**Title**
Estimating the Full Economic Costs of Truck Incidents on Urban Freeways



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# Estimating the Full Economic Costs of Truck Incidents on Urban Freeways

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# I. INTRODUCTION

The impact of large trucks on urban freeways has been the subject of increasing concern among traffic engineers and transportation agencies. Fueled by the publicity given to major truck accidents, the perception has developed that trucks contribute disproportionately to accidents and to congestion caused by incidents on urban freeways. Major truck incidents, including vehicular collisions, overturned trucks, 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 of truck-related incidents on urban freeways, 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 operation, there has been little analysis of either the actual extent of the problem or the impacts of truck incidents on freeway congestion. This study addresses one aspect of the impact of truck-related freeway incidents, namely the economic costs of such incidents. Such costs consist of accident-related costs (vehicle repairs, medical expenses, economic losses associated with fatalities), increased vehicle operating costs due to the additional congestion, clean-up costs for such events as spilled loads or fires, and the economic costs of delay to motorists. Travelers' time has economic value, and congestion caused by truck-related incidents imposes economic costs on the community. The losses to society of this additional delay to individuals and commercial enterprises must be added to accident costs, increased vehicle operating costs, and clean-up costs to determine the full economic costs of truck-related incidents on urban freeways. This is the purpose of this study.

This study uses Los Angeles County as the setting for examining the full economic costs of truck-related freeway incidents. Los Angeles County was selected as a setting due to its size--over 7.5 million population in an area of 4,080 square miles, the highly developed nature of its freeway system (504 miles of freeway), the heavy truck traffic on that system (over 12 millon truck miles of travel per day), and the availability of data to facilitate analysis of this problem.

Another reason for using Los Angeles as the site for this study is that truck-related incidents are a significant and growing problem on the Los Angeles freeway system, one which the California Department of Transportation is also examining. The majority of major incidents on the Los Angeles freeway system involve one or more trucks. 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 trucks occurred on the freeway system. In other words, a major truck-related incident occurred nearly three out of every five working days of the week. Moreover, data collected for this study indicates that 6,700 to 8,000 total truck incidents occur annually on the Los Angeles County freeway system, or approximately 20 to 25 truck incidents per weekday. The scope of the problem in Los Angeles makes it an excellent setting for analyzing the costs of truck-related freeway incidents.

# II. METHODOLOGY

## 1. COMPONENTS OF FULL ECONOMIC COSTS

In examining the full economic costs of truck-related urban freeway incidents, this study focuses on four major cost components: (1) delay costs; (2) vehicle operating costs; (3) accident costs; (4) clean-up costs. Delay costs are defined as the monetary value of time lost in travel to occupants of both personal and commercial vehicles due to delay imposed by truck-related incidents. Only delay over and above that experienced without the incident is attributable to truck-related accidents; thus the delay caused by normal peak period congestion is factored out of the delay calculations. Additional vehicle operating costs are those attributable to congested flow conditions caused by incidents. These additional costs are almost exclusively a function of increased fuel consumption caused by speed changes. Accident costs consist of all property damage, injury-related costs (medical expenses, lost wages, etc.), and estimated fatality costs (which vary widely) caused by truck-related accidents on the freeway system. Clean-up costs are defined as the costs to public agencies and private organizations of removing material from the roadway and returning the roadway to a serviceable condition.

In the sections that follow, the methodology used for estimating the annual costs of truck incidents on the Los Angeles County freeway system is outlined and explained for each of these four major cost components. Before describing each cost methodology, however, it is necessary to describe the two major data sources which were used to determine the annual incidence of various types of truck-related incidents.

## 2. PRIMARY DATA SOURCES FOR DETERMINING THE NUMBER AND TYPE OF TRUCK-RELATED INCIDENTS ON LOS ANGELES COUNTY FREEWAYS

Two major data sources were used to estimate the number and type of truck-related incidents on the Los Angles County freeway system. One data source was the TASAS (Traffic Accident Surveillance and Analysis System) accident reporting system of the California Highway Patrol. This reporting system theoretically contains data on all accidents on the state highway system that involve police reports. In 1984, TASAS recorded nearly 3,200 truck-related accidents on the Los Angeles freeway system (not including ramp accidents). While TASAS provides comprehensive information on the characteristics of truck-related accidents, its usefulness for this study was limited because it does not include non-accident incidents. In addition, it does not include information on either the duration or the number of lanes closed by the accident. Thus TASAS was used primarily as a supplement to a second data source which included this information.

The second data source, and the major source of data for this study, was a 13-day sample of 239 truck-related incidents drawn from the dispatch logs of the California Highway Patrol's central dispatch center in Los Angeles County (which encompasses essentially all of the urbanized portion of the county). A random sample of 13 days in 1985 was sampled to ascertain the characteristics of both accident and non-accident truck incidents. Every truck-related incident which occurred on the 13 days selected and which either lasted at least 15 minutes or which closed at least 1 lane was recorded. Information collected included type of incident (accident, spilled load, stalled truck, or fire), incident location and time of incident, duration of the incident, and the number of lanes closed by the incident. It bears emphasizing that incident duration is defined as the time from when the incident was reported to the CHP--which may be several minutes, or even much longer, after the incident actually began--to the time when the CHP officer in the field reported that the incident had been cleared. Traffic congestion caused by the incident could continue long after the incident was reported to be cleared. Incident duration, as defined in this study, is thus understated by an unknown amount. It was assumed that incidents which lasted less than 15 minutes and closed no lanes had sufficiently small impact on traffic that they could be excluded from the analysis. (As noted below, provision was made in the analysis for the TASAS accidents which did not appear in CHP incident logs.) A separate data set was used to determine daily and hourly traffic volume at the freeway location where the incident occurred.

## 3. THE 13-DAY INCIDENT SAMPLE

In order to determine the characteristics of truck-related incidents, data were collected on all such incidents meeting the above criteria for 13 randomly selected days in 1985. A total of 239 truck-related incidents occurred on the Los Angeles freeway system during these 13 days. Figures 1 through 5 provide information on the characteristics of these incidents.

Approximately 28 percent of these incidents were accidents; the remainder involved spilled loads, fires, and stalled vehicles (Figure 1). Nearly 50 percent of the incidents did not close any freeway lanes, but were nonetheless serious enough to warrant a CHP response, and probably caused at least minor slowing of traffic

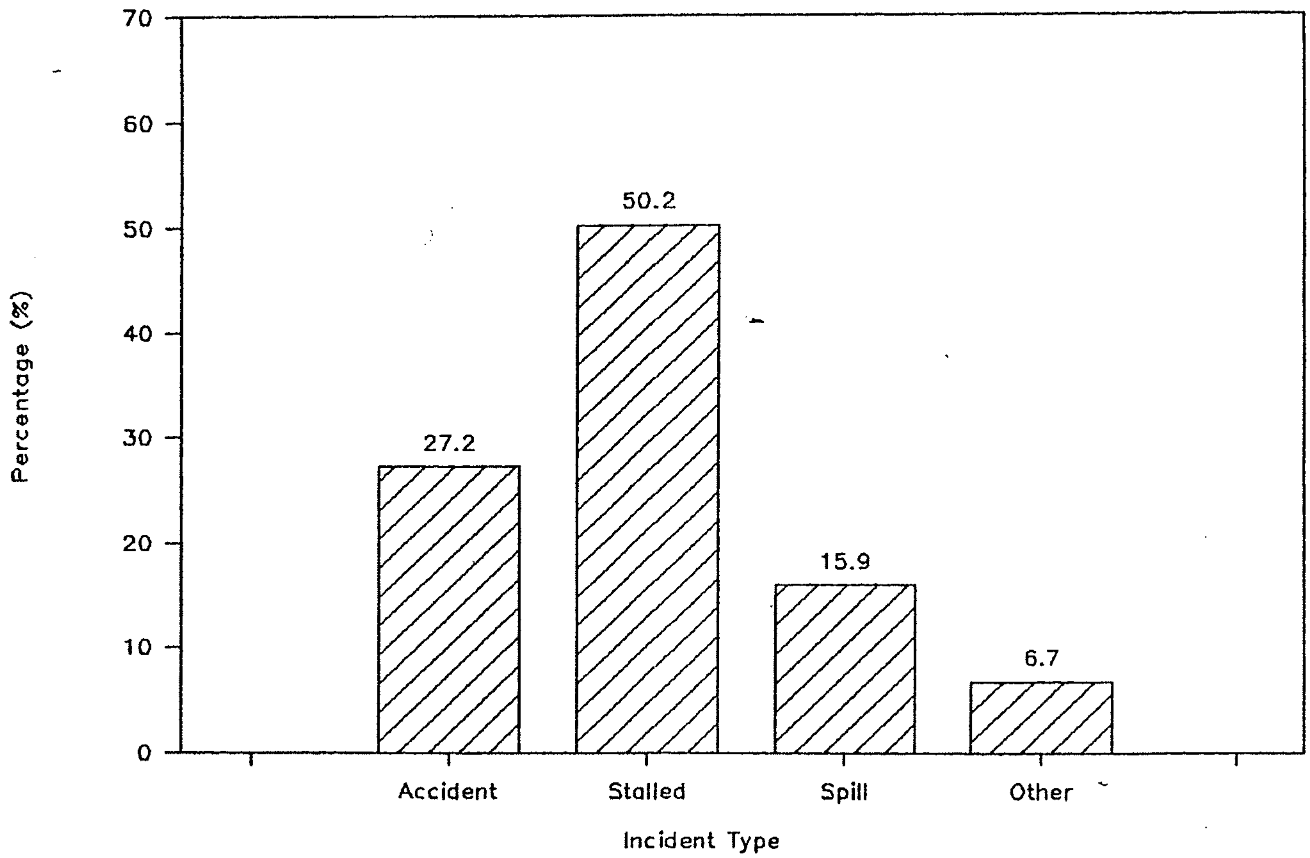


**FIGURE 1**

SAMPLE DISTRIBUTION BY INCIDENT TYPE

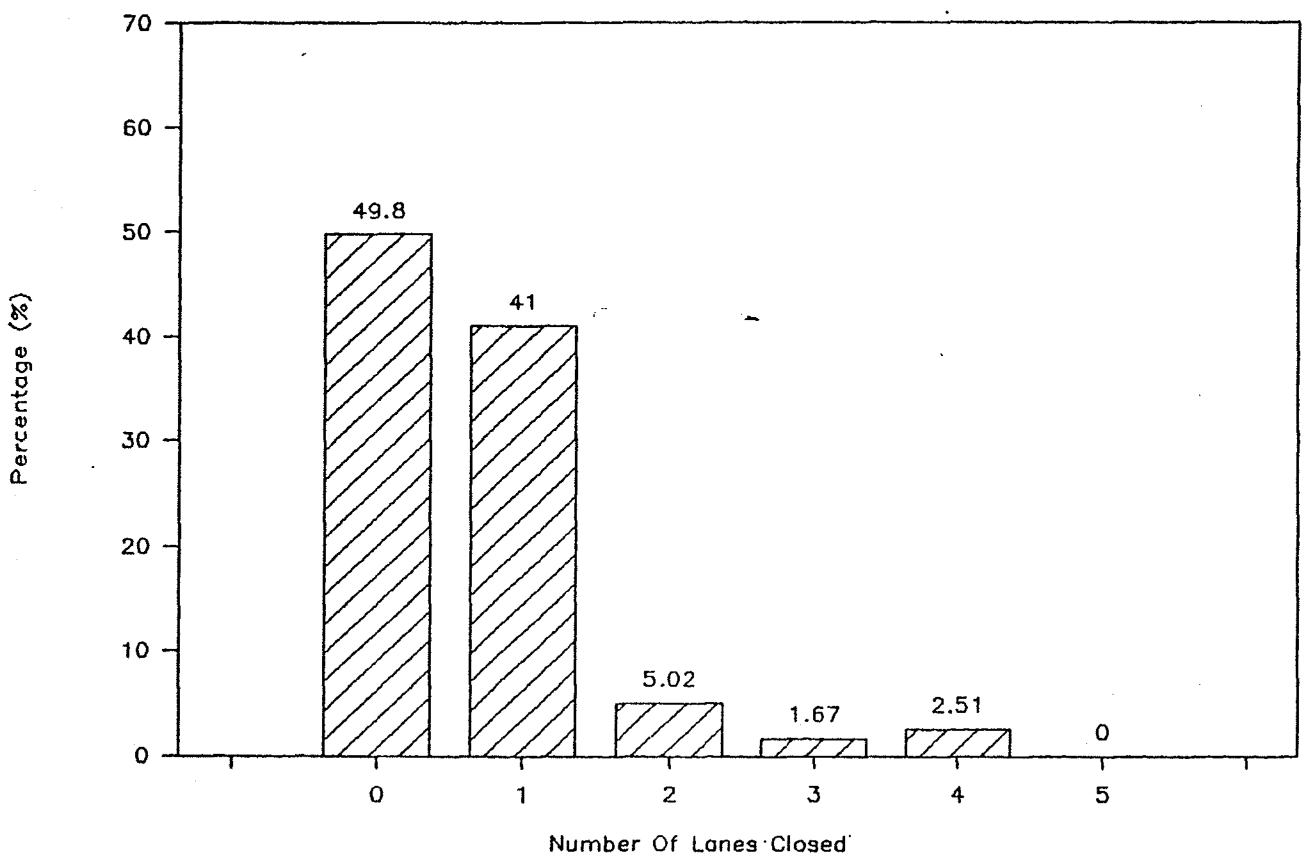


**FIGURE 2**

SAMPLE DISTRIBUTION BY NUMBER OF LANES CLOSED

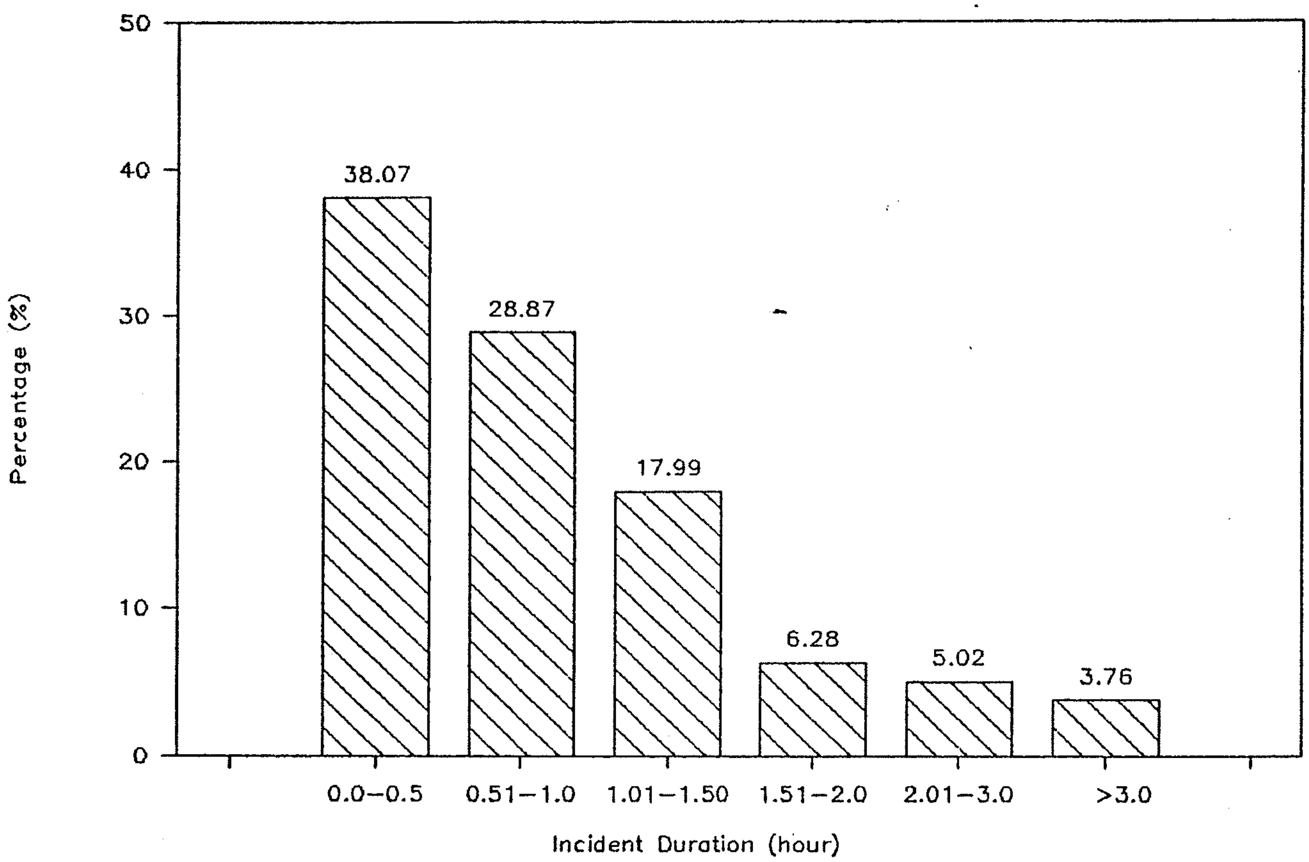


**FIGURE 3**

SAMPLE DISTRIBUTION BY INCIDENT DURATION

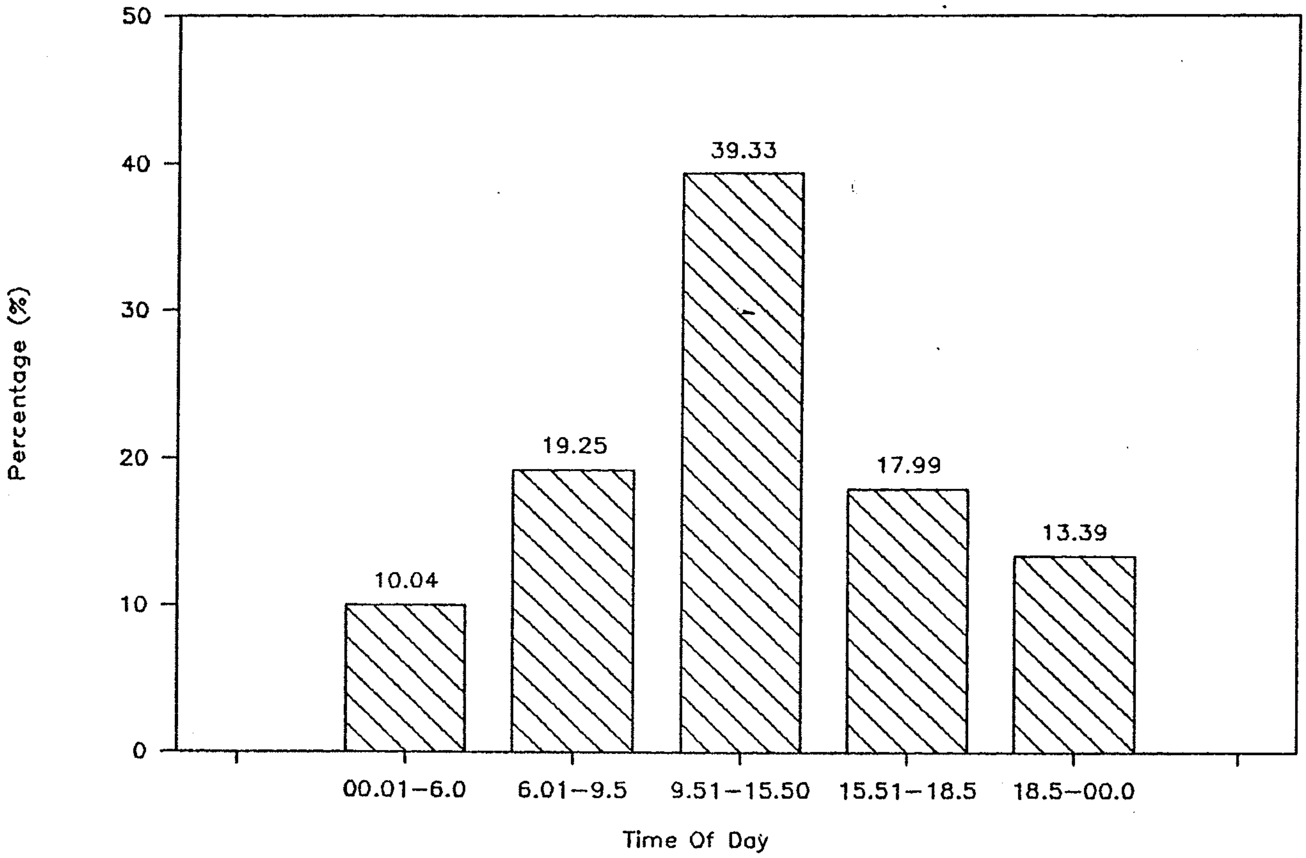


**FIGURE 4**

SAMPLE DISTRIBUTION BY TIME OF DAY

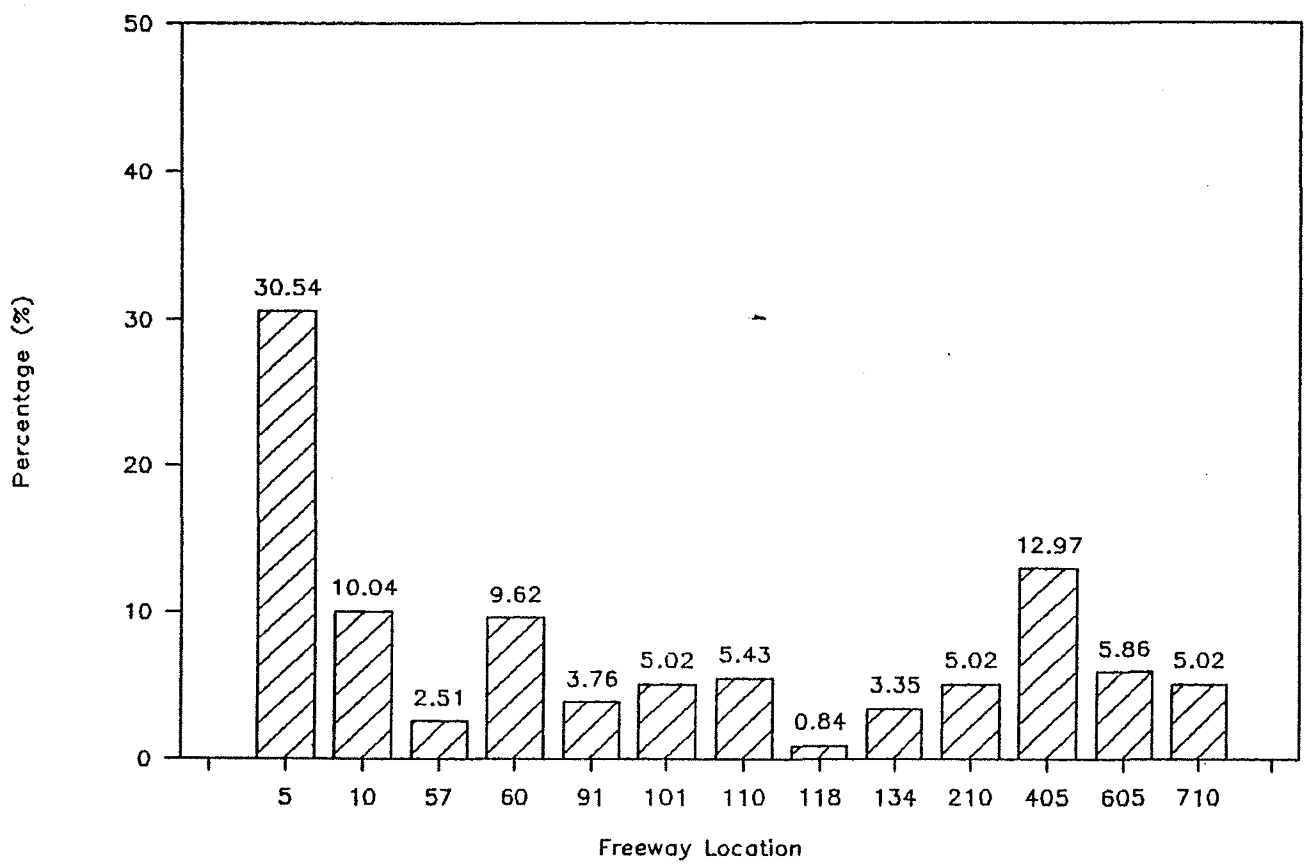


**FIGURE 5**

SAMPLE DISTRIBUTION BY FREEWAY LOCATION

(Figure 2). While two-thirds of the incidents lasted less than 1 hour, 9 percent had a duration of more than 2 hours (Figure 3). The incidents were spread throughout the day, with no noticeable peaking during periods of heavy or (relatively) light traffic (Figure 4). In addition, the incidents occurred throughout the freeway system. Some freeways were impacted more heavily than others, however, primarily those with more miles in the County and heavier truck traffic. In particular, I-5, which has both the largest number of freeway miles and the highest truck traffic (it is the major truck route from San Diego to Los Angeles, and from Los Angeles to San Francisco and Sacramento), is heavily impacted by truck-related incidents, with 30 percent of all incidents in the sample occurring on this freeway.

Comparison of the CHP incident sample with the TASAS data for the same days revealed underreporting of accidents for the CHP sample. The TASAS data set recorded nearly twice as many freeway accidents on these 13 days as did the CHP logs. For all of 1985, the 13-day incident sample predicted 1,825 truck-involved accidents would occur, when in fact about 3,200 did occur. The reasons for this discrepancy are not apparent; nonetheless, the difference indicates that accidents represent a higher percentage of truck-related incidents than the CHP logs would imply, and the overall number of incidents is greater. However, these accidents (and the resulting incidents) must have been minor since they either did not warrant a CHP response or if they did, it was of less than 15 minutes duration. These accidents almost certainly did not close any lanes. Thus they probably caused little delay. Accordingly, these additional accidents were used in the calculation of incident costs, but only a small level of delay was associated with them.

## 4. SELECTION OF REPRESENTATIVE INCIDENTS FOR DELAY SIMULATION

Because the freeway simulation model used for determining the delay caused by truck-related incidents requires significant computer resources, it was not possible to simulate all 239 incidents which occurred on the 13 days in 1985. Instead, a smaller sample was selected to represent the total number of incidents in the CHP sample. Computer simulations were done for 92 incidents, 20 of which were selected from the 239 incident sample and 72 of which were selected from a similar sample of 332 truck-involved accidents obtained from the CHP logs. (The accident sample was selected for use in another study.) The selection was based on the type of the incident, the duration of the incident, the number of lanes closed by the incident, and the location of the incident on the freeway system. In addition, because freeway volume at the time of the incident has a major influence on the magnitude of any resulting delay, ADT (Average Daily Traffic) at the freeway location of the 92 selected incidents was compared to the frequency distribution of ADT for the entire 239 incident sample. Tables 1 through 4 show comparisons of the relevant characteristics of the 92 incidents used for the simulation analysis and the entire 239 incident sample. This comparison indicates that the 92 incidents used in the computerized traffic simulations are reasonably representative of the entire incident sample in terms of volume and time of day of incident occurrence, but tend to be slightly longer and to have more lanes closed. This indicates that the simulation results may overpredict delay relative to the true situation.

## TABLE 1

DURATION OF INCIDENT

| Duration (Hours) | 92 INTRAS Simulations | 239 Incident Sample |
|---|---|---|
| 0 - .5 | 25.5% | 38.1% |
| .5 - 1.0 | 40.4% | 28.9% |
| 1 - 1.5 | 12.8% | 18.0% |
| 1.5 - 2.0 | 10.6% | 6.3% |
| 2 - 3 | 6.4% | 5.0% |
| > 3 | 4.3% | 3.8% |

## TABLE 2

NUMBER OF LANES CLOSED BY INCIDENT

| Number of Lanes Closed | 92 INTRAS Simulations | | 239 Incident Sample | |
|---|---|---|---|---|
| 0 | 44.6% | | 49.8% | |
| 1 | 30.4% | | 41.0% | |
| 2 | 15.2% | 25.0% | 5.0% | 9.2% |
| 3 | 6.5% | | 1.7% | |
| 4 | 3.3% | | 2.5% | |

## TABLE 3

AVERAGE DAILY TRAFFIC AT INCIDENT LOCATION

| Annual ADT | 92 INTRAS Simulations | 239 Incident Sample |
|---|---|---|
| < 100,000 | 8.5% | 17.3% |
| 100 - 133,000 | 16.0% | 14.4% |
| 133 - 167,000 | 29.8% | 26.7% |
| 167 - 200,000 | 26.6% | 20.8% |
| 200 - 233,000 | 14.9% | 14.4% |
| > 233,000 | 4.3% | 6.4% |
| | | **(N = 207)** |

## TABLE 4

TIME OF DAY OF INCIDENT

| Time of Day | 92 INTRAS Simulations | 239 Incident Sample |
|---|---|---|
| 12 p.m. - 6 a.m. | 6.4% | 10.0% |
| 6 a.m. - 10 a.m. | 24.5% | 22.5% |
| 10 a.m. - 3 p.m. | 35.1% | 32.8% |
| 3 p.m. - 7 p.m. | 27.6% | 22.5% |
| 7 p.m. - 12 p.m. | 7.7% | 12.2% |

## 5. TRAFFIC SIMULATION MODEL

In order to determine the delay caused by the truck-related incidents, a traffic simulation model was used to simulate traffic conditions on the freeway both with and without the incident. This traffic simulation model, INTRAS, is a detailed microscopic simulation model which is based on car-following theory. The INTRAS model actually generates individual vehicles and follows their progression through a section of freeway using equations developed from car-following theory. The model is capable of handling lane changing and generates congestion internally when too many vehicles try to occupy a section of roadway. The model has been validated for Los Angeles conditions and appears to be capable of accurately simulating actual freeway situations.

The basic input data needed to operate the model are flow rates for the freeway section (including flow rates for on-and off-ramps), the number of lanes in the freeway section, and the prevailing free flow speed. To simulate incident conditions, the model also requires data on the number of lanes closed and the duration of the incident. Even when the incident does not close any lanes, the model has the capability of reducing freeway capacity to reflect "rubbernecking" by drivers, that is, the phenomenon of driver slowing to observe the incident.

## 6. SIMULATION OF DELAY BY INTRAS

To facilitate the INTRAS simulations, the entire Los Angeles County freeway system was first coded according to information contained in the TASAS highway records and in Caltrans postmile books. A corresponding incident file was created containing information pertinent to the incident (e.g., location, duration, time-of-day, lane closure pattern, etc.) The freeway network coded for each case study comprised a one-mile section of the mainline freeway immediately downstream of the incident, a section of the mainline freeway immediately upstream of the incident location of sufficient length (subject to certain limitations) to encompass any disruptive impact of the incident, and all ramps and connectors associated with the segment of mainline freeway modeled. 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 (which accounted for all but a few cases), the upstream length was selected such that the 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 accident 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. Consequently, additional arterial delay caused by diversion of freeway traffic to the surface streets is neglected. On the other hand, because INTRAS constrains vehicles to remain on the freeway, delay is overestimated for major incidents, when freeway traffic can reduce delay by diverting to the surface streets.

Traffic volumes loaded onto the network for each simulation were derived from Caltrans' published Annual Average Daily Traffic (AADT) counts (both for 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 10) and Harbor (Route 110) Freeways in July 1984, together with directional factors obtained from Caltrans for each freeway segment. Although it is judged that the volumes obtained from this process are the best estimates available, they nonetheless may be subject to considerable error; the effect of such error on the simulation results is unknown.

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 (commonly referred to as "gawking" or "rubbernecking") are subject to an input "rubbernecking factor" that represents the percentage decrease in ambient speed associated with this behavior. In the accident simulations, a "rubbernecking factor" of forty percent was assumed for all lanes within 250 feet downstream of the incident; a factor of twenty percent was assumed for all lanes between 250 and 500 feet downstream of the incident. Rubbernecking occurring on the opposite side of the freeway is not considered; this would result in an underestimation of the total incident delay.

For each "incident case" simulated, a "base case" corresponding to conditions exclusive of the incident was also simulated. Simulation of each "incident case" was continued beyond the actual duration of the incident until such a time that freeway conditions had returned to that predicted by the corresponding "base case" 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. Incident 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.

The simulations were performed on a MICRO VAX II with 16 MB of core memory. Computer time required for the simulations varied depending on the characteristics of any particular incident; typical times were on the order of twelve to twenty-eight hours per incident simulated.

## 7. GENERATING TOTAL ANNUAL DELAY CAUSED BY INCIDENTS

In order to estimate the total annual delay caused by truck-related incidents, the results of the 92 INTRAS simulations were used to develop predictive delay equations. Using multiple regression techniques, equations were developed which predicted incident delay as a function of the four variables which were statistically (and logically) determined to have the greatest impact on delay: (1) incident duration; (2) volume/capacity ratio (assuming a capacity of 2,000 vehicles per hour per lane with all lanes open) at the time and location of the incident; (3) whether any lanes were closed by the incident (a 0-1 variable); (4) number of lanes closed by the incident. These variables were used in linear, log-linear, and exponential forms in an attempt to develop the best regression equations.

Table 5 summarizes the effect of these variables on the INTRAS simulated delays. As expected, lane closures, high V/C ratio, and long durations are associated with the highest levels of delay. There is substantial variation in the sample, however, with the standard deviation exceeding the mean value of delay in many categories. Overall, the average incident produced 999 vehicle hours of delay, with a standard deviation of 2,040 vehicle hours. This high standard deviation is a function of many incidents with small delays and a few with large delays. For example, 23 percent of the incidents account for 74 percent of the total delay for the sample. These 21 incidents generated an average delay of 3,225 vehicle hours, whereas the 71 other incidents generated an average delay of only 342 vehicle hours, barely 10 percent as much.

A preliminary correlation analysis revealed that the log of delay was most highly correlated with candidate explanatory variables, suggesting a log linear relationship between the variables. Various model forms and variable combinations were tested using the SPSS multiple regression routines.

The log formulation greatly compresses the wide range of delay values represented by the 92 data points used in the estimation of the models. Because of this feature, relatively small errors in the estimates of the logarithms of large delays are

## TABLE 5

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

| Lanes Closed | Duration Hours | V/C | Cases | Mean Delay (Veh.-Min.) | Standard 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** |

magnified greatly upon inversion. This problem is exacerbated by the skewedness of the sample toward incidents which result in small 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.

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

$$ADELAY = D^{0.73} \exp[-1.09 + 1.85L + 5.68 (V/C)]$$

where

ADELAY = Additional delay per vehicle.
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 2,000 VPH.
D = Duration of the incident in hours (measured as the time from the initial reporting of the incident until the incident is cleared).

The $R^2$ for the model is .70, and all coefficients are statistically significant at the .01 level.

## 8. DELAY COSTS

In order 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 AASHTO's, *A Manual on User Benefit Analysis of Highway and Bus-Transit Improvements, 1977* (AASHTO, 1978). The approach used in this manual is to assign a different value of time to Low, Medium, and High time savings, based on 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 small time savings as less than 5 minutes, medium time savings as 5 to 15 minutes, and high time savings as more than 15 minutes. The values cited for 1975 time values in the AASHTO manual were adjusted to 1985 (all economic analysis was conducted using 1985 dollars) values by using the increase in the annual compensation per full-time equivalent worker over this 10 year time period. This resulted in a Low time value of $.42 per traveler hour, a Medium time value of $3.60 per traveler hour, and a High time value of $7.80 per hour. These values were multiplied by an average automobile occupancy of 1.30 to obtain the value of time per vehicle hour for various levels of time changes. AASHTO cited a value of about $7.50 per hour for time savings for trucks for 1975, and this was updated to $15.00 per truck hour for 1985 conditions.

## 9. 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 running costs and, in particular, fuel consumption costs. The 1975 values cited in the manual were adjusted to 1985 values by applying the increase in the transportation CPI for personal transportation for this ten year period.

## 10. ACCIDENT COSTS

Cost data for accidents involving trucks are relatively sparse. A 1982 study (Rollins and McFarland, 1986) provides direct costs for urban truck accidents, categorized by accident type and severity--namely property damage only (PDO) accident, injury accident, and fatal accident--in 1980 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 directly, they were used to adjust Caltrans values for accident costs for these three categories. The Caltrans accident cost values are not disaggregated by truck and auto accidents. Therefore, if the Rollins and McFarland data indicated that PDO truck accidents had 20 percent greater costs than PDO auto only accidents, the Caltrans accident costs were adjusted upwards for trucks by using this cost differential and the percentage of accidents in which trucks were involved.

As the values for accident costs in this study are a function of type of accident, the TASAS data set was used to determine the relative percentage of accidents occurring annually for each accident type. These percentages were then applied to the number of annual accidents which were classified as truck-related, yielding the estimated annual number of truck-related accidents of different types. The Caltrans accident costs are an average of 1983, 1984, and 1985 costs, so they are reasonably close to 1985 values.

## 11. CLEAN-UP COSTS

Estimates of clean-up costs are very difficult to ascertain. Because these costs are a function of the composition of the major incidents which occur during the year, they can vary significantly from year to year. Caltrans does not record information on the costs of cleaning up major incidents, but these do not represent total clean-up costs associated with all incidents during a year. Based on conversations with Caltrans officials, it was determined that a range of $500,000 to $2 million was probably reasonable for annual clean-up costs. Fortunately, clean-up costs are not a major component of the total economic costs of truck incidents, so the imprecision associated with these estimates does not have a major impact on the overall results.

# III. APPLICATION

## 1. DETERMINING THE COST OF DELAYS

Developing Delay Cost Factors

In order to determine the annual cost of delays associated with truck-involved incidents, it was necessary to estimate vehicular delays for the incident sample and then to apply a value of time to the delays experienced. These costs could then be extrapolated to the annual delay cost for incidents. This would have been a simple process if a single value of time had been used in the analysis. Because three different values of time were used, however, a more complex procedure was needed to produce estimates of the economic cost of delay.

The actual procedure used to produce estimated delay costs is as follows. To develop a relationship between a particular level of average vehicular delay and the value of that delay, 39 INTRAS simulated incidents were analyzed. For each of these simulated incidents, vehicles were classified during each 15 minute 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 congested section of roadway caused by the incident. This apportionment was based on a simple formula derived from empirical analysis of several incidents. 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 shows how the formula was established.

For an average delay of 4 minutes, for example, 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 who 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

**TABLE 6**

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% |

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 or the sum of all vehicle delays will be too low.)

Because the volume of trucks by time of day on any particular freeway was not known, the overall truck percentage on the Los Angeles County freeway system was used in determining the commercial vehicle delay costs of the 39 incidents. In 1985, the overall truck percentage was 8.2 percent of ADT. Because the economic cost of individual truck delays does not depend on the actual level of the delay, the value of $15.00 per hour was applied to the total truck hours of delay associated with the incident.

After applying this procedure, the total automobile (which includes light trucks) volume affected by the incident during each 15 minute time interval was categorized by one of the four levels of delay per vehicle--100, 75, 50, or 25 percent--using the formula in Table 6. Depending on the actual number of minutes associated with that level of delay, one of the three values of time was assigned to that level of delay, and the affected volume multiplied by the number of minutes of delay and the relevant value of time. The result was added to the delay cost for trucks for that time period. This produced an economic cost of delay for that time period. This procedure was repeated for all time periods in which congestion occurred, and the results were then summed to produce an economic cost of delay for the entire incident.

With this procedure, incidents which produced small delays per vehicle yielded disproportionately lower economic costs of delay than incidents which resulted in large delays per vehicle, due to the use of different values of time. An incident which caused 100 vehicle hours of delay might have a calculated delay cost of $150, whereas an incident with 1,000 vehicle hours of delay--10 times as much delay--might have a calculated delay cost of $6,000, or 40 times greater than the first incident.

This procedure was applied to each of the 39 incidents, yielding economic costs of delay for each incident. From these results, total delay costs were determined for all 39 incidents, as well as total vehicle hours of delay. The ratio of these two values was the average economic cost for one hour of vehicle delay. This value was $8.28 per vehicle hour. In addition, a simple two-variable linear regression was done between the delay costs and the total vehicle delay for the 39 incidents, with the regression line constrained to go through the origin. This yielded a second estimate of the cost of one hour of vehicle delay, namely $8.99 per vehicle hour. (The regression had an $R^2$ of 0.97.)

To check the reasonableness of these results, they were compared to the cost of delay computed from a study by the Southern California Association of Governments (SCAG) entitled, *The Costs of Congestion in the SCAG Region* (SCAG, 1987). The SCAG study used a rather different methodology than that employed in this study, and it focused on recurrent delay, but the intent was the same: to determine the economic cost of delay. The SCAG study appears to have significantly underestimated truck hours of delay, so only the economic cost of auto delays were compared. In addition, the SCAG study used a very high value of time for automobile business trips--approximately $28 per hour. While this may be justified, it is not consistent with the AASHTO methodology. Consequently, the SCAG results were modified to give automobile business trips a time cost of $10.14 per vehicle hour, the highest value of the AASHTO methodology. With this modification, the results of the SCAG study implied a delay cost of $5.70 per person hour of delay for automobile users. This value is exactly the same as that found in costing out the 39 INTRAS simulated incidents using the above methodology. (After factoring out the truck delays and dividing by an auto occupancy of 1.3, the value of $8.28 per vehicle hour is transformed into $5.70 per person hour of delay for automobile users.) The delay cost factor developed here thus appears to be consistent with at least one other major study of congestion costs.

Not only do the delay cost factors appear reasonable, but it is significant that the 39 incidents used to develop the delay cost factors had predicted delays (from the regression model) which were similar in magnitude to the incident sample (at least that part of the sample to which the regression model of delay could be validly applied). The 24 simulated incidents from this subsample to which the regression equation could be applied had an average predicted delay per vehicle only 3 percent less than the 156 incidents from the total incident sample to which the regression equation could be applied.

Determining Annual Incident-Related Vehicle Delays

To determine annual truck incident-related delay, the regression model of delay described previously was applied to the 239 incident sample. Because some data elements were missing for some of these incidents, delay estimates could be made for only 207 incidents. Of these 207 incidents, 56 either had all lanes closed (in which case the model could not be used) or the model predicted either a total incident delay of more than 7,500 vehicle hours or a delay per vehicle of more than 60 minutes. These upper bound values for the valid range of the regression model represent, respectively, the upper limit of total incident delay and the 95th percentile of delay per vehicle.

For the 156 incidents to which the model could be validly applied, the model predicted an average delay of 779 vehicle hours per incident, or about 17.4 minutes of delay per affected vehicle. The delay varied significantly by type of incident, with accidents having the highest predicted delay, followed by spills, stalls, and fires and miscellaneous incidents. Table 7 shows the mean values of delay per incident and per affected vehicle for each of the four major incident types. As would be expected, the distribution of delay per incident is heavily skewed, with the majority of incidents having a predicted delay of less than 100 vehicle hours, or less than 20 percent of the mean delay. Table 8 shows the distribution of delays for the 156 incidents.

**TABLE 7**

INCIDENT DELAY BY TYPE OF INCIDENT

| Type of Incident | Delay per* Incident | Delay per Vehicle |
|---|---|---|
| Accidents | 1,179 VH | 18.4 minutes |
| Spills | 780 VH | 19.6 minutes |
| Stalls | 530 VH | 13.4 minutes |
| Fires, Other | 154 VH | 4.8 minutes |

* Does not include estimates of delay for "major" incidents.

**TABLE 8**

DISTRIBUTION OF DELAYS

| Predicted Delay | Percent |
|---|---|
| 0 - 100 VH | 59.0% |
| 100 - 500 VH | 19.1% |
| 500 - 1,000 VH | 6.9% |
| 1,000 - 2,500 VH | 6.4% |
| 2,500 or more VH | 8.5% |

Because the 56 incidents whose delays could not be predicted by the model were all "major" incidents, a separate calculation of delay needed to be performed for these incidents. These other incidents affected an average of 8,710 vehicles per incident (this was determined based on the flow rate in vehicles per hour at the point of the incident multiplied by the duration of the incident). A primary reason that these were major incidents is that they affected so many vehicles, more than 3 times as many per incident as the incidents to which the predictive model could be applied.

Three different assumptions, corresponding to three different magnitudes of delay, were used to estimate the level of delay experienced by the vehicles affected by these major incidents. For the Medium scenario, each affected vehicle in any incident which did not block all freeway lanes was assigned a delay of 30 minutes, except for incidents of less than one hour duration for which each vehicle was assigned a delay of 15 minutes. For incidents which did block all freeway lanes, vehicles in the Medium scenario were assigned delays of 45 minutes or 60 minutes depending on the duration of the incident, with the larger values assigned to incidents of more than 2 hours' duration. These values were based on judgment, but were reasonably consistent with the results of INTRAS simulations for major incidents which blocked either all lanes or all but one lane. Delays per vehicle were adjusted downward somewhat from the INTRAS values to reflect the presumption that major incidents will cause some vehicles to divert to the surface streets to avoid the congestion created by the incident (although the alternate routes will themselves have higher travel times than the freeway without the incident). These assumptions yielded an average delay per incident in the Medium scenario of 4,022 vehicle hours for the major incidents.

For the Low scenario, the average delay per incident for the major incidents was taken to be 50 percent of the Medium scenario, or 2,011 vehicle hours per incident.

For the High scenario, different criteria were used to determine which incidents were regular or major incidents. Regular incidents were defined as those which either did not close all lanes or which had a predicted delay of less than 90 vehicle minutes per vehicle, the upper limit of the INTRAS simulations. There were 164 such incidents, with an average delay of 1,227 vehicle hours per incident. Major incidents were assigned delays per vehicle of 60 minutes or 30 minutes (for duration less than one hour) for incidents which did not block all lanes, and 45 to 90 minutes (depending on duration) to incidents which did block all lanes. These assumptions yielded an average delay per incident of 6,499 vehicle hours for the 43 major incidents.

Combining the delay calculations for regular incidents and major incidents yielded an estimated average of 1,656 vehicle hours of delay per incident for the Medium scenario, 2,322 vehicle hours of delay for the High scenario, and 1,112 vehicle hours of delay for the Low scenario. The effect of the contribution of the major incidents, therefore, is to increase the average delay per incident by 40 percent to 110 percent, depending on the assumptions made. The average delay per vehicle increases by a smaller amount, by 32 percent for the Medium and High scenarios.

To check the reasonableness of this procedure, the results of the delay calculations for the accidents in the incident sample were compared to two other calculations of delay for truck-related accidents. For accidents whose predicted delay was outside the range of the regression model, one procedure truncated the estimates obtained from the regression model, while the other used Caltrans' estimate of delay for major incidents (as a function of duration) to assign a value of delay. The first procedure yielded an average delay per accident of 2,722 vehicle hours, while the second procedure yielded an average delay of 1,183 vehicle hours per accident. The procedure used here for the Medium scenario resulted in an average delay per accident of 2,179 vehicle hours, well within the range of these other two estimates. The High scenario yields an estimate of 2,952 vehicle hours per accident and the Low scenario results in 1,490 vehicle hours per accident.

The estimates of vehicle delay per incident for each incident type were then applied to the annual estimate of number of incidents of each type to obtain total annual vehicle hours of delay for all truck-related incidents. Factoring up the 239 incidents for 13 days to an annual total yields 6,710 incidents in 1985. These 6,710 annual incidents are predicted to result in a total annual delay of 7.46 million to 15.58 million vehicle hours on the freeway system.

In addition, any delay associated with the accidents recorded in the TASAS data base, but not recorded as part of the CHP incident sample, must be added to this value. In 1985, 3,171 truck-related accidents were recorded in TASAS for the Los Angeles County freeway system, while the incident sample projects to only 1,825 annual accidents. These additional 1,346 accidents clearly had minor impacts, as they did not block a lane, lasted less than 15 minutes, or did not even result in a CHP response. How many vehicles were affected by these accidents is unknown, as is the level of delay they caused. As a conservative estimate, it was assumed that these accidents affected as many vehicles as the average non-major incident, and that they caused a delay per affected vehicle approximately equal to the median value of delay per vehicle predicted for the non-major incidents. This value was slightly more than 1.5 minutes, which was rounded upwards to 2 minutes. The result was an average delay per accident of 90 vehicle hours for these 1,346 accidents. Total annual delay is 121,140 vehicle hours. This value was added to the results for the 6,710 incidents.

Table 9 provides a summary of the delay calculations for the Medium scenario. As can be seen, incidents caused by stalled trucks and truck breakdowns represent about half of the total incident delay, a rather surprising finding. Accidents cause over one-third of total truck-related delays. In contrast, spilled loads, which have the potential for causing truly massive delays, represent the source of only one-eighth of annual truck

**TABLE 9**

ANNUAL DELAY BY TYPE OF INCIDENT

| Type of Incident | Vehicle Hours of Delay | Percent |
|---|---|---|
| Accident | 4,097,815 | 36.3% |
| Stalled Truck/Breakdown | 5,717,193 | 50.7% |
| Spilled Load | 1,398,837 | 12.4% |
| Fire, Other | 69,370 | 0.6% |
| **TOTAL:** | **11,283,215** | **100.0%** |

incident-related delay. It bears noting that truck overturns which cause spilled loads may be classified by the CHP as an accident, so this category probably underestimates the total magnitude of the delay caused by spilled loads. On the other hand, major spilled load incidents are not particularly common events. In 1985, Caltrans recorded 64 major spilled load incidents (2 or more lanes closed for a predicted duration of 2 or more hours), of which over half were associated with an overturned truck. Yet the CHP incident data indicates that there were over 1,000 spilled load incidents in 1985. The vast majority of these incidents, therefore, must have involved relatively little spilled material which was quickly removed from the roadway, and probably did not involve an overturned truck.

Determining the Annual Cost of Incident-Related Delays

To determine the annual cost of delays associated with truck-related incidents, the delay cost factors previously developed were applied to the annual estimates of incident caused delays. Three estimates of delay cost were made. The High estimate uses the delay cost factor of $8.99 per vehicle hour developed from the regression equation for the 6,710 incidents and a value of time of $1.73 per vehicle hour for the 1,346 TASAS accidents. The latter is the weighted average of the truck value of time of $15.00 per hour and the auto value of time of $0.55 per vehicle hour for Low time savings. A separate delay cost factor is used for the TASAS accidents because of the small amounts of delay per vehicle associated with these accidents. The Medium and Low estimates use the average delay cost factor of $8.28 per vehicle hour for the incidents and the value of time of $1.73 per vehicle hour for the additional accidents.

The estimates of annual delay cost for each of these three computations are shown in Table 10.

## 2. DETERMINING INCREASED VEHICLE OPERATING COSTS

Increased vehicle operating costs are essentially a function of major speed changes which result in increased fuel consumption. The AASHTO manual provides estimates of the costs of speed changes per 1,000 vehicle cycles in 1975 dollars. The analytic task, therefore, was to determine how many vehicles in the incident sample were affected by speed changes, and the magnitude of the speed change involved, as different costs are associated with different types of speed changes.

**TABLE 10**

ANNUAL DELAY COSTS OF TRUCK INCIDENTS

| Scenario | Cost |
|---|---|
| High | $140,279,342 |
| Medium | $ 92,214,944 |
| Low | $ 61,990,957 |

The computations were carried out as followed. First, the 1975 costs in the AASHTO manual were updated to 1985 values using the change in the transportation CPI. Second, costs for truck speed changes were computed using a truck composition of 40 percent single unit trucks and 60 percent combination units. These percentages were derived from Caltrans data for the Los Angeles County highway system. Third, it was assumed that every incident caused a speed change from 60 MPH to 25 MPH. Any incident 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. This was purely an assumption, although it is not inconsistent with actual traffic flow behavior.

This procedure was applied to the 207 incidents, yielding an average increased vehicle operating cost per incident of $947. The same procedure was applied to the additional TASAS accidents, yielding an increased operating cost per accident of $160. (Recall that these accidents were assigned an average of only 2 minutes of delay per affected vehicle.) Factored up to the annual number of incidents and additional accidents, the result was an increase in vehicle operating costs of $6,569,730 for 1985.

### 3. DETERMINING ACCIDENT COSTS

Caltrans' accident cost data indicate a cost per urban freeway accident of $2,500 for property damage only 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 used by Caltrans is no exception, although it is reasonably consistent with values of life determined from other studies.

A comparison of truck and auto accident costs from studies compiled by Rollins and McFarland (1986) indicated that only for single vehicle accidents were the costs of truck involved accidents higher than those in which only automobiles were involved. This is a surprising finding, but no more adequate data are available to determine its validity. As single vehicle truck accidents represent about 10.5 percent of all truck accidents, the effect of higher truck accident costs for this category on the overall cost differential between auto and truck accidents is relatively minor. Truck involved accident costs for PDO accidents are probably about 30 percent greater than for auto only PDO accidents, based on the dated Rollins and McFarland study. The comparison is more difficult for injury and fatality accidents, but a reasonable assumption would be that truck involved injury accidents are 10 percent more costly than auto only injury accidents and that truck involved fatal accidents are no more than 5 percent more costly than auto only fatal accidents. Applying these adjustments to the Caltrans accident cost data, results in the following estimates of the cost of truck involved accidents: PDO--$3100; injury--$11,150; fatality--$556,500. These estimates were used for the Medium and High scenarios. The average Caltrans accident costs were used for the Low scenario.

Of the 3,171 truck involved accidents which occurred on the Los Angeles freeway system in 1985, 68.2 percent were PDO accidents, 30.5 percent were injury accidents, and 1.3 percent were fatal accidents. Applying these percentages to the total universe of truck involved accidents and using the appropriate accident cost factors results in the annual accident costs shown in Table 11. The total annual cost of truck involved accidents is estimated to be $40.3 million for the Medium scenario. Of this amount, about 55 percent is attributable to fatal accidents which, although few in number, have extremely high costs. Since considerable uncertainty is associated with the costs of fatal accidents, the total annual cost of truck involved accidents is also subject to uncertainty. Nonetheless, the annual truck accident costs determined by this analysis are consistent with standard Caltrans methodology for determining accident costs.

**TABLE 11**

ANNUAL COSTS OF TRUCK INCIDENT

| Number | Medium-High | Low | |
|---|---|---|---|
| PDO | 2,163 | $ 6,705,300 | $ 5,407,500 |
| Injury | 967 | 10,782,050 | 9,960,100 |
| Fatality | 41 | 22,816,500 | 21,894,000 |
| **TOTAL:** | **3,171** | **$40,303,855** | **$37,261,600** |

## 4. DETERMINING CLEAN-UP COSTS

As mentioned previously, definitive estimates of annual clean-up costs are not available, although some information on clean-up costs does exist. For purposes of this study, high, medium, and low values of $2 million, $1 million, and $0.5 million, respectively, were assumed, based on available information. As clean-up costs represent 1 percent or less of the total annual economic costs of incidents, the exact value of this estimate is not particularly important.

## 5. TOTAL ECONOMIC COSTS OF TRUCK-RELATED INCIDENTS

Table 12 provides an estimate of the total annual economic cost of truck-related incidents on the Los Angeles freeway system. The analysis undertaken for this study indicates that the annual cost of these incidents is in the range of $107 million to $189 million. As can be seen in Table 13, incidents which are accidents account for the majority of this cost, about $76 million of the Medium estimate of $140 million (54 percent). Delay costs are the largest component of total economic cost, representing 66 percent of the Medium total cost estimate. It also bears emphasizing that a relatively small portion of the incidents are responsible for the bulk of the costs. The "major" incidents and the fatal accidents (some of which are also major incidents) account for only 27 percent of the truck-related incidents in this cost estimation procedure, but are responsible but for over 60 percent of the economic costs of the incidents. The more

**TABLE 12**

TOTAL ANNUAL ECONOMIC COSTS OF TRUCK INCIDENTS

| | High | Medium | Low |
|---|---|---|---|
| Delay Costs | $140.28 million | $ 92.21 million | $ 61.99 million |
| Accident Costs | 40.30 million | 40.30 million | 37.26 million |
| Increased Vehicle Operating Costs | 6.57 million | 6.57 million | 6.57 million |
| Clean-up Costs | 2.00 million | 1.00 million | 0.50 million |
| **TOTAL ECONOMIC COSTS:** | **$189.15 million** | **$140.08 million** | **$106.82 million** |

typical incident imposes a relatively small cost on society, usually no more than a few thousand dollars, and frequently much less.

## IV. POLICY IMPLICATIONS

The procedures used in this analysis yielded an economic cost of truck incidents in Los Angeles County of over $100 million annually. The obvious question raised by

**TABLE 13**

TOTAL ECONOMIC COSTS BY TYPE OF INCIDENT
(MEDIUM COST SCENARIO)

| Incident | Cost (in millions) |
|---|---|
| Accident | $ 76.16 |
| Stall/Breakdown | 50.08 |
| Spill | 13.25 |
| Fire/Other | 0.59 |
| **TOTAL:** | **$140.08** |

this estimate is its comparative significance--that is, how much of the cost of all freeway incidents are trucks responsible for? While the dollar magnitude of the cost of truck incidents is impressive, it means little except when compared to a similar cost estimate for all incidents, or to the overall cost of congestion in the region.

Reliable estimates of the total economic cost of all freeway incidents in Los Angeles County are simply not available. The best benchmark for comparison is the Caltrans estimate of vehicle hours of delay. For 1986, Caltrans estimated that recurrent and non-recurrent congestion were responsible for 485,000 vehicle hours of delay per day on the Los Angeles County freeway system. Of this amount, approximately 50 percent--240,000 vehicle hours of delay--is believed attributable to non-recurrent delay, i.e., incidents. Using the overall average value of time of $8.28 determined from this study, these 240,000 daily vehicle hours of delay result in $506.7 million of delay cost per year, assuming 255 working days per year. There is additional delay--albeit of a proportionately smaller amount--on the weekends, but its magnitude has not been estimated by Caltrans. If non-recurrent delay caused by weekend incidents totals 10 percent of the weekday amount, the overall delay cost of incidents would be about $557 million per year.

SCAG's *Cost of Congestion* estimates of delay cost are virtually identical. SCAG estimated that the annual delay cost of recurrent weekday congestion is $507 million annually for the Los Angeles freeway system. Since non-recurrent congestion is assumed to be equal in magnitude to recurrent congestion, this indicates a delay cost for all weekday incidents of about $507 million per year. Adding 10 percent for weekend incidents would increase this estimate to $557 million per year.

The Caltrans estimate that non-recurrent delays are essentially equivalent to recurrent delays is not based on convincing empirical evidence, but represents professional judgment in combination with observation of the freeway system's operation. It is not implausible that non-recurrent delay is only 50 percent of recurrent delay. If this were the case, the delay cost of incidents would be about $280 million per year.

As the previous analysis has shown, estimates of the delay cost of truck-related incidents range from $62 million to $140 million annually. Depending on which of these estimates is accepted, and which of the estimates of total non-recurrent delay appears most plausible, this analysis indicates that truck incidents account for 12 percent to 50 percent of the total incident-related delay on the Los Angeles County freeway system. As noted previously, the level of delay per incident associated with the High cost scenario is probably unrealistically high, so the upper bound of the above range is a relatively unlikely estimate of the contribution of trucks to incident-related delay. Assuming that the Low and Medium cost scenarios are more realistic, and that total incident related delays cost about $420 million per year--the midpoint of the upper and lower bound estimates--truck incidents represent 15 percent to 22 percent of total incident delay costs.

To place these results in perspective, truck vehicle miles of travel represent approximately 8 percent of total vehicle miles of travel on the Los Angeles County freeway system. Thus, trucks appear to contribute 2 to 3 times as much delay cost as their proportion of the traffic stream. If this is an accurate analysis of the relative contribution of truck incidents to the total delay cost of incidents, it indicates a disproportionately heavy impact by truck traffic on non-recurrent congestion.

Although the estimate that truck-related incidents cause 2 to 3 times as much delay as their proportion of traffic is not one that can be made with high statistical confidence, the range of estimates made here indicate a high probability that trucks contribute to more incident-related delay than their share of traffic. Given this probable situation, what strategies are available which might mitigate this situation?

It bears noting that not only do trucks appear to cause a disproportionate share of non-recurrent congestion, but that the <u>impacts</u> of truck incidents are disproportionately concentrated in the peak periods. For the 239 incident sample, 37 percent of all incidents occurred during the peak period, but these peak period incidents accounted for 50 percent of all the delay caused by the total incident sample. The average peak period incident caused 70 percent more delay than the average off-peak incident, according to the modeling results. The reason for this phenomena is easy to discern. Peak-period incidents occur at a time when the volume to capacity ratio of the freeway is already high, and there is little or no spare capacity to absorb the impact of the incident. The result is substantial delay over and above that associated with freeway operations without the incident. This problem is not limited to trucks, of course. Automobile-only incidents during peak periods also have a disproportionately heavy impact on delay.

A second phenomena of relevance is that certain freeways are disproportionately impacted by truck incidents, namely those with the highest truck volumes. In Los Angeles County, this is primarily I-5. In addition, SR-60, I-405, and I-10 experience relatively high amounts of delay caused by truck incidents.

Given that truck-related incidents are not distributed uniformly in time and space on the Los Angeles freeway system, it may seem reasonable to advocate strategies which would restrict truck usage on certain freeways during certain hours of the day. Such strategies, however, would be extremely costly to the trucking industry and the shippers who use trucks. High volumes of trucks on certain freeways at certain hours of the day reflect a pattern of demand for truck transportation which is exogenous to conditions on the freeway system. To force the trucking industry to comply with time of day and route restrictions will, without major changes in labor agreements in the trucking industry and hours of operation for shippers, lead to significantly higher costs for many shippers and trucking companies. Widespread time-of-day and route restrictions, while offering the greatest potential for relief from the truck incident problem, are probably economically infeasible.

More moderate route and time-of-day restrictions might offer some potential for reducing incident related problems at lower cost to society. In particular, a decision to restrict trucks from certain freeway segments for perhaps 2 hours during both the morning and afternoon peak periods could have important beneficial impacts. Certain freeway segments are characterized by combinations of geometric conditions and volume levels which tend to result in major incidents when a truck incident occurs. (Much of I-5 south of downtown Los Angeles is an example of such a freeway segment.) By restricting trucks from these segments during peak periods, it may be possible to minimize the impact on the trucking industry and still provide significant reduction in the impact of truck incidents. A more detailed analysis, using data not available for this study, would be necessary to determine the economic and delay impacts of such a strategy of limited restrictions on peak-period truck movements.

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