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ABSTRACT

Using two years of crash and average annual daily traffic data we examine the locations and conditions linked to truck-involved crashes (accidents). A binomial logit model is used to describe how the probability that a crash involves a truck is a function of the percentage of annual average daily traffic that is accounted for by trucks, time of day, day of the week, weather conditions, mix of truck types, and the absolute level of average annual daily traffic. That model can then be used to identify locations with higher or lower than expected truck involved accident rates, controlling for all of the factors that influence truck crash rates. A multinomial logit model was then estimated in order to better understand patterns of truck-involved crashes by separating crashes by type, with the main types being rear-end, lane-change, and run-off collisions. We propose that results from applications of these kinds of models, applied in a specific region, can be useful to public agencies seeking to identify and remedy problem areas either with better driver education or investments in physical or intelligent transportation system infrastructure.

BACKGROUND

One important measure of the level of safety of any road network is the number of crashes (accidents), either total crashes or crashes 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 (*1*), 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 crashes 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 crashes. 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.

There are few published journal articles concerning truck crash statistics specifically, but there have been several recent relevant reports. An exception, and one that provides an excellent literature review related to studies of accident severity is found in Chang and Mannering (*2*). The USDOT 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 crashes and about eight percent of fatal crashes (*3*). A recent study performed at the University of Michigan for the AAA foundation for traffic safety examines the unsafe driver actions that leads to fatal car-truck crashes (*4*). Their key findings were that four factors were more likely to occur in fatal car-truck crashes than fatal car-car crashes. These were following improperly, driving with obscured vision, drowsy or fatigued driving and improper lane changing. Another recent study examined in 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 (*5*). Another recent study, performed for the US Federal Motor Carrier Safety Administration (FMCSA), examined the link between driver schedules and safety (*6*). Their key findings were that company driving environments, economic pressures and carrier support for safe driving were the main factors influencing driver fatigue. Finally, a 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 (*7*). Our study also identifies sections of roadway that are disproportionately the site of truck involved crashes.

DATA

This research uses two years of crash and average annual daily traffic (AADT) data from the Traffic Accident Surveillance and Analysis System (TASAS) database maintained by the California Department of Transportation (*8*). TASAS covers police-reported crashes 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 mainline crashes 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 TASAS 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) 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 to passenger cars, motorcycles, pickups and vans, trucks, and other types of specialized vehicles, such as buses and emergency vehicles. The database does not cover collisions for which there are no police reports.

The TASAS database also contains AADT estimates for all freeway sections. AADT data are also available online (*9*). 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.

Truck traffic is available on an average annual basis (*10*). 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 six Orange County freeways ranges from 4,080 to 24,300, with a mean of 14,770 and a standard deviation of 4,706. A histogram is shown in Figure 1. Truck AADT as a percentage of total AADT: ranging from 2.1% to 10.6%, with a mean of 6.4% and a standard deviation of 1.85% (Figure 2).

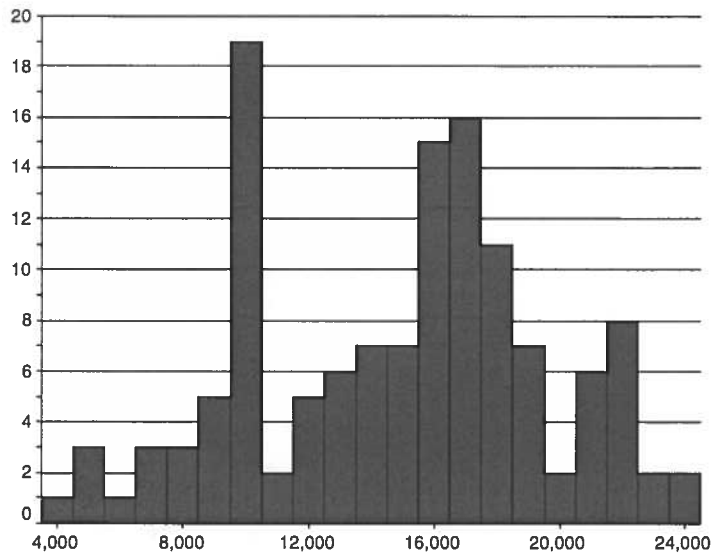

Figure 1 Histogram of Truck (Six Tires or More) Average Annual Daily Traffic on 131 Sections of Six Orange County Freeways in 2000.

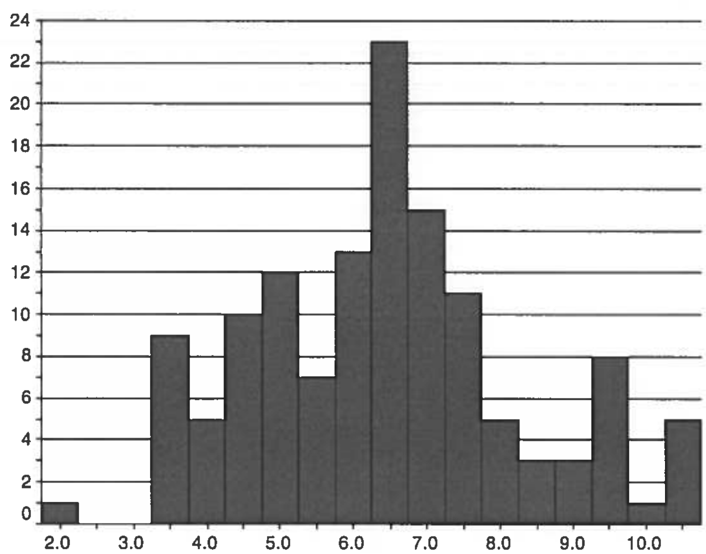

Figure 2 Histogram of Truck Average Annual Daily Traffic as a Percentage of Total Average Annual Daily Traffic on 131 Sections of Six Orange County Freeways in 2000.

TRUCK-INVOLVEMENT AS A FUNCTION OF TRAFFIC MIX BY TIME PERIOD

A descriptive analysis of the hourly distribution of crashes involving trucks versus all other crashes shows that truck-involved crashes have a different distribution of time (Figure 3).

Truck-involved crashes are relatively evenly distributed over the 8AM to 6 PM period, with highest levels during the hours beginning at 8:00AM, 4:00PM and 7:00AM. Crashes not involving trucks peak in the 3:00PM to 6:59PM period, especially in the 5:00PM hour. These differences between truck-involved and non-truck-involved crashes can be captured by using a probabilistic model in which time period variables are combined with traffic flow variables. The traffic flow variables in such a model capture the relationships between the probability of truck involvement in a crash and the level of truck traffic compared to non-truck traffic, controlling for other relevant conditions.

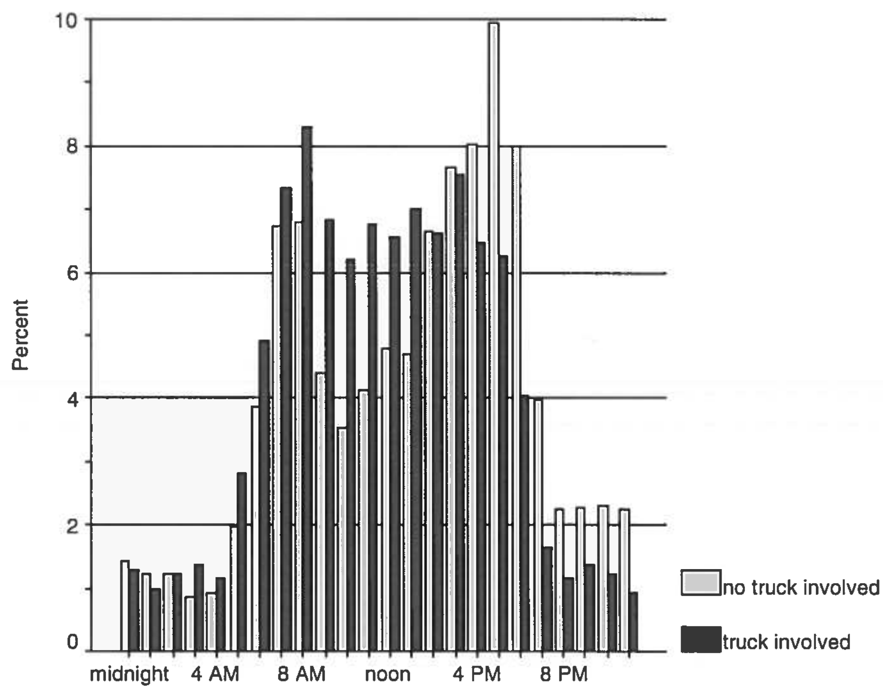

Figure 3 Breakdowns of Truck-involved and Non-truck-involved Crashes by Hour of the Day Six Orange County Freeways in 2000.

A logistic regression model was estimated in which the dependent variable is the dichotomous variable indicating whether or not a truck (6 tires or more) was involved in a specific crash. The sample size was 19,202 crashes 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 independent variables are average annual daily traffic (AADT) for the freeway section in which the crash is located, truck traffic as a percentage of AADT on that section, percent of truck traffic that is 5-or-more axle, eight dummy variables designating time periods, and a weather condition variable. The time period dummy variables account for the previously noted uneven distributions of truck and on-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. Results are shown in Table 1. All variables were significant at $p < .01$. These results are interpreted in the next four sections.

Table 1 Logit Model of Truck Involvement in Mainline Freeway Crashes, 2000-2001, as Function of Average Annual Daily Traffic (AADT), Time Periods, and Weather Conditions (N = 19,202).

Independent Variable	Coefficient	z-statistic
Percent AADT trucks	0.101	7.53
Percent of truck traffic 5+ axles	0.026	10.49
AADT, in 100,000's	-1.874	-2.97
Time period 12AM to 2:59AM	0.869	6.08
Time period 3AM to 6:59AM	0.982	10.23
Time period 7AM to 7:59AM	0.664	6.30
Time period 8AM to 8:59AM	0.766	7.51
Time period 9AM to 1:59PM	1.166	16.20
Time period 2AM to 3:59PM	0.630	7.33
Time period 4PM to 4:59PM	0.378	3.44
Weekday	1.168	13.80
Road surface is wet	-0.352	-3.41
Constant	-4.523	-19.15
Goodness of fit measures		
Constant only –2 log likelihood		12743.26
Model -2 log likelihood		12046.22
Model (–2) log likelihood ratio Chi-square versus constant only		697.03
Model chi-square degrees of freedom		12
Probability		0.000

Traffic Effects

The model confirms that the probability that a truck is involved in a crash is an increasing function of the percentage of traffic due to trucks. Also, for any given proportion of traffic that is due to trucks, the probability of a truck-involved crash is an increasing function of the proportion of the truck traffic that is 5-or-more axles. However the model contradicts the commonly held perception that truck accidents increase with an increase in AADT (with truck percentages held constant). This result is consistent with the observation by Golob, Recker and Alvarez (*11*) that the proportion of crashes that are rear-end collisions increases with flow at high flow rates, and rear end crashes are less likely to involve trucks, as described in Section 5 below.

Truck-Involved Crashes by Time Period

All else held constant, truck-involved crashes are more prevalent earlier in the day. The predicted probabilities by time period as a function of truck percentage of AADT are graphed in Figure 4. Beginning at midnight, the percentage of crashes that involve trucks is relatively high until about 3 AM. The likelihood of a truck-involved crash then increases in the 3 AM to 7 Am period, then decreases in the 7 AM to 8 AM hour, but increases again in the 8 AM to 9 AM hour. The likelihood of a truck being involved in a crash is highest in the 9 AM until 2 PM period. In the afternoon and evening, there is a continual decrease in the likelihood over the 2 PM to 4 PM, 4 PM to 5 PM, and 5 PM until midnight periods. These temporal differences are substantial; on a route section with 8% truck AADT, the predicted probability of a truck being involved in a crash ranges from 0.20 for the 9am to 2pm period, to 0.07 for the 5pm to midnight period, an odds ratio of 2.8. These results imply that truck-involved crashes are more likely on route sections which have a higher concentration of their traffic earlier in the day, controlling for all other factors, because this is the time more trucks are on the road.

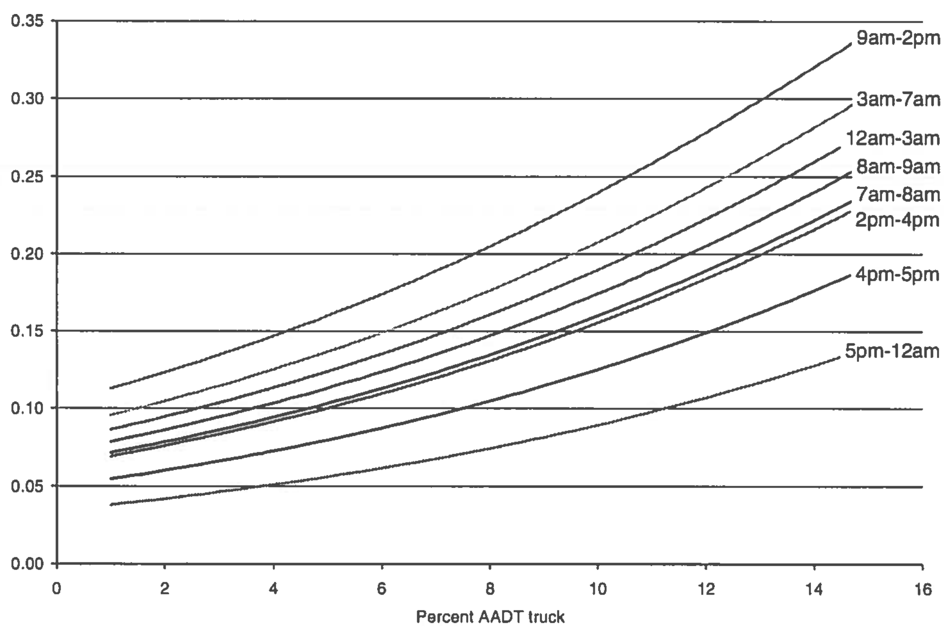

Figure 4 Predicted Probability of Truck Involvement in Mainline Freeway Crashes, 2000-2001, as Function of Truck Percent of Average Annual Daily Traffic, by Time Periods, Weekdays, for Average Percent Trucks 5 Axles, Average AADT, and Dry Weather Conditions

Regarding day-of-the-week, truck-involved crashes are far more prevalent on weekdays, all else held constant. On a route section with 8% truck AADT, the predicted probability of a truck being involved in a crash at between 9Am and 2PM on a weekday is 0.20, versus 0.07 for the same period on Saturday or Sunday.

Truck-Involved Crashes by Weather Conditions

The predicted probabilities for wet and dry conditions as a function of truck percentage of AADT are graphed in Figure 5. Truck-involved crashes are less prevalent on wet roads, *ceteris paribus*. On a route section with 8% truck AADT, the predicted probabilities of a truck being involved in a crash are 0.13 for wet freeways and 0.09 for dry freeways. A plausible reason for this is that professional truck drivers perform better than average automobile drivers when faced with rainy road conditions.

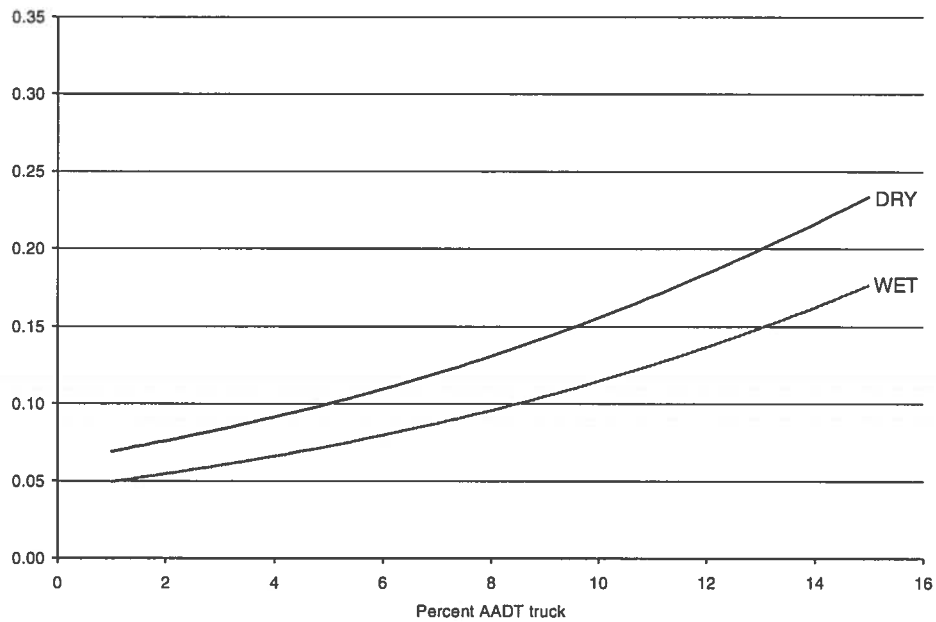

Figure 5 Predicted Probability of Truck Involvement in Mainline Freeway Crashes, 2000-2001, as Function of Truck Percent of Average Annual Daily Traffic, by Wet Versus Dry Road Conditions, for 2PM-4PM Period on Weekdays, Average AADT, and Average Percent Trucks 5 Axles.

Truck-Involved Crashes by Total Traffic and Percentage of 5-Axle Trucks

In 2000, total AADT on Orange County freeway sections varies from a minimum of 120,000 to a maximum of 380,000, with a mean of 240,384. Eight percent of the distribution lies between 183,000 (the 10^{th} percentile) and 285,000 (90^{th} percentile). Truck-involved crashes are more likely on freeway sections with lower total AADT, all else held constant. The predicted probabilities of a truck being involved in a crash ranges from 0.12 for a high-volume freeway section with an AADT of 285,000, to 0.14 for a low-volume freeway section with an AADT of 183,000, both with 8% trucks. At 14% truck AADT, the predicted probabilities of truck involvement are 0.20 for the same high-volume section, and 0.24 for the low-volume section.

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%. Eighty percent of the distribution lies between 18.0% heavy trucks (the 10th percentile of the distribution) and 45.8% heavy trucks (90th percentile). Truck-involved crashes are more likely on freeway sections with higher percentage of five or more axle trucks, all else held constant (Figure 6). For example, if trucks are 8% of AADT and 46% of trucks are 5-axle or more (so that 3.7% of AADT is 5-axle trucks), the model predicts that about 18% of all crashes will involve some type of truck. In contrast, if trucks are 8% of AADT but only 18% of trucks are 5-axle or more (so that 1.4% of AADT is 5-axle trucks), the model predicts that less than 10% of all crashes will involve some type of truck, for the same time period, level of AADT and weather conditions.

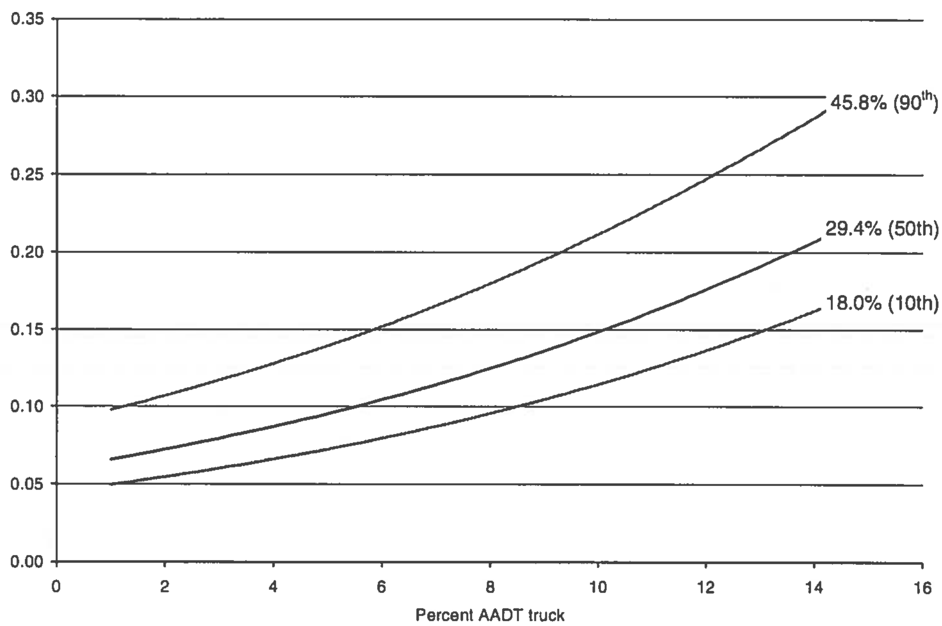

Figure 6 Predicted Probability of Truck Involvement in Mainline Freeway Crashes, 2000-2001, as Function of Truck Percent of Average Annual Daily Traffic, by Three Percentiles of % 5-Axle trucks, for 2PM-4PM Period on Weekdays, Average AADT, and Dry Weather Conditions

USING THE MODEL TO IDENTIFY SAFETY LEVELS OF FREEWAY SECTIONS

The model described in Table 1 can be used to identify freeway sections that have truck-involved crash rates that are higher or lower than expected, controlling AADT, truck AADT, percentage of 5-axle trucks, time of day, day of week, and weather conditions. This is accomplished by comparing predicted versus observed rates for sections along a freeway route. Sections are defined in the usual manner as segments with homogenous traffic volume between access entry or exit points. A sufficient time observation period is required for this exercise so that there are sufficient numbers of observed crashes.

As a case study, observed and predicted percentages of truck-involved crashes are plotted for Interstate Route 5 in Orange County, California. There are 48 sections on this route, averaging 0.94 miles in length, with an average of 120 crashes per section over the two-year, 2000-2001 period. The sections with exceptionally high or low rates of truck-involvement, as measured by the difference between the observed and predicted rates, in standard deviation terms, are highlighted in Figure 7. Three sections have abnormally high levels of truck-involved crashes, and two adjacent sections have abnormally low levels of such crashes.

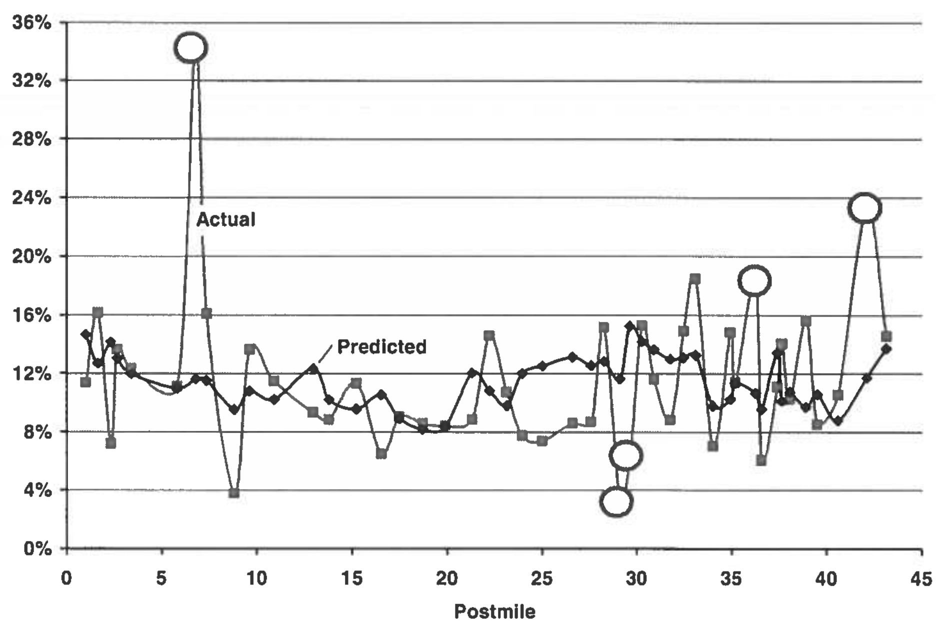

Figure 7 Predicted and Observed Probabilities of Truck-involved Crashes for Sections of Interstate 5 in Orange County, California, Highlighting Sections with Greatest Statistical Deviation

Similarly, observed and predicted percentages of truck-involved crashes are plotted for sections along the approximately 24 miles of the portion of Interstate Route 405 in Orange County. In this case, two sections have abnormally low levels of truck-involved crashes, and one section has an abnormally high level. An investigation of the physical layout of the roadway for the highlighted sections on both of these routes, including the arrangement of ramps at the end of each of the sections, should aid in refining design standards for improved truck safety.

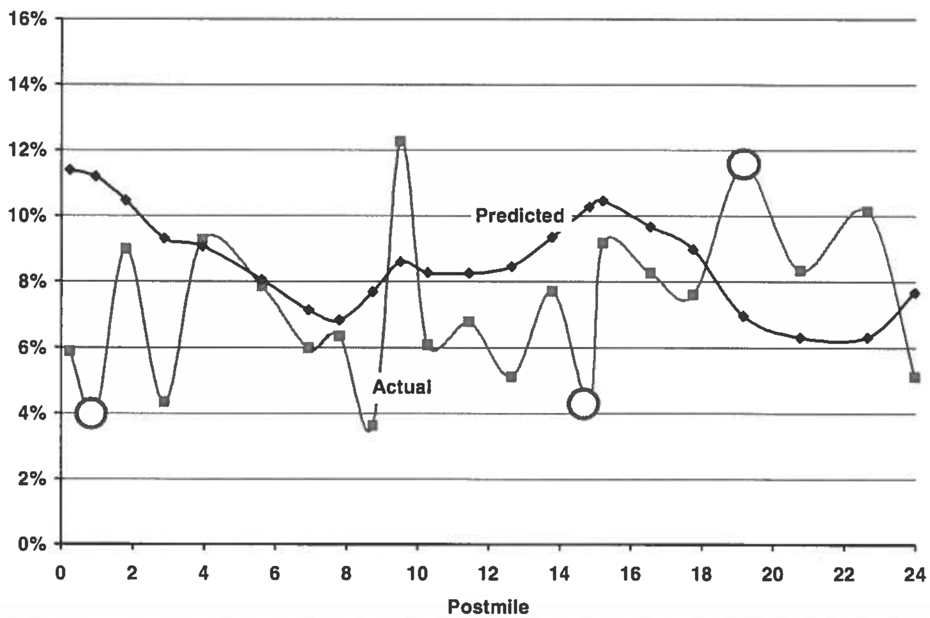

Figure 8 Predicted and Observed Probabilities of Truck-involved Crashes for Sections of Interstate 405 in Orange County, California, Highlighting Sections with Greatest Statistical Deviation

TYPES OF TRUCK-INVOLVED CRASHES

Urban freeway crashes involving a truck, compared to those not involving a truck, tend to entail a lane change or merging maneuver. Figure 9 shows that about 42.5% of truck-involved crashes involve one of the first two vehicles changing lanes or merging, compared to only about 17% of crashes not involving trucks. In contrast, 45% of crashes 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 crashes are similarly rear-end collisions.

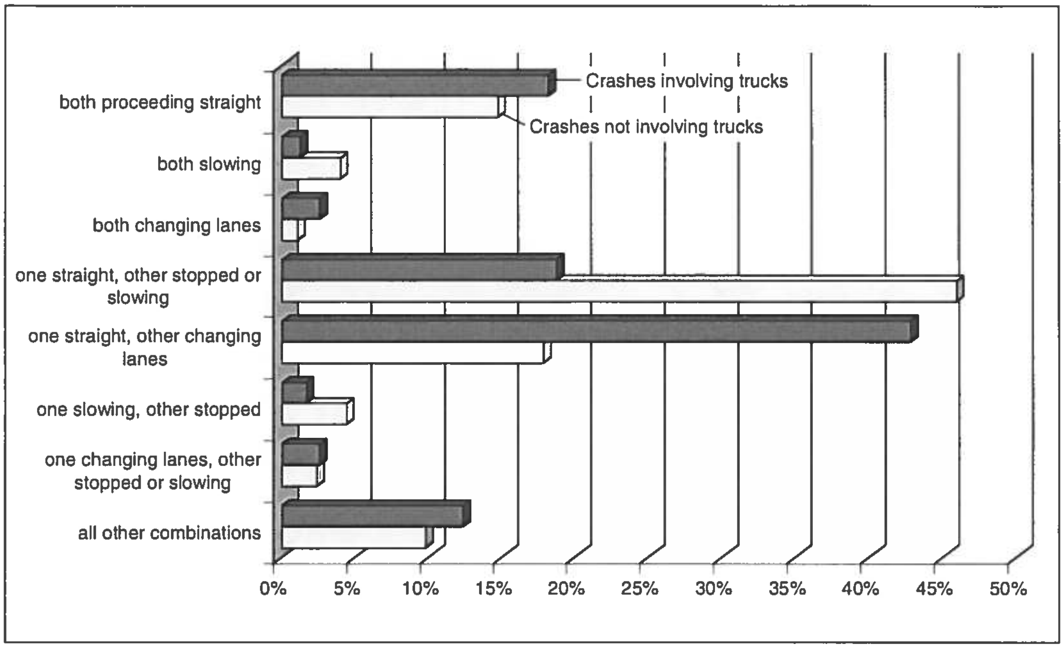

Figure 9 Breakdown of Truck-involved and Non-truck-involved crashes by types of Movements Prior to Collision of the First Two Vehicles

An investigation of the reported movements of the vehicles in truck-involved crashes 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-tire 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 crashes in the 2000-2001 data, the truck was engaged changing lanes or merging while the other vehicle was proceeding straight. In 52% of the crashes, the other vehicle was changing lanes or merging while the truck was proceeding straight. In the remaining 5% of the 859 crashes, both vehicles were changing lanes.

TYPES OF CRASHES AS A FUNCTION OF TRAFFIC AND TEMPORAL FACTORS

The relationships between the different types of truck-involved crashes to traffic and environmental factors is explored by expanding the binary logistic regression model of Section 3 to a multinomial logit model in which there are three main types of truck crashes, compared to a base category of non-truck crashes. The same twelve independent variables used in the binary model are used in the multinomial model. Results are shown in Table 2.

Table 2 Multinomial Logit Model of Type of Mainline Freeway Crash, 2000-2001, as Function of Average Annual Daily Traffic, Time Periods, and Weather Conditions (Reference Category is "No truck involved") (N = 19,202)

Independent Variable	Truck-involved run off (1.2%)		Truck-involved weaving (6.1%)		Truck-involved rear end (2.9%)	
	β	z	β	Z	β	z
Percent AADT trucks	0.018	0.471	**0.118**	**6.737**	**0.114**	**4.697**
Percent of truck traffic 5+ axles	**0.044**	**6.272**	**0.026**	**8.172**	**0.019**	**4.240**
AADT, in 100,000's	-2.657	-1.440	-0.912	-1.075	**-2.868**	**-2.368**
Time period 12AM to 2:59AM	**1.284**	**3.280**	**0.666**	**3.492**	**1.127**	**4.766**
Time period 3AM to 6:59AM	**1.250**	**4.308**	**0.843**	**6.877**	**1.112**	**6.748**
Time period 7AM to 7:59AM	**0.915**	**2.820**	**0.513**	**3.758**	**0.768**	**4.241**
Time period 8AM to 8:59AM	0.145	0.340	**0.841**	**6.836**	**0.683**	**3.668**
Time period 9AM to 1:59PM	**1.896**	**8.777**	**1.054**	**11.633**	**1.017**	**7.704**
Time period 2AM to 3:59PM	**0.725**	**2.597**	**0.611**	**5.715**	**0.601**	**3.878**
Time period 4PM to 4:59PM	0.338	0.909	0.347	**2.519**	**0.435**	**2.250**
Weekday	**0.849**	**4.225**	**1.140**	**10.489**	**1.378**	**8.109**
Road surface is wet	-0.333	-1.260	-0.206	-1.650	**-0.789**	**-3.482**
Constant	**-5.439**	**-17.071**	**-5.439**	**-17.071**	**-5.102**	**-11.030**

Goodness of fit measures	
Constant only –2 log likelihood	7106.37
Model -2 log likelihood	6347.38
Model (–2) log likelihood ratio Chi-square versus constant only	758.99
Model chi-square degrees of freedom	36
Probability	0.000

By comparing the multinomial logit model results of Table 2 with the binomial logit model results of Table 1, we can see how different types of truck-involved crashes vary by traffic conditions and time periods. For example, the probability of truck-involved run-off crashes is independent of percent AADT accounted for by trucks. On the other hand, higher percentages of large trucks means higher probabilities of truck-involved crashes of all types, controlling for the overall proportion of truck traffic and the level of AADT.

The negative relationship between AADT level and the probability of truck involvement seen in the model documented in Table 1 is shown in the model of Table 2 to be due to a negative relationship between AADT and truck-involved rear-end accident only. In other words, the proportion of crashes that are rear-end collisions involving trucks is lower on higher-volume freeway sections, *ceteris paribus*. Also, the probability that a crash is a truck-involved rear-end is lower for wet road conditions. Explanations of the reasons for these results, which could be related, are outside of the present research, but this suggests that truck drivers are better trained to deal with congestion and adverse weather conditions.

SUMMARY AND CONCLUSIONS

This research uses two years of crash data combined with AADT and truck AADT data to examine the conditions linked to truck-involved crashes. We developed a binomial logit model that can identify the relationship between temporal, weather, average daily traffic and percent truck traffic and overall truck involved accidents. That model can also be used to identify locations with higher or lower than expected truck-involved accident rates. We next developed a multinomial logit model which can further link specific accident types with conditions. These kinds of models can be useful to public agencies seeking to identify and remedy problematic freeway locations for different time periods through real-time traveler information, traffic management, improved driver education, or infrastructure investments.

Results show that combining total ADDT with truck AADT is not particularly effective in measuring exposure to truck-involved accidents at a given time period on a section of urban freeway such as those in Southern California. The probability of a truck being involved in a crash is a function of time of day, day of the week, wet versus dry road conditions, and the breakdown of truck traffic by small versus large trucks. Further analyses show that the individual probabilities of three main types of truck-involved crashes – run offs, weaving crashes, and rear-end crashes – vary differently by truck percentage of AADT, AADT level, weather conditions, and certain time periods. These results hold the promise that further research using these types of data will aid in identifying ways of improving the level of truck safety on high-volume urban freeways.

ACKNOWLEDGMENT

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