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INTRODUCTION

Trucks are a major contributor to non-recurrent congestion in the region that comprises Los Angeles, Ventura, and Orange Counties of California. In 1987, for example, a total of 5,203 mainline freeway collisions (i.e., no ramp or connector collisions) involving trucks were reported (according to the state-maintained records of California Highway Patrol field investigations) in this tri-county region. Approximately 91 percent of all mainline truck incidents on Southern California freeways occur on weekdays (Monday through Friday) and 95 percent of these weekday freeway incidents occur during the period of heavy freeway usage (6:00 a.m.--6:00 p.m.) with approximately 56 percent occurring during the morning (6:00 a.m.-- 9:00 a.m.) and evening (3:00 p.m.-- 7:00 p.m.) peak periods. This amounts to an average of approximately 19 truck incidents per weekday on the tri-county freeway system, the majority of which (15 per day) occur on the heavily traveled freeways of Los Angeles County.

With congestion increasing on this and other metropolitan freeway systems, it is important to determine the impact of truck-related incidents on the freeway system, and to seek ways to mitigate this impact. The research reported here focuses on a particular aspect of the truck incident problem: Estimation of the impact of 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.)

DATA

The primary data source for this study was the TASAS (Traffic Accident Surveillance and Analysis System) data base maintained by the California Department of Transportation (Caltrans, 1978). This data base contains all accidents on the State Highway System that involved police investigations at the scene of the incident. For 1987-1988, 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.

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 which were obtained from 1983-89 TASAS records. 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 the incident was reported, obstructions and hazards were cleared, and police left the scene. The times during which specific numbers of lanes or ramps were closed were also typically reported on the logs. Biases in these data probably involve the under-reporting of closures that are of short duration.

OVERVIEW OF APPROACH

A simulation procedure was used to develop estimates of motorist delay attributable to truck-involved freeway collisions. The simulation approach had two distinct phases. First, a microscopic traffic flow model (INTRAS) (FHWA, 1980) was used to simulate the added delay associated with a randomly selected subset of collisions taken from California Highway Patrol logs. These incidents were selected in a manner that ensured adequate representation of collisions in each of ten categories found to have significantly different characteristics. 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 Los Angeles, Orange, and Ventura Counties of California during the two-year period 1983 through 1984. 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 performed for each incident 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. The subsample was created from a random selection of collisions involving at least one truck. A total of 332 highway collisions were drawn and matched against the state-maintained accident records by comparing time, date, and location of the incidents.

Golob, et al. (1987) reported tests 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 highway collisions used in the present study (Table 1). Based on differences in either means or standard deviations, rear-end and sideswipe collisions were found to be mutually indistinguishable, as were hit-objects, 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

TABLE 1

TRUCK HIGHWAY COLLISIONS GROUPED ACCORDING TO
DIFFERENCES IN INCIDENT DURATION

(Reproduced from Golob, et al., 1987, Table 7)

COLLISION TYPE		INCIDENT DURATION		PERCENT OF ALL TRUCK HIGHWAY ACCIDENTS
CATEGORY	SUB-CATEGORY	MEAN	STANDARD 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

(second major category only). For both of the major categories of incidents in Table 1, the variances, rather than the means, of duration for incidents with lane closures are related to the number of lanes closed. For each of the ten types of truck-involved freeway collisions in Table 1, the distributions of incident duration were determined through Kolmogorov-Smirnov tests to be log-normal (Golob, et al., 1987). That is, the log-normal distribution could not be rejected as representations for the sample distributions of incident duration for each type of collision. The best-fitting log-normal probability density functions for the ten collision categories are graphed in Figures 1 and 2 (from Golob, et al., 1987). The differences among the incident durations for collision categories are clearly demonstrated in these graphs.

The ten categories provide 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 durations of many hours 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

A total of 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 (subject to certain limitations) to encompass any disruptive impact of the incident, and all ramps and connectors associated with the mainline segment. The

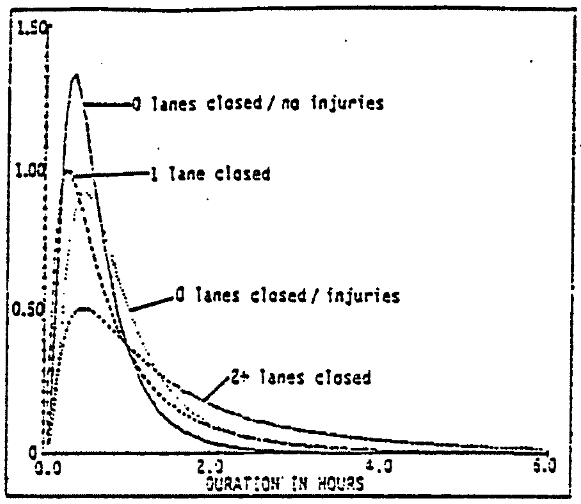

FIGURE 1

PROBABILITY DENSITY FUNCTIONS FOR HIGHWAY REAR-END
AND SIDESWIPE COLLISIONS
(Reproduced from Golob, et al., 1987, Figure 3)

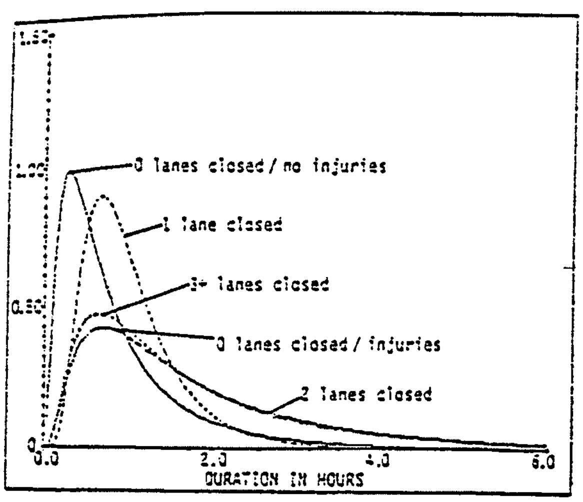

FIGURE 2

PROBABILITY DENSITY FUNCTIONS FOR HIGHWAY HIT-OBJECT,
BROADSIDE, AND "OTHER" COLLISIONS
(Reproduced from Golob, et al., 1987, Figure 4)

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 (which accounted for all but a few cases), the upstream length was selected such that the entire mainline extent of the effect of the incident was encompassed by the network coded; where this was not possible, procedures were set up 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 Annual Average Daily Traffic (AADT) counts, using data for both the freeway mainline and for all associated ramps. A growth factor of six percent per year was assumed and applied to all non-current mainline counts; non-current ramp 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 fifteen-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) are not considered in the simulations; the effect of this simplification is expected to overestimate delay by an unknown amount.

However, this overestimation is counterbalanced by the additional travel time spent by diverted vehicles on 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 forty percent was assumed for all lanes within 250 feet downstream of the collision; a factor of twenty percent was assumed for all lanes between 250 and 500 feet downstream of the collision. Rubbernecking occurring on the opposite side of the freeway is not considered, and this contributes 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 a 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 fifteen minutes; output from the simulation model was produced for each fifteen-minute interval simulated.

Regression Models of Nonrecurrent Delay

Because of the obvious impracticabilities of using INTRAS to simulate the delay associated with all of the 10,805 truck-involved mainline freeway collisions that occurred during the 1987-1988 period, regression models were developed to extrapolate results to the population of such incidents. From simulations of the 92 collisions, three resultant variables were extracted as delay indicators:

1. ADDED 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; i.e., the total of 10,805 truck-involved mainline freeway collisions that occurred on freeways in Los Angeles, Orange, and Ventura Counties during 1987-88. 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 2 presents a summary of the range of types of incidents included in the simulation sample categorized by lane closures, duration of incident, and 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, a scheme in which the data points in the regression estimation were weighted by the logarithm of the respective outcome variable was used.

TABLE 2

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**

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

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

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	=	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 3 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.*

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* This is only an indicator and not a true measure of average delay per vehicle since, in general, the volume of traffic affected will be greater than V . D because D does not include the time required for freeway recovery following removal of the incident.

TABLE 5-3

MODELS OF DELAY

Dependent Delay Indicator	Estimated Parameters (t-statistics)				R^2
	α	β_1	β_2	γ	
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

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 regressions results indicate 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. Theses models provide a basis for estimating the total delay associated with the 10,805 truck-involved freeway collisions in 1987-88 in the three-county Los Angeles area.

APPLICATION OF DELAY MODELS TO TRUCK-INVOLVED FREEWAY COLLISIONS

The TASAS records provide information on the route, postmile, lane number, and time of the 10,805 collisions; simulation procedures were developed to estimate values for the duration of the incident and the number of lanes closed. First, in the generation of lane closure information, each of the 10,805 collision cases was categorized according to the classifications of Table 1. Lane closure values were then randomly assigned to each case according to the probabilities represented by the category frequencies listed in Table 1 and more detailed TASAS data. Table 4 represents a summary of the resulting breakdowns of simulated lane closures for each collision type.

TABLE 4

SIMULATED DISTRIBUTION OF LANE CLOSURES

Collision Type	Lanes Closed	Percent of Cases in each Type
1. Rear-end, Sideswipe, & No Injury	0 lanes closed	84.0
	1 lane closed	11.8
	2 lanes closed	3.7
	$\geq$ 3 lanes closed	0.5
2. Rear-end, Sideswipe, & with Injury	0 lanes closed	69.1
	1 lane closed	19.1
	2 lanes closed	6.8
	$\geq$ 3 lanes closed	5.0
3. Hit-Object, Broadside, & No Injury	0 lanes closed	37.6
	1 lane closed	42.4
	2 lanes closed	8.8
	$\geq$ 3 lanes closed	11.2
4. Hit-Object, Broadside, & with Injury	0 lanes closed	28.1
	1 lane closed	29.7
	2 lanes closed	24.8
	$\geq$ 3 lanes closed	17.4
5. Overturns	0 lanes closed	26.4
	1 lane closed	19.6
	2 lanes closed	36.8
	$\geq$ 3 lanes closed	17.2

TOTAL PERCENTAGE FOR EACH COLLISION TYPE: 100%

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

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

TABLE 5

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 and, 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 is found to be 1,911 vehicle hours, and the average additional delay per vehicle affected by an incident is 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 6. The actual distribution of delays is shown in Figure 3, and the corresponding cumulative distribution is shown in Figure 5.

These figures show that the majority (approximately two-thirds) of truck-involved incidents cause delays below the mean. The relatively small number of accidents that contribute disproportionately to delay typically are 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 result in the greatest vehicle hours of delay per incident (Figure 5), their relatively small number (accounting for 1.5 percent and 2.5 percent of all truck-involved freeway collisions, respectively) leads to a correspondingly small contribution to total delay (Figure 6). Conversely, the relatively small amount of delay per incident associated with **sideswipes** and **rear-end** collisions is counterbalanced by their high frequencies of occurrence, leading to significant contributions to the overall delay situation.

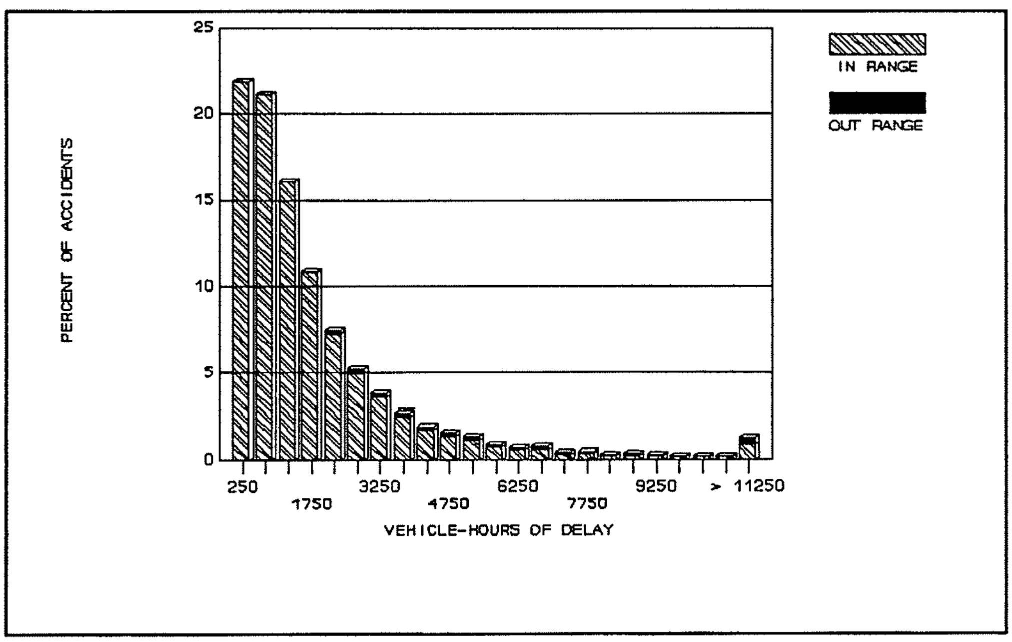

FIGURE 3
DISTRIBUTION OF TOTAL DELAY

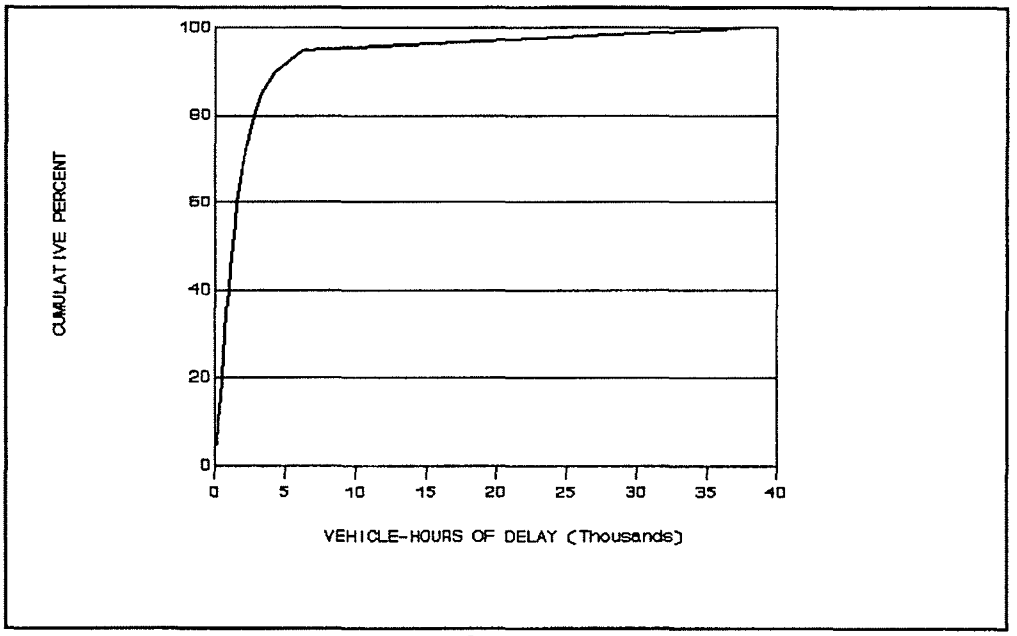

FIGURE 4
CUMULATIVE DISTRIBUTION OF DELAY

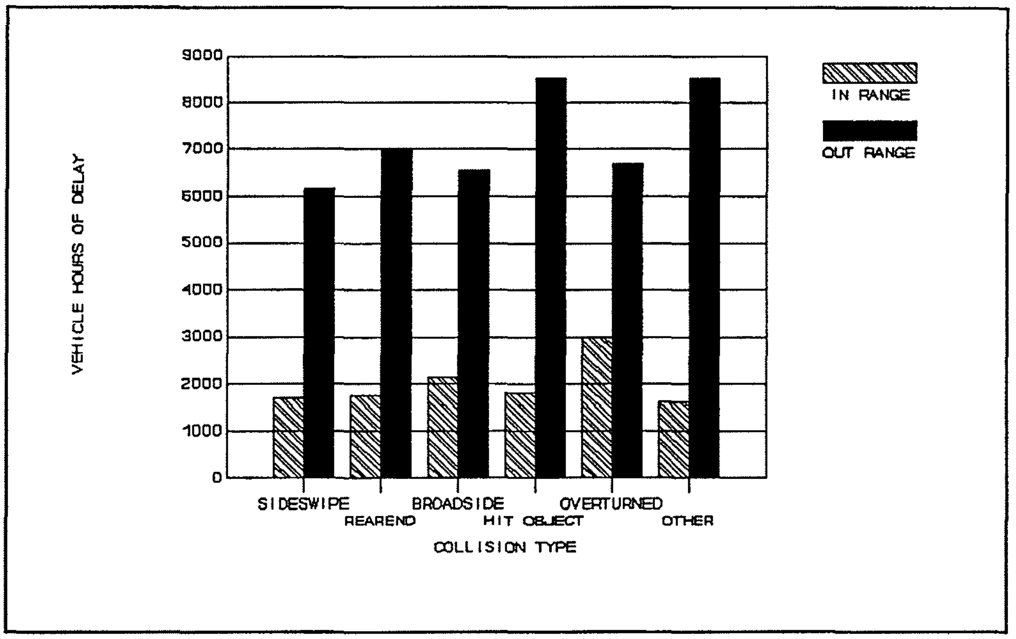

FIGURE 5
VEHICLE HOURS OF DELAY PER INCIDENT
BY COLLISION TYPE

TABLE 6
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 7 and 8 provide an indication of congestion levels resulting from incidents of various types. Figure 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 7. This pattern is repeated in Figure 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**, is mitigated by the relatively low frequency of occurrence of these types of incidents (Figures 9 and 10). The large number of typically relatively minor **rear-end** and **sideswipe** collisions account for approximately 80 percent of the congestion effects (as defined by speed) associated with truck-involved collisions; the next largest category involves **hit objects**, accounting for approximately 8.7 percent.

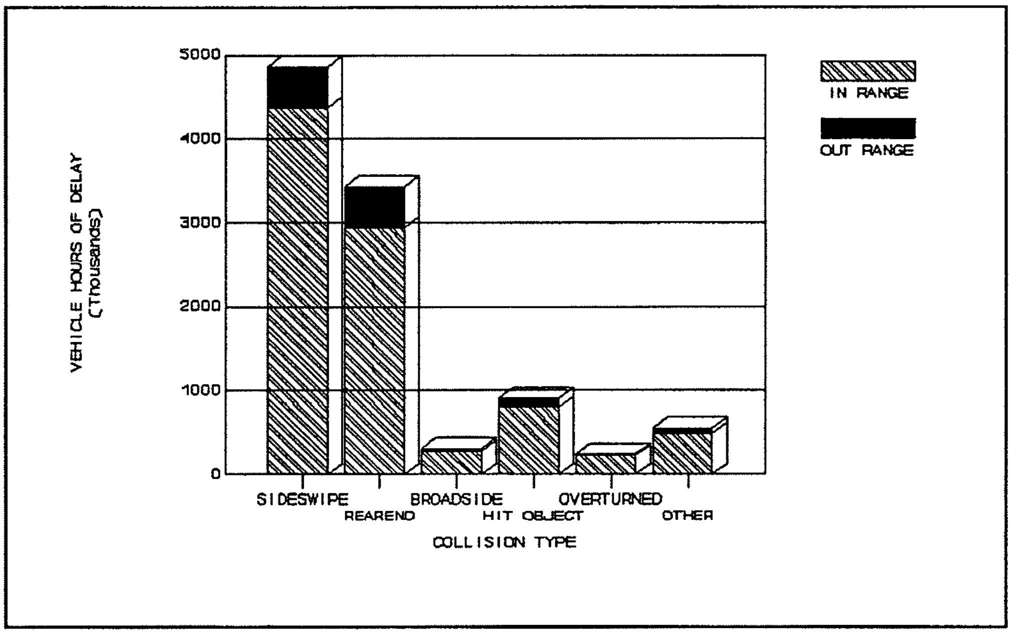

FIGURE 6
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY COLLISION TYPE

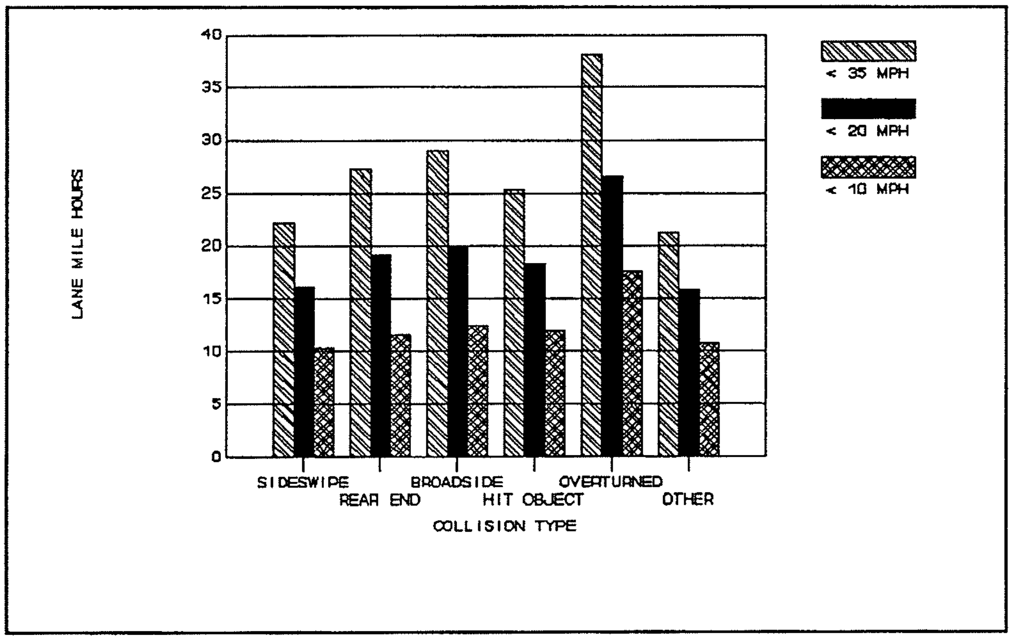

FIGURE 7
LANE MILE HOURS PER INCIDENT BY SPEED
BY COLLISION TYPE

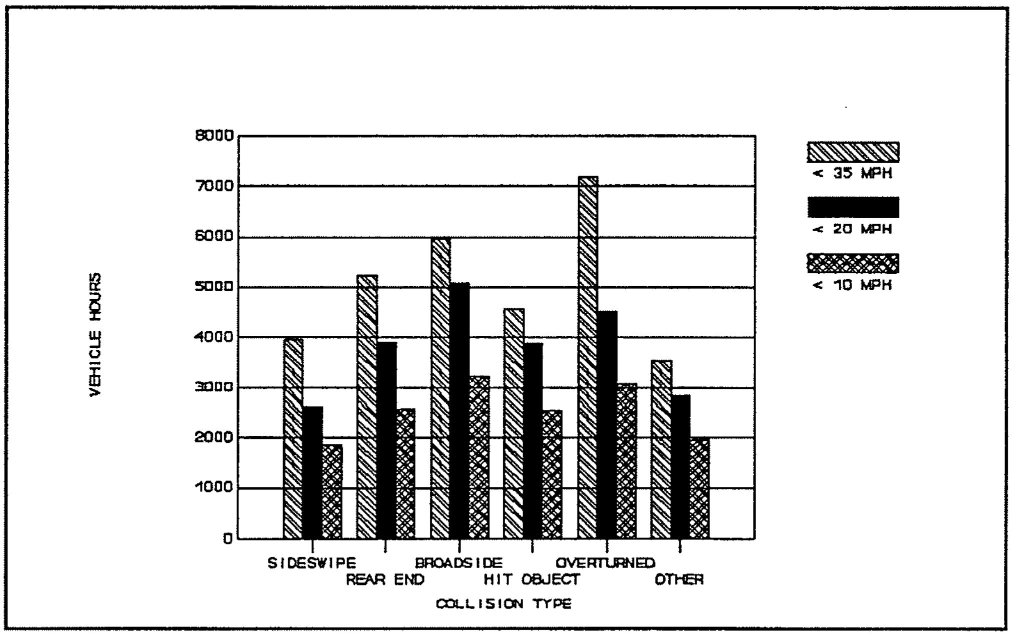

FIGURE 8
VEHICLE HOURS PER INCIDENT BY SPEED
BY COLLISION TYPE

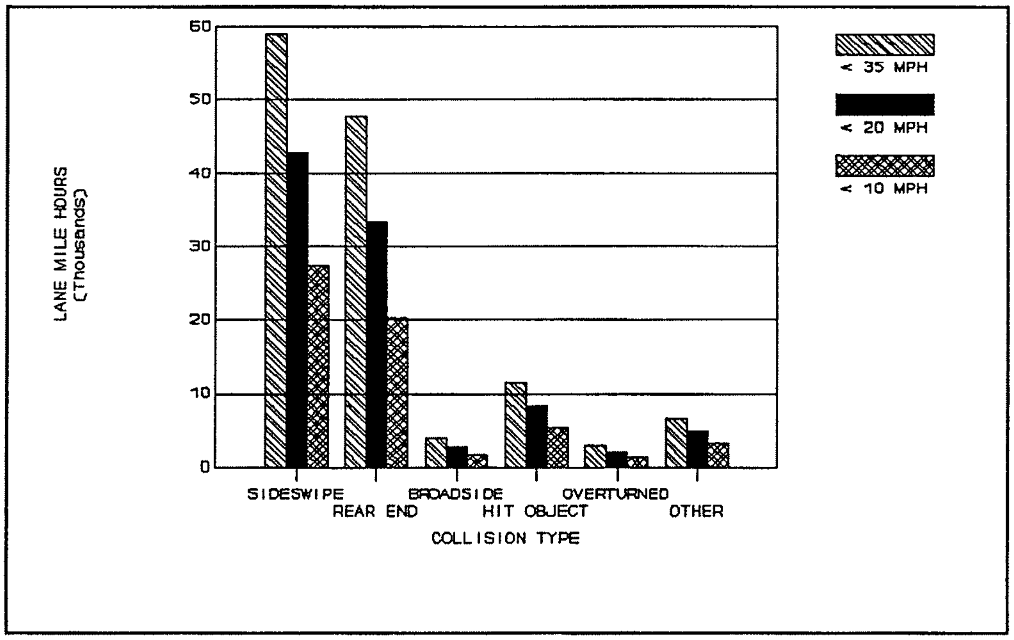

FIGURE 9
TOTAL LANE MILE HOURS PER YEAR BY SPEED
BY COLLISION TYPE

Figures 11 and 12 summarize the influences of primary collision factor on resultant delay. For "in-range" incidents, the resultant delay per incident is 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) is typically or associated with heavy traffic conditions. Although the average delay per incident for most of the factors is similar, the frequency of these factors is not.

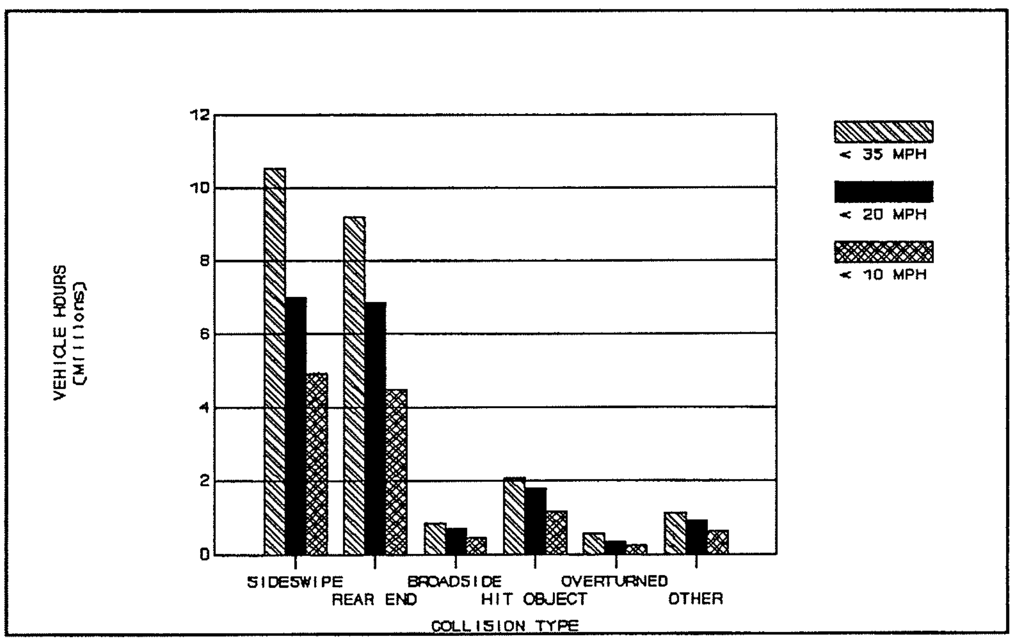

FIGURE 10
TOTAL VEHICLE HOURS PER YEAR BY SPEED
BY COLLISION TYPE

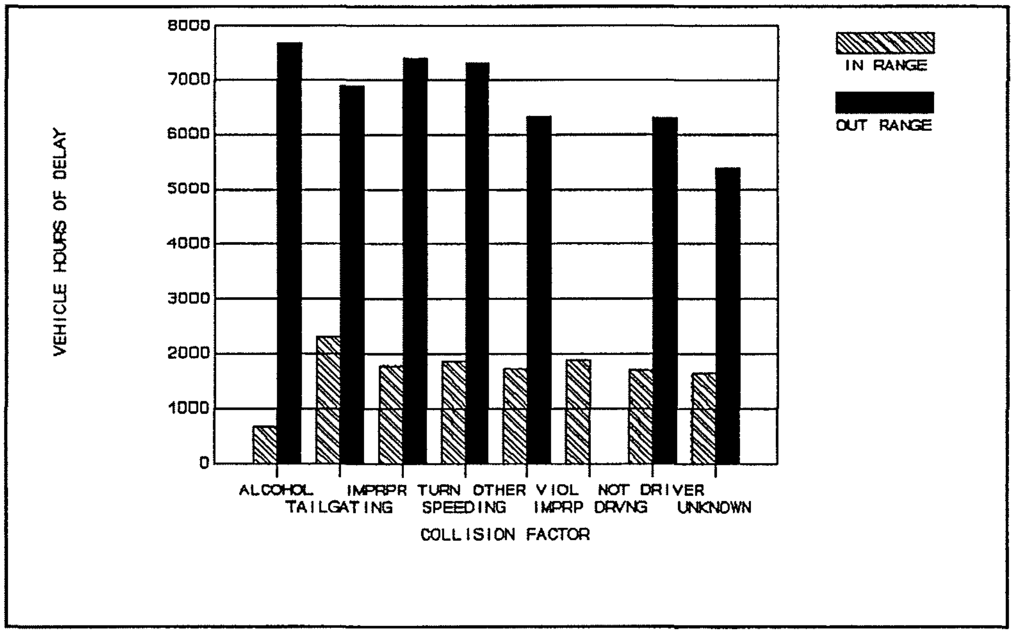

FIGURE 11
VEHICLE HOURS OF DELAY PER INCIDENT
BY PRIMARY COLLISION FACTOR

Other violations account for approximately 50 percent of total delay caused by truck-involved incidents, followed by **speeding** with 30 percent. While these two factors contribute the bulk of delay, it is not disproportional to their frequency in the population. The other incident factors are less frequent and combined they account for approximately 20 percent of total added delay.

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

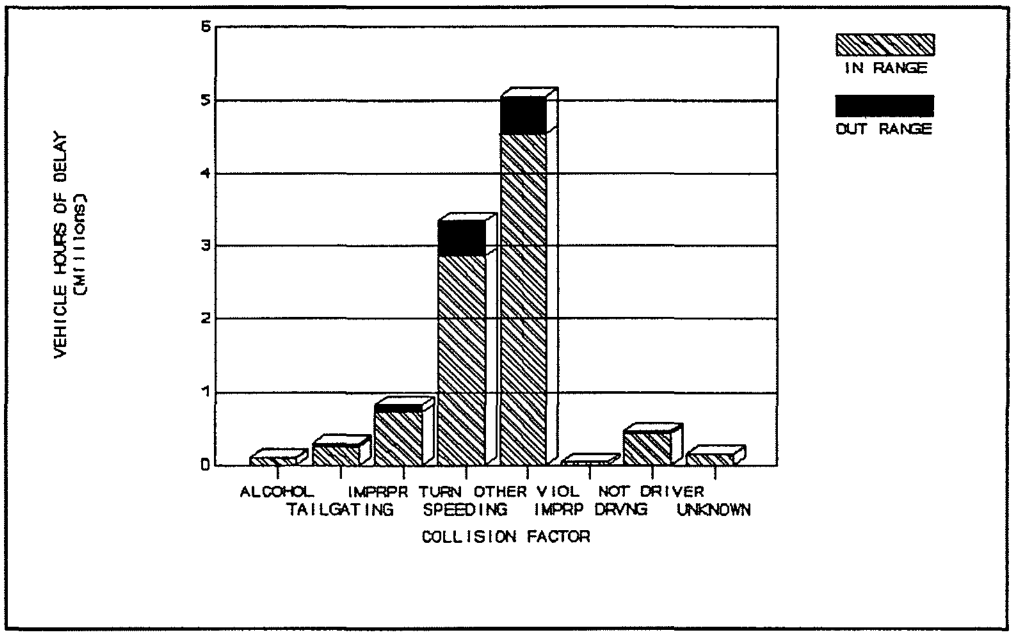

FIGURE 12
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY PRIMARY COLLISION FACTOR

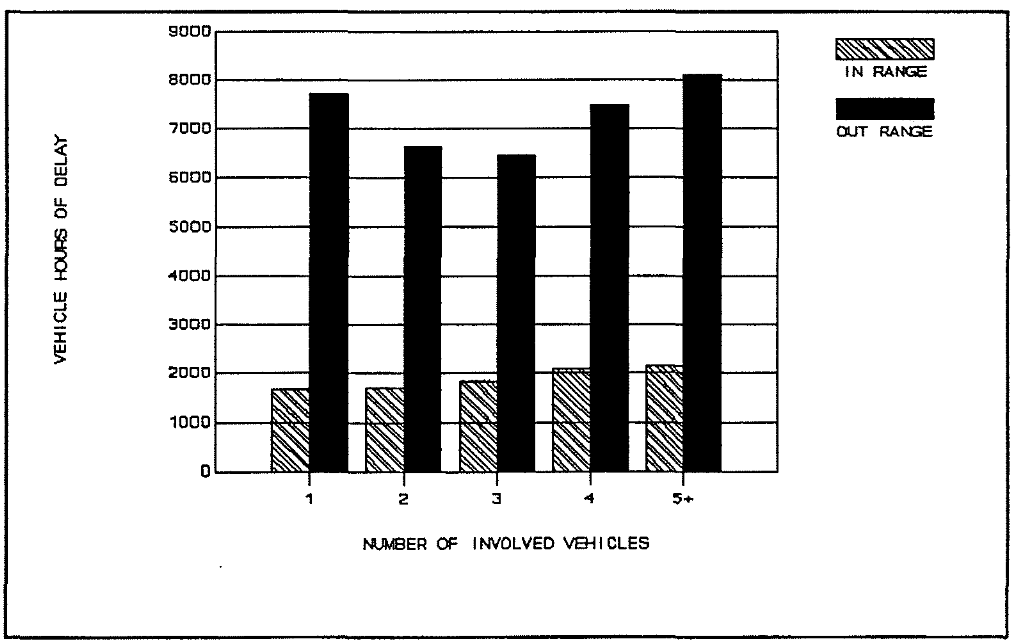

FIGURE 13
VEHICLE HOURS OF DELAY PER INCIDENT
BY NUMBER OF INVOLVED VEHICLES

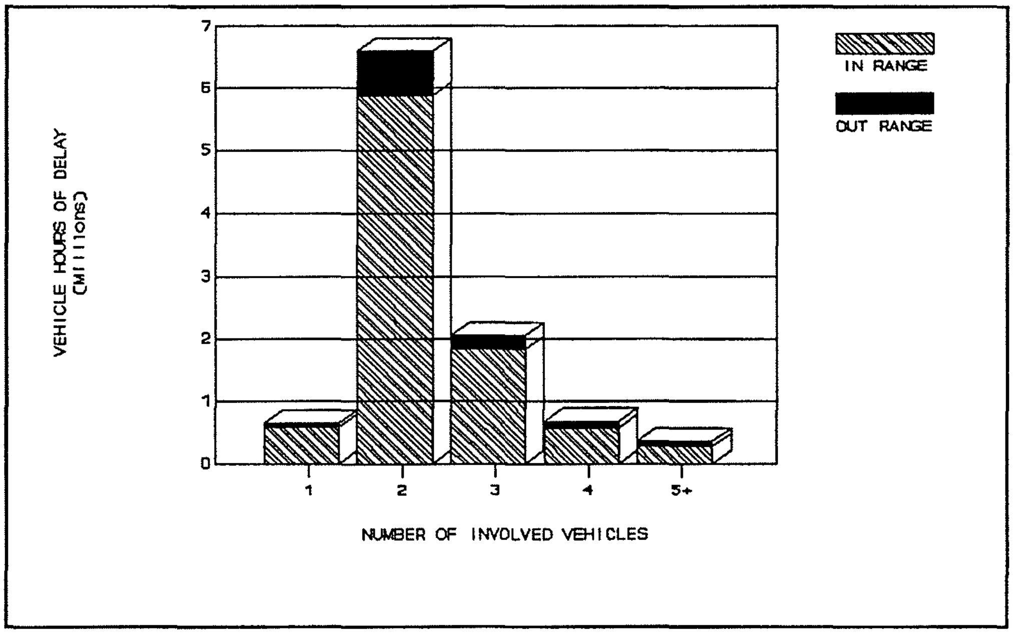

FIGURE 14
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY NUMBER OF INVOLVED VEHICLES

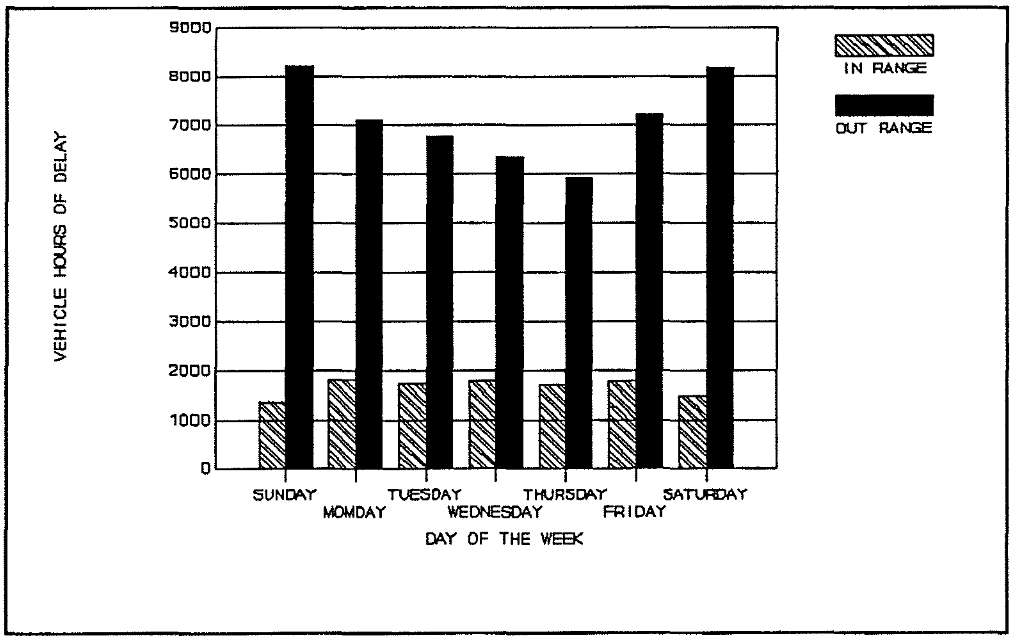

FIGURE 15a
VEHICLE HOURS OF DELAY PER INCIDENT BY
DAY OF WEEK

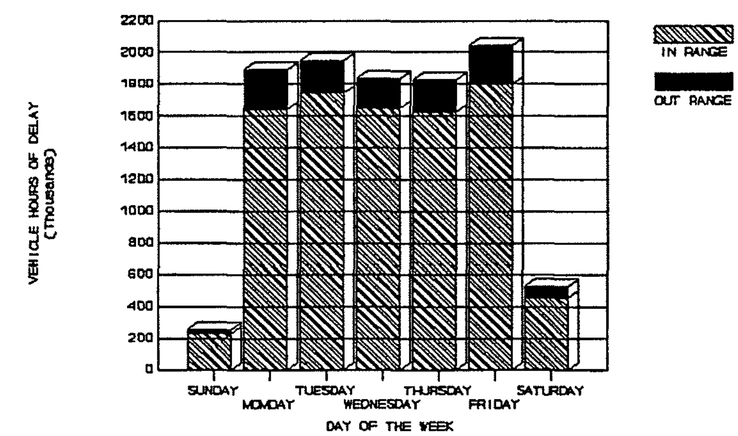

FIGURE 15b
TOTAL VEHICLE HOURS OF DELAY PER YEAR BY DAY OF WEEK

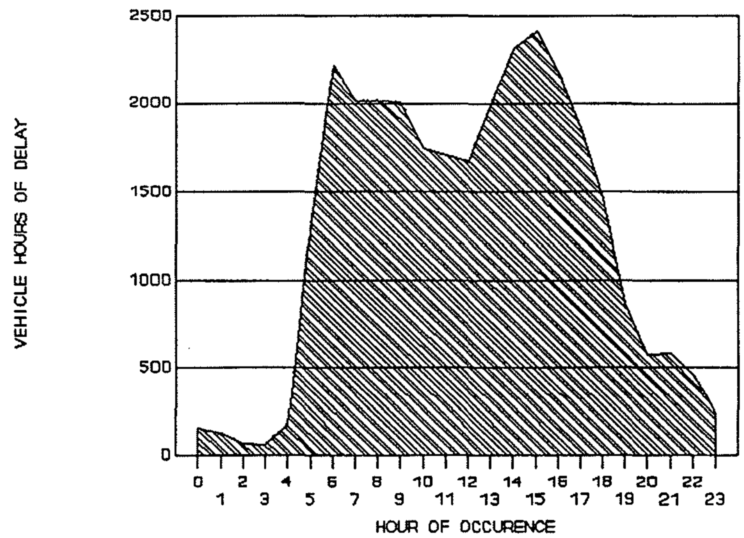

FIGURE 16a
VEHICLE HOURS OF DELAY PER INCIDENT
BY HOUR OF THE INCIDENT
(IN-RANGE CASES)

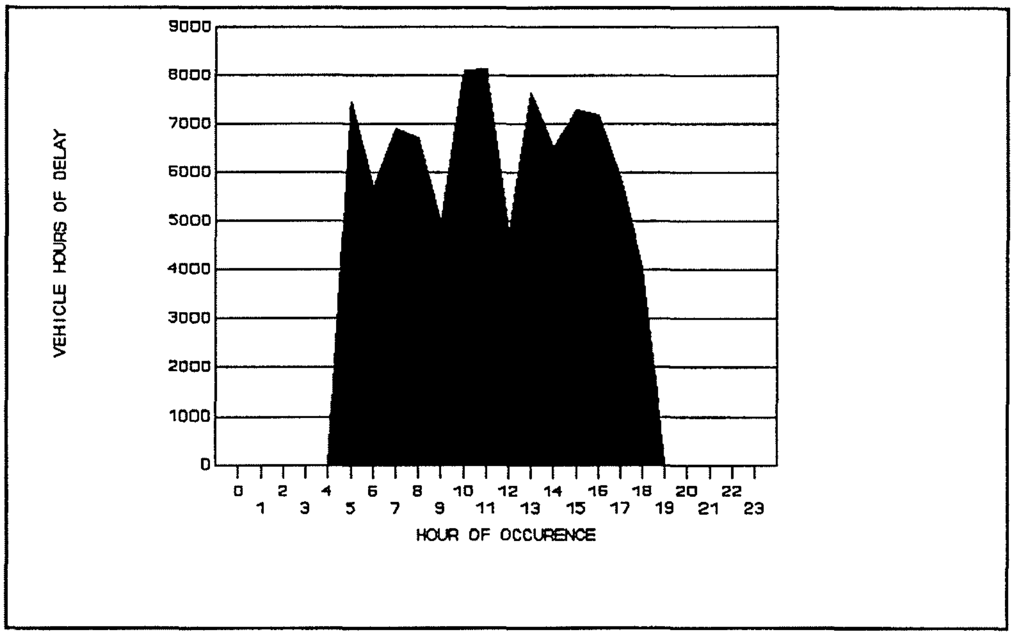

FIGURE 16b
VEHICLE HOURS OF DELAY PER INCIDENT
BY HOUR OF THE INCIDENT
(OUT-OF-RANGE CASES)

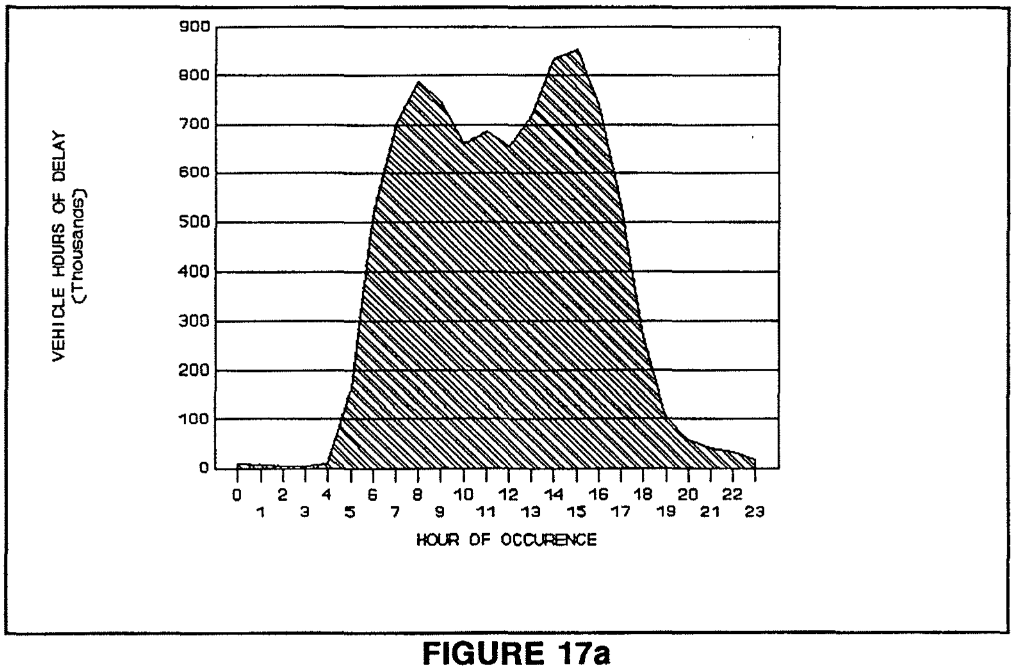

FIGURE 17a
TOTAL VEHICLE HOURS OF DELAY PER YEAR
BY HOUR OF THE INCIDENT

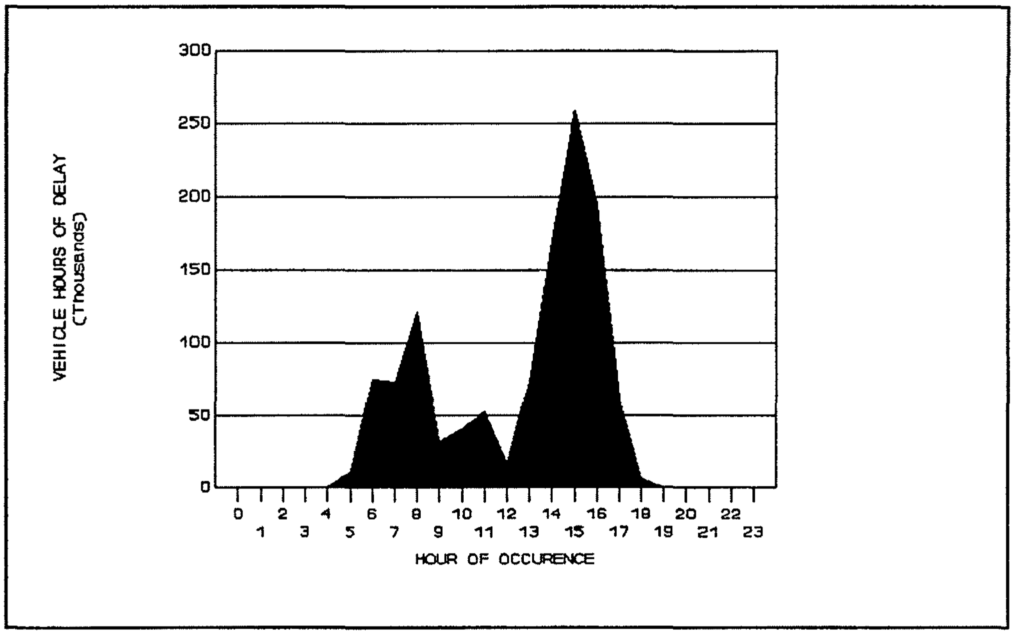

FIGURE 17b
TOTAL VEHICLE HOURS OF DELAY PER INCIDENT
BY HOUR OF THE INCIDENT
(OUT-OF-RANGE CASES)

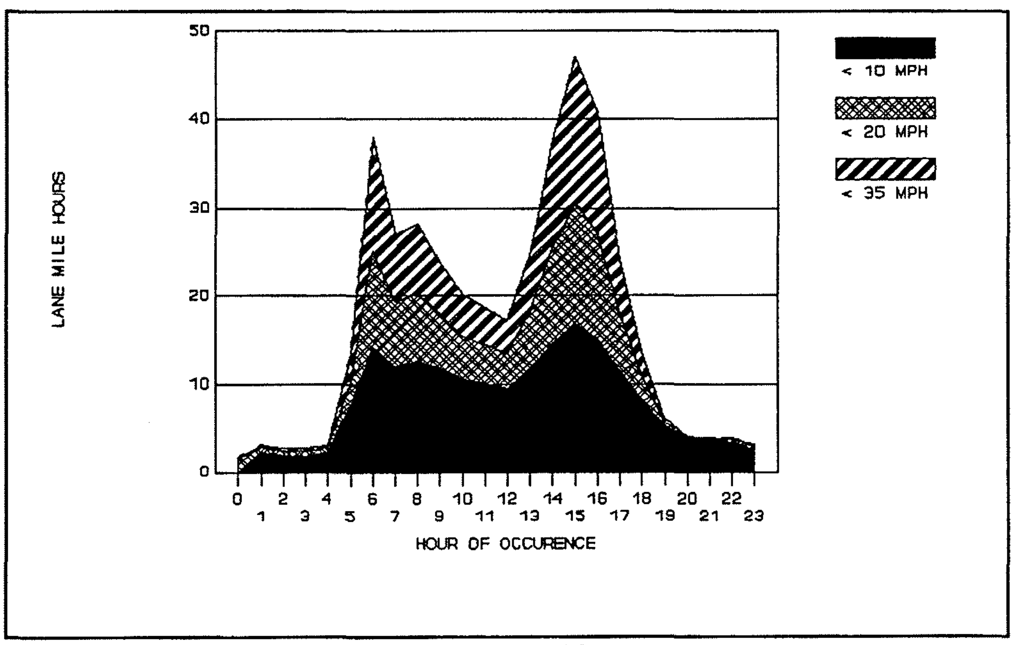

FIGURE 18
LANE MILE HOURS PER INCIDENT BY SPEED
BY HOUR
(IN-RANGE CASES)

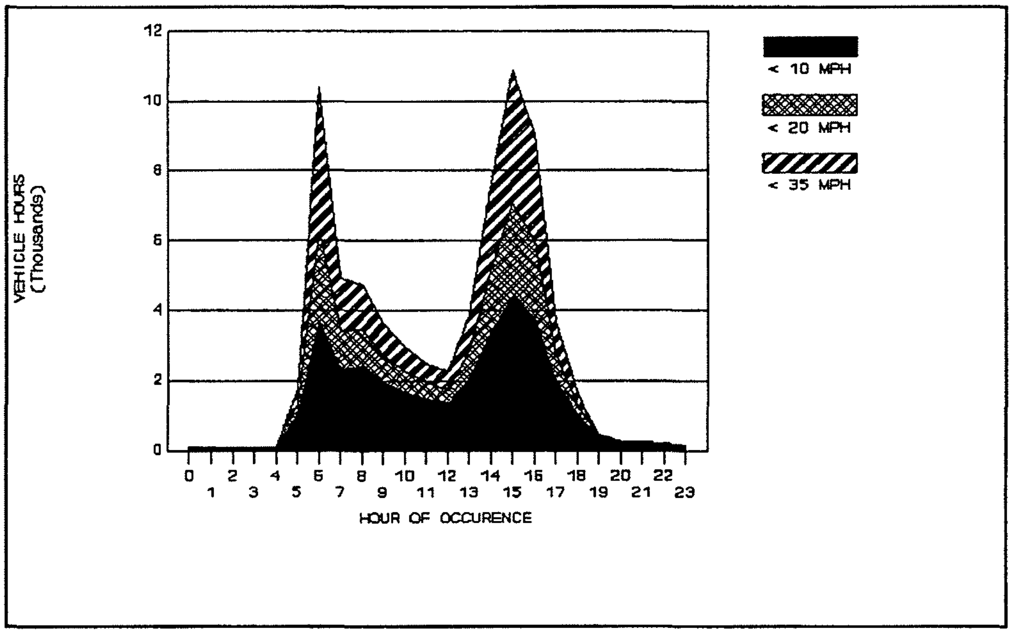

FIGURE 19
VEHICLE HOURS PER INCIDENT BY SPEED
BY HOUR

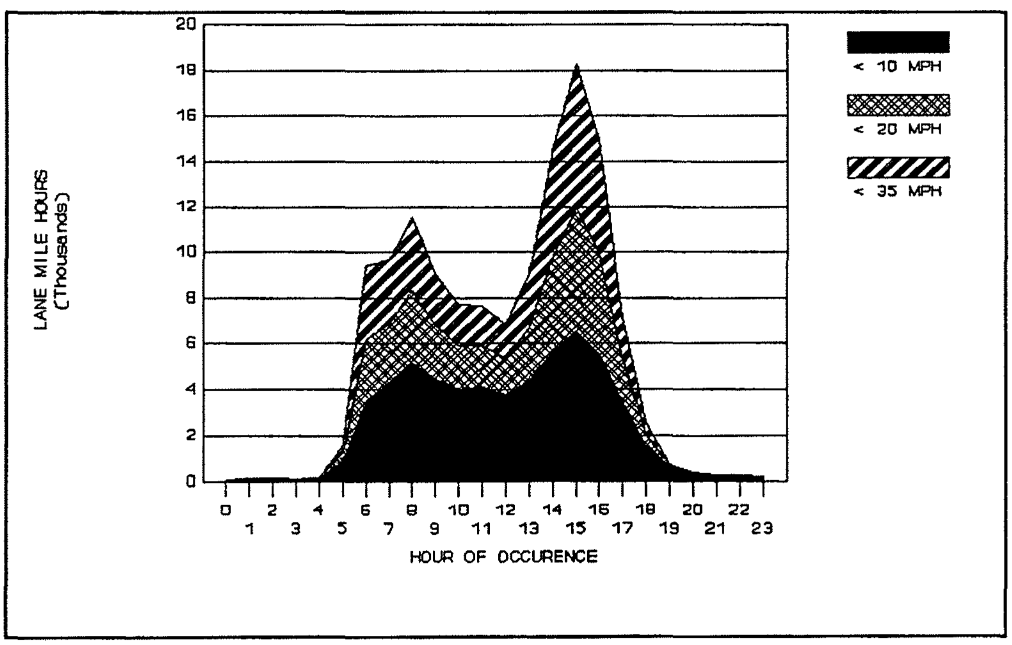

FIGURE 20
TOTAL LANE MILE HOURS PER YEAR BY SPEED
BY HOUR

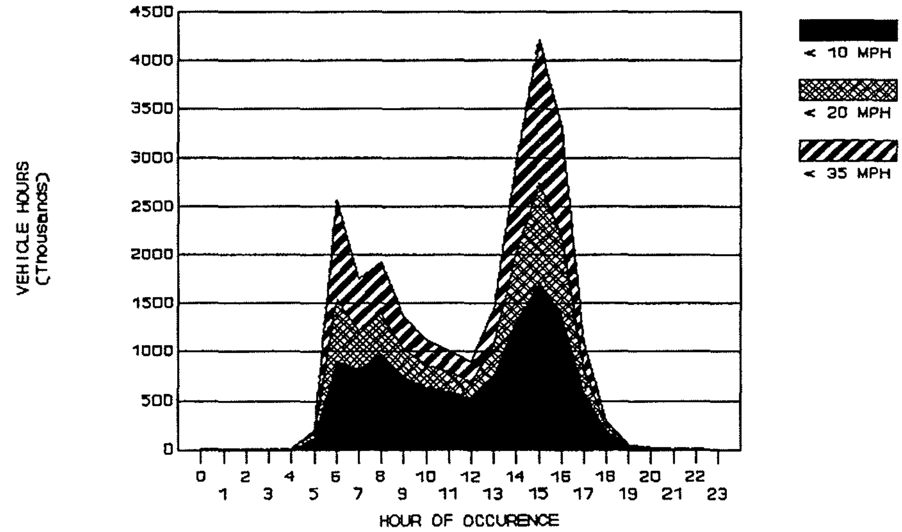

FIGURE 21
TOTAL VEHICLE HOURS PER YEAR BY SPEED
BY HOUR

Figure 15a shows the average vehicle hours of delay/incident by day of the week. Weekdays have slightly higher average delays than weekends which in part may be attributable to greater overall congestion (greater impedance for response vehicles). The variation of total delay estimates with the day of the week on which the incidents occurred is as expected (Figure 15b). The results, in general, show 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 has a significant influence on resulting delay (Figures 16 through 21). The highest delays per incident are associated with the afternoon and early evening peak hours, followed in intensity by the morning peak periods (Figures 16a, 16b). An approximately uniform distribution of collisions throughout the period 6:00 a.m. through 4:00 p.m. results in a pattern of total delay that roughly parallels the distribution of delay per incident (Figures

17a, 17b). The results indicate that incidents due to collisions occurring during the 3-hour period of 2:00 to 5:00 p.m. (which constitutes 21 percent of the total collision incidents) account 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 includes 19 percent of the total collision incidents) accounts for approximately 22 percent of total delay. Thus, collisions during peak-period hours contribute 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 18 through 21 present similar results for delay measures based on speed indicators.

Finally, impacts of truck-involved collisions on delay vary 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 stand out as causing relatively severe delays (Figure 22.) A more detailed breakdown of the severity of these incidents by freeway route segment (Figure 23) reveals 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 arise from collisions on five freeway routes: I-5, I-10, SR-91, SR-101 and I-405 (Figure 24), 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 25) 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 occurs in this segment. In terms of the total picture of delay, truck-involved collisions on this segment contribute 15 percent of the total annual additional delay, while comprising less than 10 percent of the total collisions recorded.

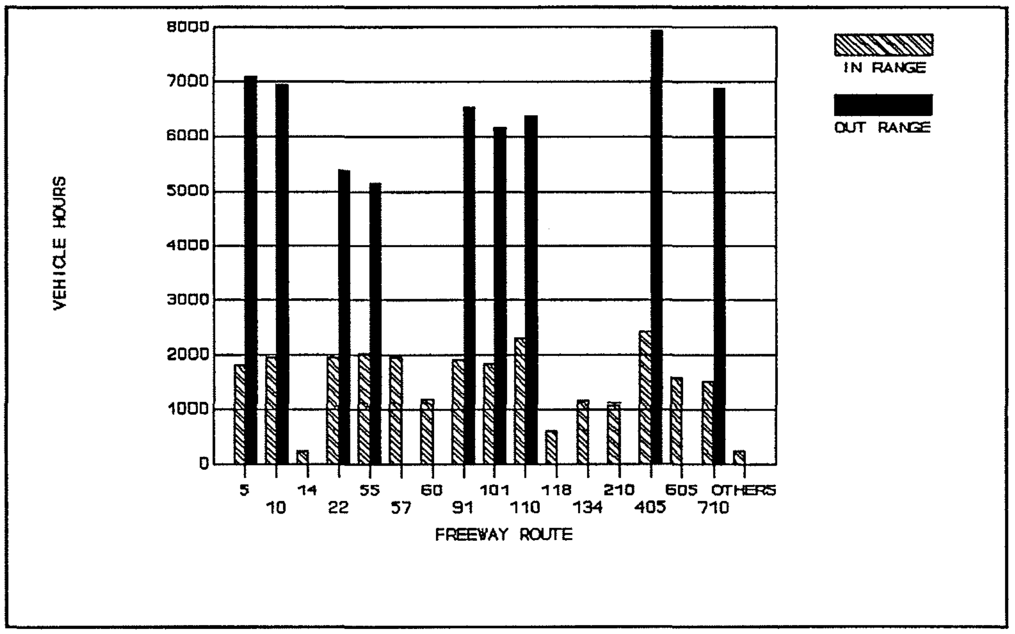

FIGURE 22
VEHICLE HOURS OF DELAY PER INCIDENT BY FREEWAY ROUTE

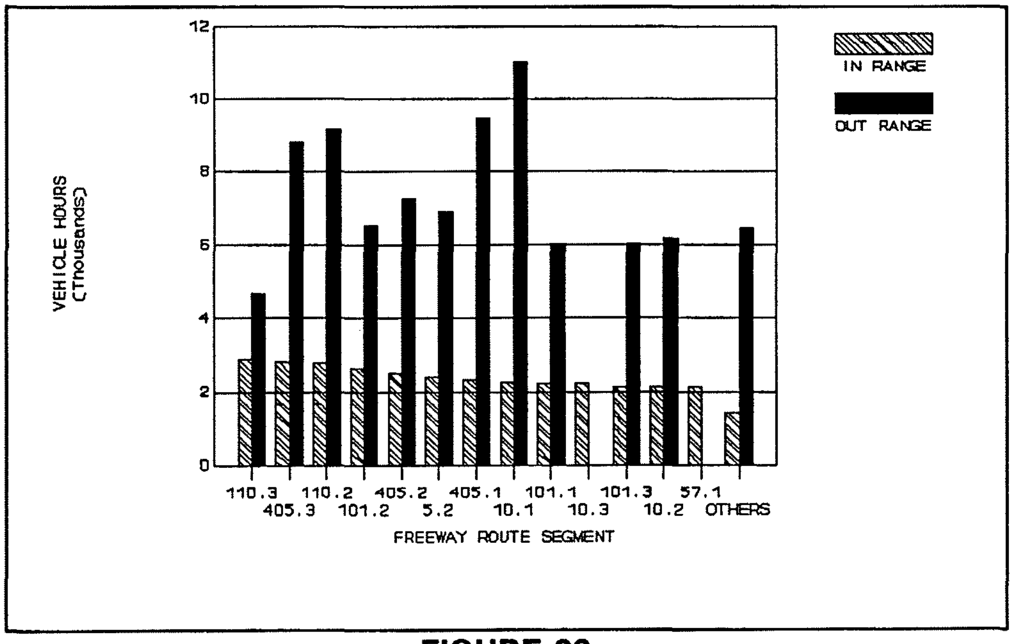

FIGURE 23
VEHICLE HOURS OF DELAY PER INCIDENT BY FREEWAY ROUTE SEGMENT

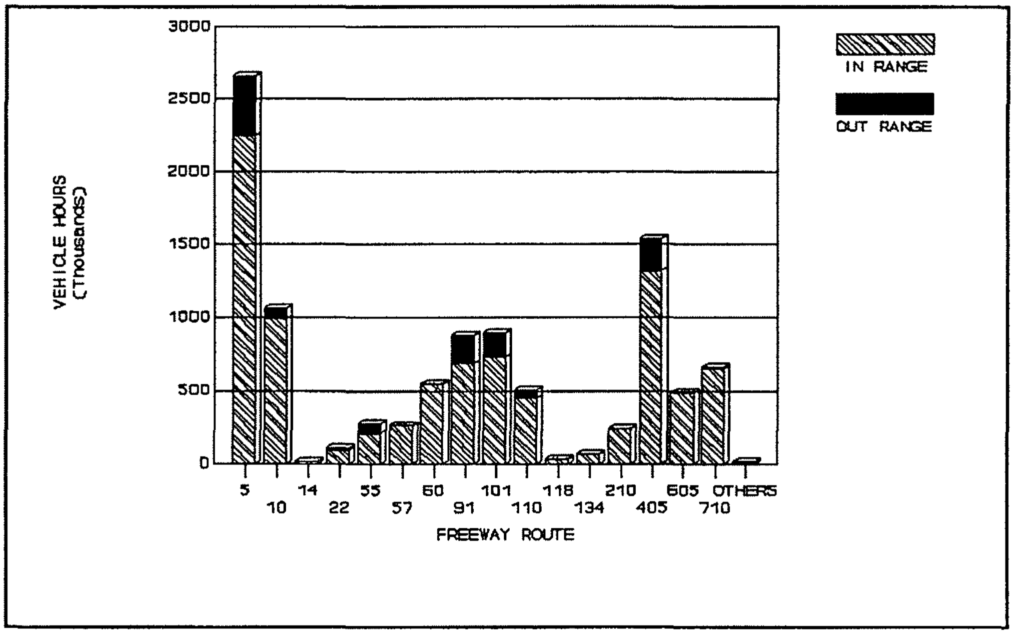

FIGURE 24
TOTAL VEHICLE HOURS OF DELAY PER YEAR BY FREEWAY ROUTE SEGMENT

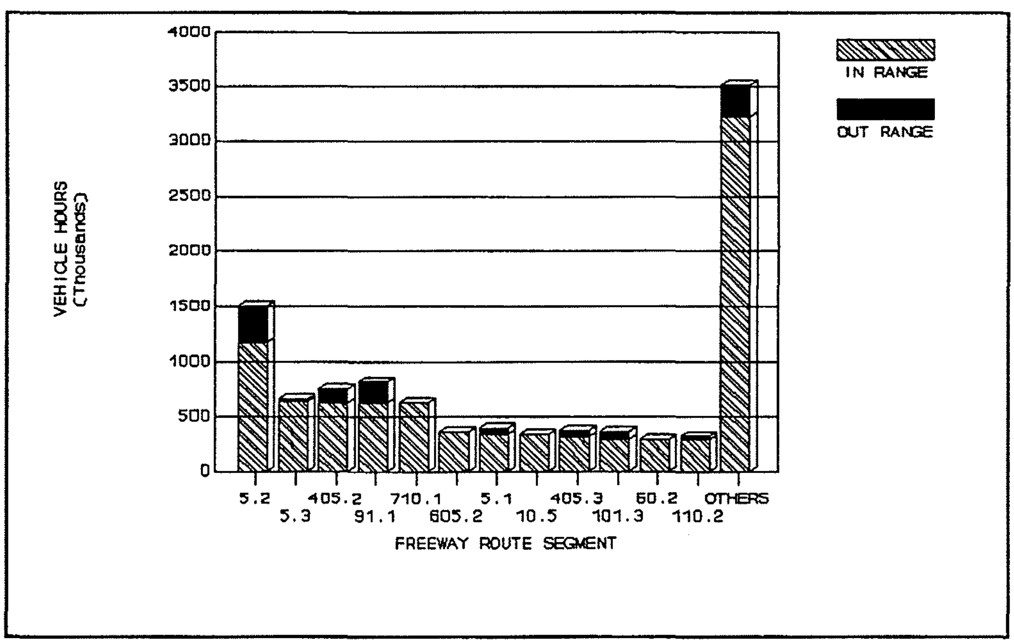

FIGURE 25
TOTAL VEHICLE HOURS OF DELAY PER YEAR BY FREEWAY ROUTE SEGMENT

CONCLUDING REMARKS

This study 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 is introduced in the estimation process that is in addition to that associated with the limiting assumptions of the models used. As a result, the estimates of delay presented here 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. (These latter issues are currently being addressed in a follow-up study.) However, few would argue that an annual additional delay of over 10 milliion vehicle-hours is insignificant.

ACKNOWLEDGMENTS

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