Title
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Publication Date
2004-07-01

UCI-ITS-WP-04-3

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July 2004

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Submitted for presentation at the 2005 Annual Meeting of the Transportation Research Board

July 28, 2004

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ABSTRACT

Our objective is to determine how various types of truck accidents are related to traffic flow conditions and roadway characteristics on urban freeways. The case study involves data on 19,000 accidents that occurred over two years on six freeways in Orange County, an urbanized area of Southern California; over 10% of these accidents involved trucks with at least six wheels on the road. The propensity of truck-involved accidents is found to be a decreasing function of the number of lanes and the average annual daily traffic (AADT) per lane, and an increasing function of truck percentages of AADT, all factored by time of day and day of week effects and weather conditions. The likelihood of a truck being involved in an accident is particularly sensitive to proportion of large (five axle or more) trucks. Accidents involving lane changes are the prevailing type of truck accident, and about 42% of truck-involved accidents involve one of the first two vehicles changing lanes or merging, compared to only about 17% of accidents not involving trucks. In contrast, 45% of accidents not involving trucks are rear end collisions in which the involved vehicle are proceeding straight ahead, compared to only about 18% of truck-involved accidents. A multinomial logit model is used to determine differences in the traffic and roadway conditions conducive to three types of truck accidents: weaving, runoff, and rear-end accidents. Results show that patterns of truck and non-truck involved accidents vary substantially, and we point out some implications regarding mitigation strategies.

1 BACKGROUND

Little is know about how accidents involving trucks on urban freeways are different from accidents not involving trucks. Particularly, how do roadway and traffic conditions affect the likelihood of each type of accident, and are prevailing conditions different for different types of truck-involved accidents? In the future, it will be possible to effectively monitor traffic conditions in real-time. A solid understanding of the contributors to serious accidents should lead to the development of tools that will enable public agencies to intervene and prevent some of those accidents from occurring. Using the data that are currently available, our research examines how truck accidents are related to traffic flow conditions and roadway characteristics.

One important measure of the level of safety of any road network is the number of accidents, either total accidents or accidents of a specific type, per vehicle mile of travel. Considerable effort has been spent refining the analytical methods that relate crash rates to exposure measures (TRB, 1990), but there has been much less work in examining the effectiveness of aggregate data, such as average annual daily traffic (AADT), as the basis of exposure measures. When focusing on accidents involving trucks, it is unclear how annual data on truck traffic can be combined with total AADT as an effective measure of exposure to the risk of various types of accidents. It is quite common for motorists who travel on routes shared with trucks to complain about the negative impacts those vehicles have on driving conditions. However, little research has examined the safety impacts of commercial vehicle operations. In the future, accurate disaggregate data on traffic volumes and vehicle classifications may become available. Algorithms for accurately discerning speed and flow data from loop detectors have improved significantly over the past few years. However the use of existing loops for the accurate classification of vehicles will not be possible for some time. The use of loops for vehicle classification requires the wide spread installation of double, rather than single inductance loops. Its much more likely that before such an installation will take place, that other classification technologies will be adopted. However, the development and adoption of appropriate technologies has been much slower than previously predicted. In some sense, this work is a follow-on study to one produced using similar data (but different modeling techniques) nearly twenty years ago (Golob et al, 1986). That study examined over 9000 accidents involving large trucks and combination vehicles during a two-year period in the greater Los Angeles area. During the intervening period, despite the promises of intelligent transportation systems, almost no new accurate data sources for this type of analysis have become available. Therefore it is important that researchers find ways to combine and analyze all available data on traffic flow conditions and accidents.

An excellent literature review related to studies of accident severity is found in Chang and Mannering (1999). The U.S. Department of Transportation provides an analysis of motor vehicle crash data. The most recent of these examines 2001 data. That report shows that heavy trucks are involved in about four percent of accidents and about eight percent of fatal accidents (U.S. DOT, 2001). A recent study performed at the University of Michigan for the AAA foundation for traffic safety examines the unsafe driver actions that lead to fatal car-truck accidents (Kostyniuk, Streff and Zakarajsek, 2002). Their key findings were that four factors were more likely to occur in fatal car-truck accidents than fatal car-car accidents. These were following improperly, driving with obscured vision, drowsy or fatigued driving and improper lane changing. Another recent study examined the incidence of night time truck accidents, relative to car accidents and found that truckers driving at night were not more likely to be involved in accidents, while night time drivers of passenger cars were (Hendrix, 2002). And a study performed for the US Federal Motor Carrier Safety Administration (FMCSA), examined the link between driver schedules and safety (Crum, Morrow and Daecher, 2002). Their key findings were that company driving environments, economic pressures and company support for safe driving were the main factors influencing driver fatigue and hence truck-involved accidents. Another recent study of the impact of large trucks on interstate highway safety was conducted at the University of Kentucky in an effort to identify counter measures to be implemented in dangerous spots and sections on the interstate highways (Agent and Pigman, 2002). And, most recently, a study by Zaloshnja and Miller (2004) estimated the costs associated with large truck-involved accidents in the US. Their study put the costs at $59,153 per accident.

The Insurance Institute for Highway Safety examined twenty-five years of U.S. data on vehicle occupants in truck-involved accidents. Their key findings were that large truck involvement in fatal crashes has dropped substantially when measured per unit of travel, but the public health burden of large truck crashes, as measured by deaths per 100,000 population, has not improved over time because of the large increase in truck mileage (Lyman and Braver, 2003). Finally, a recent study of freight vehicle accidents in Taiwan uses a generalized linear interactive model to analyze major freight vehicle accidents across road types. The study found that accident rates on non-freeway roads were significantly higher than on freeways (Tsai and Su, 2004).

The goal of our study is to quantify relationships between truck-involved accidents and traffic flow on urban freeways, using Orange County California as a case study. The freeways in question, while somewhat heavily congested, are a more representative case study than those in LA County, several of which are suffering from critical levels of truck traffic. A preliminary report on our findings can be found in Golob and Regan (2004). That study identified sections of roadway with unusually heavy accident rates, relative to factors predicting accidents.

Our primary objective is to improve our understanding of how truck accident rates are related traffic flow conditions and to examine how patterns of truck-involved accidents differ from non-truck involved accidents. We show that the patterns of truck-involved and non-truck involved accidents are very different when compared to levels of traffic volumes. Our analysis could be used to inform resource allocation decisions involving accident mitigation and traffic calming. As far as we know, ours is the first study to examine traffic flow conditions and truck involved accidents.

2 DATA

This research uses two years of accident, roadway, and traffic data from the Traffic Accident Surveillance and Analysis System (TASAS) database maintained by the California Department of Transportation (Caltrans, 1993). TASAS data form the basis for California's contribution to the eight-state Highway safety Information System (HSIS). HSIS was set up in 1987 by the U.S. Federal Highway Administration to support studies of traffic safety on major U.S. highways (FHWA, 2004).

TASAS covers police-reported accidents that occur on the California State Highway System. Our study area encompasses six major freeways in Orange County, California, an urban area of about three million population located between Los Angeles and San Diego. These six routes account for a total of approximately 131 centerline miles. Of the 19,202 police reported accidents on these routes in 2000 through 2001, 1,952 or 10.2% involved trucks or tractor-trailers larger than two-axle, four-tire pickups and vans. The database contains information regarding the characteristics of each collision, including: (a) the postmile location of the primary collision, (b) the number of parties (usually vehicles) involved, (c) the movements of each vehicle prior to collision, (d) the location of the collision involving each party, (e) the object(s) struck by each vehicle, and (f) the severity, as represented by the numbers of injured and fatally injured parties in each involved vehicle. The database also includes information regarding weather and roadway conditions and ambient lighting. No information was available to us concerning drivers or vehicle makes and models, but vehicles are categorized as passenger cars, motorcycles, pickups and vans, trucks, and other types of specialized vehicles, such as buses and emergency vehicles. The database does not include collisions for which there are no police reports.

The TASAS database for freeways also contains roadway cross-sectional information on roadway width and surface type, number of lanes, shoulder width and width of shoulder pavement, median type and width, and terrain type. Most stretches of freeway in our study area have between three and six lanes in each direction, and the average number of lanes at the locations of the 19,202 accidents in 2000 and 2001 was 4.66. The database does not contain potentially important information on road alignment, such as the radius, deflection angle, and length of horizontal curves and the grade and direction of vertical curves. This unfortunate lack of roadway alignment data is not unique to California, as such data is available in limited form for only two of the eight states that encompass the Highway Safety Information System (FHWA, 2004).

Traffic data are available in terms of aggregate estimates of average annual daily traffic (AADT) for all freeway sections (Caltrans, 2003). AADT is defined to be total annual traffic (from October 1st of the previous year though September 30th of the year in question), and applies to all sections of a freeway bounded by on- and off-ramps and freeway-to-freeway connectors. Sample counts are performed using both portable counting instruments and permanent inductive loop detectors, and AADT is estimated using adjustments for seasonal and weekly variations. Sections refer here to bi-directional stretches of a route between complexes of on- and off-ramps at interchanges with arterials and other freeways, and the six freeways in our study account for a total of 131 sections. Due to the high correlation between the number of lanes at the location of an accident and the AADT on that freeway section, AADT per lane is used in some of our analyses. Roadway data on the number of ramps per freeway mile and the distance from an accident location to a ramp were computed using the postmiles of ramps that define the sections and the postmile of each accident.

Truck traffic counts are also available on an average annual basis (Caltrans, 2002). Truck counting is done throughout the State of California through a program of continuous truck count sampling. For freeways, this sampling includes partial day, 24-hour, and continuous vehicle classification counts, usually taken only once a year. Only selected freeway sections are sampled, and intermediate sections are interpolated. About one-sixth of the selected sections in California are counted annually, and field counts are adjusted to an estimate of truck AADT by compensating for seasonal influence and weekly variation. The stated current policy in California is to count trucks on each route at least once every six years. For 2001, truck AADT on the 131 sections on six Orange County freeways ranges from 4,080 to 24,300, with a mean of 14,770. Truck AADT as a percentage of total AADT ranges from 2.1% to 10.6%, with a mean of 6.4%. In our dataset, trucks are involved in more than 10% of the accidents for which there are police reports. This does not necessarily mean that trucks are involved in a disproportionate share of accidents, because it is highly likely that truck-involved accidents are more often reported, due to potentially higher levels of damage and insurance considerations that might lead to a higher level of reporting of minor accidents that involve commercial vehicles.

We also used data collected from single inductive loop detectors at various locations on the six freeways in our study area, in order to study the temporal distribution of traffic volumes. We acquired one full week of complete traffic volume data for 280 locations on the six major freeways in our study area. Each location corresponds to a single freeway direction, and total hourly traffic volume was computed from 30-second observations for all lanes at each location. The week chosen was in March 2001, a period with no unusual wet weather or holiday effects approximately in the middle of the two-year interval of accident data. After sampling many of the 280 locations, we determined that, for all days of the week, the differences among freeway locations are generally within the spread of patterns represented by eight typical locations.

Differences between weekdays are minor for almost all locations, so the hourly distributions of traffic for the eight typical locations can be represented as averages across the five days. The average weekday plots in Figure 1 have similar morning and afternoon peak periods, with the afternoon peak being of a slightly longer duration. For freeway locations corresponding to “inbound” commuter traffic from predominantly residential locations to employment centers – locations labeled G and H in Figure 1 – the morning peak hours are generally higher than the afternoon peak hours. For locations corresponding to “outbound” commuter traffic – locations labeled A, E and F – the opposite is true. The remaining three locations have more balanced splits of traffic between the peak periods. The general pattern at all of these typical locations is that the weekday peak hour, whether in the morning or afternoon, accounts for between seven and eight percent of daily weekday traffic and that traffic levels for all of the hours from the beginning of the morning peak until the end of the afternoon peak in the evening account for at least five percent of daily traffic. Even during the mid-day period, traffic is typically not less than about 75 percent of peak hour traffic.

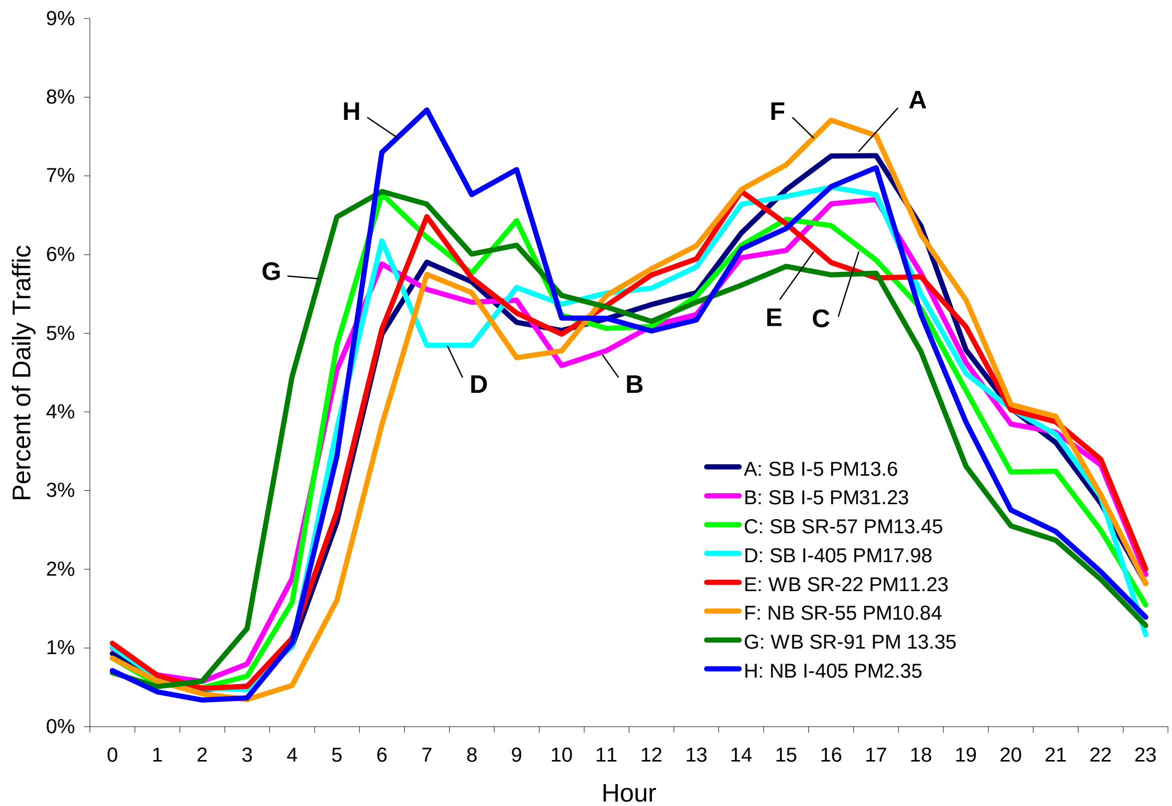

Figure 1 Hourly distributions of Average March 2001 Weekday Traffic at Eight Typical Freeway Locations.

On Saturdays and Sundays, the hourly distributions of traffic are similar for the eight locations, except that the buildup of traffic on Saturday is about one hour in advance of the buildup of traffic on Sunday, and there is more traffic on Saturday during the hours of 10 p.m. through midnight. The two days have been combined in Figure 2, which shows that traffic levels are relatively constant between 10:00 or 11 a.m. and about 6 p.m.

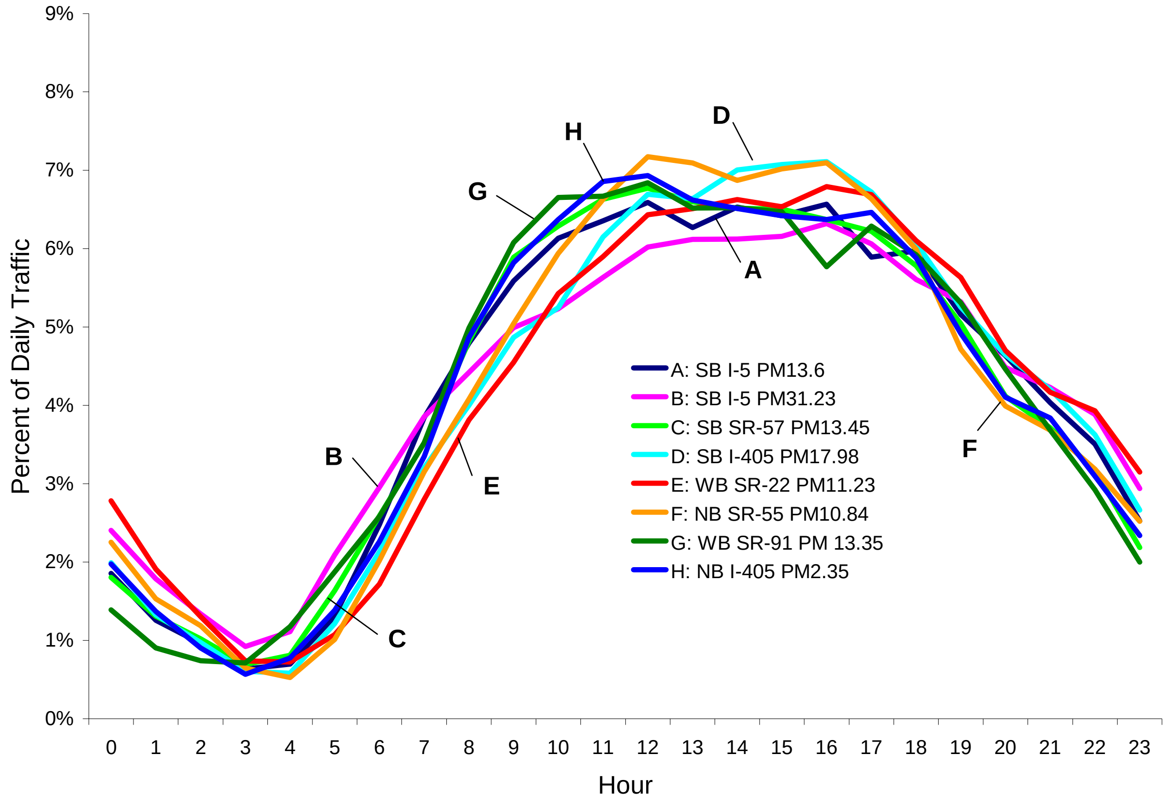

Figure 2 Hourly distributions of Saturday and Sunday Traffic for a Week in March 2001 at Eight Typical Freeway Locations.

3 TEMPORAL PATTERNS OF TRUCK ACCIDENTS AND TRAFFIC

3.1 Weekdays

Descriptive analyses of the hourly distributions of accidents involving trucks versus all other accidents shows that truck-involved accidents have different distributions over time for both weekdays and weekends. On weekdays (Figure 3), truck-involved accidents are fairly evenly distributed over the 8 a.m. to 6 p.m. period, with highest levels during the hours beginning at 8 a.m., 4 p.m. and 7 a.m. Non-truck accidents peak in the 3 p.m. to 7 p.m. period, especially between 5 and 6 p.m.

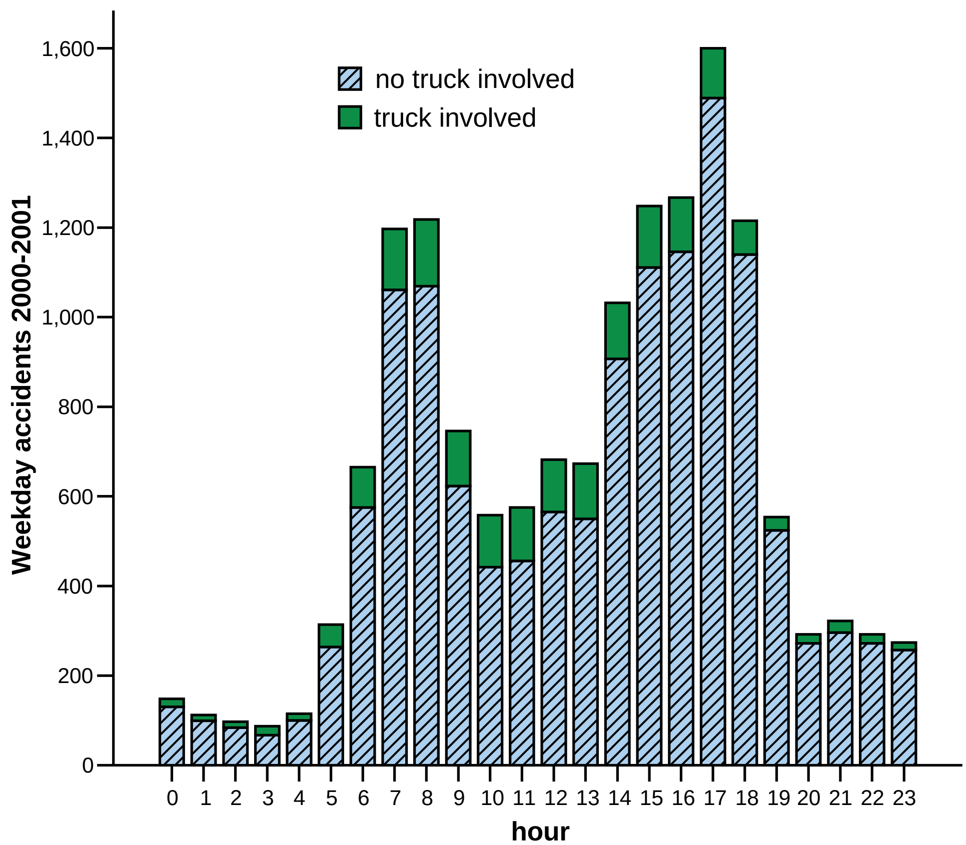

Figure 3 Hourly Distributions of All Weekday Truck-involved and Non-truck-involved Accidents for 2000 and 2001.

In Figure 4 the hourly distributions of truck-involved weekday accidents and non-truck-involved weekday accidents are superimposed onto the hourly distribution of traffic for the eight typical freeway locations shown previously in Figure 1. On a weekday morning, both truck and non-truck accidents increase with increasing traffic volumes in the 6 to 8 a.m. period. This increase lags the increase in traffic flow, indicating that the earlier morning rush hours are potentially safer than the later hours at many freeway locations. Beginning at 9 a.m. the rates of non-truck and truck accidents diverge, with truck accidents initially dipping down at 9 a.m., but then maintaining a consist level of about 80% of the 8 p.m. peak through 3 p.m. Non-truck accidents dip down substantially from 9 a.m. until 2 p.m. On weekday afternoons, truck accidents reach a peak in the hour beginning at 3 p.m. that is approximately 90% of the 8 a.m. peak. Non-truck accidents, on the other hand, continue to grow throughout the afternoon peak traffic period, reaching 140% of the 8 a.m. figure in the 5 p.m. hour. It is highly likely that truck traffic falls off dramatically at the end of the normal business day, and it has been noted that commercial firms tend to schedule truck traffic to avoid peak commuting hours (Niles, 2003). Hourly truck volumes are not available for our study area, and available data for other freeway locations in Southern California vary substantially by freeway location and by method used to count trucks (SCAG, 2002). However, the general trends for other locations show drop-offs in truck traffic in the afternoon, typically beginning at 4:00 p.m.

These weekday results reveal that non-truck accidents are the primary reason that accident rates are positively related to traffic density as well as traffic flow. Garber and Subramanyan (2001) observed that peak accident rates do not occur at peak flow; rather, rates peak at densities other than the optimal density at which flow is at capacity. Similarly, Ceder (1982), Sullivan (1990), and Persaud and Dzbik (1992), and Golob, Recker and Alvarez (in press) demonstrated that accident rates are higher for congested versus free-flow conditions. This appears to be caused in part by positive relationships between accident rates and variations in speed and flow (as shown by Garber and Ehrhart, 2000; Aljanahi, Rhodes, and Metcalfe, 1999; Garber and Gadiraju, 1990; Baruya and Finch, 1994; and Lave, 1985). A recent French study showed that crash rates (as a function of vehicle kilometers traveled) were highest in light traffic (defined as between 1000 and 1500 vehicles per hour), concluding that drivers are more likely to speed or to drive recklessly in light traffic (Martin, 2002). None of these studies separated truck-involved and non-truck-involved accidents, a need strongly suggested by our analysis.

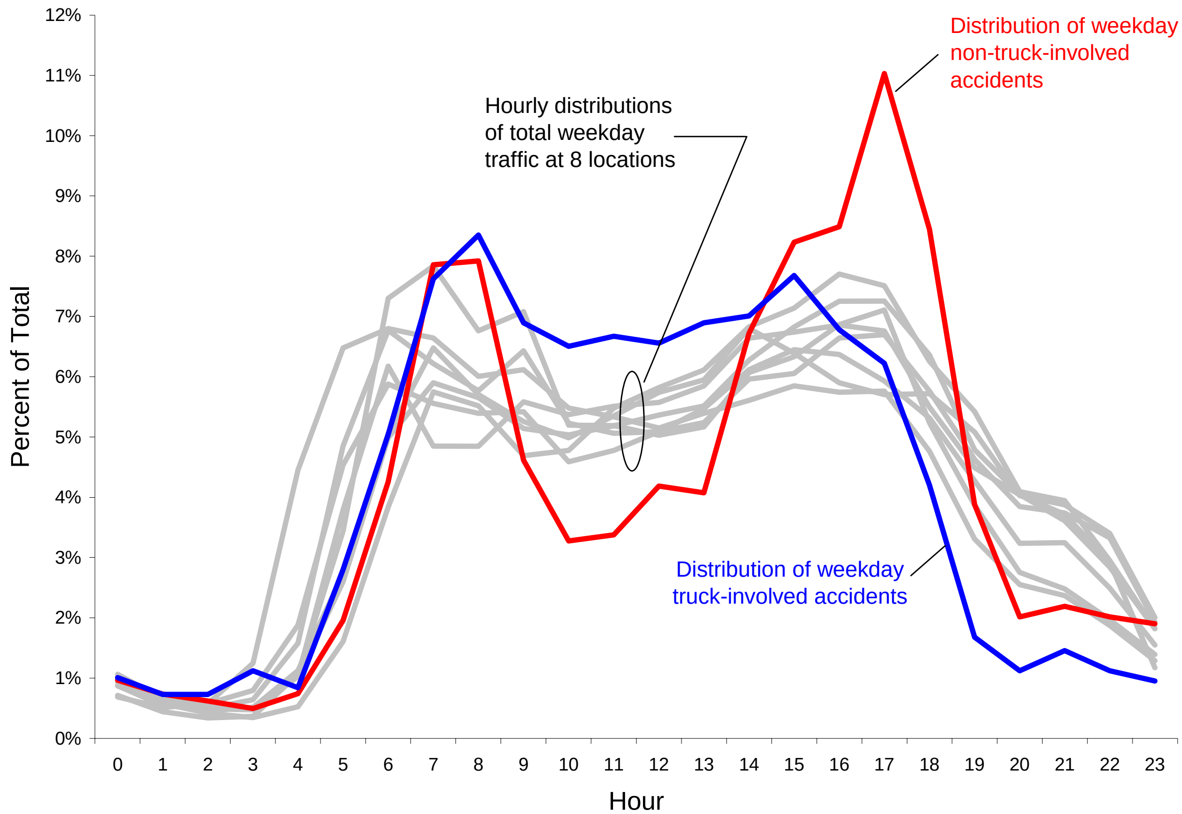

Figure 4 Hourly Distributions of 2000-2001 Truck-involved, and Non-truck-involved Accidents and Average March 2001 Weekday Traffic at Eight Freeway Locations.

3.2 Weekends

On Saturdays and Sundays (Figure 5), truck-involved accidents are relatively evenly distributed over the entire day, until about 5 p.m. Non-truck accidents are highest in the 11 a.m. to 7 p.m. period. In Figure 6 we superimpose the hourly distributions of weekend truck- and non-truck-accidents onto the hourly distribution of weekend traffic for eight typical freeway locations (previously shown in Figure 2). Peak traffic at most locations on Saturdays and Sundays occurs during the 10 a.m. to 9 p.m. period, while non-truck accidents are more concentrated in the 11 p.m. to 7 p.m. period. There were relatively few truck-involved accidents on Saturdays and Sundays in 2000 and 2001, so there is considerable hour to hour variation in the number of truck accidents, but the rate of truck accidents is approximately constant from midnight through about 6:00 p.m. The weekend pattern again reveals that linkages between traffic congestion and accident rates apply more to non-truck, rather than truck accidents. Truck accidents appear to be more closely tied to the truck volumes than to overall traffic volumes.

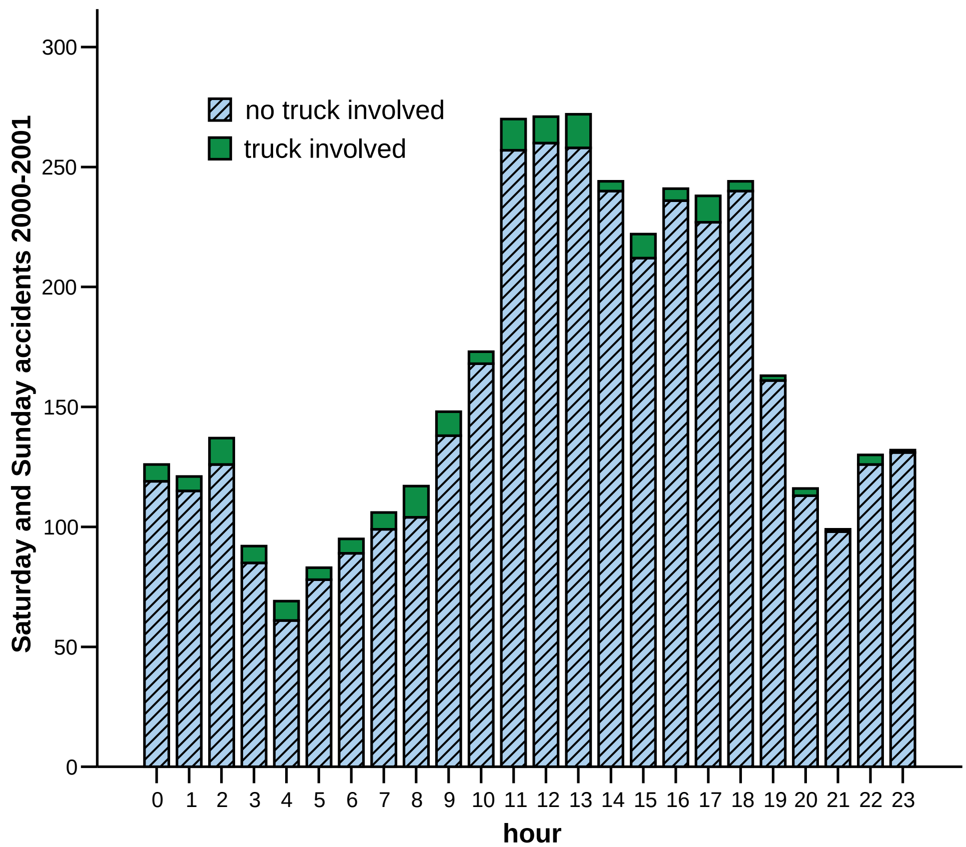

Figure 5 Hourly Distributions of All Saturday and Sunday Truck-involved and Non-truck-involved Accidents for 2000 and 2001.

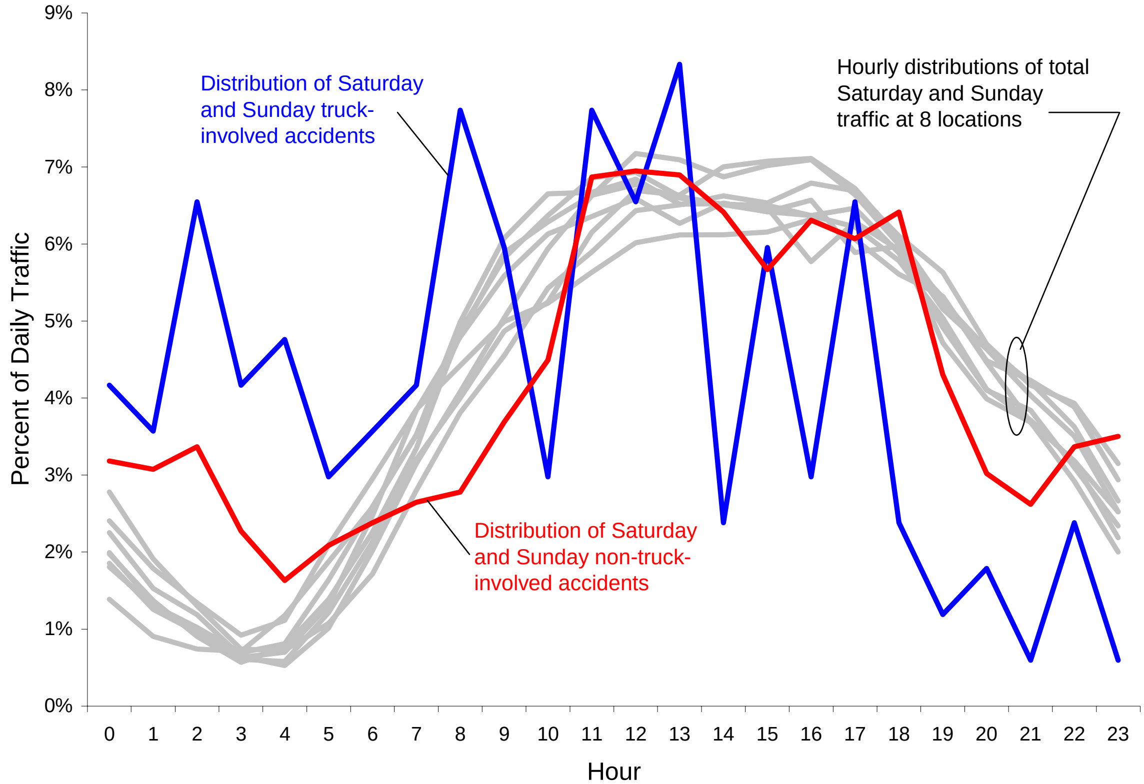

Figure 6 Hourly Distributions of 2000-2001 Total, Truck-involved, and Non-truck-involved Saturday and Sunday Accidents and Average Saturday and Sunday Traffic at Eight Freeway Locations.

4 A MODEL OF TRAFFIC CONDITIONS FOR TRUCK ACCIDENTS

The object of this phase of the analysis is to determine how truck accidents are related to aggregate traffic flow variables and roadway characteristics, controlling for the uneven distribution of truck traffic over hours of the day and days of the week. Differences between the traffic conditions conducive to truck-involved and non-truck-involved accidents can be captured by using a logistic regression model in which the dependent variable is the dichotomous variable indicating whether or not a truck (with six or more wheels on the road) was involved in an accident, and the independent variables represent time periods and aggregate measures of overall traffic and truck traffic levels on the freeway section on which the accident occurred. The sample size for the model was 19,202 accidents over two years, broken down into 89.8% collisions not involving trucks (coded as zero) and 10.2% collisions involving at least one truck (coded as one). The specific independent variables are average annual daily traffic (AADT) for the accident freeway section, truck traffic as a percentage of AADT on that section, percent of truck traffic that has 5-or-more axles, and nine dummy variables designating time periods. The time period dummy variables account for the uneven distributions of truck and non-truck traffic over time of day and day of week. Trial and error was used to identify hourly groupings that yielded the best fitting model. A weather condition variable was also included to control for the weather effect, because it was found that truck-involved accidents were less likely to occur during wet weather conditions. (For truck-involved accidents, 5.3% occurred on wet pavements, while for 7.3% of non-truck accidents occurred on wet pavements; p = .015 for Fisher's Exact Test for the two-by-two contingency table of weather versus accident type.) Seasonal variables, which would be important to include in many locations, were not included due to the relative uniformity of Southern California weather.

Results are listed in Table 1. All variables are significant at $p < .05$. The model quantifies the positive relationship between the likelihood of truck involvement in an accident and the percentage of AADT due to trucks. Also, for any given percentage of overall truck traffic, the probability of a truck-involved accident is an increasing function of the proportion of truck traffic that is accounted for by large (5-or-more-axle) trucks. However, for a constant share of truck and heavy truck traffic, and controlling for the temporal and weather effects, the likelihood that a truck is involved in an accident is a decreasing function of the number of urban freeway lanes and AADT per lane. These results are interpreted in Sections 4.1 through 4.5 of this paper. Roadway variables available to our study such as the number of ramps per mile were not found to be significant in distinguishing truck and non-truck accidents.

Table 1 Logit Model of Truck Involvement in Orange County, California Freeway Accidents, 2000-2001 (N = 19,202)

Independent Variable	Coefficient	t-statistic
Percent of section AADT that is truck	0.106	7.630
Percent of section truck traffic that is 5+ axles	0.027	10.565
Number of lanes on accident side of freeway	-0.075	-2.354
Section traffic volume (AADT) per lane (10^6)	-8.087	-3.025
Time period 12AM to 2:59AM weekdays	0.747	4.321
Time period 3AM to 6:59AM weekdays	0.920	8.992
Time period 7AM to 7:59AM weekdays	0.611	5.583
Time period 8AM to 8:59AM weekdays	0.702	6.592
Time period 9AM to 1:59AM weekdays	1.196	15.806
Time period 2AM to 3:59PM weekdays	0.642	7.188
Time period 4PM to 4:59PM weekdays	0.392	3.461
Day is a Saturday	-0.311	-2.712
Day is a Sunday	-0.601	-4.058
Road surface is wet or slippery	-0.352	-3.384
Constant	-3.063	-9.382
Goodness of fit measures		
Model (–2) log likelihood ratio Chi-square versus constant only		672.75
Degrees of freedom for Chi-square		14
Probability		0.000

4.1 Truck Traffic Mix

In 2001 the mean truck percentage of AADT on the 131 freeway sections in the study area was 6.4%, the minimum was 2.1%, and the maximum was 10.6%. The model predicts that, for the time period of maximum truck exposure – 9 a.m. to 2 p.m. weekdays – trucks will be involved in about 25% of reported accidents on a roadway section with the mean level of 6.4% truck AADT; in the low exposure period of 5 p.m. to midnight, this same section would experience 9% truck accidents (for average levels of heavy truck mix, number of lanes and AADT per lane, and during conditions of good weather). Our model predicts that a doubling of the truck penetration level (to 12.8%), all else held constant, would lead to 39% truck involvement (from 25%) during the peak exposure midday period, and 16% (from 9%) during the low exposure weekday period.

The percentage of truck traffic that is five or more axle vehicles varies by freeway section from a minimum of 10.9% to a maximum of 51.1%, with a mean of 32.1%. Eighty percent of the distribution lies between 18.0% heavy trucks (10^{th} percentile) and 45.8% heavy trucks (90^{th} percentile). The model predicts that truck-involved accidents are more likely on freeway sections with higher percentages of trucks with five or more axles, all else held constant. For example, on a freeway section with an average 6.4% truck AADT but a concentration of heavy trucks at 46% (so that 2.9% of total AADT is 5-axle trucks), the model predicts that about 32% of all accidents will involve some type of truck during the peak 9 a.m. to 2 p.m. time period on weekdays. In contrast, if trucks are 6.4% of AADT but only 18% of trucks are 5-axle or more (so that 1.2% of AADT is 5-axle trucks), the model predicts that about 18% of all accidents will involve some type of truck, for the same time period, level of AADT and weather conditions. This high sensitivity to large truck traffic is undoubtedly due to restricted driver vision; we investigate this in more detail in Sections 6 and 7 below.

4.2 Number of Freeway lanes

Trucks are less likely to be involved in rear end accidents on sections of urban freeways with more lanes, for the same level of AADT per lane and the percentage of truck traffic. This is consistent with the fact that large trucks are generally restricted to the right two lanes on freeway sections with four or more directional lanes in the study area. Consequently, potential conflicts between trucks and automobiles are reduced when there are more lanes.

4.3 AADT per Lane

The likelihood of a truck-involved accident decreases as AADT per lane increases. Miaou et al. (1992) found that truck accident rates increased as a function of AADT per lane, but that study was limited to large trucks and involved all types of roadways. Our conflicting result, which pertains to all types of trucks (with six or more wheels on the road) on urban freeways, typically with more than two directional lanes, is likely due to relationships between traffic flow characteristics and type of collision. It has been demonstrated that, in heavy traffic, the proportion of accidents that are rear-end collisions increases dramatically with the level of flow (Golob, Recker and Alvarez, in press). If rear end accidents are less likely to involve trucks, a higher proportion of rear-end collisions in areas of heavy traffic implies a lower proportion of truck-involved accidents. This is investigated in Section 6 below.

This result is consistent with aggregate trends in accidents and traffic over the two years of our study data. According to a study performed by the California Department of Transportation, total AADT on the all California State Highway routes in Orange County increased from 54,053,000 kilometers in 1999 to 58,488,000 kilometers in 2001, an increase of 8.2%, while truck AADT fell from 3,344,000 to 3,206,000, a slight decrease of 0.4% (Adamu and Nowshiravan, 2003). Most of that AADT on State Highways in Orange County is on the freeways in our study area. During this same period, the accident data for the six freeways show that average number of accidents per dry day increased slightly from 25.2 in 1999 to 25.4 in 2001. Truck-involved accidents per dry day decreased from 3.1 in 1999 to 2.5 in 2001, a 19.4% decrease. (It is prudent to confine accident statistics to dry days when comparing years because there are substantially more accidents on wet days in Southern California and the number of wet days varies substantially from year to year.) Thus, between 1999 and 2001: (1) traffic increased, (2) infrastructure remained about the same, so AADT per lane increased, (3) truck traffic remained about the same, so trucks as a percentage of AADT decreased, (4) total accidents increased, and (5) truck accidents decreased. While it is impossible to separate the effects of truck percent of AADT from AADT per lane with such aggregate data, the trends are consistent with both a positive effect of truck traffic and a negative effect of AADT per lane.

4.4 Time of Day and Day of Week

Regarding the temporal distribution of truck-involved accidents, the model predicts that, the percentage of accidents that involve trucks is relatively high from midnight until about 3 a.m. The likelihood of a truck-involved accident then increases in the 3 a.m. to 7 a.m. period, decreases in the 7 a.m. to 8 a.m. hour, but increases again in the 8 a.m. hour. The likelihood of a truck being involved in an accident is highest in the period 9 a.m. until 2 p.m. In the afternoon and evening, there is a continual decrease in the likelihood over the 2 p.m. to 4 p.m., 4 p.m. to 5 p.m., and 5 p.m. until midnight periods. These temporal differences are substantial; on a route section with average 6.4% truck AADT, the predicted probability of a truck being involved in a accident ranges from 0.243 for the 9am to 2pm period, to 0.089 for the 5pm to midnight period, an odds ratio of 2.7. These results imply that, controlling for other factors, truck-involved accidents are more likely on route sections that have a higher concentration of their traffic earlier in the day, primarily because this is the time more trucks are on the road. Regarding day-of-the-week, truck-involved accidents are less prevalent on Saturdays, and especially on Sundays, *ceteris paribus*. On Sundays, the probability that a truck is involved in an accidents is 0.05 on a freeway section with 6.4% truck AADT.

These results point out the importance of temporal factors in assessments of truck safety on network links and the design of treatments aimed at reducing truck accidents. Driver education, route planning, and real-time traffic information all should have time of day and day of week dimensions when dealing with issues of truck safety.

4.5 Weather Conditions

Finally, regarding weather conditions, on a route section with 8% truck AADT, the predicted probabilities of a truck being involved in an accident are 0.13 for wet freeways and 0.09 for dry freeways. A possible reason for this is that professional truck drivers perform better than average automobile drivers when faced with wet road conditions. Alternatively, traffic flow conditions on wet days will be different from conditions on dry days, and wet conditions might be less conducive to truck-involved accidents. Further research is required to understand effects of weather on traffic safety involving trucks.

5 ACCIDENT SEVERITY

Overall, truck-involved accidents are more likely to involve property damage only (PDO), as opposed to injuries or fatalities (injury accidents). The mean number of injuries per truck-involved accident is 0.308 for the two-year period, contrasted to a mean of 0.400 for non-truck-involved accidents. This difference in means is statistically significant at $p < .0005$. Due to the relatively small number of fatal crashes (76, of which 10 involved trucks), the differences in the mean number of fatalities for truck and non-truck accidents is not statistically significant ($p = .727$). The relationship between truck involvement and a dichotomous severity variable (with the states of injury or fatality versus PDO) is highly significant ($p < .0005$ for Fisher's exact test).

The difference in severity holds for both for accidents that occur on weekdays and for those that occur on weekends. On weekdays, 19.8% of the 1,784 truck-involved accidents in the two-year sample were injury accidents, while 24.1% of the 13,507 non-truck accidents were injury accidents. This difference is statistically significant ($p < .0005$ for Fisher's exact test). On Saturdays and Sundays, 22.0% of 168 truck-involved accidents were injury accidents, while 32.1% of 3,743 non-truck accidents were injury accidents ($p = .006$ for Fisher's exact test). While these results are highly statistically significant, they might be due in part to the fact that non-injury truck accidents are more likely to be reported than non-injury non-truck accidents.

As shown in Figure 7, weekday truck-involved accidents are generally less severe than non-truck accidents in the period from 7 a.m. until 10 p.m. During periods of heavier traffic, especially during the morning and evening peak periods, the prevailing type of accident is a multi-vehicle rear-end or sideswipe collision (Golob and Recker, 2004; Golob , Recker and Alvarez, in press), and, truck-involved multi-vehicle collisions are less severe than non-truck multi-vehicle collisions. Further analysis, described in the next section, reveals that collisions involving a vehicle changing lanes is responsible for this difference in severity between truck- and non-truck accidents.

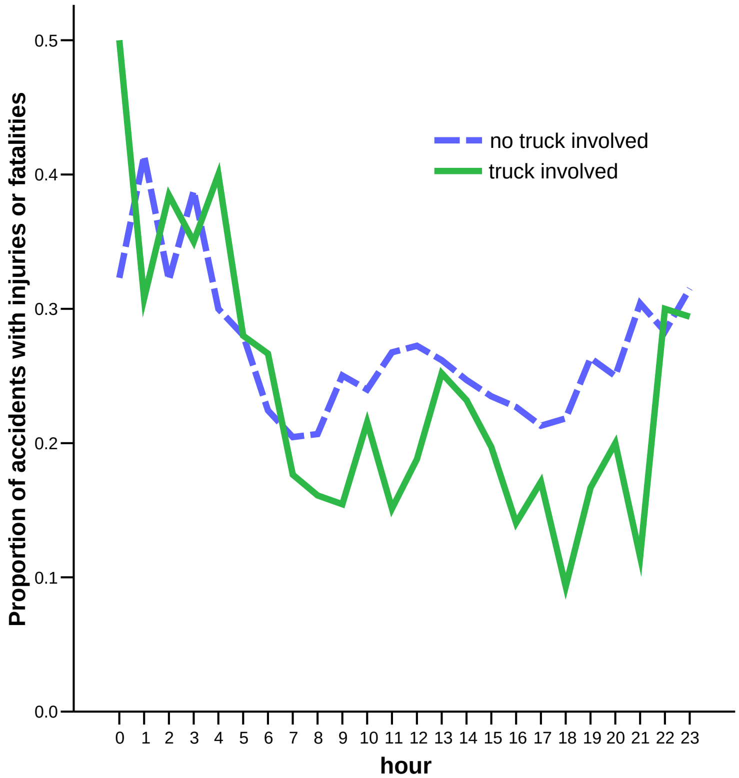

Figure 7 Severity Levels for Truck-involved and Non-truck-involved Accidents by Weekday Hour, 2000-2001

6 TYPES OF TRUCK-INVOLVED ACCIDENTS

Urban freeway accidents involving a truck, compared to those not involving a truck, tend to entail a lane change or merging maneuver. Figure 8 shows that about 42.5% of truck-involved accidents involve one of the first two vehicles changing lanes or merging, compared to only about 17% of accidents not involving trucks. In contrast, 45% of accidents not involving trucks are rear end collisions in which one vehicle is stopping or slowing while the other vehicle is proceeding straight ahead; only about 18% of truck-involved accidents are similarly rear-end collisions.

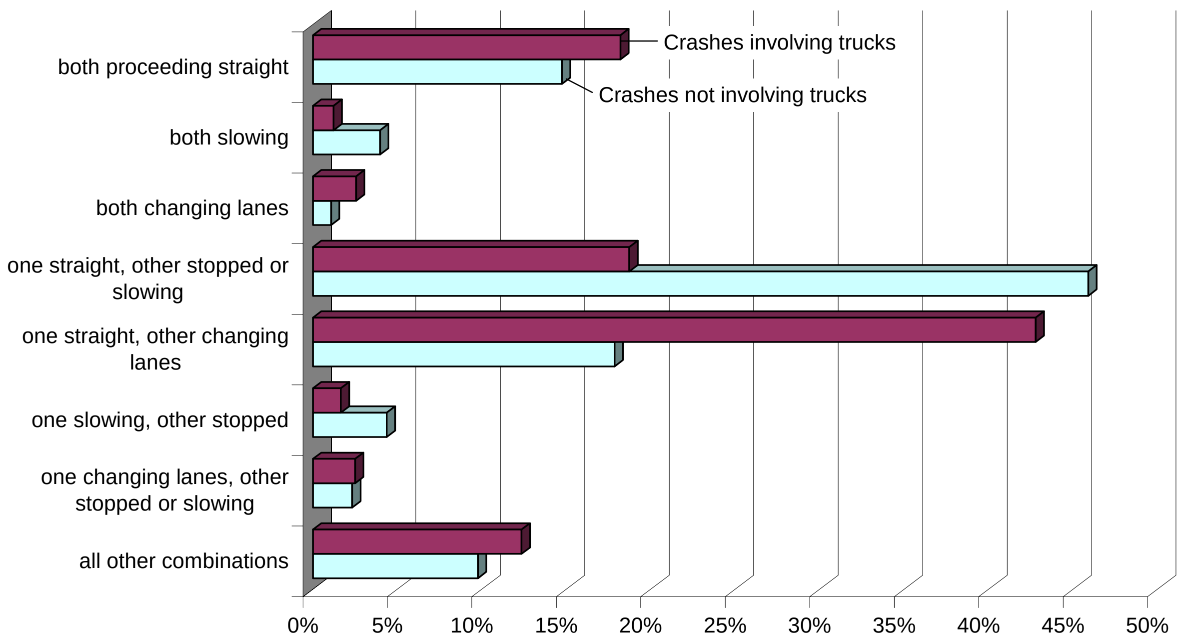

Figure 8 Breakdown of Truck-involved and Non-truck-involved accidents by types of Movements Prior to Collision of the First Two Vehicles

An investigation of the reported movements of the vehicles in truck-involved accidents that involved a lane-change or merging maneuver shows that there is a relatively even split between trucks and the other vehicle (automobiles, sport utility vehicles and four-wheel pickups and vans) in terms of which type of vehicle was engaged in a lane change or merging maneuver. In 43% of the 859 such accidents in the 2000-2001 data, the truck was changing lanes or merging while the other vehicle was proceeding straight. In 52% of the accidents, the other vehicle was changing lanes or merging while the truck was proceeding straight. In the remaining 5% of the 859 accidents, both vehicles were changing lanes. This is consistent with the finding that blind spots for truck drivers and passenger car drivers' lack of understanding of truck-related visibility issues are important factors in truck-involved accidents (e.g., Kostyniuk, Streff and Zakarajsek, 2002).

Regarding severity by type of accident, we focus on three types of accidents: (1) run-offs or overturns, usually involving a collision with an object other than another vehicle, (2) weaving accidents that involve at lease one vehicle changing lanes and an initial sideswipe or rear-end collision, and (3) rear end accidents involving two or more vehicles traveling in the same lane. Listed in Table 2 are the severity breakdowns for truck and non-truck accidents for these three types of accidents. Non-truck run-off and weaving accidents are less severe than non-truck accidents of the same type ($p < .0005$ for Fisher's Exact Tests for both associations), but there is no statistically significant difference between the severity of truck and non-truck rear-end accidents ($p = .150$). For run-offs, 21.8% of truck-involved accidents involve injuries or fatalities, compared to 36.0% of non-truck accidents. For weaving accidents, injuries occur in 16.8% of truck-involved accidents and 23.6% of non-truck accidents. However, in the case of rear ends, the percentages are 26.0% for truck-involved accidents and 23.3% for non-truck-involved accidents. This is likely because of the increased impact of heavier vehicles. The result for run-off and overturn accidents is probably due to better protection for occupants of trucks and higher automobile speeds.

Of the 196 weaving accidents involving trucks, 28 (14.3%) involved injuries to occupants of the truck(s) while 168 (85.7%) involved injuries only to occupants of the cars involved in the accident. For weaving accidents, injuries occur in 16.8% of truck-involved accidents and 23.6% of non-truck accidents. Of the 145 rear-end accidents involving trucks, 25 (17.2%) involved injuries to occupants of the truck(s) involved, and

120 (82.8%) involved injuries only to occupants of the cars involved. Clearly, the impact of such collisions will be felt much more by the drivers of smaller vehicles.

Table 2 Breakdown of Three Types of Truck-involved and Non-truck-involved Accidents, by Severity, 2000-2001

		Severity		Total
		PDO	Injury	
Run-off or overturn	Non-truck	2,103 (64.0%)	1,181 (36.0%)	3,284 (100%)
	Truck	179 (78.2%)	50 (21.8%)	229 (100%)
	Total	2,282 (65.0%)	1,231 (35.0%)	3,513 (100%)
Weaving	Non-truck	2,950 (76.2%)	921 (23.6%)	3,871 (100%)
	Truck	969 (83.2%)	196 (16.8%)	1,165 (100%)
	Total	3,919 (77.8%)	1,117 (22.2%)	5,036 (100%)
Rear end	Non-truck	7,739 (76.7%)	2,356 (23.3%)	10,095 (100%)
	Truck	413 (74.0%)	145 (26.0%)	558 (100%)
	Total	8,152 (76.5%)	2,501 (23.5%)	10,653 (100%)

There are distinct patterns of these accident types over time. The sample size allows us to plot the temporal distributions of these three mutually exclusive types of truck and non-truck accidents for weekdays. (There are too few observations to allow us to conduct a similar analysis of the hourly distribution of truck-involved accidents for weekends.) Hourly distributions by accidents type are given in Figure 9 for truck-involved accidents, and Figure 10 for non-truck accidents.

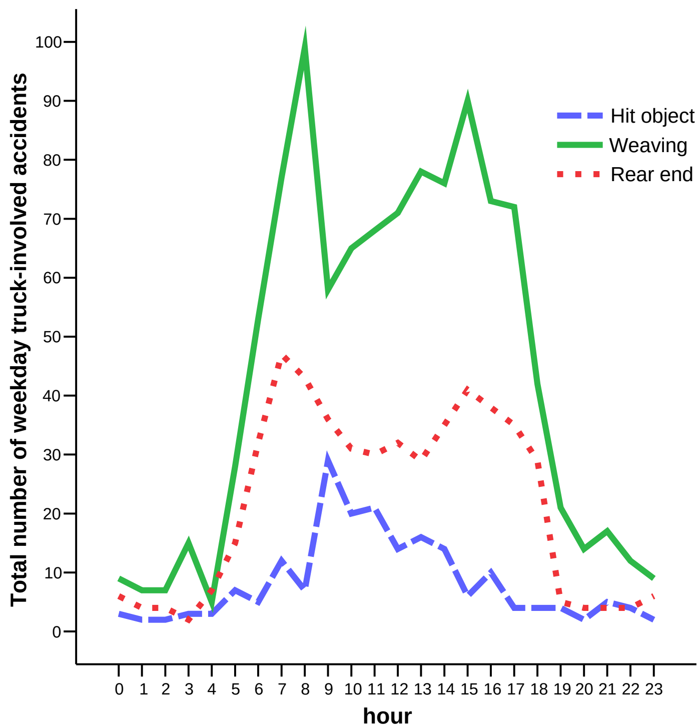

Figure 9 Three Types of Truck-involved Accidents by Weekday Hour, 2000-2001

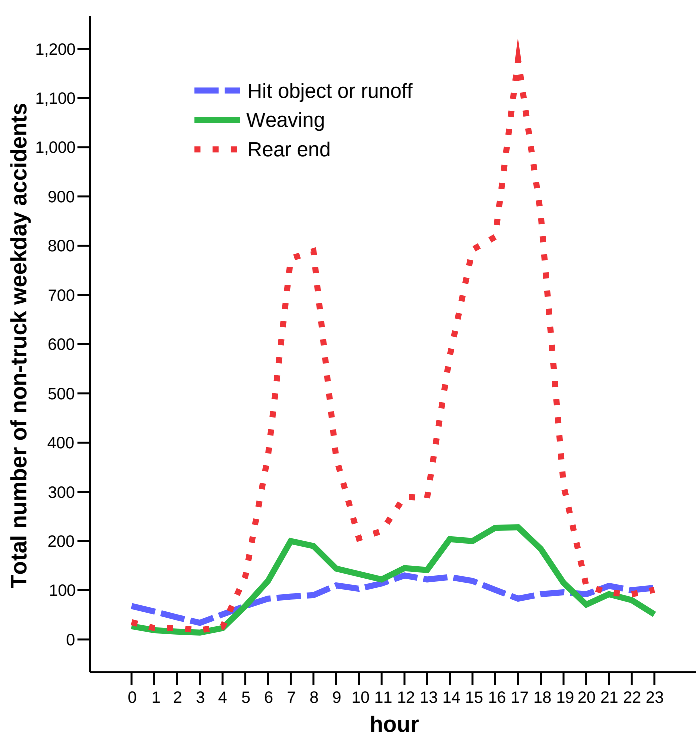

Figure 10 Three Types of Non-truck Accidents by Weekday Hour, 200-2001

The prevailing type of truck accident – weaving accidents that involve a vehicle changing lanes and either a sideswipe or rear-end collision – have a bimodal distribution that first peaks at the peak hour of the morning peak period (8 a.m.), then peaks again at the start of the afternoon peak period (3:00 p.m.). In the period between these two peaks (9 a.m. to 2 p.m.), the level of truck-involved weaving accidents maintains a level of at least 60% of the maximum level. In contrast, the hourly distribution of prevailing type of non-truck accident – rear-end collisions – has two more outstanding peaks, and these peaks are coincident with the morning and evening peak hours (8 a.m., which is slightly higher than 7 a.m., and 5 p.m.). The secondary types of accidents in each set – rear-end collisions in the case of truck-involved accidents, and weaving accidents for non-truck-involved accidents – are in each case moderately related to traffic volumes, with the afternoon peak period for truck-involved rear-end accidents occurring earlier than the peak for non-truck weaving accidents. Finally, run-offs and overturns represent the third most prevalent type of accident in each group. For truck-involved accidents, run-offs and overturns reach a peak at 9:00 a.m., then gradually decrease until 5:00 p.m., and are constant for the remainder of a weekday. For non-truck-involved accidents, run-offs and overturns are relatively constant over an entire weekday. Analysis of the temporal patterns of truck-involved accidents should be useful to enforcement officials who may want to assign extra enforcement vehicles to the highways during peak accident periods. Or, other traffic calming measures could be employed.

7 TYPES OF TRUCK-INVOLVED ACCIDENTS AND TRAFFIC CONDITIONS

We expand the binary logistic regression model of Section 4 to a multinomial logit model in which there are three types of truck accidents – runoffs, weaving accidents, and rear end accidents – compared to a base category of non-truck accidents. The same fourteen independent variables used in the binary model are used in the multinomial model, and the estimation results are listed in Table 3. In the following Sections we compare these multinomial results with those of the binomial logit model, as a means of exposing the underlying factors in aggregate patterns of truck accidents.

Table 3 Multinomial Logit Model of Three Types of Freeway Accidents, 2000-2001 (N = 19,202)

Independent Variable	Truck-involved runoff (1.2%)		Truck-involved weaving (6.1%)		Truck-involved rear end (2.9%)	
	β [a]	t [b]	β	t	β	T
Percent of section AADT that is truck	0.019	0.499	**0.120**	**6.851**	**0.115**	**4.775**
Percent of section truck traffic that is 5+ axles	**0.046**	**6.517**	**0.026**	**8.084**	**0.021**	**4.509**
Number of lanes on accident side of freeway	-0.135	-1.547	-0.027	-0.667	**-0.147**	**-2.577**
Section traffic volume (AADT) per lane (10^6)	**-17.625**	**-2.451**	-3.276	-0.974	**-14.058**	**-2.919**
Time period 12AM to 2:59AM weekdays	**1.391**	**3.210**	**0.560**	**2.440**	**0.848**	**2.876**
Time period 3AM to 6:59AM weekdays	**1.156**	**3.700**	**0.828**	**6.404**	**1.028**	**5.846**
Time period 7AM to 7:59AM weekdays	0.704	1.993	**0.509**	**3.633**	**0.774**	**4.191**
Time period 8AM to 8:59AM weekdays	0.154	0.358	**0.761**	**5.883**	**0.685**	**3.606**
Time period 9AM to 1:59AM weekdays	**1.910**	**8.454**	**1.099**	**11.570**	**1.092**	**8.005**
Time period 2AM to 3:59PM weekdays	0.571	1.893	**0.654**	**5.921**	**0.632**	**3.959**
Time period 4PM to 4:59PM weekdays	0.372	0.989	**0.359**	**2.522**	**0.465**	**2.354**
Day is a Saturday	0.577	1.984	**-0.387**	**-2.622**	**-0.615**	**-2.645**
Day is a Sunday	-0.262	-0.609	**-0.623**	**-3.325**	**-0.682**	**-2.421**
Road surface is wet or slippery	-0.336	-1.267	-0.199	-1.588	**-0.778**	**-3.429**
Constant	**-4.874**	**-5.448**	**-4.251**	**-10.212**	**-3.043**	**-5.184**

Goodness of fit measures	
Model (–2) log likelihood ratio Chi-square versus constant only	771.38
Degrees of freedom for Chi-square	42
Probability	0.000

[a] Coefficient
[b] Ratio of coefficient to its standard error

7.1 Truck Traffic Mix

The probability that a truck is involved in a run-off or overturn accident is independent of the percent of AADT that is accounted for by trucks. While weaving and rear-end accidents on the other hand appear to be proportional to the truck traffic mix.

Higher percentages of large (5-or-more-axle) trucks means higher probabilities of truck-involved accidents of all three types, particularly truck-involved run-offs and overturns. The probability of truck involvement in a weaving accident also increases with increase in the mix of large trucks. Longer trucks have more extensive driver blind spots, and they also block more of the view of automobile drivers. Recent advances in rear- and side-view cameras, other types of rear and side sensors, lane departure warning devices, and improved braking systems for trucks might help alleviate weaving and rear-end accidents involving large trucks. Mitigating large truck run-off accidents involves treatments aimed at keeping vehicles from encroaching on roadsides and minimizing the likelihood of crashing or overturning if a vehicle travels off the shoulder. Such treatments can include widening shoulders, eliminating shoulder drop-offs, eliminating posts and other collision hazards for vehicles that have inadvertently left the road, and enhanced delineation and detection of roadside edges (AASHTO/NCHRP, 2004). In the case of large trucks, which are prohibited from the leftmost lanes on most freeway sections in the study area, the focus should be on the side of the road to driver's right. Treatments aimed at mitigating large truck overturns on the roadway itself include driver education, hazard warning signs, and signals to reduce speeds on curves and in other locations where maneuvers to avoid collision might lead to an overturn.

7.2 Number of Freeway Lanes

Trucks are less likely to be involved rear end accidents on sections of urban freeways with more lanes, for the same level of AADT per lane and the percentage of truck traffic. This is consistent with the fact that large trucks are generally restricted to the right two lanes on freeway sections with four or more lanes in a single direction the study area. Consequently, potential conflicts between trucks and automobiles are reduced when there are more lanes. An important result is that the likelihood of truck-involved weaving accidents is independent of the number of freeway lanes, *ceteris paribus*.

7.3 AADT per Lane

The binomial logit model of Table 1 captured the effect that the likelihood of a truck (six wheels or more) being involved in an accident is negatively related to the level of average annual daily traffic (AADT) per lane at the location of the accident. The results of the multinomial model show that this effect holds for truck-involved runoffs and rear-end accidents, but not for truck-involved weaving accidents. The model thus predicts that, for the same percentage of truck traffic, as traffic levels increase trucks are less likely to be involved in all types of accidents except weaving accidents.

7.4 Time of day and day of Week

The weekday hourly distributions are similar for truck-involved weaving and truck-involved rear-end accidents. This reflects the similar hourly distributions for the two types of accidents (Figure 9). However, run-off and overturn accidents are relatively more likely than all other types of accidents in the hours after midnight and in the 9:00 a.m. to 1:59 p.m. period. They are less likely to occur in the peak 8:00 a.m. hour.

Regarding weekdays and weekends, the patterns are very different for the three types of accidents. Truck-involved run-off and overturn accidents are relatively more prevalent on Saturdays, while the opposite is true for other types of truck-involved accidents. All three types of truck-involved accidents are relatively less prevalent on Sundays, but this effect is weaker for run-offs and overturns.

7.5 Wet Weather Factor

Compared with non-truck-involved accidents (the base model category), all three types of truck-involved accidents are less likely to occur during conditions of wet roads. The strongest weather effects are for run-offs and weaving accidents. Possibly, this is because professional truck drivers are more likely than drivers of passenger cars to slow down in wet weather.

8 CONCLUSIONS AND DIRECTIONS FOR FURTHER RESEARCH

This research uses two years of accident data combined with AADT and truck AADT data to examine the traffic conditions linked to truck-involved accidents. We first show that the hourly distributions of truck-involved and non-truck-involved accidents are quite different for both weekdays and weekends, and both distributions deviate from typical patterns of traffic volumes. A logistic regression model was used to describe the probability of a truck being involved in a accident as a function of AADT, truck traffic as a fraction of AADT, time of day, day of the week, wet versus dry road conditions, and the breakdown of truck traffic by small versus large (5 axle or more) trucks. The time of day effects control for variations in truck volumes over the day. It was found that, controlling for the other influences, the likelihood of truck involvement is a decreasing function of AADT per lane. However, controlling for AADT per lane and truck traffic as a percentage of AADT, the likelihood of truck involvement is an increasing function of the proportion of overall truck traffic that is accounted for by large trucks. Also, truck accidents are also less likely to occur on wet roads, *ceteris paribus*.

To better understand the underlying causes of these relationships between urban freeway traffic and truck involvement in accidents, we analyzed different types of truck accidents. We found that about 42.5% of truck-involved accidents involve one of the first two vehicles changing lanes or merging (weaving accidents), compared to only about 17% of accidents not involving trucks. In contrast, 45% of accidents not involving trucks are rear end collisions in which one vehicle is stopping or slowing while the other vehicle is proceeding straight ahead; only about 18% of truck-involved accidents are similarly rear-end collisions. In 43% of truck-involved weaving accidents, the truck was engaged changing lanes or merging while the other vehicle was proceeding straight; in 52% of the accidents the other vehicle was changing lanes or merging while the truck was proceeding straight; and in the remaining 5% of the accidents, both vehicles were changing lanes. This confirms that driver visibility is an important factor in truck-involved accidents and is the likely reason why the truck involvement is strongly related to the fraction of truck traffic accounted for by five or more axle trucks, *ceteris paribus*.

With regard to accident severity, we found that truck-involved accidents are more likely to entail property damage only (PDO), as opposed to injuries or fatalities, and this distinction holds for both weekday and weekend accidents. Weaving and run-off or overturn accidents are responsible for this difference in severity between truck- and non-truck accidents. For rear-end accidents there is no statistically significant difference between truck-involved and non-truck-involved accidents.

A multinomial logit model was then used to link specific accident types with traffic conditions. Results showed that the probabilities of the three main types of truck-involved accidents – run-offs, weaving accidents, and rear-end accidents – vary differently by truck percentage of AADT, number of lanes, AADT per lane, weather conditions, and by time periods. With regard to traffic volume, the model predicts that, as ADDT per lane increases with a constant percentage of truck traffic, trucks are less likely to be involved in all types of accidents *except* weaving accidents. With regard to the penetration of truck traffic, truck involvement in run-off or overturn accidents is independent of the percent of AADT that is accounted for by trucks, while weaving and rear-end accidents are proportional to truck traffic mix in similarly positive ways. Finally, higher percentages of 5-or-more-axle trucks means higher probabilities of truck-involved accidents of all three types, particularly truck-involved run-offs and overturns. We can conclude that future research involving truck accidents need to distinguish accidents involving small and large trucks.

As better data sources become available, these kinds of analyses can be significantly improved so that their results could be used by public agencies seeking to reduce truck-involved freeway accidents through infrastructure improvements, real-time traveler information, traffic management, or improved driver education. Eventually, we will be able to identify unsafe conditions in real-time so that immediate traffic calming measures can be employed. The kind of analysis described in our paper lays the foundation for the development of models developed with more advanced data.

9 ACKNOWLEDGMENTS

This research was supported in part by grants from the National Science Foundation (NSF), the University of California Transportation Center (UCTC), California Partners for Advanced Transit and Highways (California PATH) and the California Department of Transportation (Caltrans). The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the National Science Foundation, the University of California, California PATH, or the California Department of Transportation.

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