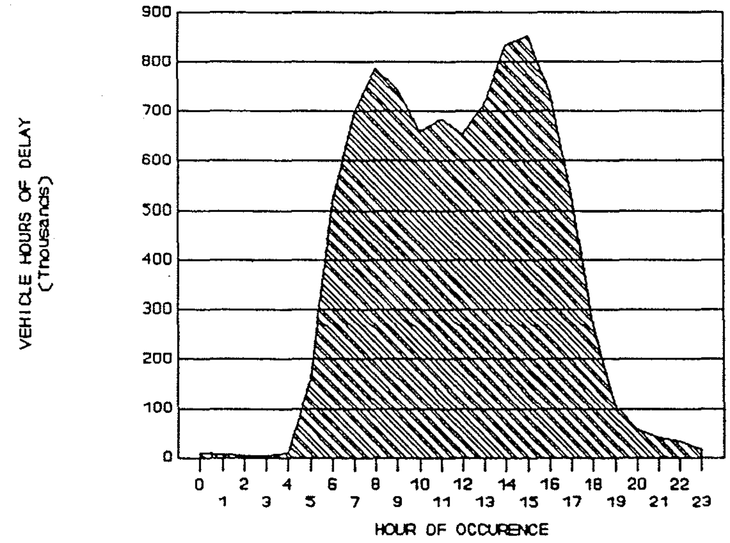

FIGURE 5-19
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY HOUR OF THE INCIDENT
(IN-RANGE CASES)

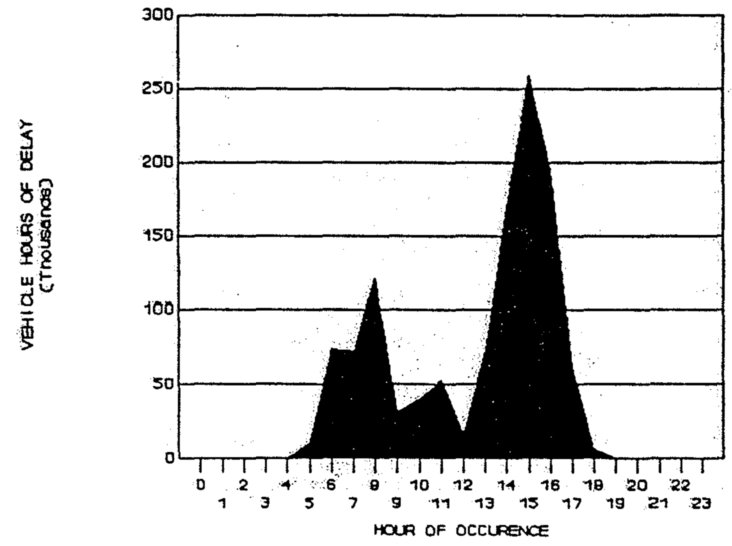

FIGURE 5-20
TOTAL VEHICLE HOURS OF DELAY PER INCIDENT
BY HOUR OF THE INCIDENT
(OUT-OF-RANGE CASES)

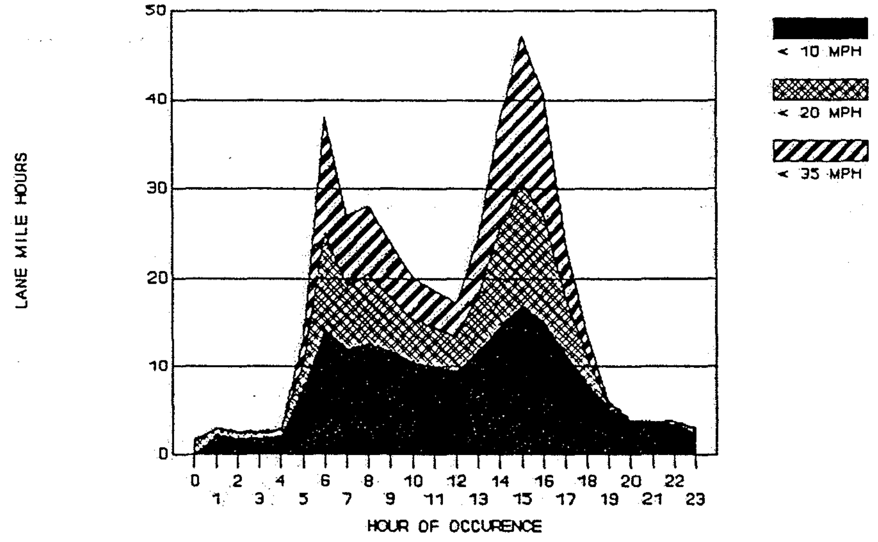

FIGURE 5-21
LANE MILE HOURS PER INCIDENT BY SPEED
BY HOUR
(IN-RANGE CASES)

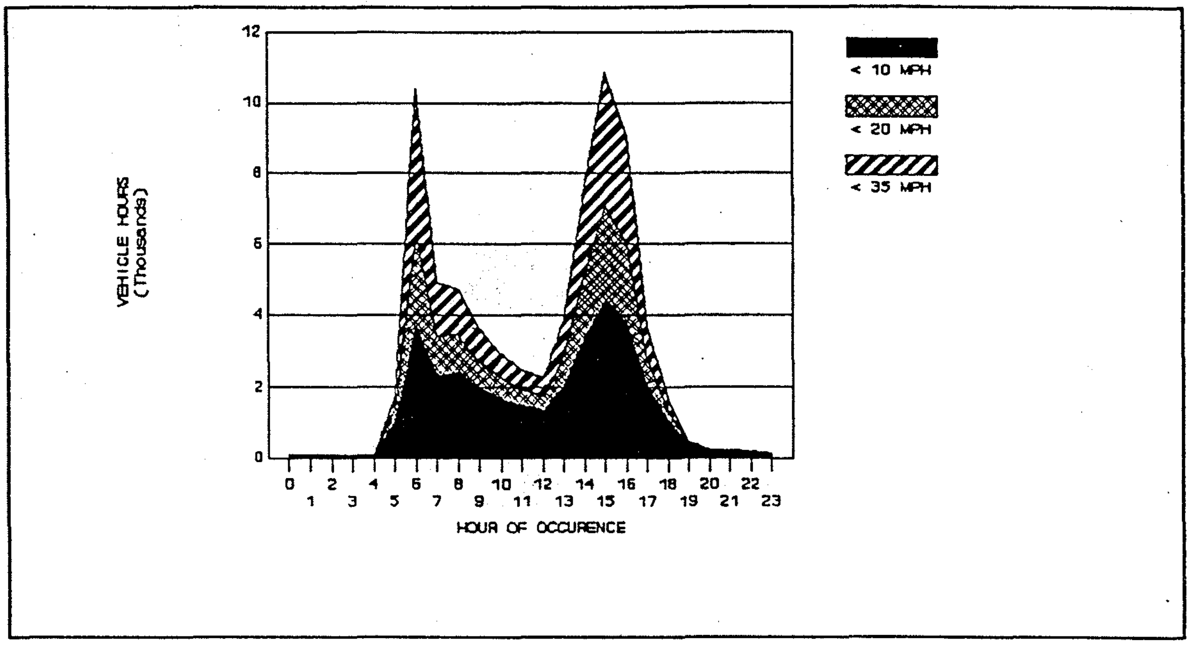

FIGURE 5-22
VEHICLE HOURS PER INCIDENT BY SPEED
BY HOUR

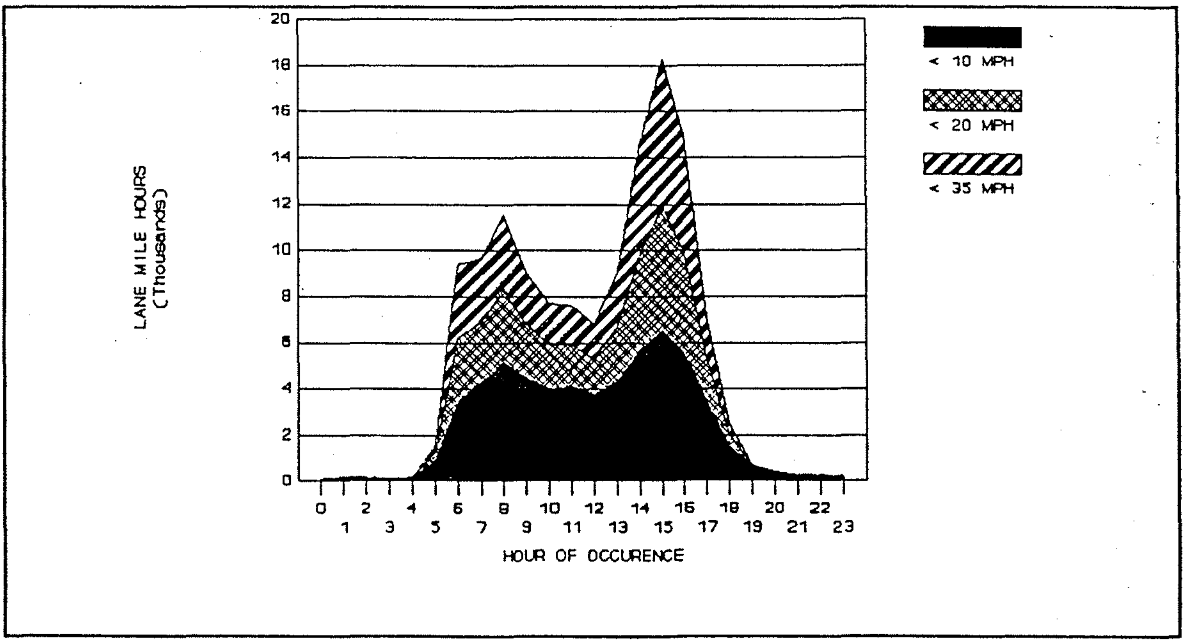

FIGURE 5-23
TOTAL LANE MILE HOURS PER YEAR BY SPEED
BY HOUR

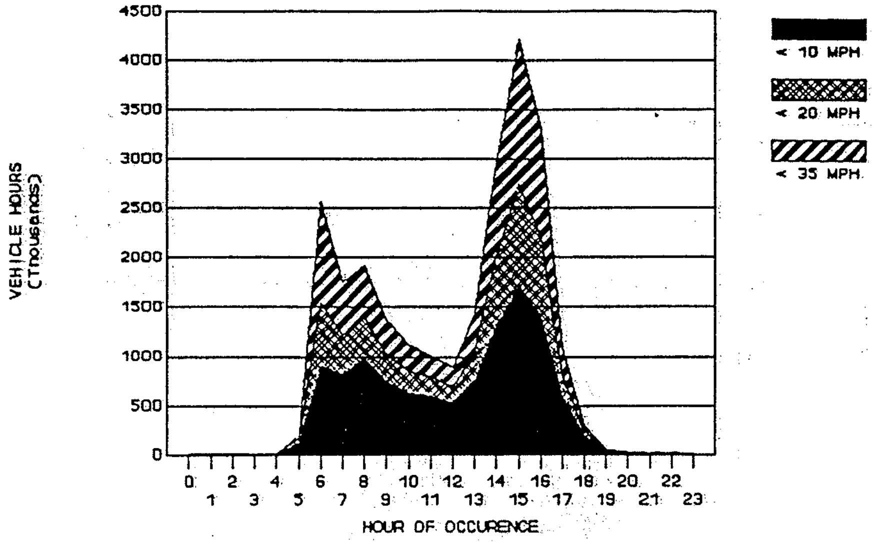

FIGURE 5-24
TOTAL VEHICLE HOURS PER YEAR BY SPEED
BY HOUR

Figure 5-15 shows the average vehicle hours of delay/incident by day of the week. Weekdays had slightly higher average delays than weekends which, in part, may be attributable to greater overall congestion (i.e., greater impedence for response vehicles). The variation of total delay estimates with the day of the week on which the incidents occurred was as expected (Figure 5-16). The results, in general, showed little variation within weekdays and smaller total delays on weekends, especially Sunday.

Also as expected, the time of day of the occurrence of an incident had a significant influence on resulting delay (Figures 5-17 through 5-24). The highest delays per incident were associated with the afternoon and early evening peak hours, followed in intensity by the morning peak periods (Figures 5-17, 5-18). An approximately uniform distribution of collisions throughout the period 6:00 a.m. through 4:00 p.m. resulted in a pattern of total delay that roughly paralleled the distribution of delay per incident (Figures 5-19, 5-20). The results indicated that incidents due to collisions occurring during the

3-hour period of 2:00 to 5:00 p.m. (which constituted 21 percent of the total collision incidents) accounted for approximately 30 percent of the total additional delay due to truck-involved freeway collisions. The morning peak period of 6:00 to 9:00 a.m. (which included 19 percent of the total collision incidents) accounted for approximately 22 percent of total delay. Thus, collisions during peak-period hours contributed approximately 52 percent of delay while involving only 40 percent of the incidents. This is most likely due to the relatively congested state of traffic existing during these periods. Figures 5-21 through 5-24 present similar results for delay measures based on speed indicators.

Finally, impacts of truck-involved collisions on delay varied considerably by freeway location. Incidents on the I-5, I-10, SR-22, SR-101, I-110, SR-55, SR-57, SR-91 and I-405 stood out as causing relatively severe delays (Figure 5-25.) A more detailed breakdown of the severity of these incidents by freeway route segment (Figure 5-26) revealed a relatively constant average delay (for in-range cases) over those segments contributing the highest levels of expected resultant delay from an incident. The major contribution to annual total vehicle hours of delay arose from collisions on five freeway routes: I-5, I-10, SR-91, SR-101 and I-405 (Figure 5-27), with collisions on I-5 responsible for the greatest share of the delay associated with these freeways. The breakdown of total delay by freeway segment (Figure 5-28) is striking in the relative contribution of freeway segment 5.2 to the total annual delay occurring on I-5; approximately 67 percent of the total annual estimated delay for I-5 occured in this segment. In terms of the total picture of delay, truck-involved collisions on this segment contributed 15 percent of the total annual additional delay, while comprising less than 10 percent of the total collisions recorded.

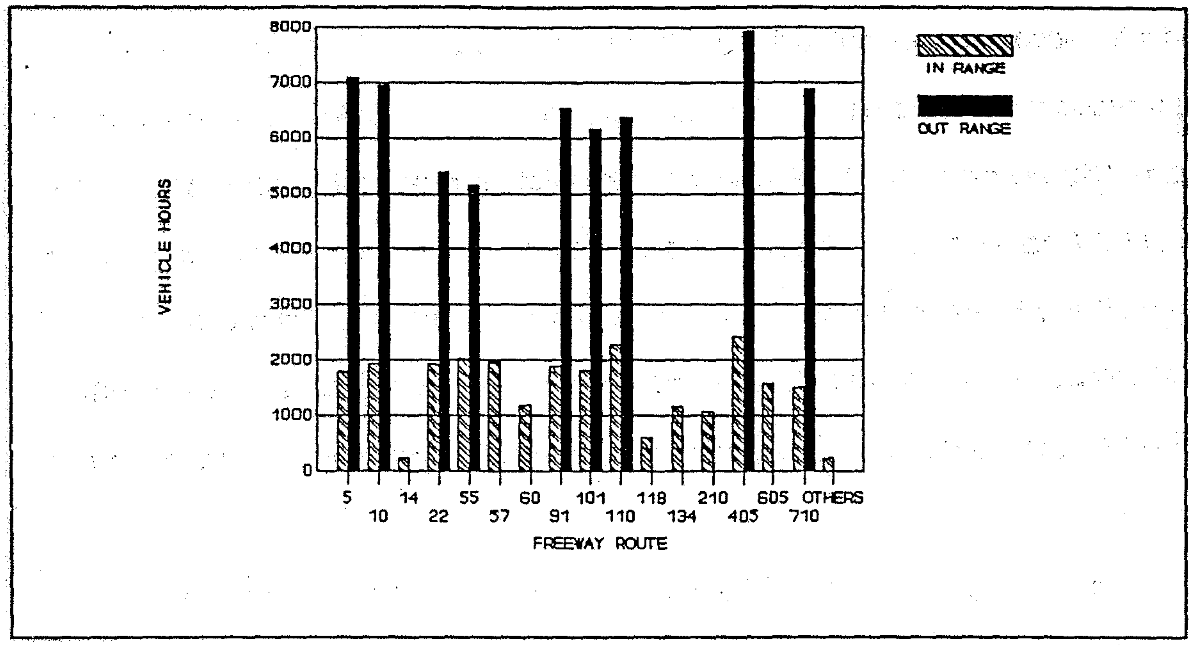

FIGURE 5-25
VEHICLE HOURS OF DELAY PER INCIDENT BY FREEWAY ROUTE

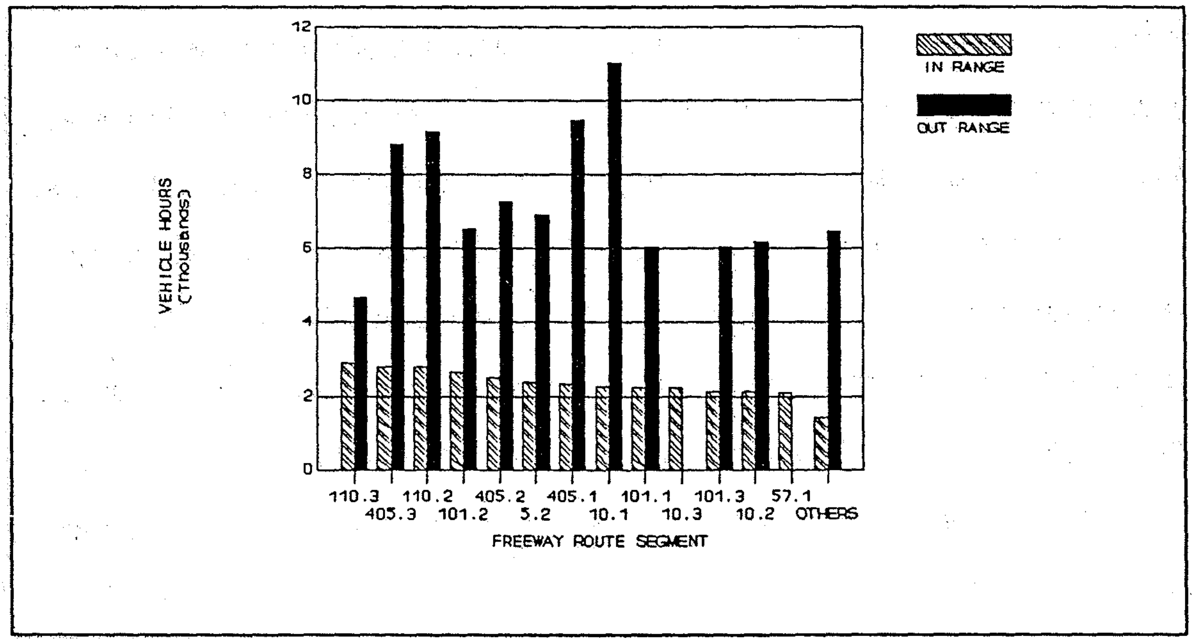

FIGURE 5-26
VEHICLE HOURS OF DELAY PER INCIDENT BY FREEWAY ROUTE SEGMENT

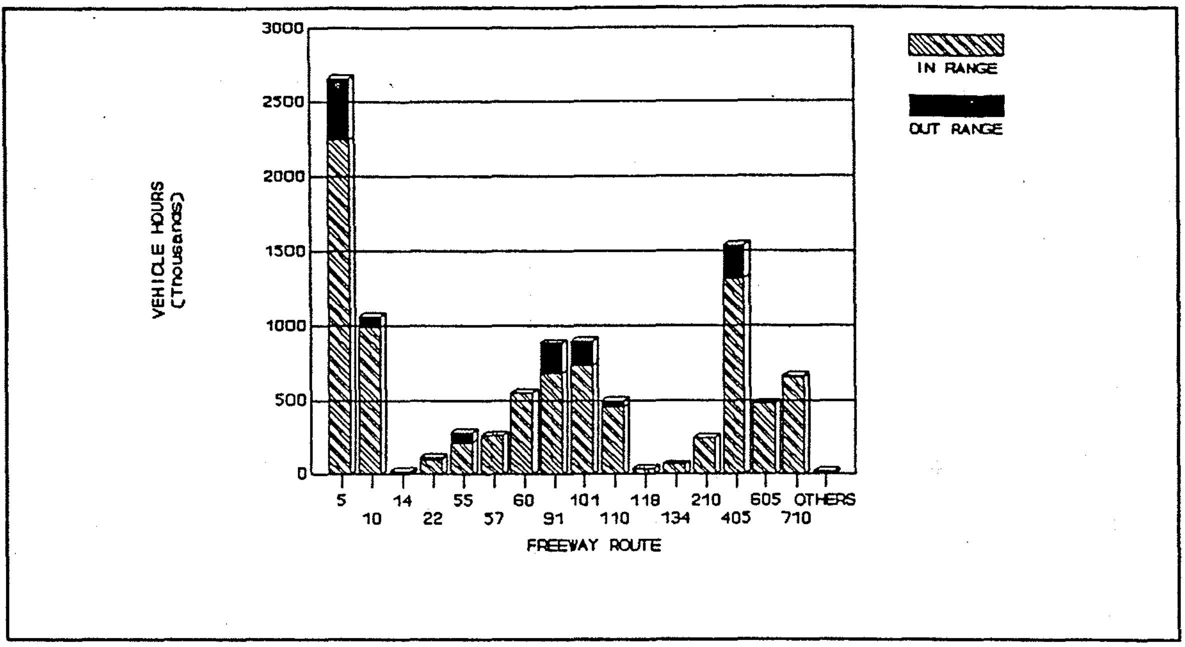

FIGURE 5-27
TOTAL VEHICLE HOURS OF DELAY PER YEAR BY FREEWAY ROUTE

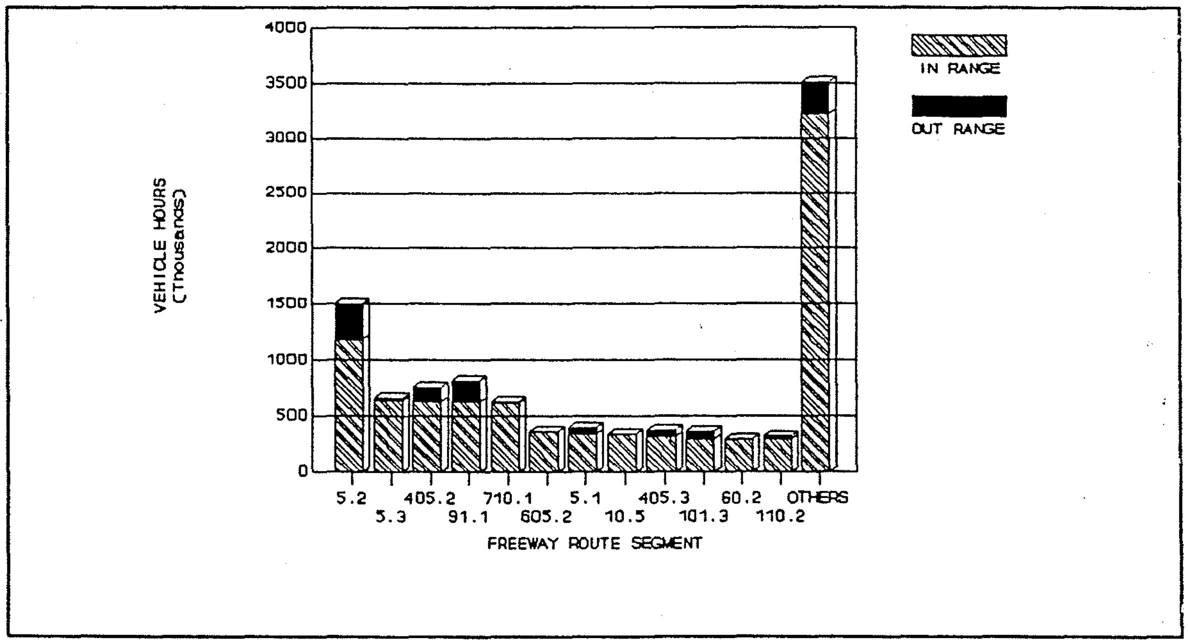

FIGURE 5-28
TOTAL VEHICLE HOURS OF DELAY PER YEAR BY FREEWAY ROUTE SEGMENT

CONCLUSION

This chapter has presented estimates of annual additional delay associated with truck collisions on one of the nation's busiest freeway systems. The procedures used in this estimation point out both the inherent difficulties and uncertainties of such estimations. Although detailed accident records are generally maintained and accurate, correspondingly detailed data relative to ambient traffic conditions at the time and place of the collisions are generally unavailable. A significant degree of uncertainty introduced in the estimation process was exacerbated by inherent limitations of the models used. As a result, the estimates of delay presented in this chapter should be viewed as *reasonable* bounds on the actual values.

The question naturally arises as to whether or not truck collisions are responsible for a disproportionate share of nonrecurrent delay. This question cannot be answered from the results of this study, since corresponding delay estimates for car-only collisions were not investigated; nor have the results been normalized by such measures as vehicle miles traveled. However, few would argue that an additional delay of over 10 million vehicle hours per year is insignificant.

CHAPTER SIX

ECONOMIC COSTS

Truck-related accidents can cause travel delay, additional vehicle operating costs, vehicle damage, as well as personal injuries and loss of life. This final chapter estimates the economic impacts of these factors on society.

Delay costs are defined as the monetary value of time lost to occupants of both personal and commercial vehicles due to travel delays imposed by truck-related accidents. The delay values used are the delays calculated in the previous chapter. Additional vehicle operating costs are costs attributable to congested flow conditions caused by the accidents. These additional costs are almost exclusively a function of increased fuel consumption caused by speed changes. Vehicle damage costs are the costs incurred to repair the vehicle after the accident (or its salvage value). Injury and fatality costs include costs for medical treatment and lost wages due to the injury or fatality. These latter three aspects are grouped together as accident costs.

DELAY COSTS

To convert vehicle delay into an economic cost, a value of time must be determined. The values of time developed for this study were based upon the approach used in the American Association of State Highway and Transportation Officials' (AASHTO) *Manual on User Benefit Analysis of Highway and Bus-Transit Improvements* (American Association of State Highway and Transportation Officials, 1978). The approach used by AASHTO is to assign a different value of time to Low, Medium, and High time savings, based upon the premise that small changes in travel time have little utility (hence little economic value), but that as the amount of time saved (or lost) increases, the utility -- and the economic value -- of the time change becomes significant. THe AASHTO manual defines Low time savings as less than 5 minutes, Medium time savings as 5 to 15 minutes, and High time savings as more than 15 minutes. In the present study, the 1975 time values cited in the AASHTO manual were adjusted to 1987 values by using the increase in the annual compensation per full-time equivalent worker over this period. [NOTE: All economic analyses conducted are in 1987 dollars]. This resulted in a Low time value of $0.46 per traveler hour, a Medium time value of $3.90 per traveler hour, and a High value of $8.47 per traveler hour. The automobile volume affected in each accident was multiplied by an average automobile occupancy of 1.13 (Southern California Association of Governments, 1985) to correspond to the values of time per traveler hour for various levels of time changes. The commuter value of 1.13 was used as the average auto occupancy rate (AOR) because data were unavailable for an overall AOR. Thus, the values for delay costs probably underestimate the true delay costs by a small fraction. AASHTO cited a value of about $7.50 per hour for time savings for trucks for 1975; this was updated to $16.26 per truck hour for 1987 conditions.

VEHICLE OPERATING COSTS

The relevant increases in vehicle operating costs relate to speed change cycle costs as defined in the AASHTO manual. These costs are essentially a function of automobile/truck running costs and, in particular, fuel consumption costs. The 1975 values for the cost of speed cycle changes cited in the manual were adjusted to 1987 values by applying the increase in the transportation Consumer Price Index (CPI) for personal transportation for this period.

ACCIDENT COSTS

Cost data for accidents involving trucks are relatively sparse. A study of the costs of motor vehicle accidents in Texas (Rollins and McFarland, 1985) provides direct costs for urban truck accidents, categorized by accident type and severity: property damage only (PDO) accidents, injury accidents, and fatal accidents in 1983 dollars. This appears to be the most comprehensive source of information available, even though it is now somewhat dated, and it in turn is based on data that in some cases are quite old. Rather than using the Rollins and McFarland values, published Caltrans values for these three categories of accident costs were used. The Caltrans accident cost values are not disaggregated by truck and auto accidents, and without additional data on the differential between auto and truck accident costs, it was assumed they were equal. [In reality, truck accident costs are probably higher than auto accident costs, thus giving us a lower bound on accident costs]. The Caltrans accident costs were updated to 1987 dollars.

DETERMINING THE COST OF DELAYS

To develop a relationship between a particular level of average vehicular delay and the value of that delay, 39 INTRAS simulated accidents were analyzed. For each of these simulated accidents, vehicles were classified during each 15-minute simulation time period according to whether they experienced 25, 50, 75 or 100 percent of the delay per vehicle associated with traveling the entire length of the section of roadway congested by the accident. This apportionment was based on a simple formula derived from empirical analysis of several accidents. The formula itself depended on the overall level of vehicular delay for the time period, and the levels used were a function of the three value of time categories. Table 6-1 shows how the formula was established.

TABLE 6-1

FACTORS USED TO ADJUST DELAY EXPERIENCED BY VEHICLES IN SECTION

	Percent of Bottleneck Volume Experiencing Different Levels of Total Section Delay			
Average Delay Per Vehicle	100% of Delay	75% of Delay	50% of Delay	25% of Delay
Less than 5 minutes	100%	0	0	0
5 - 15 minutes	85%	0	30%	0
15 - 30 minutes	70%	20%	20%	20%
More than 30 minutes	50%	26.7%	40%	40%

For an average delay of 4 minutes, the formula specifies that all vehicles passing out of the bottleneck section experience the entire 4 minutes of delay. In contrast, when the level of delay is 18 minutes, only 70 percent of the volume passing through the bottleneck is assigned 18 minutes of delay, while 20 percent of the volume passing through the bottleneck is assigned 13.5 minutes of delay, another 20 percent is assigned

9.0 minutes of delay, and 20 percent more is assigned only 4.5 minutes of delay. These latter vehicles would be those which either exited from the freeway in the congested section before reaching the bottleneck or entered the freeway somewhere along the congested section and did not have to traverse its entire length. Note that for all cases where the delay in traversing the entire congested section exceeds 5 minutes, the total affected volume is more than 100 percent of the bottleneck volume. It is necessary to factor up the volumes which experience less than the full delay in order to conserve the INTRAS-generated level of total vehicle delay for the time period. [Because the delay per vehicle is reduced by 50 percent, for example, it is necessary to double the number of affected vehicles to conserve the sum of all vehicle delays.]

Because the volume of trucks by time of day on any particular freeway was not known, the overall truck percentage on the Los Angeles area freeway system was used in determining the commercial vehicle delay costs. In 1985, the overall truck percentage was 8.2 percent of ADT; this value was assumed to apply for 1987-88 as well. Because the economic cost of individual truck delay is not categorized by level of the delay, the value of $16.26 per hour was applied to the total truck hours of delay associated with each accident.

To compute the cost of additional delays, the following procedure was followed. For each of the 10,805 TASAS accidents, the affected vehicles were categorized by the percent of delay they experienced using Table 6-1. These categories were then split between automobiles and trucks, using the Caltrans value of 8.2% trucks, and multiplying the automobile volume by the 1.13 AOR to obtain traveler hours. The value of the delay was then applied. For trucks, this was $16.26 for all categories. For automobiles, the values were either the Low value of $0.46, the Medium value of $3.90, or the High value of $8.47, depending on the time value (i.e. less than 5 minutes, between 5 and 15 minutes, or greater than 15 minutes) for the percent of delay experienced. For example, if an accident had an average delay of 18 minutes per vehicle, the 100 percent of delay category (18 minutes) would be assessed at the High time value, the 75 percent of delay category (13.5 minutes) would be assessed at the Medium time value, the 50 percent of delay category (9.0 minutes) would be assessed at the Medium time value, and the 25 percent of delay category (4.5 minutes) would be assessed at the Low time value.

Applying the above procedure to each of the 10,805 accidents resulted in an average annual delay cost of $91.9 million dollars (Table 6-2). This corresponds to a value of $8.90 dollars per vehicle hour of delay caused by a truck-related accident.

TABLE 6-2

DELAY COSTS FOR TRUCK-RELATED ACCIDENTS
FOR 1987-88

Average Delay	Number of Accidents	Mean Cost per Accident	Total Cost
Less than 5 min.	69	$48.97	$3.38 thousand
5 to 15 min.	4778	$3136.50	$15.0 million
15 to 30 min.	4191	$16,921.92	$70.9 million
Greater than 30 min.	1767	$55,349.81	$97.8 million
		Total Delay Costs 1987-88	$183.7 million

Delay cost/year = $91.9 million dollars/year

Delay Cost/accident = $17,002 dollars/accident

DETERMINING INCREASED VEHICLE OPERATING COSTS

Increased vehicle operating costs due to delay are essentially a function of major speed changes which, in turn, result in increased fuel consumption. The AASHTO manual provides estimates of the costs of speed changes per 1,000 vehicle cycles by automobile, single unit trucks, and combination unit trucks in 1975 dollars. These values were updated to 1987 values using the change in the transportation Consumer Price Index (CPI). Costs for truck speed changes were computed using a truck composition of 40 percent single-unit trucks and 60 percent combination unit-trucks. These percentages were derived from Caltrans data for the Los Angeles County highway system. It was assumed that every accident caused a speed change from 60 MPH to 25 MPH. Any accident with more than 2 minutes average delay per vehicle was assumed to cause additional speed changes, namely one speed change from 35 MPH to 10 MPH for every 3 minutes of additional delay per vehicle. [These latter assumptions are justified only in that they appear to be grossly consistent with actual traffic flow behavior; data to support any assumption in this regard apparently do not exist.] The values obtained for the speed change costs are shown in Table 6-3.

TABLE 6-3

SPEED CHANGE COSTS PER 1,000 VEHICLE CYCLES

Vehicle type	Change from 60 to 25 MPH	Change from 35 to 10 MPH
Passenger Car	$30.12	$19.46
Trucks	$175.92	$121.09

Applying this procedure to the TASAS accident sample yielded increased operating (e.g., speed reduction) costs of $5.98 million per year. This is an average operating cost increase of $1,106 per accident.

DETERMINING ACCIDENT COSTS

Caltrans' accident cost data indicate a cost per urban freeway accident of $2,500 for property damage only (PDO) accidents, $10,300 for injury accidents, and $534,000 for fatal accidents. [The latter value is subject to the greatest amount of uncertainty, as it includes the value of lost future earnings of individuals killed in the accident. The question of the appropriate value of life to use in accident studies is always controversial. The value use by Caltrans is no exception, although it is reasonably consistent with values of life determined from other studies.] Updating these values to 1987 dollars yields $2,600 for PDO, $10,900 for injury, and $564,000 for fatal accidents.

Of the 10,805 truck-involved accidents which occurred on the Los Angeles area freeway system in 1987 and 1988, 69.4 percent were PDO accidents, 29.6 percent were injury accidents, and only 1.0 percent were fatal accidents. Multiplying the number of accidents in each category by its respective cost results in accident costs of $56.7 million dollars per year. These costs are shown in table 6-4. Of this amount, about 50 percent is attributable to fatal accidents which represent 1 percent of total truck accidents.

TABLE 6-4

TRUCK-RELATED ACCIDENT COSTS
FOR 1987 AND 1988

ACCIDENT TYPE	NUMBER	COST PER ACCIDENT	COSTS (MILLIONS)
PDO	7504	$2,639.41	$19.8
INJURY	3195	$10,874.35	$33.8
FATAL	106	$563,776.91	$59.8
		TOTAL COSTS FOR 1987-88	$113.4

COST/YEAR = $56.7 MILLION DOLLARS
COST/ACCIDENT= $10,500 DOLLARS

TOTAL ECONOMIC COSTS OF TRUCK-RELATED ACCIDENTS

The total annual cost of truck-related accidents is the sum of additional delay costs, additional vehicle operating costs, and accident costs. This is estimated to be $154.6 million dollars per year (1987 dollars). This corresponds to $28,600 dollars per accident. Table 6-5 shows the breakdown of this estimate. Additional delay imposed on motorists is the largest contributing factor, accounting for 59.4 percent of total delay costs. Accident costs account for 36.7 percent, and additional vehicle operating costs account for only 3.9 percent.

TABLE 6-5

TOTAL ANNUAL ECONOMIC COSTS OF TRUCK-RELATED ACCIDENTS
($ IN MILLIONS)

DELAY COSTS	$91.9
INCREASED VEHICLE OPERATING COSTS	$ 6.0
ACCIDENT COSTS	$56.7
TOTAL ANNUAL COSTS	$154.6

It is emphasized that these estimates are based on a number of unsubstantiated assumptions. However, it is believed that they represent a reasonable conjecture based on the data available.

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APPENDIX A

LOG-LINEAR MODELS

Log-linear models were used in this study to identify structural relationships between two or more categorical variables. In the following, the relationship between freeway route segment and collision type is used as an example to illustrate the modeling approach. The objective in this example is to determine whether or not there are differences among the types of collision that occur on specific route segments. Given that a certain number of truck-involved accidents occur on a specific segment, and that there is a known distribution among types of collisions for all segments, is there a significant interaction between route segment and collision type that indicates that the distribution of collision types might be different for the segment in question? The approach to this question involves estimating a saturated log-linear model for the contingency table represented by the cross-tabulation of route segment by collision type. In this case, it is a 38 x 6 contingency table, because there are 38 freeway segments and 6 collision types.

A test of independence between route and accident type involves whether or not the entries in the contingency table can be considered the result of a random process that depends only on the expected number of accidents for each route (for all types) and the expected number of accidents by collision type (for all routes). Defining n_{ij} = observed number of accidents of type j on route i, the hypothesis of independence between route and type involves comparison of each n_{ij} with the randomly expected numbers, m_{ij}, given by the product of the sample size times the probability that an observation falls into the i^{th} row times the probability that the observation falls into the j^{th} column:

$$m_{ij} = N(n_{i.}/N)\ (n_{.j}/N) = n_{i.}n_{.j}/N \tag{1}$$

where

$n_{i.}$ = total accidents of all types on route i,

$n_{.j}$ = total accidents of type j on all routes, and

N = total accidents (size of the sample)

The most common measure of association between n_{ij} and m_{ij} is given by:

$$\chi^2 = \sum_{ij} (n_{ij} - m_{ij})^2 / m_{ij} \tag{2}$$

which has the known chi-square distribution for hypothesis testing under the usual assumption of multinomial distributions and sufficient expected cell frequencies.

Taking the natural logarithm of both sides of equation (1),

$$\ln m_{ij} = \ln N + \ln (n_{i.}/N) + \ln(n_{.j}/N) \tag{3}$$

the test of independence for the (i,j) cell of the contingency table translates into a test of whether or not there is a statistically significant β_{ij} term in the log-linear equation

$$\ln n_{ij} = \alpha + \beta_i + \beta_j + \beta_{ij} \tag{4}$$

where α accounts for the sample size (grand mean), β_i accounts for the route effect, β_j accounts for the accident type effect, and β_{ij} represents the interaction between route i and type j.

It is logical that the probability process underlying the accident counts is Poisson. The usual assumption for stochastic processes of Equation (4) is then assumed to include a Poisson error term and represents a saturated log-linear model (Birch, 1963; Plackett, 1962). [Extensive overviews of general families of such models are provided in Bishop, Fienberg, & Holland, 1975; Goodman, 1972, 1978; Haberman, 1974, 1978; McCullagh & Nelder, 1984; Plackett, 1974.]

Estimation of the parameters of Equation 4 and their error terms is effectively accomplished using maximum likelihood methods (Bock & Yates, 1973; Haberman, 1973a; Nelder & Wedderburn, 1972). T-statistics, given by the ratios of the β_{ij} parameter estimates to the standard errors of the estimates, are used to determine which of the combinations of route (i) and accident type (j) have interaction terms that are significantly different from zero under the assumption of Poisson distributions.

The log-likelihood ratio statistic, given by

$$L^2 = 2 \sum_{ij} n_{ij} \log (n_{ij} / m_{ij}) \qquad (5)$$

has a distribution that is asymptotically chi-square (Cochran, 1954; Haberman, 1978) and can be used to test the hypothesis that the structure of the contingency table can be represented by a log-linear model with some coefficients set to zero.

A direct measure of the degree to which any route-accident type combination (in general, any cell i,j in a contingency table) varies from its expected value is given by the standardized chi-square residual for the cell:

$$r_{ij} = [n_{ij} - (n_{i.}n_{.j}/N)] / \sigma_{ij} \qquad (6)$$

where σ_{ij} is the standard error for the cell, given by

$$\sigma_{ij} = (n_{i.}\, n_{.j} / N)^{1/2} \qquad (7)$$

This residual is distributed as a standard normal variate under the probability assumptions and sufficient cell frequencies (Haberman, 1973b). The residuals are employed in the present analyses as indices of variation from expected values. They are listed for variable combinations (or interaction terms) that have significant coefficients in the log-linear models. They are not residuals associated with the fits of the log-linear models, which are exact because there are as many parameters as there are cells in the contingency tables ("saturated" models). The standardized residuals merely are one measure of the degree of variance between actual counts and counts expected under the assumption of independence between the variables.

The log-linear models for this example, as well as for the remaining associations tested in this report, were implemented using the GLIM (Generalized Linear Interactive Modeling) program (Baker & Nelder, 1978; McCullagh & Nelder, 1983; Nelder & Wedderburn, 1972). Log-linear models are also available in most commonly used statistical analysis packages such as SAS, SPSS-X, and BMDP.

APPENDIX B

RESULTS OF KOLMOGOROV-SMIRNOV STATISTICAL TESTS

In Chapter Three, truck-involved incident duration distributions were determined to be log-normal in shape for all categories and sub-categories of incident types. 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 shown in Table B-1.

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 B-1 are far from the critical values, and the evidence on the extent of the bias (Massey, 1951) indicates that the test conclusions are not affected.

TABLE B-1

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

INCIDENT TYPE: MAINLINE 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

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 shown in Table B-2: 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.

In Figure B-1, the empirical cumulative distribution functions for each of the ten sub-categories of mainline accidents are compared against theoretical log-normal cumulative distribution functions. 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 shown in Table B-3.

The log-normal probability density functions for the four sub-categories of mainline rear-end and sideswipe collisions are graphed together for comparison purposes in Figure B-2. 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.

TABLE B-2

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

INCIDENT TYPE: MAINLINE 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

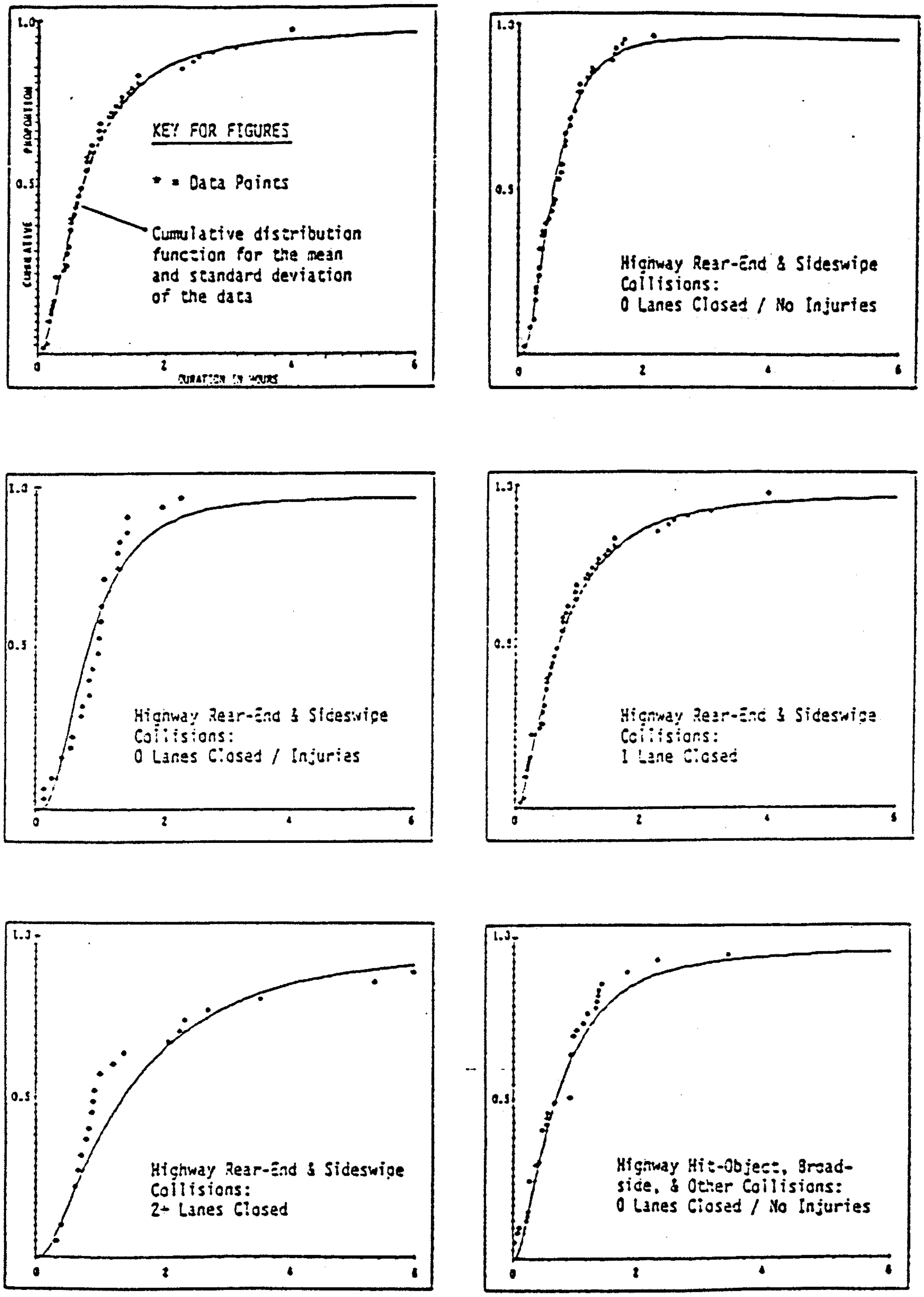

FIGURE B-1

FITTED CUMULATIVE DISTRIBUTION FUNCTIONS OF DURATION--
MAINLINE ACCIDENTS

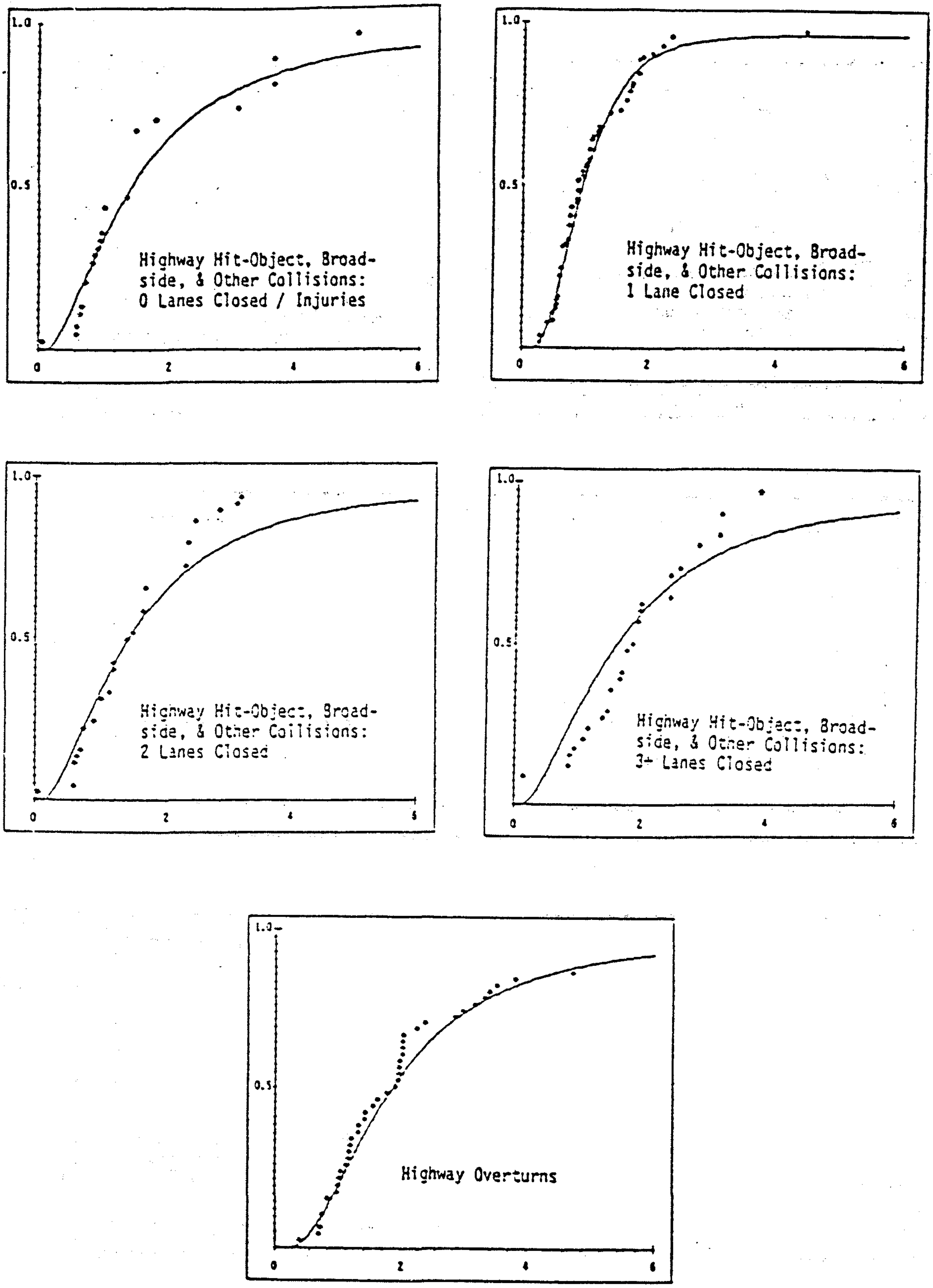

FIGURE B-1 (continued)

TABLE B-3

LOG-NORMAL DISTRIBUTIONS OF INCIDENT DURATION FOR MAINLINE ACCIDENTS

INCIDENT TYPE: RAMP ACCIDENTS		PARAMETERS OF LOG-NORMAL DURATION DISTRIBUTION	
CATEGORY	SUB-CATEGORY	MEAN	STD. DEV.
Rear-end, & Sideswipe Collision	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	-.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	-.41	0.88
Overturns	(All)	0.60	0.70

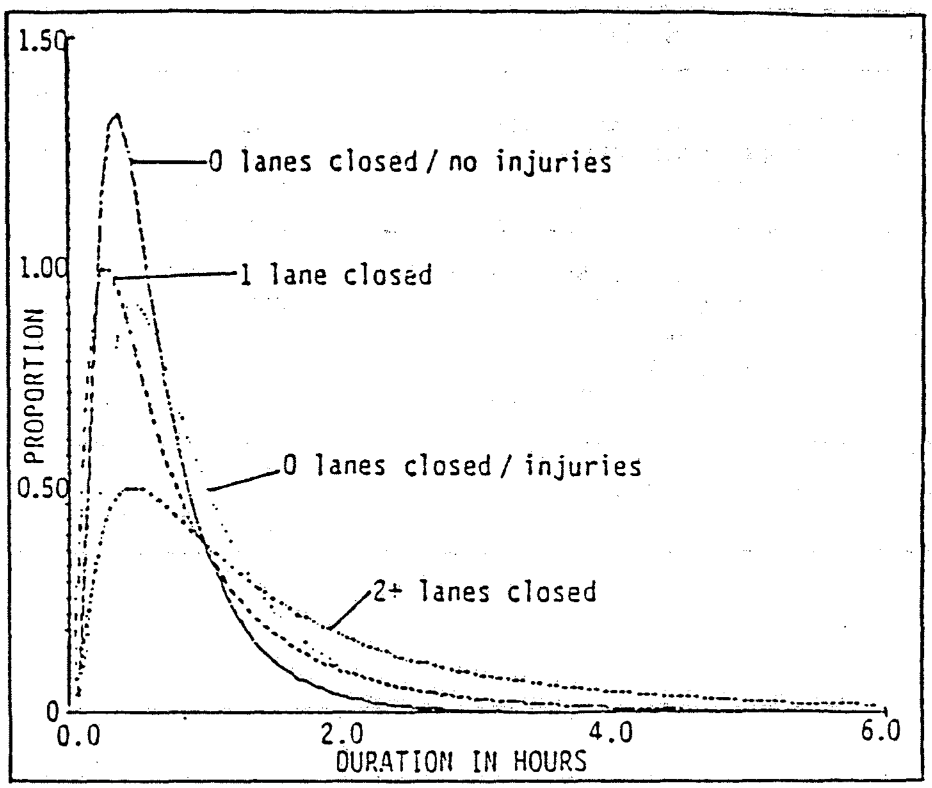

FIGURE B-2

PROBABILITY DENSITY FUNCTIONS FOR MAINLINE REAR-END AND SIDESWIPE COLLISIONS

Similarly, the density functions for the five sub-categories of hit-object, broadside, and "other types of collisions are graphed in Figure B-3. 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.

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 shown in Table B-4, and tests results for alternative comparisons with log-uniform distributions are shown in Table B-5. As in the case of the mainline 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 B-4. The probability density functions are graphed in Figure B-5. Parameters for these distributions are shown in Table B-6.

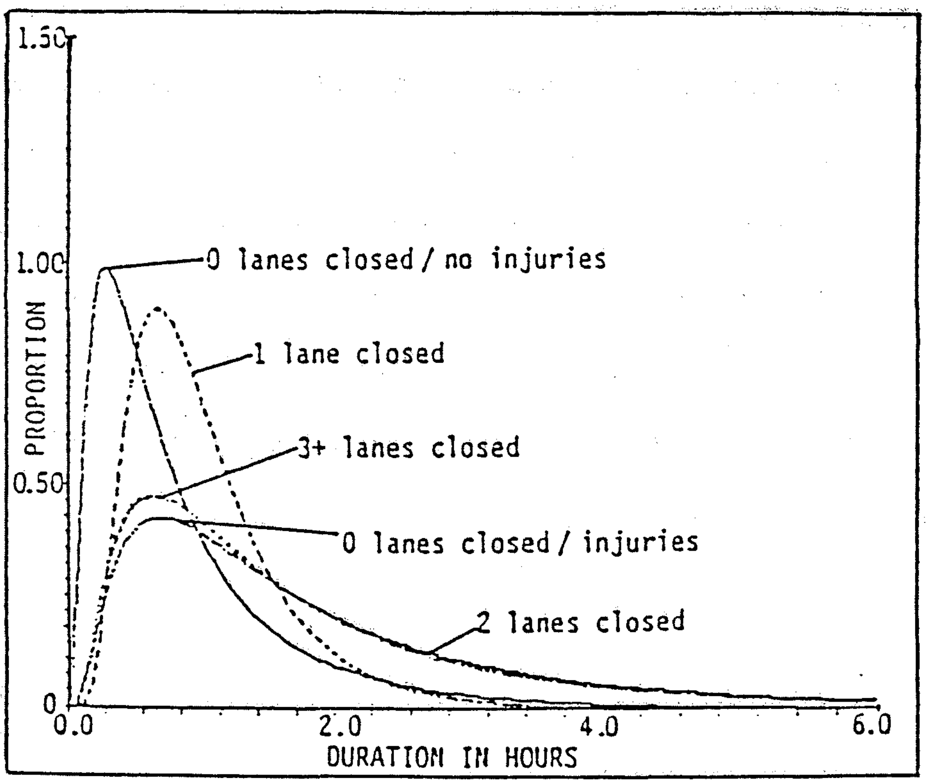

FIGURE B-3

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

TABLE B-4

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

INCIDENT TYPE: RAMP 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, 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 B-5

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

INCIDENT TYPE: RAMP 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

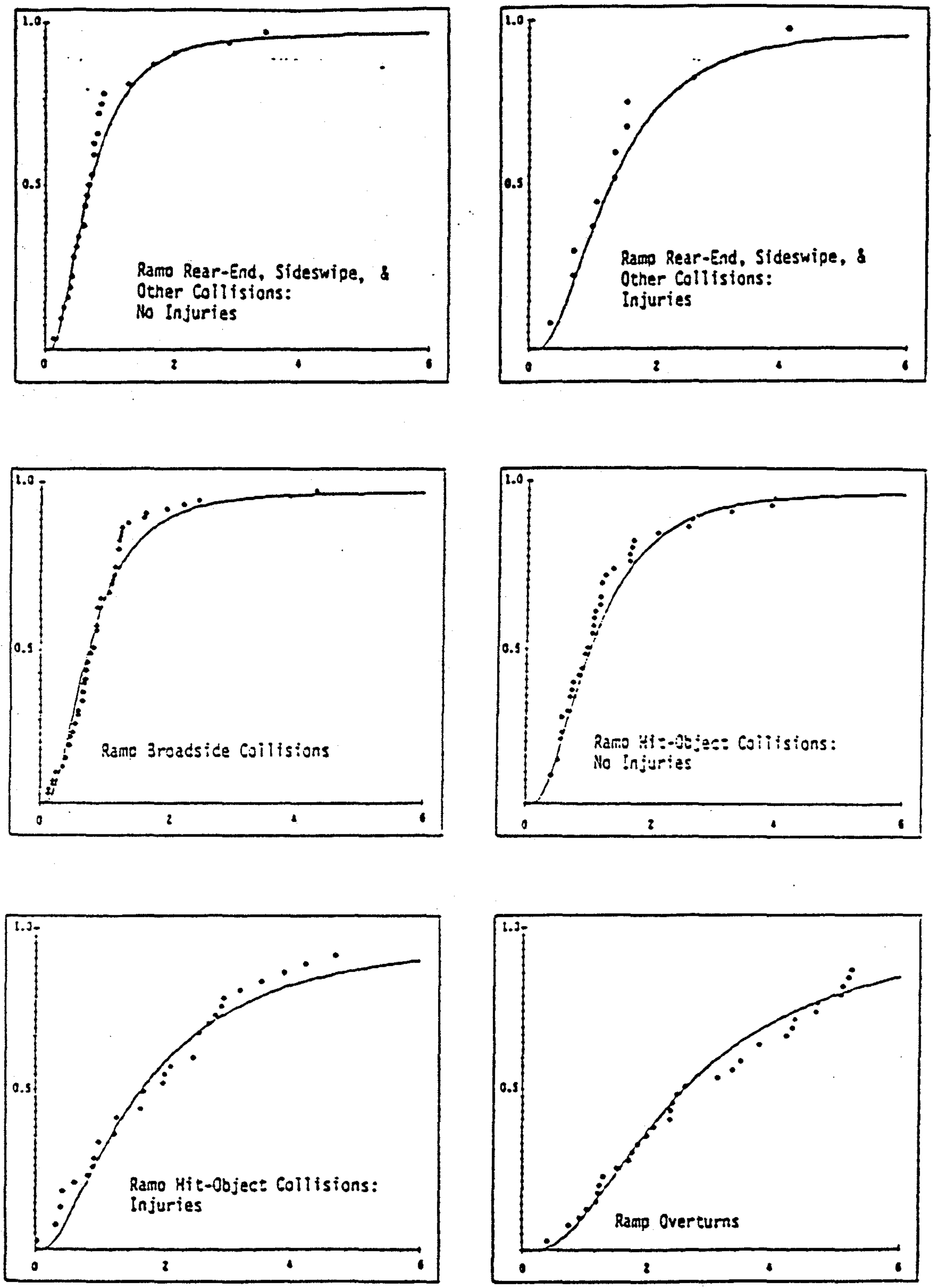

FIGURE B-4

FITTED CUMULATIVE DISTRIBUTION FUNCTIONS OF DURATION: RAMP ACCIDENTS

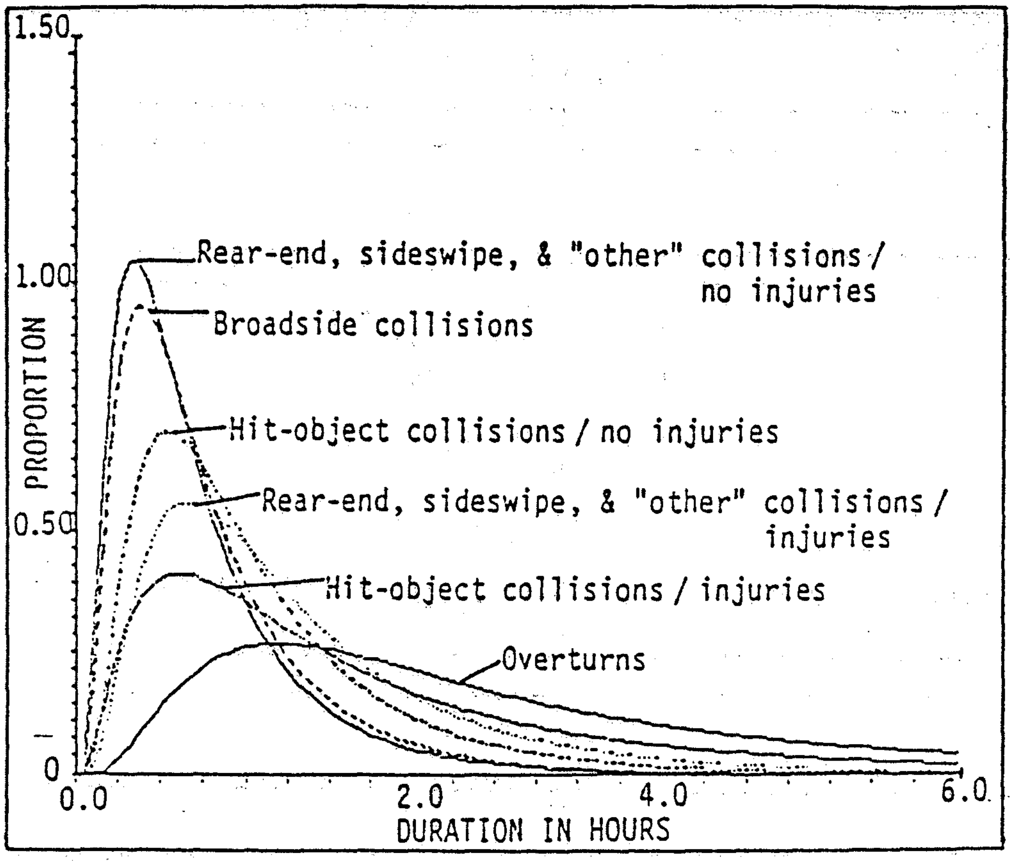

FIGURE B-5

PROBABILITY DENSITY FUNCTIONS FOR RAMP ACCIDENTS

TABLE B-6

LOG-NORMAL DISTRIBUTIONS OF INCIDENT DURATION FOR RAMP ACCIDENTS

INCIDENT TYPE: 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

APPENDIX C

DESCRIPTION OF THE INTRAS MODEL[1]

The INTRAS (INtegrated TRaffic Simulation) model was developed under the sponsorship of the Federal Highway Administration for the study of disruptive incidents occurring in freeway traffic, incident detection methods, and alleviation of incident effects through control and detector placement. The INTRAS model is a highly detailed microscopic simulation which may be used to model a wide range of network geometrics, control strategies, and traffic characteristics.

The geometric representation of a roadway system in the INTRAS simulation model is accomplished by constructing a network analog of links (roadway segments) and nodes (intersections or geometric discontinuities).

In INTRAS, a "freeway" link is defined as a one-way roadway segment of a controlled-access highway, characterized by generally constant geometric features (grade, curvature, number of through lanes). The extremities of a "freeway" link correspond to either ramp junctions or significant geometric changes. Each "freeway" link may contain up to five through lanes and two auxiliary lanes. Each auxiliary lane may be described as "acceleration," "deceleration," or "full." Ramp links are defined as one-way non-freeway roadway segments which connect directly to a freeway link. Ramps may be one or two lanes in width. "Ramp" links are further characterized as either on or off-ramps, indicating that end of the link which connects to the freeway. Vehicles traversing

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[1] The description of the INTRAS model provided above is largely abstracted from material contained in the original documentation of the model (Federal Highway Administration, 1980 a,b). Readers interested in a more detailed description of the model are referred to those documents.

"freeway" and "ramp" links move in accordance with the logic of component car-following and lane-changing models specially designed for INTRAS.

The lane alignment of freeway links and on-ramp links with the next downstream freeway link is defined by the number and type (through, auxiliary, etc.) of lanes which comprise each link and by the lane in the downstream link which receives traffic from the right-most through lane of the upstream link. Freeway links are logically connected to downstream off-ramps by specifying the number of ramp lanes and whether it is a right-hand or left-hand off-ramp. The outside lanes on the designated side of the freeway are then internally assigned as connecting to the off-ramp.

Each driver-vehicle pair in a traffic stream behaves as an individual entity having different motivations and standards of performance from those around it. INTRAS provides for five vehicle types, each possessing its own family of vehicle characteristics (length, speed, acceleration, profile, etc.) Variations within vehicle type are attributed to differences in driver performance. Decile distributions of these characteristics (variation about mean free-flow speed, queue discharge headway, etc.) are implemented in the INTRAS model.

Traffic assignment on a given network is accomplished through controlling entering volumes and routing. INTRAS allows specification of entering volumes, by vehicle type. The volume for each entry link is held constant over a period of simulated time referred to as a subinterval. At the end of each subinterval any number of these demand volumes (both entering and internal) may be revised. The duration of each subinterval is a user specification, thereby providing complete freedom in the variation of traffic loading with time. Routing is normally performed by specifying the percentage (or count) of vehicles negotiating each possible turn movement on a link-specific basis. Turn movements may also be varied by the user from subinterval to subinterval.

INTRAS contains a comprehensive freeway incident simulation procedure. The user may specify either blockages or "rubbernecking" (e.g., spectator slowing) to occur on a lane-specific basis. Each incident may occur at any longitudinal position on a freeway link and extend for any desired length of time.

The character of an incident may be changed with time. It is possible to specify, for example, a two-lane blockage which, after some specified duration, becomes only a one-lane blockage. The lane from which the blockage is removed may then become unrestricted or subject to "rubbernecking." "Rubbernecking" may be applied, without a corresponding blockage, to simulate a shoulder incident. In this case, the user specifies a factor indicating the percentage reduction in speed for vehicles traversing the affected lane segment.

In INTRAS, the traffic stream is updated each time step (second or fraction of a second) using car-following procedures patterned after the PITT algorithm, a "fail-safe" simulation car-following model. A detailed derivation of the PITT car-following model is provided in the original documentation of the INTRAS model (Federal Highway Administration, 1980a, Appendix B).

The PITT model has two elements: a car-following model which calculates the follower's behavior based on a prescribed desired following distance, which is a function of the vehicle's speed; and an overriding collision prevention model which is based on the following vehicle being able to avoid a collision when the leader undergoes its most extreme deceleration pattern.

The PITT model is based on a combination of the Northwestern car-following

(Worrall and Bullen, 1969) and the UTCS-1 collision avoidance procedures (Lieberman, Worrall, and Bruggemen, 1972). The primary car-following relationship is that a following vehicle will attempt to maintain a space headway of $L+kv+10$ feet. The factor, k, which is a function of driver type, regulates maximum lane capacity since it determines the average headway at high volumes. This factor, k, is also used to establish bottleneck conditions since a reduction in lane capacity can be achieved through an increase in k.

The car-following formula is:

$$a = 2[x-y-L-10-(k+Tv-bk(u-v)^2] / (T^2 = 2kT)$$

where:

a = acceleration of follower in the interval $(t, t+T)$

x = position of leader at time t

y = position of follower at time t

L = length of the leading vehicle

k = car following parameter (driver sensitivity)

T = time-scanning interval

u = speed of leader at time t

v = speed of follower at time t

b = constant.

A lag, c, is introduced into the car-following calculations after "a" has been calculated. The lag is applied to the calculations of the following vehicle's speed and position.

Overriding this car-following relationship is a collision avoidance set of equations which prevent collisions when vehicles are undertaking maximum emergency decelerations. The formulae for the emergency constraints are:

$$a \leq B/2 + [(B^2 + 4C)]^{1/2} / 2$$

where $b = e + 2(e\,c + v) / (T - c)$

in which e = maximum emergency decelaration,

and $C = [2\,e/(T - c)^2] \cdot [x - y - vT - L - cv - (v^2 - u^2) / 2\,e]$

provided $a \geq [(u^2 + e^2 + c^2)^{1/2} - ec - v] / (T - c) > 0$

or $a < 2\,(x - y - vT - L) / (T-c)^2$

provided $-v / (T=c) < a < [(u^2 + e^2\,c^2)^{1/2} - e\,c - v] / (T-c)$

or $a \geq - v^2 / 2\,(x - y - L)$

provided $a < -v / (T-c)$.

The PITT algorithm easily accommodates variable scanning periods, and different driver and vehicle types. Capacity conditions can be replicated and congestion is internally generated. Bottleneck conditions can be imposed over the full range of potential capacity reductions.

Within INTRAS, lane changing is fully integrated with the car-following component of the model. With the INTRAS lane changing process, basic checks are made to ensure that both the lead headway to the gap leader, as well as the lag headway to the gap follow-up, satisfy the basic car-following rules; the lane change itself takes place over a finite period of time corresponding to the time usually taken for a vehicle to physically change lanes. In determining a safe headway for lane changing, the changing vehicle must satisfy only the non-collision constraint equations for the gap in the new lane, rather than the car-following equations. This expedites lane changing in heavy flow conditions and enables the representation of forced lane changing, with a vehicle crowding into what might normally be considered an unavailable gap.

The lane changing process used in INTRAS is particularly suitable for simulating merging and weaving under very congested traffic conditions. The model was calibrated using general freeway capacity characteristics data generated from the Long Island Expressway, and the Ohio State vehicle trajectories, as described in the original documentation (Federal Highway Administration, 1980a, p. 115). Validation of the simulation procedures was accomplished using the Ohio State trajectory data, the Long Island Expressway data, the PINY weaving data from the Long Island Expressway, and a portion of the Los Angeles closely-spaced data set that involved 30 minutes of data for three sets of detectors with spacings of approximately 600 feet.

The standard output of INTRAS consists of such measures of effectiveness as vehicle miles, vehicle minutes, volume, density, speed, delay per vehicle, lane changes, etc., which are normally reported at the end of each simulation subinterval, on both a link-specific and a networkwide basis. These statistics are cumulative either from the start of simulation or, optimally, from the beginning of each subinterval.