Exposure-Based Analysis of Motor Vehicle Accidents

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The concept of exposure to accident risk includes characteristics of the amount of travel, the conditions of travel, and the characteristics of the driver and vehicle undertaking the travel. An empirical investigation of this broad definition of exposure was conducted by using accident, travel, and environmental data from the Indiana Tollway for 1978. A comparison of automobile and truck accident involvement rates indicates that trucks generally have a higher overall accident rate, primarily due to a higher rate during clear weather. Comparison of automobile accident rates with the rates of two-axle, six-tired vehicles (small trucks) and five-axle vehicles (large trucks) showed that the small trucks had higher accident rates in all weather conditions than the automobiles or large trucks. The highest accident rates for each vehicle type occurred during snowy days. Automobiles had higher accident rates at night than during the day, whereas truck rates stayed the same or decreased at night. Regression analysis of automobile and truck accident rates indicated that the occurrence of snow was the single most significant exposure variable associated with an increase in accident rates. Automobile accident rates were found to increase significantly with truck vehicle miles of travel, a result consistent with concerns for mixing high levels of automobile and truck traffic. In general, automobile accidents were much more sensitive to travel conditions than truck accidents; this may be due to a combination of driver experience and/or vehicle technology. The study demonstrated that diverse existing data sources can be combined to investigate a broad definition of exposure and thus gain useful insights concerning accident patterns.

The safe, efficient use of the highway system requires the accommodation of vehicles of different sizes and weights serving different purposes. The trend in recent years is for automobiles used in passenger transportation to be lighter and smaller while trucks, particularly those used to haul intercity freight, are becoming larger and heavier. Pressure continues to increase truck size and weight limits beyond current levels (1). In addition to economic and regulatory issues concerning increased truck weights, there is a substantial controversy concerning the safety record of heavy and large trucks. A recent major study conducted for FHWA (2) has not completely resolved the safety issue due to apparent methodologic shortcomings (1,3).

Numerous studies (4-7) have compared various characteristics of truck accidents. Although these studies aid the understanding of truck safety issues, a major shortcoming is their lack of consideration of the amount of travel, typically measured by vehicle miles of travel (VMT). Not considering the amount of travel means that consideration is only given to the characteristics of the accidents that have occurred, not the vehicle miles and conditions of travel during which accidents have not occurred.

Later studies (8,9) use estimates of statewide VMT obtained from motor fuel sales tax receipts to consider the amount of travel. These estimates of VMT are intended to provide what is commonly described as a measure of "exposure" to potential accidents. Presumably, as the number of miles driven increases, the risk of potential accidents increases.

A more refined definition of exposure is given by de Silva (10), who refers to it as "the number and relative danger of the hazards he (the driver) encounters." Carroll (11) defines exposure as "the frequency of traffic events which create a risk of an accident" and suggests that distance or driving time should be classified by variables that denote relative risk--driver, vehicle, roadway, and environmental characteristics including traffic speed and density. Chapman (12) discusses these issues at length, concluding that the concept of exposure really combines the notions of the attributes of the driver and vehicle and the conditions of travel (e.g., day or night and rain, snow, or dry) as well as the amount of travel. Consideration of VMT alone does not capture the potentially important effects that conditions of travel may have on the relative risk or danger of an accident.

STUDY OBJECTIVE

Estimates of VMT do not lend themselves to detailed analysis of conditions of travel. The estimates are frequently obtained for a large spatial area (e.g., a state) as well as a long period of time (e.g., a year). This level of aggregation makes it difficult to obtain an accurate measure of the effects of other exposure-based variables, particularly weather and daylight or darkness. The estimates themselves may also be inaccurate since they are derived from other variables (e.g., gasoline or diesel fuel sales).

This research focused on an empirical investigation of a broader definition of exposure, emphasizing study of the accident experience of automobiles and trucks during different conditions of travel. Measured VMT for different classes of vehicles was the basis of the study. Weather and sunrise-sunset times were combined with VMT and police accident records. The study sought to explore the usefulness of combining diverse data sources to study exposure to accidents in the hope of gaining insights regarding the safety performance of different types of vehicles under various environmental conditions.

STUDY SITE

Several studies of truck safety (13-16) have used measured values of automobile and truck VMT obtained from closed-system toll roads. The closed toll systems classify all vehicles by type and precisely measure on-ramp to off-ramp trip length to determine the amount of the toll. The availability of accurate travel mileage data indicated that toll roads could be a primary data source for the study.

Several toll authorities were contacted to determine their willingness to cooperate with the study team and their ability to provide the accident and vehicle travel information required. The Indiana Tollway, a 160-mile-long east-west highway in northern Indiana, was selected because measured VMT was available for nine classes of vehicles differentiated by axle count. Although this classification did not differentiate some important truck types (e.g., five-axle doubles from five-axle tractor-semitrailers), it did permit computation of vehicle mileage for automobiles, large trucks (five-axle), and small trucks (two-axle, 6-tired). Comparison of these three vehicle types resulted in the inclusion of approximately 97 percent of the automobile vehicle miles and more than 80 percent of the truck vehicle miles.

Although it would have been desirable to obtain VMT for segments of the tollway (between entrance and exit ramps), the Tollway Authority data collection system computed daily VMT for the entire facility. Because more spatially disaggregated VMT could not be obtained, weather and sunrise-sunset data also had to be aggregated for the entire roadway.

Weather data for the tollway in 1978 were obtained from six recording stations operated by the National Oceanographic and Atmospheric Administration (NOAA). The stations were dispersed along the length of the tollway and recorded for each hour of the day the amount of rainfall and snowfall. These spatially and temporally disaggregate weather data were used in two ways: (a) to classify days as clear, snowy, or rainy and (b) to construct, for regression analysis, variables called "hours of rain" (HRSRAIN) and "hours of snow" (HRSNOW). The regression variables were constructed by using the following procedure:

1. Any precipitation entry beyond a trace for an hour at a station was called one hour of rain or snow at that station.
2. The total hours of rain (or snow) at all stations for a day were summed and divided by the number of reporting stations to obtain the hours of rain and snow for the entire tollway for that day. Lack of segment-specific VMT data dictated this aggregation procedure.

Data on hours of daylight and darkness for 1978 were obtained from the Old Farmer's Almanac for South Bend, Indiana--approximately the midpoint of the tollway. The 24-h VMT data used in an earlier University of Michigan study of the Indiana Tollway (14) were then entered to determine an estimate of the proportion of daily truck and automobile VMT driven during daylight and darkness. The estimate was obtained by picking the hours of the day for sunrise and sunset and taking the area under the curve.

Complete accident records were available for 1978, chosen as the year of the study. Nearly 1000 accidents that occurred on the tollway were reviewed. Accidents at tollbooths, on access roadways, in service areas, and on entrance-exit ramps were excluded from the data set in order to arrive at data that could be considered typical of Interstate highway conditions. Whereas entrance-exit ramp accidents are common to all Interstates, it was often not clear in the tollway data set whether proximity to a toll collection facility influenced the ramp accident. The more than 600 accidents that remained in the data set consisted primarily of main-line and merge accidents. In transcribing vehicle information from accident reports, care was taken to classify all vehicle involvements in one of the nine tollway VMT classifications. Each vehicle involved in an accident was thus described to allow the computation of vehicle accident involvement rates (i.e., involvements per million VMT). As discussed by Scott and O'Day (13), the use of vehicle involvement rates rather than accident rates corrects the rates for different amounts of travel by vehicle class.

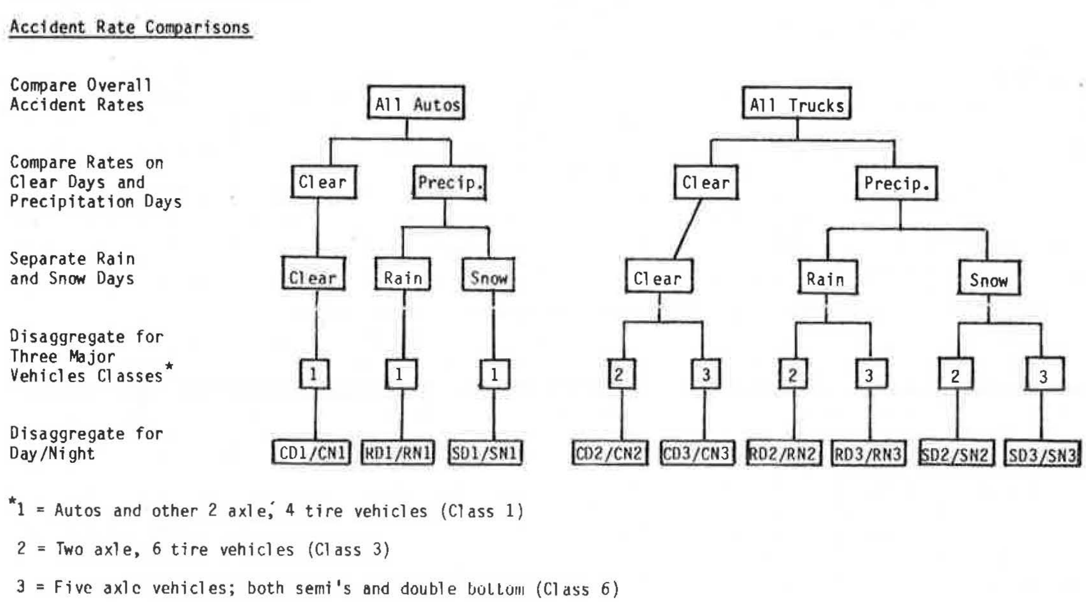
EXPERIMENTAL DESIGN

The data analysis sought to identify statistically significant differences in automobile and truck accident experience. To achieve this goal, a two-phase experiment was conducted. Initially, vehicle accident involvement rates were compared at increasing levels of disaggregation (see Figure 1). Overall accident involvement rates of automobiles and trucks were compared first; next, days with precipitation (rain or snow) were separated from clear days and separate accident rates were computed; precipitation days were further segregated into days with rain and days with snow; truck accident rates were segregated into those for class 3 (small trucks) and those for class 6 (five-axle semitrailers and doubles); finally, separate day and night rates were computed based on when each accident actually occurred.

Conceptually, more than three vehicle classes could have been included in the study, but small sample sizes of accidents in the remaining six vehicle classes precluded their separate analysis. Because an involvement rate is computed for each day (our fundamental data analysis unit), the mean and variance of the daily accident involvement rate can be computed for each cell and used to test statistical hypotheses concerning equality of means. These comparisons provided broad indications of the accident experiences of different vehicles in different travel conditions.

The second phase of the experiment was the development of regression models to predict the mean daily accident involvement rate as a function of several explanatory variables. Regression allowed the examination of rain and snow as continuous rather than dichotomous variables; the models provided an understanding of the effect of the amount of rain or snow as well as its occurrence. The effect of traffic mix was also examined; i.e., are

Figure 1. Design of hypothesis tests.



automobile accident rates higher on days with high truck VMT?

Preliminary examination of the data revealed the presence of two winter days on which the tollway was closed for part of each day due to extremely heavy snows and icy conditions. The poor weather contributed to a high number of accidents and, combined with very low VMT, very high accident rates. The conditions of travel on these two days were so extreme as to be considered very unlikely to occur with any frequency. Therefore, these two days were removed from the data set, which left 363 days of usable data.

DATA ANALYSIS

Accident Rate Comparisons

The mean and variance of the daily accident involvement rate for each cell in Figure 1 are summarized in Figure 2. A series of paired comparisons of accident rates were conducted by using the following test statistic:

$$t = (m_1 - m_2)/[(S_1^2/n_1) + (S_2^2/n_2)]^{1/2} \quad (1)$$

where m_1, S_1^2, and n_1 are the sample mean, sample variance, and sample size of the variable in one group and m_2, S_2^2, and n_2 are comparable measures for variables in the second group. The test statistic is asymptotically t-distributed with degrees of freedom,

$$V = [(S_1^2/n_1) + (S_2^2/n_2)]^2 / \left\{(S_1^2/n_1)^2[1/(n_1 - 1)] + (S_2^2/n_2)^2[1/(n_2 - 1)]\right\} \quad (2)$$

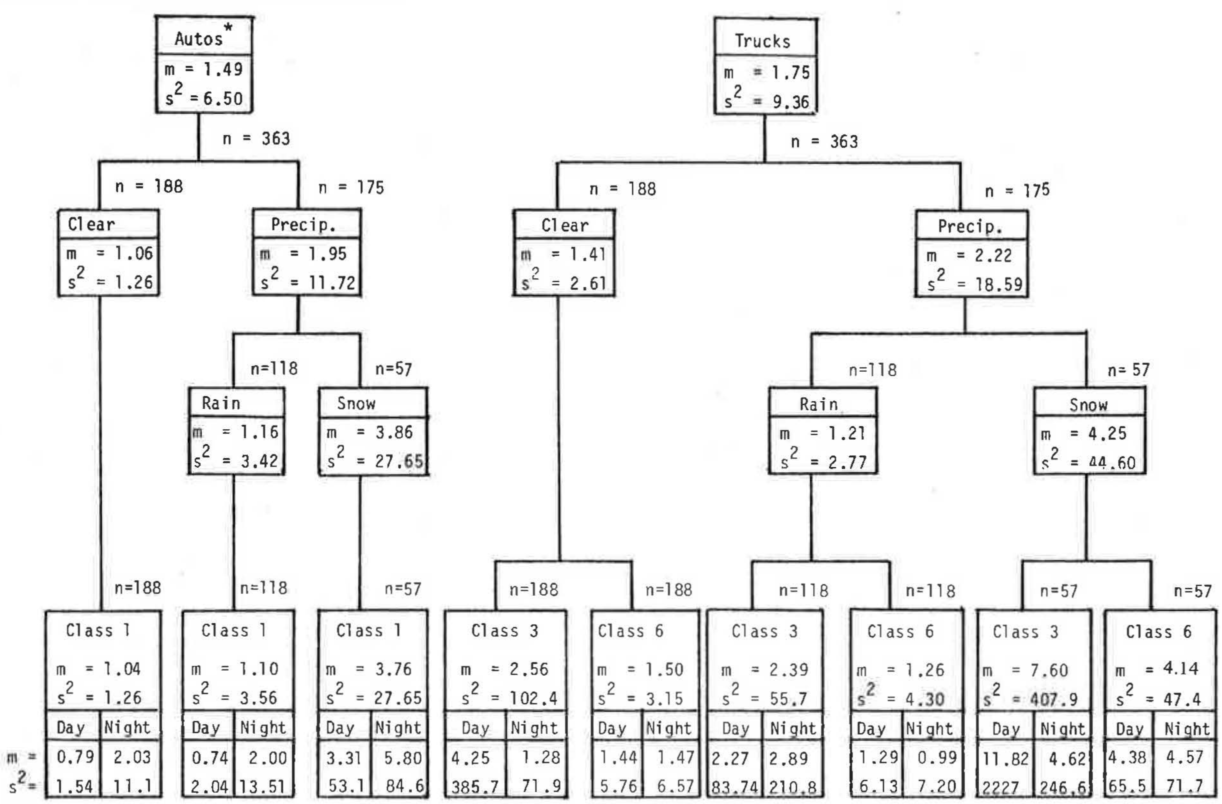
The null hypothesis is that the sample means are equal, and the alternative hypothesis is that they are not equal. The test statistic is used because initial comparisons of the variances in Figure 2 resulted in rejection of the null hypothesis of equal variances in all cases.

Table 1 presents t-statistics and significance probabilities for the null hypothesis that the mean clear-weather accident rate of different vehicle types is equal to the accident rate for days with rain or snow. Compared with rates during clear days (m_A = 1.06 accidents/million vehicle miles), automobiles experienced significantly higher accident rates during snow ($p < 0.0001$) and insignificantly higher rates during rain ($p = 0.30$). All trucks have a similar accident experience that shows significant increases during snow but a marginal decrease during rain.

The comparisons for the three separate vehicle classes indicate that results for class 1 closely match results for all automobiles (hardly surprising since class 1 contains 97 percent of automobile VMT). Very different results are obtained when comparisons are conducted separately for small trucks (class 3) and large trucks (class 6). The large trucks continue to show large increases in accident rates during snow and marginal, nearly significant decreases during rain. Small trucks, however, show a small but significant increase during snow and no significant difference during rain.

These results suggest that rainy conditions have less influence on the accident rates of large trucks than on those of automobiles and small trucks. Perhaps drivers of large trucks are more alerted to danger during these conditions and their driving experience and training provide them with better

Figure 2. Summary of accident involvement rates.



*m = mean daily accident involvement rate in involvements/million VMT.

Table 1. Comparison of accident involvement rates in clear weather with rates during snowy and rainy days.

	Rain		Snow	
Vehicle Type	t	p	t	p
All automobiles	0.520	0.30	3.99	<0.0001
All trucks	-0.81	0.79	2.84	0.002
Vehicle class				
1	0.340	0.37	3.88	<0.0002
3	0.175	0.44	1.81	0.035
6	-1.02	0.15	2.87	0.003

Table 2. Summary of statistical tests comparing accident involvement rates for different vehicle types.

Vehicle Type	Clear		Rain		Snow	
Comparison	t	p	t	p	t	p
All automobiles versus all trucks	2.64	0.004	0.499	0.31	0.004	0.5
Class 1 versus class 3	2.06	0.02	1.82	0.035	1.39	0.08
Class 1 versus class 6	2.98	0.001	0.611	0.27	0.329	0.63
Class 3 versus class 6	1.43	0.08	1.59	0.055	1.22	0.12

Table 3. Comparison of day and night accident involvment rates.

Vehicle	Clear		Rain		Snow	
Class	t	p	t	p	t	p
1	-4.79	<0.0001	-3.47	<0.0002	-1.63	0.10
3	1.90	0.06	-0.39	0.70	1.09	0.28
6	-0.12	0.90	0.89	0.37	-0.12	0.90

judgment on how to safely operate the vehicle. Automobile and small-truck drivers are likely to have less experience and training and may not be able to make judgments of the same quality. Vehicle technology in terms of tires, steering, and braking may also be sufficiently advanced to allow the more experienced large-truck driver to take corrective action to avoid danger.

Comparisons of all vehicle types indicate that accident rates increase significantly on snowy days.

A comparison of vehicle performance in the same weather conditions is summarized in Table 2. The null hypothesis is that the automobile (or vehicle class 1) accident rate for the given weather condition is equal to the truck accident rate for the same weather condition. The results indicate that automobile accident rates are lower than truck accident rates only in clear weather. In snow, rates are very similar; in rain, approximately similar. Rate comparisons by vehicle class yield a somewhat different picture. Compared with rates for two-axle, six-tired trucks, automobile rates are significantly lower for all weather conditions. Although the results for snow days are only marginally different (p = 0.08), the results are very different from those of comparisons in which all truck classes were aggregated. The findings for large trucks are consistent with previous results: Clear-weather accident rates are significantly higher for large trucks (class 6) than for 'automobiles. Accident rates are not significantly different on rain and snow days: Comparisons of rates for the two truck classes indicate that rates are marginally higher for small trucks than for large trucks.

The most disaggregate comparison of mean accident involvement rates included a breakdown of day and night accidents and accident rates. Table 3 summarizes the results. The null hypothesis is that the daytime accident rate is equal to the nighttime accident rate for each vehicle class in each weather condition, and the alternative hypothesis is that the rates are unequal. It is interesting that automobile accident rates increased significantly at night for both clear and rainy days. Both small and large trucks had generally the same accident rate during the day and night except for two instances in which the rate was marginally lower at night. These results provide further evidence of different safety performance for different vehicle types; in fact, the automobile nighttime accident rate during clear weather was marginally higher than the large-truck accident rates during both clear and rainy days.

It is clear, and somewhat surprising, that the accident rates for small trucks are consistently higher in all weather conditions than the rates for large trucks. Furthermore, large trucks have higher accident rates than automobiles only during clear weather and exhibit marginally lower accident rates than automobiles during rain. Large trucks have generally similar (or lower) accident rates at night. Automobiles are exactly the opposite, having significantly higher rates at night. In general, the comparison of means revealed very different accident characteristics for automobiles and trucks: Automobiles were much more sensitive to travel conditions than either truck type.

Regression Analysis

Regression models were constructed to further study variable interrelations, particularly the influence of one mode's VMT on the other's accident rate (e.g., truck VMT on automobile accident rate) and the effect of the amount of snow, rain, and nighttime travel on accident experience. The variables used in the models can be defined as follows:

- AUTODAY = percentage of daily automobile VMT driven during daylight hours;
- HRSNOW = average snowfall for a day, estimated as described earlier in this paper;
- HRSRAIN = average rainfall for a day, estimated as described earlier in this paper;
- TRUCDAY = percentage of daily truck VMT driven during daylight hours;
- VMTCL1 = daily VMT for vehicle class 1;
- VMTCL16 = term measuring the interaction of the VMTs of classes 1 and 6, computed as the product of VMTCL1 and VMTCL6;
- VMTCL6 = daily VMT for vehicle class 6;
- VMTA = daily VMT for automobiles, obtained by summing VMTs for classes 1 and 2;
- VMTAT = term measuring the interaction of the VMTs for automobiles and trucks, computed as the product of VMTA and VMTT; and
- VMTT = daily VMT for trucks, obtained by summing the VMTs for vehicle classes 3-9.

The models were developed by using a linear additive specification:

$$\text{Daily accident involvement rate} = b_0 + b_1\text{HRSNOW} + b_2\text{HRSRAIN} + b_3\text{VMTAT} + \ldots \quad (3)$$

Models were developed separately for automobile, truck, and large-truck (class 6) daily involvement rate. Predictor variables were screened to remove those that were strongly intercorrelated. Model estimates are discussed below, including coefficient values, coefficient t-statistics, and equation R^2

Table 4. Summary of automobile accident rate regressions.

	All Data		Weekday		Weekend	
Variable	B	t	B	t	B	t
HRSNOW	0.52	6.33	0.85	7.33	0.29	2.29
HRSRAIN	0.23×10^{-1}	0.31	-0.06	-0.69	0.24	1.79
VMTAT	-0.83×10^{-12}	-2.25	-0.65×10^{-12}	-1.63	-0.15×10^{-11}	-1.73
AUTODAY	-0.34×10^{-1}	-0.02	0.27	0.14	0.42	0.12
VMTT	0.61×10^{-6}	0.98	0.37×10^{-6}	0.40	0.31×10^{-5}	0.97
Constant	1.56	1.19	1.29	0.82	0.59	0.20
R^2	0.16		0.23		0.13	

values. For each equation, t-statistics in excess of 1.96 in absolute value indicate parameters that are statistically significantly different from zero ($\alpha = 0.05$).

Automobile Accident Rates

A summary of the automobile regression models is given in Table 4. The R^2 value of 0.16 for the linear model with all automobiles indicates that a substantial portion (84 percent) of the variance in the data is unexplained. Although this is not completely satisfying, it is not very different from R^2 values obtained in disaggregate regressions in other transportation planning applications. The low R^2 can be explained by the presence of a number of days with no automobile accidents and significant levels of VMT. Thus, a model is being fit through these points as well as points with similar VMT and some number of accident involvements. The R^2 could be increased by aggregating involvements over several days, but one would then lose resolution on the variables that describe conditions of travel. It is believed that the low R^2 values are characteristic of the data disaggregation and that the model coefficients can still illustrate significant data association.

Only two variables are significant in the linear model. HRSNOW is very significant and positive in sign, which indicates increased automobile accident rates on days with increasing snowfall. The coefficients for the remaining weather variable (HRSRAIN) and the variable that denotes the percentage of automobile VMT during daylight (AUTODAY) are not statistically different from zero. The results for snow were certainly to be expected, given the comparisons of the accident rates in the preceding section. Daylight automobile VMT was expected to be more significant and was expected to be negative in sign.

The coefficient of the truck VMT variable (VMTT) is nearly significant and positive, which indicates that there may be higher automobile accident rates on days with higher truck volumes. The association of higher automobile accident rates with high truck VMT supports the general concern for mixing high levels of truck traffic with automobiles.

The interaction term of automobile and truck VMT (VMTAT) was significant and negative in sign, indicating lower daily accident rates when the product of automobile and truck VMT is high. The interpretation is that automobile accident rates are lower on days with high automobile and truck VMT, a surprising finding. The expectation was that automobile accident rates would increase as VMTAT increased because increased levels of automobile and truck mileage are a surrogate for high flows and possible congestion. The tollway is a rural highway throughout nearly all of its length, but congestion occurs only near the western end of the facility.

It would also be interesting to differentiate all involvements into single-vehicle/multiple-vehicle crashes and thereby determine the influence of automobile-truck VMT interaction. Other authors (17) have suggested that single-vehicle accidents increase with traffic volume to a point and then decrease as multiple-vehicle crashes predominate. Further insight could also be obtained by the spatial disaggregation of the data, although Indiana Tollway traffic data were unavailable in this form.

Examination of tollway VMT data indicated two trends:

1. Automobile volumes tend to be slightly higher and truck volumes lower on weekends during the year, which results in higher values for VMTAT during weekdays. Furthermore, weekday drivers are likely to be more regular travelers of the tollway than weekend travelers who drive for recreation purposes.
2. Automobile VMT increases (by a factor of 2) starting in the late spring and building into summer due to recreational travel; truck VMT remains nearly constant throughout the year.

To determine which of these trends is significant, separate regressions were estimated for weekday and weekend conditions (Table 4). These separate models seek to describe accident rates when conditions of travel are more uniform--i.e., when the truck-automobile vehicle mix is more nearly constant and the type of automobile driver is consistent.

The segmentation of the analysis into separate models for weekdays and weekends yielded very interesting results. HRSNOW was significant in both segmented models but was more significant on weekdays and had a substantially larger magnitude. The results can be explained by the lower VMT (and thus higher accident rates) during winter compared with other seasons. Furthermore, much of the weekday travel is done by commuters, for whom the work trip is mandatory. Weekend travelers can plan their discretionary trips in winter to keep their trips shorter and be ready to handle adverse weather; those who do travel during snow may be better able to handle the adverse travel conditions.

A significant change is observed in the sign and the statistical significance of the rainfall variable. For weekdays HRSRAIN has a negative and insignificant sign, whereas for weekends the coefficient is positive and marginally significant ($t = 1.79$, $p \approx 0.07$). This result may again reflect the inexperience of weekend vacationers or leisure drivers in dealing with rainy weather. This may be particularly true of summer vacationers who are not familiar with the tollway and who are traveling when the most severe rainfall of the year is likely to occur.

It is interesting that the VMT interaction term (VMTAT) remains negative and marginally significant for both weekdays and weekends. The interpretation is that this variable is capturing the seasonal travel trend of substantially increased automobile VMT during summer. The sign of the coefficient indicates that automobile accident rates are lower during these heavy travel days, a rather surprising result.

Table 5. Summary of truck accident rate regressions.

	All Data		Weekday		Weekend	
Variable	B	t	B	t	B	t
HRSNOW	0.69	7.16	0.66	5.50	0.68	3.68
HRSRAIN	-0.02	-0.25	-0.07	-0.79	0.07	0.33
VMTA	-0.26×10^{-6}	-0.74	-0.87×10^{-6}	-1.53	0.49×10^{-6}	0.35
TRUCDAY	0.62×10^{-2}	0.00	0.47	0.22	-2.13	-0.38
VMTAT	-0.14×10^{-12}	-0.26	0.47×10^{-12}	0.65	-0.12×10^{-11}	-0.48
Constant	1.89	2.05	1.81	1.97	2.53	1.05
R^2	0.16		0.15		0.18	

Table 6. Summary of accident rate regressions for large trucks: vehicle class 6.

	All Data		Weekday		Weekend	
Variable	B	t	B	t	B	t
HRSRAIN	-0.67×10^{-2}	-0.07	-0.05	-0.53	0.09	0.39
VMTCL1	-0.21	-0.55	-0.66×10^{-6}	-1.09	0.10×10^{-6}	0.07
HRSNOW	0.77	7.30	0.76	5.72	0.75	3.79
TRUCDAY	0.85	0.37	1.32	0.57	-0.90	-0.15
VMTCL16	-0.36×10^{-6}	-0.48	0.27×10^{-6}	0.27	-0.89×10^{-6}	-0.26
Constant	1.52	1.52	1.35	1.33	2.21	0.86
R^2	0.16		0.15		0.18	

Truck Accident Rates

The model of daily truck accident rates is summarized in Table 5. The model reveals a strong association of higher truck accident rates with days on which there are greater hours of snowfall. Surprisingly, none of the other variables in the linear specification were found to be significantly different from zero. Only VMTA, the daily automobile VMT, has a t-statistic that suggests significance; the sign of its coefficient suggests lower truck accident rates on days when automobile VMT is highest, such as on weekends and during the summer. Segmentation into weekends and weekdays resulted in VMTA being much more significant ($p = 0.12$) than in the pooled model. The sign of VMTA was still negative, which indicates decreased truck accident rates on days with high automobile VMT. Occurrence in the weekday segment implied lower truck accident rates during weekdays throughout the year.

It is interesting that none of the variables in the weekend model have significant coefficients other than the hours of snow.

To obtain a better idea of the influence of conditions of travel on large trucks, an additional set of regression analyses was conducted for vehicle class 6 (see Table 6). Results generally paralleled those for the all-truck model. Hours of snow was consistently significant and the only significant variable in the pooled model. Automobile VMT was again negatively associated with truck accident rate but not as strongly as in the models for all trucks. As before, the weekend segment contained hours of snowfall as the only significant predictor.

Summary

The findings for the large-truck and total-truck regression analyses are very similar: Hours of snowfall is the strongest predictor of truck accident rates, and high automobile VMT is associated with lower truck accident rates. in general, the truck accident analyses yielded models with slightly poorer goodness of fit than the automobile regression analyses. One may infer that the truck accidents were more likely due to factors not included in the models, whereas automobile accident rates were more heavily dependent on conditions of travel.

DISCUSSION OF RESULTS

In order to place this study's findings in the proper perspective, it is useful to compare them with previous studies. Research published by Vallette and others (2), Khasnabis and Atabak (8), and Scott and O'Day (13) presents findings useful for comparison.

In their study of accident experience in the State of Michigan, Khasnabis and Atabak (8) found that straight trucks had higher accident rates overall compared with tractor-semitrailers and panels, pickups, and vans. Compared with all other vehicles, tractor-semitrailers had a higher fatality rate but a lower overall accident rate. Although our truck classification does not identify straight trucks as such, vehicle class 3 would certainly include a large proportion of these vehicles and other small trucks. Our findings are similar to those of Khasnabis in that small trucks had a higher overall accident rate than large trucks. Our results further show that this is true for all comparable conditions for automobiles and large trucks. Our results differ from those of Khasnabis and Atabak in that large trucks in our data have higher overall accident rates than automobiles, primarily due to their higher accident rate in clear weather.

Scott and O'Day (13), using a large sample of main-line tollway accidents, found that the involvement rates for trucks and automobiles were not significantly different. These results are not the same as our findings, which are based on a smaller sample size. Scott also found that trucks were less affected by weather as a causative factor in accidents than were passenger cars. Comparison of means for our data generally supports this finding: The increase in accident involvement rate in snowy weather over that in clear weather is less for trucks than for automobiles; in addition, accident rates for large trucks are lower in rainy weather than in clear weather and change little or decrease at night.

Looking at a much broader class of roadway types, Vallette and others (2) found no significant difference in the accident involvement rate for trucks and automobiles. For urban and rural freeways, they found higher accident rates for tractor-semitrailers than for straight trucks, a finding opposite to ours for the most similar vehicle types. Whereas our "large" trucks include both singles and doubles, the accident rates we found for straight trucks (vehicle class 3) are directly opposite to those of Vallette and others and more closely related to the results of Khasnabis and Atabak.

None of the three previous research studies was able to make a statistical comparison of the accident rates of automobiles and trucks at this level of detail, describing conditions of travel.

CONCLUSIONS

The inclusion of conditions of travel can substantially aid in the understanding of the accident performance of different types of vehicles. Automobiles were consistently the most sensitive to travel conditions: Automobile involvement rates increased significantly at night during clear and rainy days; they also increased marginally during snow. Large and small trucks, however, had similar or lower accident rates at night.

Snowy weather was the single most important predictor of high accident rates for both trucks and automobiles for all the models tested. Weather conditions also appeared to affect different vehicle types in different ways: Large-truck accident rates actually were lower during rainy days than during clear days whereas automobile and small-truck accident rates remained approximately the same.

Although regression models of automobile and truck daily accident rates yielded low R^2 values (0.12 to 0.23), they frequently yielded significant and consistent results. As expected, snow was the most significant weather condition contributing to both automobile and truck accidents. Higher automobile accident rates were associated with high levels of truck VMT, which raises concerns about mixing high levels of these two vehicle groups in traffic.

A strong seasonal trend was apparent for automobiles: Lower accident rates were associated with days of high automobile and truck volumes, which occur mainly during summer months. These results somewhat contradict the findings regarding truck VMT but appear to reflect a different phenomenon--the twofold to threefold increase in automobile VMT during summer vacation months.

In summary, the study found important and significant changes in motor carrier and automobile accident rates when the concept of exposure was expanded to include weather conditions, daytime-nighttime travel, and, to a limited extent, vehicle mix.

The study illustrated the usefulness of combining data from divergent sources to conduct a detailed exposure analysis. The study also revealed important characteristics of motor vehicle performance as travel conditions change: Automobiles are much more sensitive to adverse weather and nighttime travel than trucks.

ACKNOWLEDGMENT

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