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STATISTICAL ANALYSIS OF TRUCK ACCIDENT INVOLVEMENT

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16. Abstract

This report is a statistical study of accidents involving large trucks, based primarily on police reported data from several states supplemented by carrier reports submitted to the Bureau of Motor Carrier Safety. Accident data from the Indiana, Ohio, and Pennsylvania Turnpikes was complemented by traffic flow information furnished by the turnpike authorities, thus allowing computation of accident experience relative to exposure.

By several measures, accident severity is greater when trucks are involved than when cars only are involved in a collision. The average number of fatalities for the former category is approximately that of the latter. The relative severity of truck accidents is even greater when the consequences to passenger car occupants alone are considered. The number of fatalities per passenger car in a collision with a truck is nearly ten times greater than for a collision with another car.

The turnpike accident files, which permit exposure computations to be made, give involvement rates (in terms of accidents per mile of travel) which are approximately the same for cars and trucks. A new measure of exposure, which incorporates parameters concerning the travel characteristics of both cars and trucks, was developed to investigate the relative probability of various accident configurations. By this measure, trucks on turnpikes are involved as the striking vehicle (in rear-end collisions) more than twice as often as expected.

Although mass accident data seldom provides much detail about causative factors, two such factors do stand out in the data available for this study. These are the frequency with which truck drivers are reported to be fatigued or asleep, and the frequency of vehicle defects. Both of these notations occur frequently enough to be considered problems requiring action.

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1. INTRODUCTION

The main objective of this study is to obtain a detailed statistical description of truck accident involvement, including variations of the frequency and circumstances with truck characteristics, and to compare the truck accident statistics with those of smaller vehicles. The emphasis is on larger trucks; pickups and panel trucks have generally been deleted or ignored in these analyses. Exposure information, i.e., the number of vehicles and vehicle miles by class, has been obtained where possible, and applied to the accident statistics. Finally, a stated objective of this program was to determine promising countermeasures or areas of investigation that might lead to a reduction in truck accidents or their severity. With appropriate cautions, some suggestions are made in this area.

By design this study is based on existing sets of accident data--some of which were available in digital form, and some of which were converted to that form for this program. The statistical description of some parts of the highway accident population is perhaps more art than science--it results in a sort of painting of the situation for the reader to view. This analogy can be carried further, because the interpretation of the painting depends on both the artist's method and the experience of the viewer. We have attempted to present the data as objectively as possible, first as raw accident statistics, and second as modified by considerations of exposure.

The raw statistics, for example, indicate that there are a large number of car-into-truck rear-end collisions, and that such collisions result in more serious injuries than (for example) truck-into-car rear-end collisions. When this data is adjusted for the number of vehicle miles (for cars and trucks), the car-into-truck collisions are more frequent than would be expected from accidents alone. But when an additional exposure factor is introduced, taking account of the relative speeds of cars and trucks--i.e. the number of potential overtaking conflicts--the apparent overinvolvement is much reduced. Nevertheless, this type of accident is frequently severe, and the exposure considerations may point the way toward a wiser choice of countermeasures.

The accident data used in this study was taken from two rather different sources. One represents all reported accidents occurring within a jurisdiction, and involves all kinds of vehicles and all kinds of roads; this includes data from the National Accident Summary, from the State of Texas, and from several smaller jurisdictions throughout the United States. The other includes accident data taken from three turnpikes; and this involves a very restricted set of vehicles. But it permits some detailed determination of traffic by type of vehicle and by time which could not be obtained in the more general sets of data. And although the turnpike situation is restricted, it is comparable to much of the planned 42,500 miles of interstate highway which carry a substantial fraction of the large truck mileage.

It is possible to draw conclusions from these data sources regarding the frequency of certain kinds of accidents, and to suggest possible countermeasures. It is not generally possible, however, to decide which of several countermeasures is most cost-effective. For example, in the case of car-into-truck rear-end collisions one might introduce rear bumpers for trucks, a different spacing of rear running lights for the trucks, more climbing lanes for slower vehicles (or signs indicating "slow traffic ahead"), bigger engines for trucks, better training for car drivers, or even separate roads for trucks. While some thought has been given to such countermeasures in the course of this study it has generally not been possible to evaluate their relative efficacy.

The picture of truck accident involvement which is presented here is of necessity painted with imperfect tools. We have observed reporting biases--for example the BMCS reports include accidents with injury, fire, or more than $250 in property damage; the state files generally include accidents with lesser amounts of damage. There are almost as many systems of truck classification as there are sources of data, and it is often necessary to group types of vehicles in order to present data--resulting in loss of detail and an inability to compare information from several sources. On the other hand, detailed information is important--cement mixers could be identified in Texas, the damage to the vehicle in Colodado, and the cost of fires in the BMCS file.

With the above reservations, it is suggested that data from the several state sources (and the BMCS) can be extrapolated to a national picture of truck accidents. And the data from the turnpikes can be considered as representative of accidents on the interstate system. Accordingly, some inferences to the national accident picture have been drawn in the text. with appropriate cautions.

The remainder of this report is presented in Sections 2 through 5. Conclusions and recommendations are presented in Section 2. Section 3 contains a discussion of the methodology followed in this study, emphasizing the modeling technique in the application of exposure data. Section 4 contains a description of the several data sources used in this analysis. Section 5 presents the detailed analyses in two parts--an overview of truck accidents derived from the state and national data sources, and an exposure adjusted statistical description of turnpike accidents. The appendices contain supplementary information on BMCS data and exposure modeling.

2. CONCLUSIONS AND RECOMMENDATIONS

Trucks are conspicuous in the accident population by their size, by the damage and injury involved, and by the obstruction of traffic resulting from both the vehicle weight and often from debris. In the minds of the casual observer these characteristics are often enhanced by newspaper accounts of the more bizarre events. On the other hand, large trucks are typically driven by professionals with long experience operating under stricter regulations (than do passenger cars) and they are providing a useful and necessary service in delivering goods. In this report we have attempted to paint a picture of the involvement of trucks in accidents--hoping to quantify some of these intuitive observations.

The general methodology of this study has been to obtain an overview of truck accidents using national, state, regional, and county level accident information, and then to study in more detail the truck involvement in accidents on three turnpikes. The former provide information about many kinds of roads, a mix of urban and rural situations, and many kinds of commercial vehicles. The latter provide information mainly about large tractor-trailers operating on interstate type roads. The turnpike sources have the advantage that traffic data is available in a form to permit comparison with the accident data--thus giving a measure of exposure.

A major problem in the conduct of this study is the fact that no two agencies seem to categorize trucks in exactly the same manner. While it is possible to identify and compare a few varieties of vehicles clearly between, say, Texas and Colorado, this is the exception rather than the rule. Simple definitions such as "large trucks", "vans", "straight trucks", and "light-heavy trucks" are apparently clear to their originator, but confusing to others.

A second problem concerns the reliability of the data reported by the various investigating agencies. Most of the data used here has come from police reports, although the BMCS data is furnished by the carrier. One might view this information as being of several qualities: data to be trusted with only minor reservations (this generally includes date and time of day, location, age of the driver, type of vehicle and accident configuration), and data to be used with reservation. This latter category includes quantified information because the investigating officers are not in a position to get precise readings. It also includes the softer data such as the reporting of causation factors, which may be related to local laws and law enforcement practices. This is particularly confusing in trying to compare different data sets--even in comparing the three turnpikes. The structure of data reporting forms inhibits some information by forcing choices on the investigator or the coder--e.g., he may only be able to report "jackknifing" or "struck bridge abutment", but not both, and he will choose the one which seems most important to him at the moment. Finally, the usual police accident report form is tailored more to the passenger car than to the truck, and often does not provide for recording of factors unique to the world of trucks.

In arriving at a set of conclusions the authors have attempted to take account of the accuracy and reliability of the data elements. While such considerations are not presented in this section, they are given in the appropriate places in the main sections of this report.

2.1 General Conclusions

The number of persons injured per accident involving a truck is nearly the same as for an accident involving only passenger vehicles--approximately 27 injuries per 100 accidents in the Texas data. For turnpike accidents the similarity exists, although the number injured per accident was 58 per 100 accidents (when trucks were involved) and 65 per 100 accidents when passenger cars only were involved. With regard to fatalities, some major differences exist. In Texas there were 2.39 fatalities per 100 accidents involving large trucks, and 1.14 fatalities per 100 accidents involving only passenger cars. The corresponding turnpike figures are 3.01 and 1.77. On this basis truck accidents could be considered twice as severe.

The figures given above are derived from the sum of single and multiple vehicle accidents. The relatively small difference in severity between accidents involving trucks and those not involving trucks may be explained by the lower occupancy of trucks and by the greater protection afforded the truck occupants by their vehicle. The differences are greater when considering the injuries to occupants of cars which collide with trucks as compared to those which collide with other cars.

A figure of merit which has occasionally been promulgated in the past is the ratio of passenger car occupants killed to the number of truck occupants killed in truck-car collisions. For example, in the 1969 BMCS data this ratio is 33.6. In Texas, it is 21.4. In the turnpike files used in this study it is 21.0. Although these numbers are high, they really reflect not only the danger to the car occupants but also the protection afforded the truck driver by his more rugged vehicle. In a collision between a large truck and a passenger car the car may serve as a mechanically appropriate energy absorber, and reduce the severity of the truck crash relative to a barrier impact. But it is interesting to consider this same ratio with regard to the experimental safety cars. If they protect their occupants well in car-car collisions, they may look as bad as trucks. It would seem inappropriate to interpret a high ratio as a condemnation of the safety car, and perhaps it should not be used to condemn trucks either.

The car occupant should be more interested in his chances for survival when striking a car or a truck. Two figures of merit are presented here: in Texas, the ratio of car occupant fatalities in collisions with trucks and in collision with cars is 7.7. With a more restricted set of two-vehicle accident types on the turnpikes this figure is 10.5.

In the BMCS data for 1969 it is possible to compare the frequency of fatal injury to car occupants in two kinds of rear-end collisions with trucks. When the car struck a truck in the rear there were fatal injuries in about 4% of the cases. When a truck struck the car this was about 1%. So it was four times worse to run into a truck than to be run into by a truck. For the turnpikes this ratio is 2.7 to 1.

Property damage in truck accidents is often extensive, but the reporting of this in terms of dollars is of doubtful accuracy. The few police agencies which do report damage in terms of dollars must estimate at the scene, and their ability to evaluate cargo losses must be questioned. The BMCS reports do include the value of damaged property estimated by the carrier, and are likely more reliable. For the BMCS reported accidents the average damage was approximately $2000 per accident, although accidents involving fire averaged $13,500. In other terms, fire is involved in only 1.5% of the accidents reported by BMCS, but accounts for 9.2% of the dollar loss.

The National Safety Council publishes "Fleet Accident Rates" annually, and the 1969-70 edition indicates that intercity common carrier trucks are involved in 3.8 accidents per million vehicle miles. The definition of an accident used in that publication is somewhat broader than either the Texas or turnpike police reporting requirements. The observed rates in this study are somewhat lower. For the 12 types of trucks studied in Texas, their average was 2.9 reported accidents per million vehicle miles. For vans, this was 2.0, but transit mix trucks were 9.2.

Truck accident involvement on turnpikes varied from state to state--1.58 per million vehicle miles in Ohio (vs. 1.22 for passenger cars), 1.72 per million vehicle miles in Indiana (vs. 1.60 for passenger cars), and 1.87 per million vehicle miles in Pennsylvania (vs. 2.23 for passenger cars). These values are similar for trucks to that reported by Solomon[1], 1.89 per million vehicle miles for trucks on main rural highways; but he found 2.83 accidents per million vehicle miles for passenger cars. Crosby[2], in an analysis of truck accidents on the New Jersey Turnpike (1952-57) reported 3.0 accidents per million vehicle miles for trucks vs. 1.78 for cars.

For the trucks studied in the Texas data, 58.3% of the involvements occurred on interstates or U.S. and State trunklines, 33.2% on city streets, and 8.2% on county or secondary roads. Fire trucks had 69% of their accidents in the city compared with 14% for pole (and log) trucks.

Time-wise, large truck accidents are distributed nearly uniformly by month--both in the turnpike files and in the BMCS data. Truck accidents are relatively infrequent on weekends, and occur somewhat more often during daylight hours than at night--although only slightly so on the turnpikes. Exposure information available for the turnpikes shows that large truck traffic is nearly uniform

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[1] Solomon, David, Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle, Bureau of Public Roads, Dept. of Commerce, July 1964.

[2] Crosby, J.R., Accident Experience on the New Jersey Turnpike, Traffic Engineering, Vol. 29, No. 5, Feb. 1959, pp.18-23.

over the 24-hour day period, and suggest that the increase of daytime accidents is due to the mix with heavier passenger car traffic at that time.

Fire trucks and wreckers, of course, have nearly as many accidents on Sundays as during the rest of the week, and transit mix trucks have almost none; and while vans are likely to be involved in accidents at night, wreckers exhibit a definite lull about 4:00 a.m.

2.2 Specific Conclusions

1. Using a measure of exposure which takes account of the difference in traffic characteristics of trucks and cars, the truck is overrepresented as the striking vehicle in turnpike car-truck collisions, and underrepresented as the struck vehicle. But the frequency of fatality in car-into-truck collisions is about four times that in truck-into-car collisions.

On the basis of gross vehicle miles, available in the turnpike data, trucks have been found to be overrepresented in the accident population relative to passenger cars in Ohio and Indiana, but underrepresented in Pennsylvania. Looking at single vehicle accidents alone, accident frequency for trucks and cars follow their respective traffic densities, truck involvement being nearly uniform over the year, and passenger cars peaking in summer months. Over the 24 hour day, both cars and trucks are somewhat over involved in single vehicle accidents in the early morning hours--trucks by a factor of 1.3 and passenger cars by a factor of 3.3; and these ratios are consistent for all three turnpikes. Reporting of causative factors on the accident reports is not complete enough to identify the reason for this difference.

The majority of two-vehicle collisions on turnpikes involved overtaking--rear end and side swipe accidents. If trucks constitute 20% of the gross vehicle miles (over the year), and passenger cars 80%, one might expect car-car collisions to be 64% (.8 x .8) of the total, car into truck and truck into car collisions 16% each, and truck-truck collisions 4%. An overinvolvement ratio has been computed by dividing the above numbers into the actual fraction of accidents by type. This figure is presented for the three turnpikes in the first triple column of Table 2-1, and suggests that car-into-truck accidents are somewhat overrepresented and that truck-into-truck accidents are greatly overrepresented.

Table 2-1

Comparison of Overinvolvement Ratios for Overtaking Accidents, by Collision Pairs for Passenger Cars and Large Trucks

	Gross Annual Vehicle Miles			Temporal Distribution of Vehicle Miles			Interaction Model		
	Ind.	Ohio	Pa.	Ind.	Ohio	Pa.	Ind.	Ohio	Pa.
Cars into Cars	0.97	0.84	0.96	0.97	0.84	0.95	1.08	0.97	1.05
Cars into trucks	1.06	1.26	1.22	1.09	1.31	1.27	0.50	0.59	0.60
Trucks into Cars	0.74	1.01	0.74	0.78	1.05	0.77	2.38	3.20	2.63
Trucks into Trucks	2.93	3.32	2.23	2.00	2.59	1.66	1.76	1.68	1.26

But if all truck travel were performed at night, and all passenger car travel in daytime, the prediction of truck-car collisions by the gross annual mile method would be quite inadequate. And although truck and car traffic are not as separated as this, they are quite different. The expected accident frequency was computed considering the actual traffic distribution (truck and car miles) as a function of time of day, week, and season. The overinvolvement ratios derived in this manner are shown in column 2 of Table 2-1.

One other factor which may be taken into account is that cars, having a higher average speed, are more likely to overtake a truck than vice versa, suggesting a higher probability of car-into-truck collisions than of truck-into-car. A model based on the observed differences in speed between cars and trucks has been derived to predict the relative number of overtaking situations of each type (car-car, car-truck, etc.), and column 3 presents the overinvolvement ratios based on this model. By this measure the car-into-truck is not as significant a problem as the truck-into-car. These results suggest that the probability of a collision is twice as great for a car passing a car than for a car passing a truck.

Although truck-into-car collisions occur with approximately the same frequency as car-into-truck, the chance of a fatality is about 4 times greater in the latter. So even though the overinvolvement ratio of car-into-truck accidents is low this collision configuration should not be neglected in consideration of countermeasures.

The particular rear-end collision in which a passenger car underrides a large truck can produce severe injuries. Police reported accident information is seldom detailed enough to identify the existence of underride, so that one is forced to draw inferences about this simply from the frequency of rear-end collisions. It is estimated that there may be on the order of two hundred fatalities incurred in such car-truck collisions in the United States each year.

2. Trucks are overrepresented as the struck vehicle on upgrades, and as the striking vehicle on downgrades in the turnpike data.

On the steeper upgrades on turnpikes (greater than 2½%) trucks are struck twice as often as they are on equivalent sections of level highway. Passenger cars are struck 1.4 times as often as these same upgrades. On downgrades of the same steepness truck-into-car collisions are overrepresented by a factor of 1.6 (compared with level road).

Some of these steeper grades had slow-vehicle (climbing) lanes, and an attempt was made to compare accident experience in those segments with similar slopes not so equipped. The number of accidents in a 2½ year period was not sufficient to permit an adequate evaluation of the effectiveness of such climbing lanes, although there was certainly no evidence that they were not effective.

3. Median barriers (on the Pennsylvania Turnpike) kept the striking vehicle from entering the opposing lane about as often for trucks as for passenger cars.

Given that the barrier had been struck, success was indicated 93.6% of the time for passenger cars, and 90% of the time for tractor trailers.

4. Fatigue or falling asleep is cited frequently enough among truck drivers in accidents to be considered a serious problem--particularly on the turnpikes.

Among the driver characteristics examined only this factor presented a clear problem for trucks. In Texas, for 1969, one in forty drivers of float trucks, vans, stake and tank trucks, was noted as being fatigued or asleep in connection with an accident. Truck drivers in Texas were reported asleep about 2.7 times as often as were passenger car drivers. On the Ohio Turnpike, truck drivers were reported as fatigued or asleep in 17% of their involvements as compared to 9% for passenger car drivers.

Other truck driver characteristics were more positive--use of alcohol is seldom reported for drivers of large trucks, truck drivers tend to be older on the average, but to have a smaller variation of age. For better or worse, there are few female drivers of large trucks--sex of driver is not even reported in the BMCS files.

5. Trucks are apparently less affected by weather conditions as a causative factor in accidents than are passenger cars.

On the Pennsylvania turnpike cars have 55% of their accidents in inclement weather (icy, snowy, or wet pavement), whereas trucks have only 40% of their accidents under the same conditions. Although there is a monthly variation in the ratio of car to truck traffic, precipitation is nearly uniformly spread throughout the year in this part of Pennsylvania, and this difference is taken as significant. An exception to this is the case of jackknife accidents, 60% of which, in Texas occur in wet weather.

6. Large trucks are identified as being indirectly involved in 3.1% of all accidents on the main line of the Indiana Turnpike.

This information, available only in the Indiana data, indicates that in a substantial number of accidents, the presence or action of trucks, even though the truck itself is not directly involved in the accident, may be a contributing factor. Over half of these accidents involved another vehicle overtaking or passing a truck, the stated reason for the accident being loss of control (54% of these), poor or lost vision (13%) and the remainder not stated. About one quarter of these truck-induced accidents involved loss of operating equipment from the truck (wheels, mud flaps, etc.). Load loss was given as a causative factor in 13% of the cases. The loss of control while passing is the dominant problem.

7. Trucks were cited as defective (in some equipment characteristic) 4.5 times as often as were passenger cars (in Texas) and 1.4 times as often on turnpikes.

In single vehicle accidents on turnpikes 23.5% of the trucks were noted as being defective vs. 14% of the cars. In Indiana, for example, truck tire failures (blowouts and punctures) were noted in 14% of the accidents. By contrast the most common defect reported in Texas was brakes--dump trucks being cited for bad brakes in 8% of their accidents.

An interesting failure reported in Texas was a wheel falling off the vehicle. This occurred in 0.7% of the truck involvements (compared with .04% of passenger cars), and occurred significantly more often in trucks older than three years. This 0.7% is nearly the same as the Indiana Turnpike ratio of lost wheels to the number of trucks involved in accidents. Direct involvement of such events in Indiana was not noted, but it is suggested that these two factors (wheels falling off and being struck by others, and lost wheels contributing to a truck accident) may be mutually exclusive. The total number of accidents involving a lost truck wheel may thus be the sum of these two.

8. Lowboys, fire trucks, and cement mixers and dump trucks are conspicuous in the accident data for fatalities, injuries, and accident rate respectively.

In Texas, accidents involving lowboys result in 3.3 times as many fatalities (per accident) as all large trucks taken together, and 6.9 times as many fatalities as accidents involving only passenger cars. A cursory extrapolation of the Texas data to the nation suggests lowboy accidents might account for as many as 700 fatalities annually. While the extrapolation is crude, it does serve to indicate the possible magnitude of the problem.

Fire truck accidents account for about twice the number of injuries per accident as other vehicles perhaps because this is the one truck with a large number of occupants, or because of the dangers of traveling under emergency conditions through urban intersections.

Dump trucks and cement mixers, for both their number and their mileage in the population of trucks, are overrepresented in accidents. In 360 cement mixer collisions in Texas there were no fatalities; but in 1940 dump truck collisions there were 26 fatalities. A major observed difference between these two types of trucks was the driver age--dump trucks having drivers ranging from 16 to 80, and cement mixers a much narrower age distribution.

9. Double bottom tractor trailers, uniquely identified in only one turnpike file, exhibit about half the accident rate (per vehicle mile) of other tractor trailers.

For the Indiana turnpike, large trucks had an accident rate of 172 per million vehicle miles; double bottoms had 84. In discussions with Ohio Turnpike officials, it was noted that double bottom accidents on that turnpike were considered a rarity. In Ohio the turnpike officials permit double bottom operation only bh established trucking companies (those with a credit card account) and for whom they have approved the driver (on the basis of his license record). This suggests that the lower accident rate may result from the driver's expertise rather than some property of the vehicle. But the ultimate result may be beneficial as double the load being carried with half the accidents makes the accidents per ton mile for double bottoms attractively low. The relative severity of double bottom accidents cannot be measured from the small number of involvements on the Indiana Toll Road. Data from the 1969 BMCS file indicates that the occupants of passenger cars that are in collisions with doubles suffer approximately 12 percent more casualties per accident than if involved with a tractor-semi trailer.

2.3 Recommendations

1. Driver fatigue should be recognized as a major contributing factor in truck accidents.

Falling asleep or being fatigued was not only the outstanding driver characteristic noted in the mass accident files, but the frequency in turnpike accidents (13%) was large. The Bureau of Motor Carrier Safety is currently sponsoring a program of research in driver fatigue; its conclusions and recommendations will be important. It is recommended that the Department of Transportation consider carefully the implementation of appropriate recommendations of this program with dispatch.

2. Accident investigation teams should pay particular attention to vehicle defects in their studies of truck collisions.

On the turnpikes vehicle defects were cited in a substantial fraction of single vehicle/truck accidents (nearly 25%). In Texas, where the accident population was broader than on turnpikes, the average for trucks was 6.5%. In both cases trucks were cited as defective more often than were passenger cars. Police accident reports often do not make clear whether the defect was contributory to the accident (no brakes) or even the result of the accident (a ruptured tire), so that is difficult to determine its effect on accident occurrence. Nevertheless, the reporting frequency justifies a further effort in defining this aspect of truck collisions. Objective evaluation of the incidence and causal effect of defects cannot be obtained from mass data, but must come from in-depth investigations by professional teams.

3. Physical separation of truck and passenger-car traffic should be considered where volumes are large enough to warrant parallel roadways.

While a decision to implement separate roads must be based on more than safety considerations, the evidence of the accident statistics favors truck-car traffic separation. Collisions between vehicles of similar weights produce injuries and fatalities at a substantially lower rate than collisions between dissimilar vehicles. Recent news reports of the vulnerability of sub-compact cars operating in an environment with standard sedans illustrates this point; the situation between conventional passenger cars and large trucks is worse.

Secondly, the traffic interaction model developed as a part of this study suggests that (for a given traffic flow rate) the number of conflicts is a maximum at a truck-car mix of about 30% trucks and 70% cars. Just because of the smaller deviation of speed, the road carrying a single type of vehicle should have fewer conflicts. And although conflicts are not necessarily linearly related to accidents, some positive relationship can be presumed to exist.

Traffic separation might be accomplished in any of several ways. Turnpikes could encourage trucks to travel at certain times of the day by adjusting the rate schedules; cars could be discouraged at the same time. New lanes added to existing highways could be physically separated from the old, and traffic of different types channeled appropriately. Or complete roads might be constructed to serve just car or truck traffic. This situation exists to some extent in New Jersey where portions of the Garden State Parkway are restricted to passenger vehicles, and the turnpike carries heavy truck traffic. Pennsylvania Turnpike officials have informally discussed the construction of a parallel truck-only highway, and it may be that increasing volume over the years would make this appropriate.

4. It is recommended that the Department of Transportation take steps to increase the utility and value of the BMCS accident data files for safety related studies.

The BMCS file currently does not represent a national census of truck accidents. Among other reasons, this is true because the reporting is restricted to regulated carriers in interstate commerce. This file should be expanded to include more of the total truck community; and this might better be accomplished under the auspices of NHTSA. Underreporting of reportable accidents, while not specifically determined in the present study, is a possible explanation for the disparity between state truck accident records and the BMCS file. This factor--reporting bias--deserves close attention in the development of an expanded file.

The data elements now included in the BMCS reporting form, and in turn in the digital file, are minimal for safety related studies. This should be expanded to include more detail on the size and weight of vehicles at the time of the accident, more descriptive material on the accident configuration, and more detail about equipment faults. In particular details of failure mechanisms in brakes, tires, and wheels would provide useful information to safety planners.

5. The Multidisciplinary Accident Investigation Teams should be asked to search for and investigate lowboy accidents.

The fatality rate for this class of accidents observed in Texas was sufficiently greater than for any other single class to warrant a further definition of the problem. It is not clear from the mass accident data what causes the fatal injuries in such collisions, and it is expected that a modest number of fully investigated cases would provide the information to better understand the unique aspects of these accidents and might lead to an appropriate countermeasure.

There are presently no NHTSA-sponsored teams which have truck accidents as their primary area of interest. The unique mechanical characteristics of trucks, as well as the special characteristics of truck drivers, could be more adequately reported by a team specializing in this area. For this reason it is suggested that NHTSA consider developing one of its teams to cover primarily large trucks accident involvements. Such a team could complement the present efforts of the Bureau of Motor Carrier Safety which does conduct in-depth investigations into a selected group of interstate carrier collisions.

6. An intermediate level accident data collection effort should be instituted in connection with one or more turnpikes.

The value of turnpike accident data would be greatly enhanced with the addition of detailed information appropriate to trucks, and by identifying vehicle characteristics in a manner more easily compared with the traffic data. Conversely the traffic data could be improved for the same purpose. Bi-level investigative efforts should be instituted on several turnpikes by adding provisions for truck-related factors to the normal accident information and reporting procedures. The requirement for additional traffic data does not imply a need for a change in toll structures, but may involve added instrumentation or slight modification of the data recording schemes.

This program might best be accomplished by contract directly with a turnpike commission, or with a Highway Patrol Agency. This set of investigations would complement the other accident investigation activities discussed above by providing data on a substantial number of accidents for which good exposure information is available.

In lieu of creating a specialized accident investigation program on turnpikes, NHTSA might consider the continual updating of several turnpike files using only the data presently coded by the state or turnpike authorities. While a single additional year of data is not likely to be of much value by itself, the record over several years should show trends in travel and accident rates at relatively low cost. If this is done, the Ohio and Indiana files are preferred to Pennsylvania--primarily because the existing data elements are more pertinent to accident studies.

7. It is recommended that NHTSA develop a plan for controlled experimentation with specific truck-accident countermeasures, using techniques analogous to the conflict measures presently being employed by the Federal Highway Administration.

Several possible countermeasures aimed at reducing either the frequency or the severity of car-into-truck rear end collisions have been widely discussed recently. These include increasing the horsepower to weight ration for commercial vehicles, enhanced rear lighting systems, and underride protection devices. It is difficult to evaluate the efficacy of these countermeasures by looking at the present mass accident data because: either the data do not exist (e.g., weight to horsepower ratio is not recorded in any of the data sets) or there is little or no variation in performance (as in the case of rear lighting systems).

Looking for surrogates of these factors in the accident data leads to some mixed conclusions. Increased horsepower might assist trucks in maintaining speed up grades; but trucks are overrepresented in striking cars in the rear, and it is possible that increased horsepower might make this situation worse. Trucks are indeed struck on upgrades more often than might be expected; but so are cars. And trucks are struck more often in the daytime as well as at night. It is possible that daytime use of lights might improve this situation, but some other communication technique might do an even better job.

Countermeasures will continue to be suggested by people with ideas. While this report has attempted to note peaks in the accident and injury data, it has not dwelled upon the invention of cures for these peaks. It is hoped that it will furnish material from which others can suggest specific remedies to be tried.

We note here that the body of data used in this study was quite large. Texas accounts for about 6% of the nation's accidents, and while it may be regionally biased, this is large enough to make one take notice of peaks in the data. The three turnpike files represent only about 1000 miles of controlled access highway, but there is an average of nearly four years of this data. Thus it is equivalent to some 10% of the interstate system for one year (in mileage), and because of its heavy traffic density has more than 10% of a year's accidents for the nation on this type of road.

The point to be made here is that mass accident data, at least in its present form, is just not capable of evaluating such countermeasures as larger engines, rear bumpers, or rear lighting systems to any degree of accuracy.

The techniques of conflict measurement have been developed to study the effect of changes in the highway--changes in signing, geometry, or traffic control. While these techniques have not been applied to the evaluation of vehicle modification before, it is suggested that they are appropriate to the determination of value of lighting systems, and horsepower to weight ratio, and perhaps to new countermeasures yet to be promulgated.

Many possible countermeasures deserve more than a paper evaluation, and the only chance for controlled experimentation would seem to lie in the measurement of intermediate variables such as is done in the conflict measurement technique.[1,2,3]

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[1] S.R. Perkins, GMR Traffic Conflicts Technique Procedures Manual, Research Publication GMR-895, General Motors Corporation, August 11, 1969.

[2] R.E. Campbell, L.E. King, The Traffic Conflicts Technique Applied to Rural Intersections, Accident Analysis and Prevention, Vol. 2, pp. 209-221, 1970.

[3] J. Pahl, A Comparison of Direct and Indirect Methods for Determining Accident Potential, Accident Analysis and Prevention, Vol. 2, pp. 201-207, 1970.

3. METHODOLOGY

The general objectives of this study are to describe the characteristics of truck accidents as mentioned in the Introduction and to detect outstanding factors and unique features which could lead to identification of areas appropriate for countermeasures. Ultimately the goal is to either determine appropriate countermeasures or to define areas which must be investigated further before necessary countermeasures can be specified.

The study is based on statistical analysis of accident data contained in several "files" of reports of police accident investigations. The individual files are described in the following section. Several were in existence and have been in use for general accident study for some time. Others were obtained or constructed specifically for this project. The files of police reports in aggregate contain records of accidents involving 27,000 trucks. To this base was added several years of accident data of the BMCS with 158,000 accidents, nearly all of which involve trucks. In addition to the 185,000 trucks in these files, the National Accident Summary file was available with 218,000 trucks.

The data in the ten available files varies greatly from source to source in detail and structure. Thus none of the analyses utilized all of the files. Often only a few could be used for a specific question. The lack of uniformity between accident data banks is both a curse and a blessing. The disadvantages are obvious. Since no question can be investigated using all files, nor with equal vigor from several applicable files, many subjects cannot be extended to representation of a national picture in spite of the large total sample. On the other hand, the diversity of the files means that the investigation is not limited to a least common denominator. And often, a question that can not be studied with "typical" files can be studied with a specific data bank.

The trucks in these files are of all types and sizes, with description and classification also varying from source to source. In order to exclude vehicles with operating characteristics similar to those of passenger cars, this study generally has not considered pickup and panel trucks. Emphasis was placed on tractor-trailers, but where information was available on intermediate-sized trucks they have been included.

The analysis of the majority of the files of police data, the National Accident Summary and the BMCS data is based on frequency or incidence of accidents. This general approach, both here and in previous truck accident studies, can be of rewarding value, but does not allow adjustment of incidence for relative exposure, thus allowing or even fostering misconceptions.

Since few if any recent statistical studies of truck accidents with wide applicability have included exposure data, particular emphasis has been placed on incorporating exposure measures in this study.

Toll roads were selected as an ideal "closed system" for study, in that complete accident data can be obtained from a single agency, along with a traffic "census" derived from toll data. Thus a rather precise measure of exposure is available along with complete accident coverage from an entire population. For this reason, the Pennsylvania and Ohio turnpikes and the Indiana Toll Road were selected. Nearly all the analysis of accident data from these highways is compared with corresponding exposure measures. The primary measure of exposure used is vehicle miles of travel. In addition, a traffic flow model based on frequency of potential conflict situations was developed, and it proved valuable for studying a mixture of vehicle types, particularly for analysis of involvements of a minority vehicle, i.e. trucks.

The turnpike data certainly does not represent all environments in which trucks operate, and the other files are valuable for this reason. However, turnpikes are similar in design philosophy and use to the system of interstate highways. The results of the "turnpike" analyses are important in that they are representative of both the interstate highway system of the county and of many other controlled access highways.

With the exception of the BMCS file and a file of Texas truck accidents, all of the files used in this study contain not only accidents involving trucks, but all motor vehicle traffic accidents in the jurisdiction of the reporting agency. These predominantly passenger car accidents have been included in the analysis,not as the subject of the study, but for comparison purposes. Cars are not compared with trucks as an appropriate yardstick of truck accident experience, which they certainly do not provide. Nor are the comparisons used to condemn or acclaim trucks. In addition to providing a relative measure of the magnitude of the safety problems, car involvements are included for two specific reasons:

(1) Trucks represent a minority vehicle type on nearly all highway systems. As such, the intersection of car accidents and truck accidents includes almost all of the truck accidents but few of the passenger car accidents. The world of trucks is composed largely of cars, and exclusion of cars from an analysis of the sort done here--even those accidents involving only passenger cars--would not allow examination of the whole picture.

(2) The second reason for including passenger car accidents is closely related to the determination of countermeasures or to the detection of problem areas for which countermeasures are appropriate. If a countermeasure is to be applied uniquely to trucks, it should be addressed to a problem unique to trucks or to truck accidents; i.e., the greatest potential for reducing the consequences of truck accidents would probably be realized by detecting and responding to differences in the accident experience of the two vehicle types.

Much of the information available from police reports is "hard" or objective data that has high reliability and accuracy. This category includes date, time, location, gross vehicle description, etc. Other data is highly subjective or "soft". This category includes much of the causative information and sometimes the severity of non-fatal injury. Speed of vehicles at and before impact, and property damage losses are also examples of the latter.

As much as possible, the analyses using objective and subjective information have been separated. Nevertheless subjective data can be valuable and such data has not been omitted, but only subordinated and discussed independently.

4. DATA DESCRIPTION

This study is concerned with the compilation of, and the drawing of inferences from descriptive data relative to the involvement of trucks in highway accidents in the United States. A number of sets of accident data have been used in this work, most of them deriving from police officer investigations. One collection of information results from carrier reports, and another results from a small number of very detailed accident investigations conducted by professional investigators.

Some are national in character, some cover a single state, and some cover smaller jurisdictions; and they vary in content from being entirely truck related to general coverage of all accidents within a given area.

While it would be desirable for the purpose of drawing inferences about the national population to have selected data sets which could be statistically related to the entire country, data sets were chosen instead for their availability and content. Generally, then, inferences to the national picture must be made with caution; in the analyses presented this caution; will occasionally be made explicit.

Two national sets of data have been used: that of the National Accident Summary prepared by the National Highway Traffic Safety Administration and that of the Bureau of Motor Carrier Safety. Even these are not fully representative of national statistics, and some analyses will be presented to qualify these.

In this section the principal sources of data will be described briefly, emphasizing their strengths and weaknesses with reference to defining truck accident involvement. The sources are summarized in Table 4-1.

Each of the sets of data defined in the table has been placed in a common digital form for analysis. With the exception of the Indiana and Oakland County files all were in digital form when they were acquired. For the Indiana Tollroad, data were obtained in hard copy form, coded, and keypunched locally. The Oakland County data was partially digitized, but some details were added locally.

The DENVER accident file was derived from records obtained through the State of Colorado Department of Revenue, and consists of all reported accidents occurring in 1969 in Denver, Washington, Jefferson, and Arapahoe Counties--generally described as the greater Denver area. There is little detail on type of truck--these vehicles being described as (1) trucks (2) truck tractors and (3) truck semitrailers. In addition pickup trucks and pickup trucks with camper bodies are separately identified.

The unique feature of the Denver data is the existence of a damage scale similar to the TAD scale. This permits identification of damage to the vehicle body on a 16 point compass centered on the vehicle. It has been used in this study to compare the damage incurred by various classes of vehicles involved in accidents.

Table 4-1

Summary of Principal Data Sources

NAME	DESCRIPTION	TIME PERIOD	NUMBER OF CASES
Denver	Four county area including Denver, Colorado	1969	45,000 accidents 62,000 vehicles 2,300 trucks
Texas Sample	A 5% sample of all reported accidents in the state of Texas for one year	1969	18,837 accidents 32,224 vehicles 4,747 trucks
Texas Truck*	A file of all truck accidents occurring in Texas in one year	1969	11,590 accidents 20,641 vehicles 13,413 trucks
Oakland County	A file of all reported accidents occurring in Oakland County, Michigan in one year	1969	29,265 accidents 48,000 vehicles 2,100 trucks
National Accident Summary	A file of 2.5 million involvements from 26 states	1968	2.5×10^6 vehicles 218,000 trucks
Bureau of Motor Carrier Safety	A file of involvements of inter-state carrier vehicles, reported by the carrier to BMCS	1966 (last half) through 1969	163,938 vehicles 157,898 trucks
Michigan Fatal	A file of all Michigan fatal accidents	1964-1970	13,458 accidents 20,153 vehicles 2,392 trucks
Pennsylvania Turnpike*	A file of all accidents occurring on the Pennsylvania Turnpike	1967-June 1969	11,492 accidents 16,426 vehicles 3,122 trucks
Ohio Turnpike*	A file of all accidents occurring on the Ohio Turnpike	1966 - June 1970	6,189 accidents 8,293 vehicles 2,035 trucks
Indiana Toll Road*	A file of all accidents occurring on the Indiana Toll Road	1966-1970	5,744 accidents 7,616 vehicles 1,642 trucks

* Files obtained specifically for this study.

The TEXAS SAMPLE file is a systematic sample drawn from a complete set of accidents reported in Texas during the year 1969. Since it encompasses the same time period and geographic area as the TEXAS TRUCK file it has been used to compare characteristics of truck accidents with those of the general or passenger car population.

The TEXAS TRUCK file contains reports of approximately 12,000 accidents involving large trucks in Texas during 1969. Specifically excluded were pickup and panel trucks, and they appear in this data only when they have been involved in collision with a larger truck.

The particular advantage of the TEXAS data is the detailed identification of trucks by type, a feature not found in most of the other sources of information. And because this detail is not available elsewhere some caution must be exercised in extrapolating findings here to the national population. With this warning, however, some of the frequencies observed in Texas will be multiplied by the ratio of populations in the U.S. and Texas to suggest the national extent of particular problems.

The OAKLAND COUNTY file contains police recorded information for all reported accidents occurring in the county. A second pass at the original report forms generated more detailed data in the digital file--specifically injury by seated position, Vehicle Identification Numbers, and a more complete description of the accident configuration, a fairly precise geographic coordinate for each case. Truck types are not identified in the detail of either the BMCS or Texas data sets, although single bottoms and double bottoms can be separately identified.

The NATIONAL ACCIDENT SUMMARY file was developed from digital records of accidents from 26 states by the National Highway Traffic Safety Administration. It identifies all trucks with a single code, and a detailed explanation of the types of vehicles included in this category is not available. Based on the ratio of trucks to total vehicles in this data set as compared with others it seems likely that pickup trucks and panel trucks are included. Since this study is addressed primarily to larger trucks, this data is not directly comparable with the other sets but some observations have been included in the descriptive statistics.

The BUREAU OF MOTOR CARRIER SAFETY file was developed from three and one-half years of digital data provided by BMCS. The coded information is developed from the BMC-50 accident report form furnished to the Bureau by the carrier. There is good detail on cargo, body style, and type of accident, although these items of information are not often directly comparable to the same data in other files. The BMCS file has the advantage that it reports a substantial fraction (perhaps one-third to one-half) of the large truck fatal accidents in the country. It has the disadvantage that, being restricted to the interstate carrier accidents there are reporting biases which seem to vary from state to state; it is likely that it is not a true representation of the national truck population.

The MICHIGAN FATAL file contains the records of all Michigan Fatal accidents from 1964 through 1970, but it lacks detail on the type of vehicle. For the years 1964 through 1967 all trucks are lumped in a single category (including pickups and panel trucks). For the years 1968 through 1970 tractor trailers, straight trucks, and pickups are separately identified. This set is large enough to compare truck and passenger car fatal accidents in a number of ways.

The PENNSYLVANIA TURNPIKE file was developed from digital records provided by the Pennsylvania Department of Transportation. The period covered by the file is shorter than for the other turnpikes, but it includes all records that had been coded at the time.

The file was originally created by the Pennsylvania Highway Department before organization of the state Department of Transportation. Consequently, the file was not tailored to turnpike accidents, and many of the 174 variables were not applicable to these crashes. Information on the registration, drivers, and arrest data were included on up to 9 vehicles using 75 variables. Since involvement data was included only the two principal vehicles, many of these variables were deleted. Several additional variables were derived from existing variables to increase the usefulness of the file for accident analysis or to make analysis easier to accomplish. The resulting file contains 124 variables.

Highway geometric information was obtained from the turnpike authority, including the grade of the highway at each one-tenth milepost, the same coordinate system used to locate accidents. The grade data was coded to the nearest tenth degree, and merged with the accident file.

While the Pennsylvania file contains 3122 trucks, 663 of these are straight trucks (single unit) and include an unknown number of pick-ups which are not a subject of this study. Hence many of the analyses are restricted to the remaining 2459 trucks to prevent contamination by inclusion of vehicles with size and performance characteristics similar to passenger cars.

The OHIO TURNPIKE file contains all accidents on the Ohio Turnpike, from 1966 through the first half of 1970, with total estimated property damage over one hundred dollars. The file was obtained from the Ohio Turnpike Authority on punched cards with a record of 49 variables for each of 8663 vehicles. From these cards a "vehicle" file was generated by concatenating the records for the principal two vehicles in the same accident while dropping redundant information. This resulted in an accident file of 6189 cases with 87 variables per case. Data is included on 8293 vehicles. The difference of 370 between the number of vehicles in the "vehicle" and accident files is the number of vehicles in accidents with three or more involvements that were deleted by restricting the accident file to two vehicles. Highway grade data was obtained from the turnpike authority as described for Pennsylvania, and included in the file.

The accident file was arranged so that vehicle "1" of multi-vehicle crashes is the striking vehicle when it was possible to make the distinction. This was possible in 82% of the accidents involving two or more vehicles.

The INDIANA TOLL ROAD file was generated by coding the original hard copies of the accident reports for all reported accidents on the toll road from 1966 through 1970. The reports were made available for coding of the non-personal information by arrangement with the Toll Road Authority and the Indiana State Police.

Although coding the reports on 5744 accidents was a large task, it allowed complete freedom of structuring and planning the file. The file was generated to be compatible with the Ohio Turnpike file--the first of the three obtained--with additional variables to increase the utility and value of the first for analysis of truck involvements. For example, identification of the type of vehicle included unique codes for double bottoms and recreational vehicles. While not a specific subject of this study, the latter are of considerable current interest and are not identified in most accident data files. Three distinct files were created from the Indiana data. The "Master" file contains information on the principal two vehicles of all 5744 accidents, with the striking vehicle coded as vehicle "1". This file contains 145 variables on each accident. A subfile of all accidents involving more than two vehicles was created with 346 variables on up to 6 vehicles. This "multi vehicle" file contains 197 cases. The principal two vehicles of each case are included in the master file.

While coding the accident reports, it was noted that occasionally a large truck was mentioned in the report as a possible contributor or causative factor without being directly involved. These cases (128) were coded with six extra variables describing the indirect involvement of the truck and were used to create a "Trucks Indirectly Involved" file. Again, the principal two vehicles of these cases--without the unique six variables--are included in the master file.

5. ANALYSIS AND RESULTS

In this section an overview of truck accident data taken from several large and general files is presented. This is followed by presentation of the information derived from the several turnpike files, appropriately modified or annotated for exposure considerations. Research findings are included among the results of these analyses, but the interpretation of these into the conclusions of the study were generally given in Section 2.

This section contains all of the detailed data tabulations of the report, and as such can be used by the serious reader to reach conclusions in areas not specifically addressed in this study.

5.1 An Overview of Truck Accident Data--Incidence and Loss

A truck or not a truck, that is the question. This paraphrase is indicative of the problem of generating and comparing descriptive statistics about truck accidents, and of acquiring exposure information with which to interpret the accident information. In the many sets of data available for this study there is almost no consistent definition of a truck other than to conclude that anything which is not a car, bus, or motorcycle must be a truck.

This is not to say that detail is not available. In the Bureau of Motor Carrier Safety files it is possible to identify "a tractor semi-trailer carrying live animals for biological control work--such as screw worm flies". And in Texas it is possible to identify transit mix trucks and fire trucks. In the U.S. Department of Commerce's transportation census it is possible to identify beverage trucks and insulated non-refrigerated vans. Registration records are typically kept by weight, but accident records are more likely to be kept by some visual description of the vehicle.

In this overview three principal data sources are used, supplemented by several secondary ones. The principal sources are the National Accident Summary, the Bureau of Motor Carrier Safety files, and the files of truck accidents reported by police departments in the state of Texas. These are listed in the order of increasing detail. The first defines trucks very broadly--evidently in the common use of "a property carrying motor vehicle used on public highways and streets".* The second consists entirely of interstate carrier trucks and buses (although for most purposes in these analyses the bus data has been deleted or neglected). The third, the Texas file, consists of accident records for just 12 body styles of trucks, specifically eliminating pick-up and panel trucks from consideration.

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* 1967 Census of Transportation, Vol. II, Truck Inventory and Use Survey, U.S. Department of Commerce, Bureau of the Census.

Truck accidents are characterized, then, using these information sources. The overview is presented in four sub-sections: The Accident (when, where, how, etc.), the Injuries and Property Damage, The Driver, and The Vehicle. A modest attempt at an exposure measure using the Census of Transportation and the Texas data is made, but--mostly because of the difficulty of identifying truck types from data source to data source--the reader is advised to interpret these results with caution.

5.1.1 The Accident

When Do Truck Accidents Happen?

This question may be considered relative to any standard time period--year, month, day of week, hour of day--or by combinations thereof.

Figure 5-1 shows the monthly distribution of accidents from the Bureau of Motor Carrier Safety files, and suggests that interstate truck activity varies little from month to month, although there is a consistently low April for all three years and a fairly stable December-January peak.

Accident incidence by day of the week is shown in Figures 5-2 through 5-4 for passenger cars (from the Texas sample), large trucks (from the Texas truck file), and Interstate Carriers (from BMCS-1969). Some truck types are seldom in accidents (and by inference on the road) on Sundays--only about 1% of the transit mix and dump truck accidents occur on that day. Fire trucks and wreckers, are spread more evenly through the week. A plot of the incidence of truck accidents by type of truck and day of the week, taken from BMCS 1968 files, is shown in Figure 5-5.

Hour of the day information is plotted in Figures 5-6 through 5-11. The incidence of passenger car and truck involvement shown is grouped in three-hour time periods in Figures 5-6 and 5-7 respectively. Figures 5-8 and 5-9 show the Texas truck and Bureau of Motor Carrier Safety hourly distributions. Two specific vehicle hourly distributions are shown in Figures 5-10 and 5-11, for vans and wreckers respectively. These are the most widely different, vans showing only a three to one ratio of incidence from the maximum to minimum hour and wreckers having a definite middle of the night lull.

Where Do Truck Accidents Happen?

The National Accident Summary data tabulates location as a two level variable--rural vs. urban. This is given for trucks vs. passenger cars in Table 5-1.

Table 5-1

Distribution of Involvements by Accident Location, National Accident Summary

	Passenger Cars	Trucks
Rural	766,000	106,600
Urban	1,353,300	112,200

Figure 5-1

BMCS PERCENTAGE ACCIDENTS BY MONTH
1967-69 AND AVERAGED OVER 3 YEARS
BASED ON 140,000 REPORTS

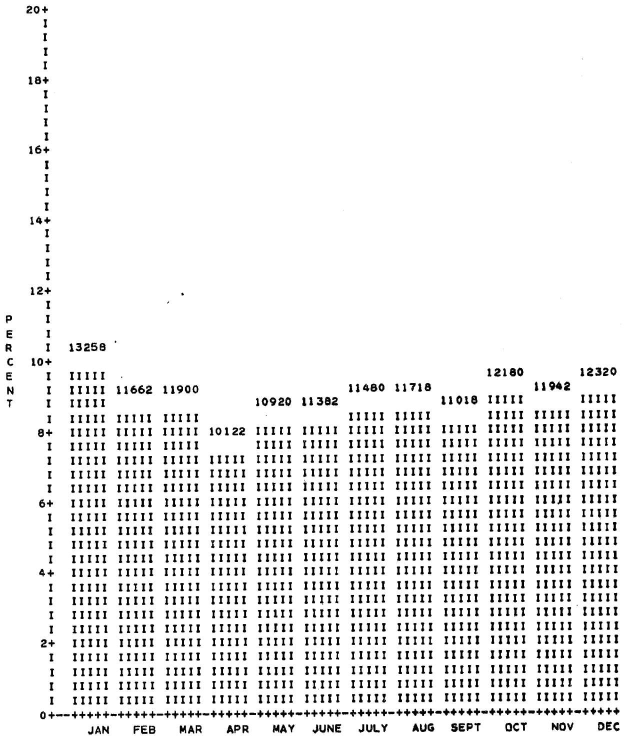


Figure 5-2

NUMBER OF ACCIDENTS BY DAY OF THE WEEK
PASSENGER CARS ONLY (FROM THE TEXAS 5% SAMPLE)

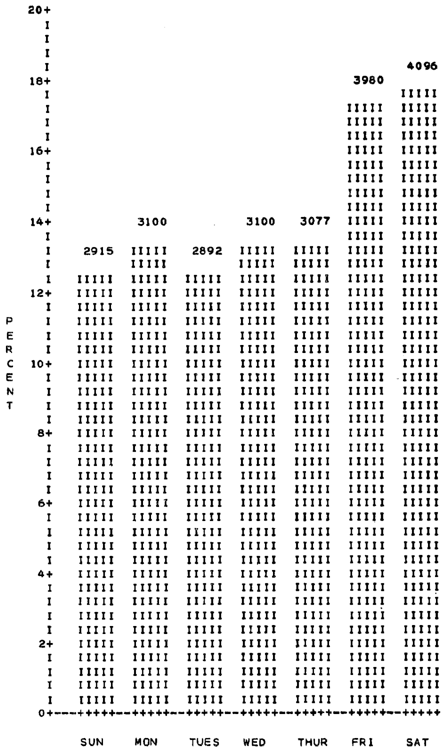


Figure 5-3

NUMBER OF ACCIDENTS BY DAY OF THE WEEK

LARGE TRUCKS(FROM THE TEXAS TRUCK FILE)

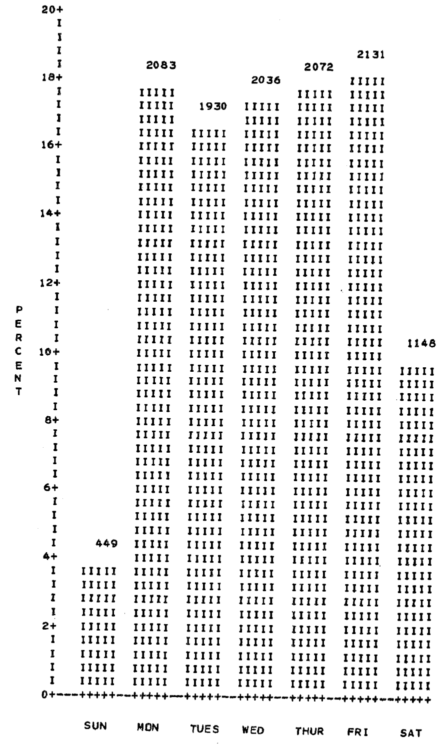
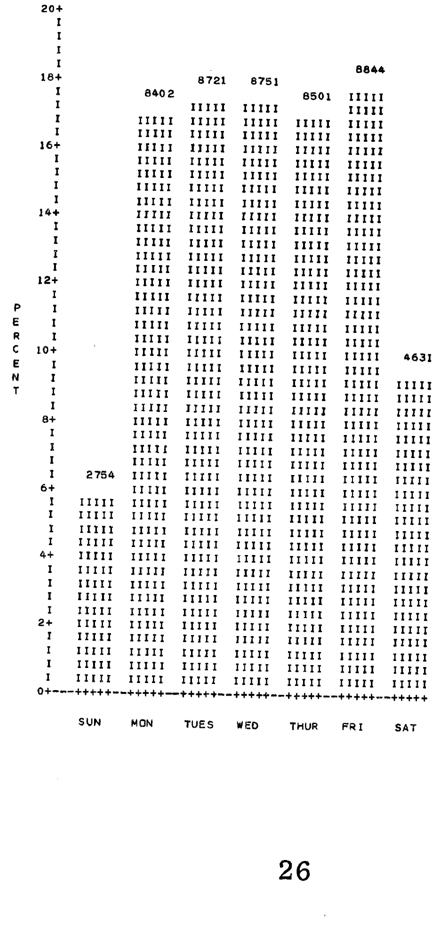


Figure 5-4

NUMBER OF ACCIDENTS BY DAY OF THE WEEK
INTERSTATE CARRIERS (FROM THE BUREAU OF
MOTOR CARRIER SAFETY FILES FOR 1969)



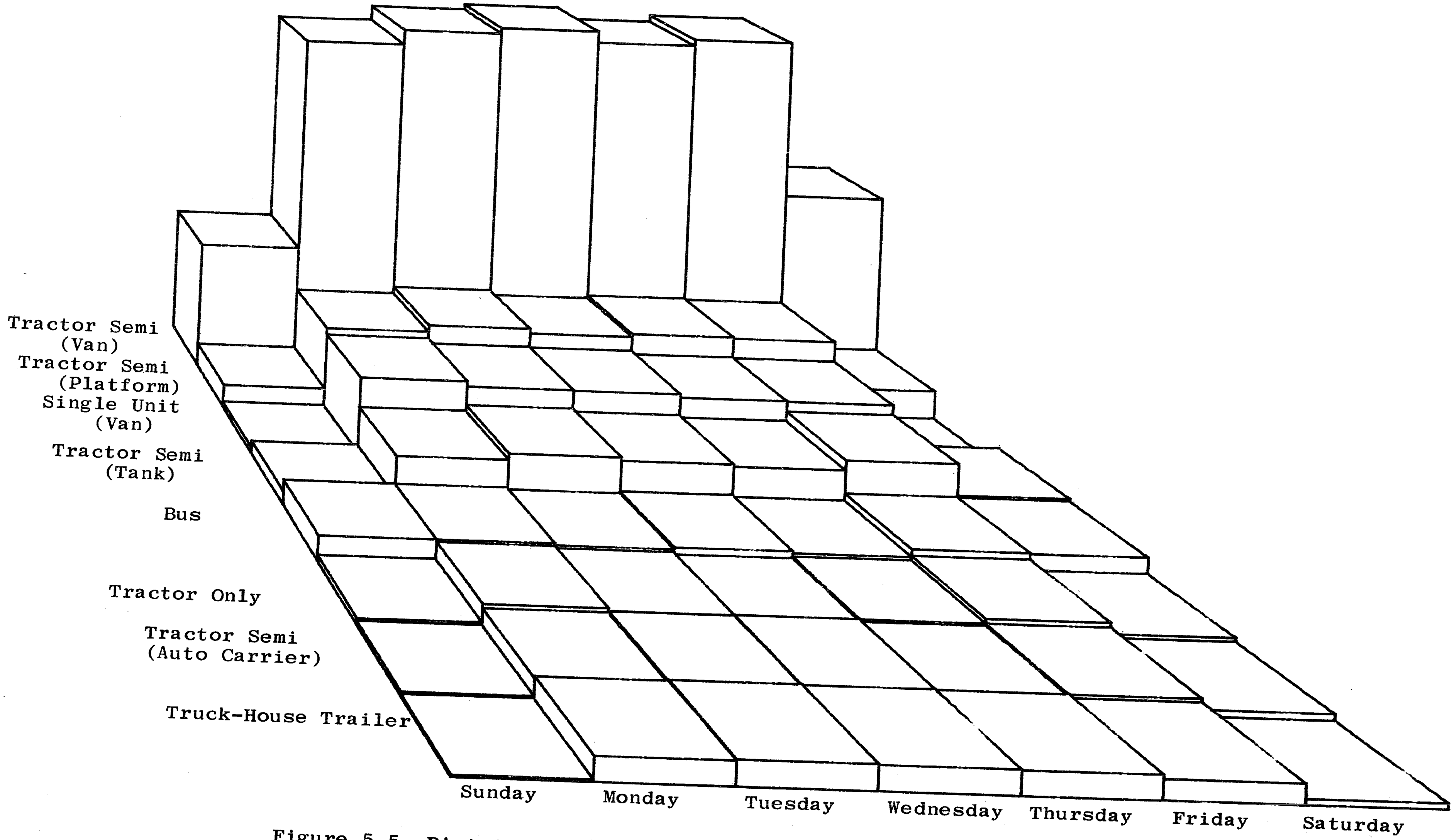


Figure 5-5 Distribution of Truck Accidents by Day of Week and Truck Type, BMCS 1968

Figure 5-6

```
NATIONAL ACCIDENT SUMMARY
    ACCIDENT INVOLVEMENTIN 100'S BY TIME OF DAY
          PASSENGER CARS ONLY

   50+
     I
     I
     I
     I
   45+
     I
     I
     I
     I
   40+
     I
     I
     I
     I
   35+
     I
     I
     I
     I
   30+
     I
P    I
E    I
R    I                                       5095
C  25+
E    I                                     IIIIII
N    I                                     IIIIII
T    I                                     IIIIII
     I                                4124 IIIIII
   20+                                     IIIIII
     I                              IIIIII IIIIII
     I                              IIIIII IIIIII
     I                              IIIIII IIIIII
     I                              IIIIII IIIIII   2944
   15+                         2798 IIIIII IIIIII
     I                  2492        IIIIII IIIIII IIIIII
     I                       IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII   1965
   10+                IIIIII IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I    1150        IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
    5+  IIIIII    632 IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
    0+--++++++-++++++-++++++-++++++-++++++-++++++-++++++-++++++
        1-4AM  4-7AM  7-10AM 10-1PM  1-4PM  4-7PM  7-10PM 10-1AM
```

Figure 5-7

```
NATIONAL ACCIDENT SUMMARY
      ACCIDENT INVOLVEMENT IN 100'S BY TIME OF DAY
        TRUCKS ONLY

   50+
     I
     I
     I
     I
   45+
     I
     I
     I
     I
   40+
     I
     I
     I
     I
   35+
     I
     I
     I
     I
   30+
     I
P    I
E    I
R    I
C  25+                                 495
E    I
N    I                              IIIIII    456
T    I                              IIIIII
     I                              IIIIII IIIIII
   20+                          395 IIIIII IIIIII
     I                              IIIIII IIIIII
     I                   353 IIIIII IIIIII IIIIII
     I                       IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII
   15+                IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII    192
   10+                IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII IIIIII    121
     I                IIIIII IIIIII IIIIII IIIIII IIIIII
     I      81     94 IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
    5+                IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
    0+--++++++-++++++-++++++-++++++-++++++-++++++-++++++-++++++
        1-4AM  4-7AM  7-10AM 10-1PM  1-4PM  4-7PM  7-10PM 10-1AM
```

Figure 5-8

NUMBER OF ACCIDENTS BY HOUR OF THE DAY
BUREAU OF MOTOR CARRIER SAFETY FILE - 1969

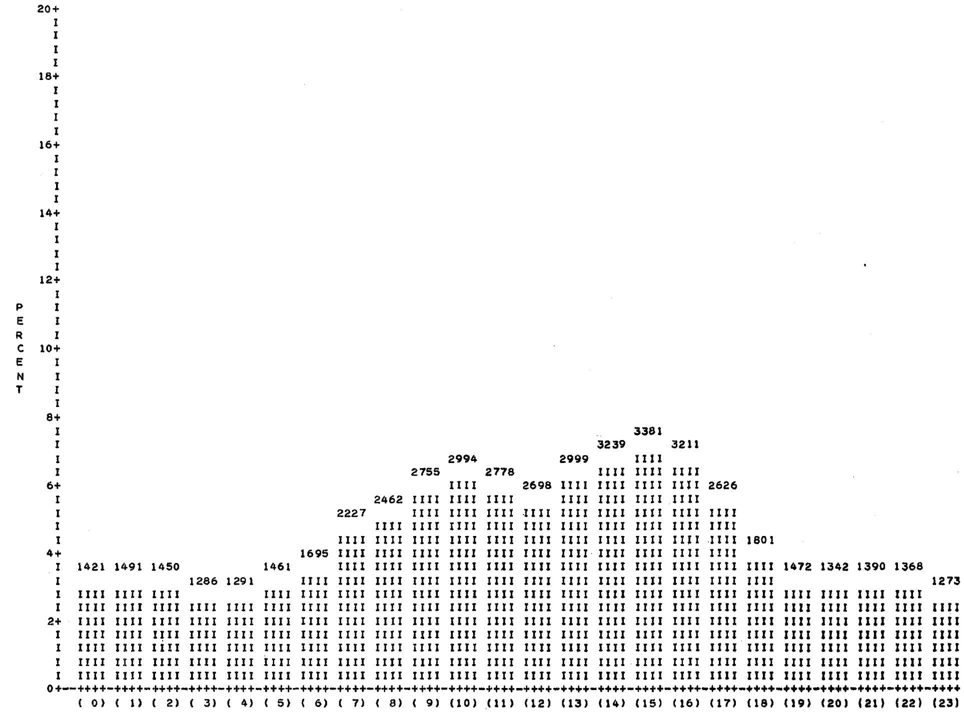


Figure 5-9

NUMBERS OF ACCIDENTS BY HOUR OF THE DAY
TEXAS TRUCK FILE - 1969

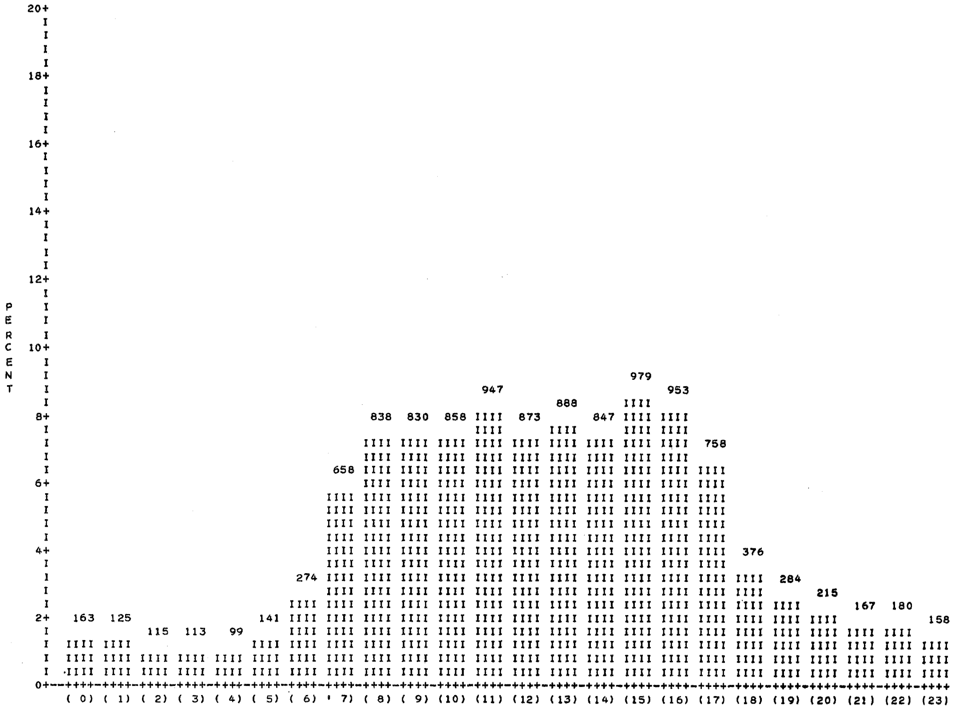


Figure 5-10

NUMBER OF ACCIDENTS BY HOUR OF THE DAY
VANS ONLY
TEXAS TRUCK FILE - 1969

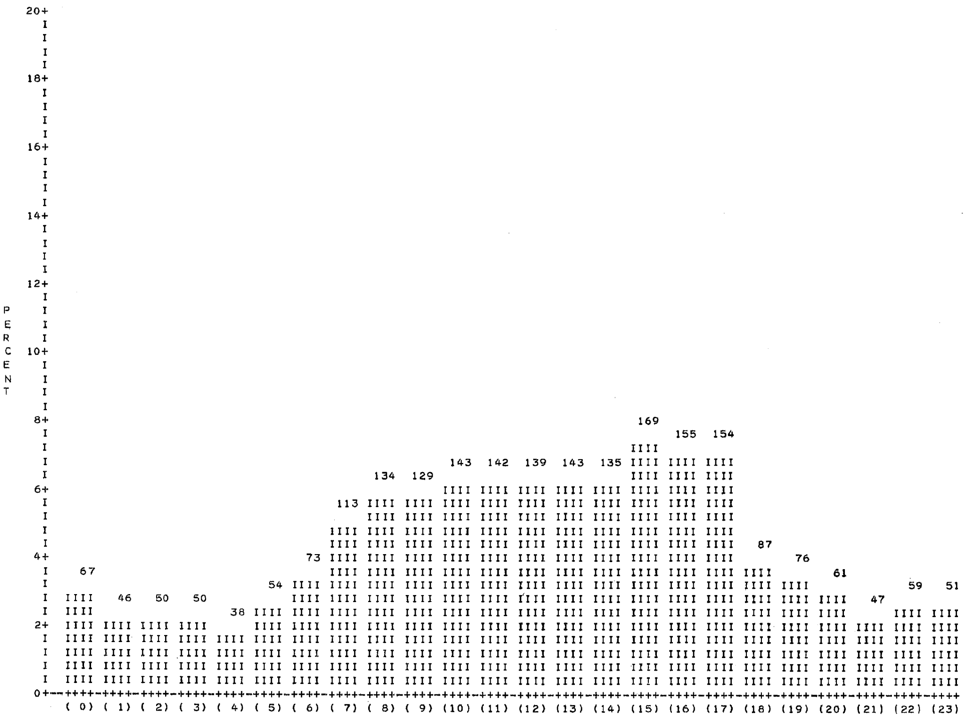
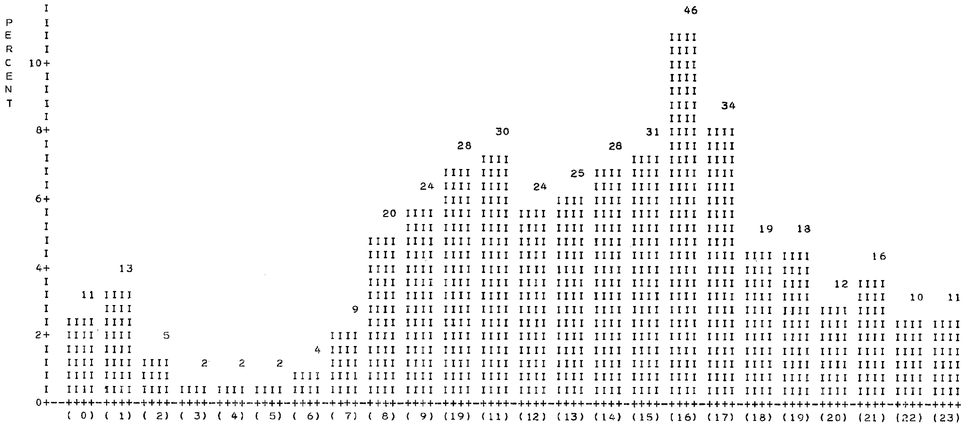


Figure 5-11

NUMBER OF ACCIDENTS BY HOUR OF THE DAY
WRECKERS ONLY
TEXAS TRUCK FILE - 1969



It can be seen that trucks, as defined in the NAS, have their accidents split about evenly between rural and urban, whereas passenger cars have about twice as many urban as rural accidents.

The Bureau of Motor Carrier Safety file provides a surrogate for the urban/rural classification of the National Accident Summary: accidents are coded as involving "local" or "inter-city" travel. Since this file consists primarily of data about interstate carriers, it could be expected that the bulk of the accidents occur in the "inter-city" category, and indeed about 80% do.

Again somewhat more detail is available in Texas data. Table 5-2 shows the several types of trucks as well as passenger vehicles relative to the location of their accidents. Although the percentages are somewhat different the passenger cars have a similarly larger urban accident rate than do trucks. Of particular note in this table is the overrepresentation of float trucks and pole trucks on U.S. and State trunklines and on secondary roads. This, coupled with the observation that float trucks are much overinvolved in fatal accident production suggests that their presence on (primarily) two lane roads may be a hazard.

Fire trucks, understandably, seem overrepresented on city streets, and are followed in this regard by bob-tails, wreckers, and transit mix trucks--all urban vehicles by nature.

The last row of Table 5-2 indicates the percentage of all accidents, by class of road, which involve trucks. In this (Texas) data, trucks of the types shown are involved in 4.52% of the interstate accidents, as compared with only 1.63% in urban areas.

How Do Truck Accidents Happen?

The National Accident Summary tabulates eight kinds of collisions. That data for passenger cars and trucks is shown in Table 5-3. Note particularly that trucks are overinvolved in overturn and run-off-the-road accidents. This data is from a large enough set that all observed differences are statistically-although perhaps not practically-significant.

Of Texas truck accidents 4% involved overturns, but these represent larger trucks whereas the National Accident Summary includes many vehicles used more like passenger cars. Another high frequency event in the Texas data was the jackknife, which occurred in 1.7% of all the truck accidents tabulated; however this represents 4.2% of the articulated vehicles involved in accidents. Understandably jackknifing occurs more frequently and at lower speeds on wet roads (60% of the jackknife accidents occurred on wet roads).

The Bureau of Motor Carrier Safety tabulations provide accident type in more detail than the National Accident Summary, but it is not possible to show these as a common set of data. The National Accident Summary evidently includes side swipe accidents within some other category (perhaps rear-end or head-on depending on direction, or perhaps angle). Thus the accident configuration data from BMCS is presented separately in Table 5-4.

Table 5-2

Location of Accident, by Road Type and Vehicle Type Percents, Texas Truck and Texas Sample

	Inter-State Highways	U.S. and State Trunklines	Secondary Roads	County Roads	City Streets
Bobtail	13.0	36.2	3.2	1.8	45.5
Dump	11.6	36.7	8.4	5.8	37.3
Fire	2.1	23.8	3.5	1.4	69.2
Flatbed	13.0	43.1	5.0	3.5	35.0
Float	14.9	60.5	9.0	4.5	16.9
Transit-mix	12.5	36.1	7.2	6.4	37.8
Pole	1.9	63.5	14.7	5.8	14.1
Refrig.	14.5	43.5	3.7	2.0	35.9
Stake	11.8	46.8	4.5	2.8	33.6
Tank	13.0	45.2	5.9	2.8	32.7
Van	20.6	52.1	2.2	1.0	23.6
Wrecker	13.7	30.0	2.6	3.8	49.5
TOTAL	14.1	44.2	5.1	3.1	33.2
Pass. Cars	8.3	32.2	4.9	2.6	51.9
% Truck Accidents	4.52	3.5	2.63	2.97	1.63

NOTE: A small number of accidents on the Texas Turnpike have been dropped from this tabulation, and all rows do not quite total 100%

Table 5-3

Type of Accident for Cars and Trucks-National Accident Summary

Type of Accident	Number of Pass. Cars	Percent	Number of Trucks	Percent
Pedestrian	41,700	1.96	3,900	1.78
Non-motor vehicle	32,900	1.55	4,100	1.87
Fixed Object	117,000	5.52	11,400	4.57
Run off road	183,100	8.63	25,000	11.43
Overturned	8,400	0.40	3,200	1.46
Head-on	110,300	5.20	13,300	6.08
Angle Collision	908,200	42.83	88,000	45.72
Rear-end	718,700	33.94	69,800	31.91

Table 5-4

Truck Accident Configurations, BMCS-1969

Configuration	Number of Accidents	Percent
Rear-End	10,675	21.1
Head-on	948	1.9
Side Swipe	5,872	11.6
Angle	8,555	16.9
Skid	2,095	4.1
Backing	1,810	3.6
RR Crossing	206	0.4
Stopped Vehicle	271	0.5
Other	20,150	39.8

At What Speeds Do Truck Accidents Happen?

Speed is an item of data which has been included in the accident reports of many states for a number of years--usually intended to indicate the speed at which the vehicle was traveling before the accident started. In that sense it is a surrogate for other severity measures, and indeed it does correlate well with the number of persons injured or killed per accident.

In its recent instructions to the states which furnish data to it the National Safety Council deleted the requirement for speed information; consequently many states have now stopped reporting this item. In spite of the subjective nature of this measurement, it seems possible to compare the distribution for passenger cars with that of trucks. In Figures 5-12 and 5-13 this has been done using data from the Texas sample and Texas truck files.

The relationship between speed and injury probability is shown graphically in Figure 5-14. The back row of this plot shows the distribution of trucks involved in accidents by speed, the center row the distribution of the number of persons injured, and the front row the number killed. Note that the number injured per accident increases regularly with speed, but that approximately the same number of persons are injured in each speed range over most of the distribution.

5.1.2 The Injuries and Property Damage

What is the Severity of Injuries in Truck Accidents?

The Texas Truck file contains data on 11,839 truck accidents involving trucks identified as listed in Table 5-5. These counts are actually derived from a file of vehicles involved in accidents, and strictly speaking represent "involvements" rather than accidents. In the analyses presented here, however, double counts would occur only if two trucks of the same type collide with each other--i.e., two transit mix trucks, two pole trucks, etc. Overall truck-truck accidents account for about 1.5% of the total, and the overlap for the individual type trucks is neglected.

Injury and fatality statistics for the various types of trucks and for passenger cars are given in Table 5-5. In each row is presented the number of persons killed or injured in the indicated type of vehicle, motor vehicles colliding with the indicated type of vehicle, and the total.

Although trucks taken as a group involve about double the number of fatalities per accident as do passing cars, they are about even with respect to non-fatal injuries. The one truck which stands out in fatality production is that identified as a float truck--i.e., a low flat-bed equipment carrier. Fire trucks, while not a large proportion of the total number of accidents, tend toward multiple injury production. They score second highest in fatalities (although the sample is so small as to be non-significant), and they score highest in injuries--both to occupants of the fire trucks and to others.

Figure 5-12

DISTRIBUTION OF PRE-ACCIDENT TRAVELING SPEED
ALL PASSENGER CARS IN TEXAS SAMPLE FILE 1969

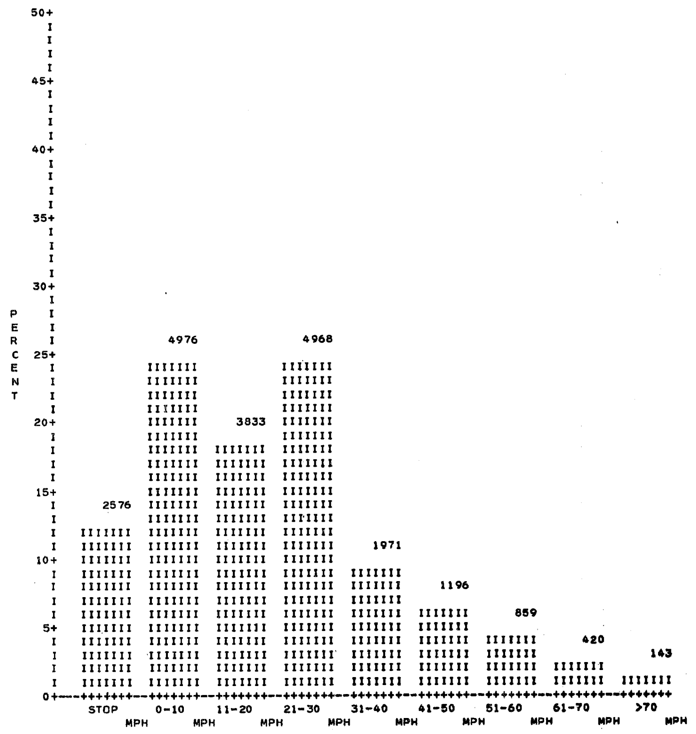
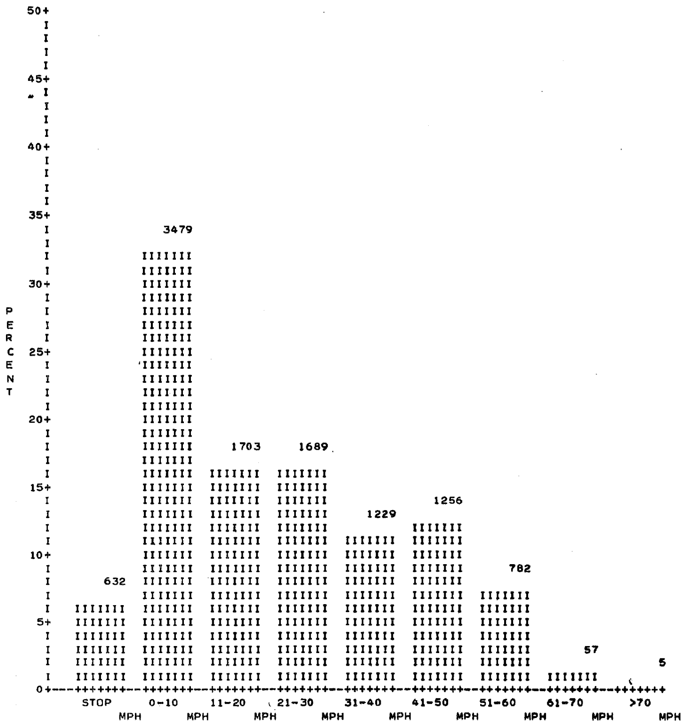


Figure 5-13

DISTRIBUTION OF PRE-ACCIDENT TRAVELING SPEED
ALL TRUCKS IN TEXAS TRUCK FILE 1969



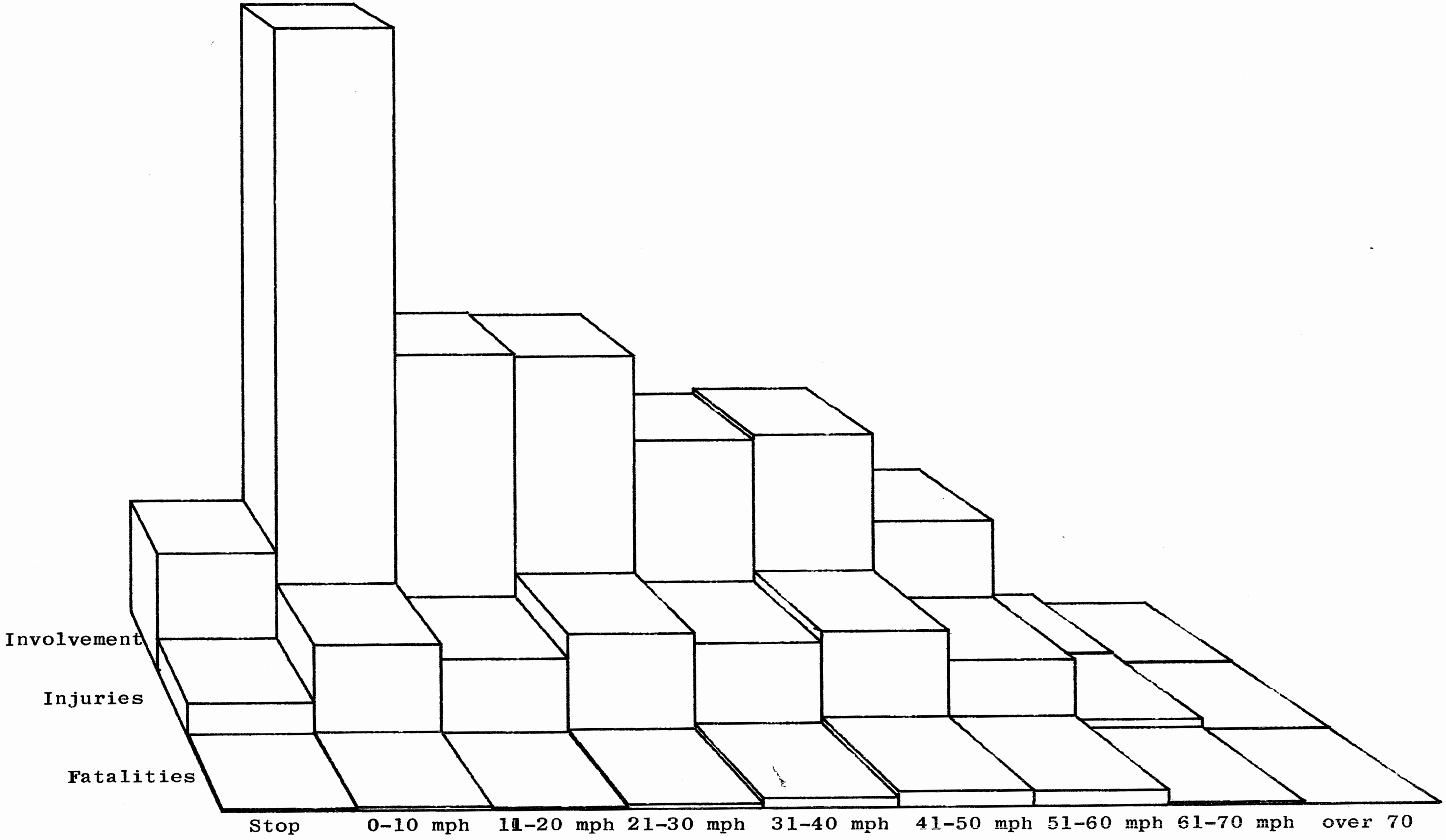


Figure 5-14 Distribution of Truck Involvements by Speed and Accident Severity, Texas Truck

Table 5-5

Texas Truck Accident Fatalities and Injuries Per 100 Accidents, By Type of Truck

Vehicle Type	Number Trucks Involved	Killed in:			Injured in:		
		Indicated Vehicle	Other Vehicle	Total	Indicated Vehicle	Other Vehicle	Total
Bobtails	981	0.31	0.81	1.12	4.18	12.82	17.0
Dump trucks	1940	0.36	0.98	1.34	7.16	18.64	25.8
Fire trucks	143	0.00	4.20	4.20	22.38	27.32	49.7
Flatbed trucks	1030	0.39	1.35	1.74	8.45	19.35	27.8
Float trucks	598	1.33	6.53	7.86	10.20	26.10	36.3
Transit-mix tr.	360	0.00	0.00	0.00	6.94	17.76	24.7
Pole trucks	156	0.64	0.00	0.64	5.77	17.33	23.1
Refirgerator tr.	891	0.67	2.47	3.14	9.20	16.60	25.8
Stake trucks	1522	0.66	1.84	2.50	8.80	20.10	28.9
Tank trucks	1479	0.74	2.10	2.84	7.30	18.00	25.3
Vans	2315	0.36	2.36	2.72	7.04	18.26	25.3
Wreckers	424	0.24	0.47	0.71	6.60	15.30	21.9
All trucks	11,839	0.5	1.89	2.39	7.68	18.42	26.1
All pass. cars[1]	(23,141)			1.14	27.2	11.8	27.5
NAS Pass.Cars[2]		0.66			37.0		
NAS Trucks[2]		0.81			26.0		
BMCS (1969)[3]	48,561	0.72	3.3	4.1	15.4	36.1	51.5

Notes:

1. This data is taken for all passenger-car-only accidents (car-car, and car single vehicle) in the Texas Sample File. This represents a 5% sample of all such accidents occurring in Texas in 1969.
2. National Accident Summary data is obtained from the 1968 National Accident Summary prepared by NHTSA. It represents approximately 2.4 million vehicles in accidents in 26 states.
3. BMCS data is taken from the 1969 file. Note that the relative severity of BMCS reported accidents is higher than either the Texas or NAS severity. BMCS "fatalities per 100 accidents" has decreased from 4.74 (1967) to 4.53 (1968) to 4.08 (1969)--evidently because of an increase in the reporting of non-fatal accidents.

A further analysis of the float truck shows that it is disproportionately represented in no-passing zones, and has the bulk of its accidents on state trunklines and interstate highways, with very few accidents in cities. Fire trucks, of course, have most of their accidents (70%) on city streets with nearly all the rest on U.S. and State trunklines. These observations may, of course, be more an indication of exposure than accident propensity.

Float trucks in the year 1969 in Texas accounted for (i.e., they were involved in accidents resulting in) 47 fatalities. Taking the liberty of estimating the national fatalities from this kind of accident by multiplying by the U.S. to Texas population ratio suggests that there may be more than 700 fatalities involving float trucks. Such a crude extrapolation is suspect for a number of reasons (this may have been a particularly bad year for lowboys in Texas, Texas may have more lowboys than other states because of the hauling of well-drilling equipment, etc.). Nevertheless, considering that the majority of the lowboy accidents (fatal and non-fatal) occurred in no passing zones, it would seem propitious to take a closer look at these giants of the highway.

At the bottom of Table 5-5 data from the National Accident Summary are presented for comparison with that of Texas. In the National Accident Summary all trucks are lumped together, including pickup trucks. As these are closer to passenger cars in weight than to the trucks listed from the Texas data, it could be expected that their injury and fatality data would not correspond. Further, the criteria for including accidents in the reporting process vary from state to state in a relatively unknown way. There are some apparent discrepancies between the national and Texas data, and some likely explanations can be offered: NAS obtains data from many states, and some may underreport "property damage only" accidents; the passenger cars in the Texas data presented here were involved in only "single vehicle" and "other passenger car" accidents. Passenger cars in NAS in some instances struck trucks. Finally, the inclusion of pickups in the NAS data would favor the higher number of injuries (to the truck occupant) per accident.

The last row of data in Table 5-5 is taken from the Bureau of Motor Carrier Safety files for 1969, and indicates a relatively higher number of injuries and fatalities per accident. Rules for accident inclusion in the BMCS file are more severe and this is evidently the reason for the difference between these figures and the others in the table.

The truck accident, injury, and fatality information from Texas 1969 is summarized in Figure 5-15. The back row represents the number of involvements by the indicated type of truck, the middle row the number of injuries, and the front row the number of fatalities. Note particularly the inversion for refrigerator trucks (both in injuries and fatalities) and the large percentage of float trucks involving fatalities.

Relative severities of truck collisions compared with passenger car collisions--for various collision types--can be used to identify some of the broad problem areas of truck accident involvement. On this basis, Table 5-6 was constructed from data derived from the

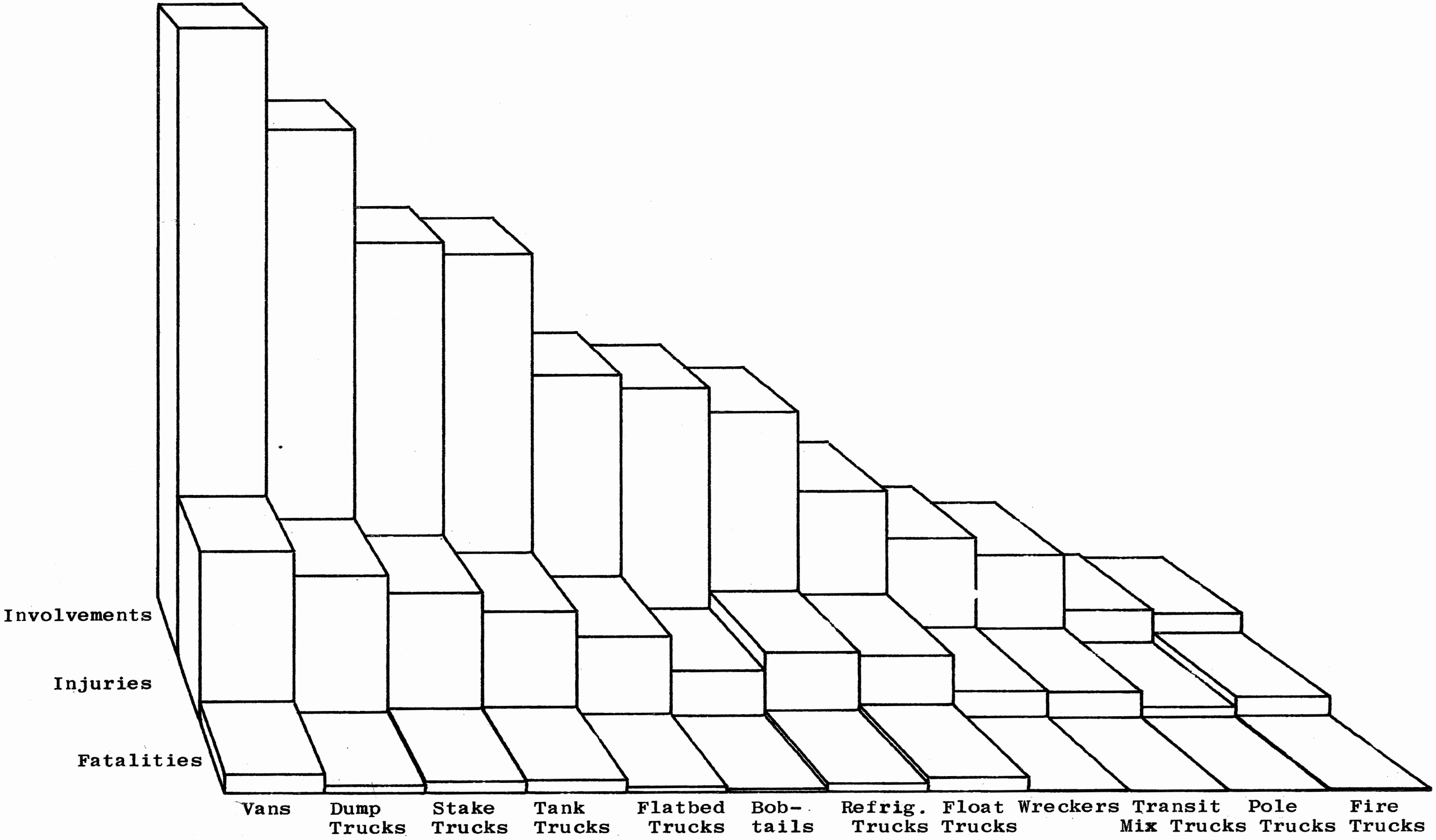


Figure 5-15 Distribution of Truck Involvements by Accident Severity and Truck Type, Texas Truck

Table 5-6

Involvement and Relative Severity of Truck and Car Accidents, by Type of Collision

	Passenger Cars			Trucks			Truck/car relative severity Index #1	Truck/car relative severity Index #2
	# vehi. involved all acc.	# vehi. involved fat. acc.	# fatal-ities	# trucks involved all acc.	# trucks involved fat. acc.	# fatal-ities		
Single vehicle collisions	74440 (15.4%)	926 (34.9%) ((1.24))	1068 (30.2%) ((1.43))	2820 (26.5%)	37 (19.2%) ((1.31))	39 (14.8%) ((1.38))	1.1	1.0
Right angle collisions	151120 (31.3%)	586 (22.1%) ((0.39))	740 (20.9%) ((0.49))	1960 (18.4%)	50 (25.9%) ((2.55))	76 (28.8%) ((3.88))	6.6	7.9
Same direction collisions (rear-end and sideswipe)	205980 (42.6%)	246 (9.3%) ((0.12))	315 (8.9%) ((0.15))	4700 (44.2%)	48 (24.9%) ((1.02))	63 (23.9%) ((1.34))	8.6	8.8
Opposite direction collisions (head-on and sideswipe)	51860 (10.7%)	894 (33.7%) ((1.72))	1405 (39.8%) ((2.71))	1140 (10.7%)	58 (30.0%) ((5.09))	86 (32.6%) ((7.54))	3.0	2.8
Total or Average	483400 (100%)	2652 (100%) ((0.54))	3528 (100%) ((0.73))	10620 (100%)	193 (100%) ((1.82))	264 (100%) ((2.49))	3.3	3.4

Texas sample and Texas fatal files. It shows the number of vehicles of each of two types involved in all accidents, the number involved in fatal accidents, and the number of fatalities associated with those collisions. The two vehicle types are passenger cars and large trucks; pickup and panel trucks have been deleted from the data to accentuate differences in vehicle size. Accidents are divided into single vehicle collisions, angle collisions, same direction collisions (rear end and sideswipe), and opposite direction collisions (head on and sideswipe). Because the sample file represents only 5% of the state's reported accidents, the numbers from the sample file were multiplied by 20 for the "total involvement" columns.

Percentages given in the cells of the table are the column percentages, and they show the relative involvement in the different categories of accidents. The values in double parentheses give 100 times ratio of the value in that column to the "involvements in all accidents" preceding it, and may be interpreted as the number of fatal involvements and the number of fatalities per 100 involvements respectively.

The two indices given in the last two columns show the overrepresentation (by severity) of trucks as compared to cars in the several kinds of accidents. They are defined in the following way:

$$\text{Index \#1} = \frac{\text{no. of trucks involved in fatal accidents} \,/\, \text{no. of trucks involved in all accidents}}{\text{no. of cars involved in fatal accidents} \,/\, \text{no. of cars involved in all accidents}}$$

$$\text{Index \#2} = \frac{\text{no. of fatalities in truck fatal accidents} \,/\, \text{no. of trucks involved in all accidents}}{\text{no. of fatalities in car accidents} \,/\, \text{no. of cars involved in all accidents}}$$

Because the table contains so much information, it must be studied carefully with respect to involvement frequencies, involvement severities, relative severities for each vehicle type, and relative severities between vehicle types. The most common type of involvement is in the rear-end or same-direction sideswipe collision, for both cars and trucks. The most severe single category of accident is the head-on collision, for both cars and trucks. The indices can be interpreted as the relative probability of being killed in a car-truck collision as compared with a car-car collision of each indicated type. There are, in fact, a few truck-truck collisions in the truck columns, but these can be neglected in the present analysis. The mean index #1 of 3.3 can be interpreted to mean that the chance of being involved in a fatal collision (given a collision) with a truck is 3.3 times greater than if it were a collision with a car. For single vehicle collisions, cars and trucks are about alike. But for right-angle and same-direction collisions the car-truck collisions are much more dangerous (6.6 and 8.6 times respectively). Index #2 is weighted by the number of fatalities per involvement, and shows a slight increase in angle and rear-end collisions at the expense of the others.

If one were seeking a countermeasure to apply to traffic generally, one might address the cell with the most frequent number of fatalities--head-on collisions. But if one were seeking a countermeasure to apply to trucks, one might focus on the collision type with the greatest difference between trucks and cars--in this case the rear-end collisions followed by the right-angle collisions.

What is the Cost of Property Damage in Truck Accidents?

Accident cost is reported by the police in several sets of data, and by the carrier in the Bureau of Motor Carrier Safety files. The police reported cost information has been generally incomplete, and although there is some data, the biases introduced by missing data make it suspect. On the other hand, damage cost is reported rather faithfully in the BMCS data, and since it is based on the carrier's post accident appraisal, has some face validity.

The average property loss of each category of accident in the BMCS 1969 file has been computed for month, day of week, type of service (local vs. intercity), severity of injury (fatal, injury, or property damage only), fire or defect, type of vehicle, class of accident and configuration. With the exception of month there was obvious variation within each of the other categories. The more notable extremes are discussed here.

On the average, an accident recorded in the BMCS files is estimated to have incurred $2184 in property damage. The total damage reported for 50,609 accidents was $110,500,000 in the year 1969.

The single most expensive category is the case of a fire on the reporting vehicle--averaging $16,588 in 405 accidents. This is only 0.8% of all accidents, but accounts for 6.1% of all dollar loss. A fire on either vehicle in the accident, or elsewhere in connection with the accident, leads to a cost of $13,447 per accident...for 747 accidents. This distribution is compared with that for all accidents in Figures 5-16 and 5-17. In this case this is 1.5% of all reported accidents in the file, but 9.2% of the dollar loss.

Fatal accidents, which may include fires, come to 3.4% of the accidents ($8642 each for 1729 accidents) and 13.5% of the dollars for the year. And railroad crossing accidents--only 206 or 0.4% of the accidents account for 1.2% of the cost with 206 accidents.

Also expensive are head-on collisions ($4336), double bottoms ($3374), and injury accidents ($3179). On the other end of the scale bicycle, pedestrian, and backing accidents average $196, $232, and $549 respectively.

5.1.3 The Driver

Driver characteristics available in the mass data are limited. Most police accident reports record driver age and sex, whether or not the driver had been drinking, injury and violations assigned to the driver. In Texas the driver's residence (in or out of state) and his license status (valid or revoked) is recorded. The BMCS files provide only driver age and injury, and the National Accident Summary provides only age and sex.

Characterizing truck drivers from these sources of information requires some explanation of the conditions under which the data were taken. In the National Accident Summary, which includes pickups and panel trucks as well as the larger variety, about 26% of the truck drivers are in the range 25-34 years of age, compared with 20% of the passenger car drivers. In the Texas truck files, restricted to 12 relatively large types of trucks, 28.4% of the drivers lie in this age range. In the BMCS data, 33.2% of the drivers are

Figure 5-16

DISTRIBUTION OF PROPERTY DAMAGE (IN DOLLARS) FOR ALL VEHICLES REPORTED
IN THE 1969 BMCS FILES WHEN A FIRE OR EXPLOSION WAS PRESENT
IN THE ACCIDENT

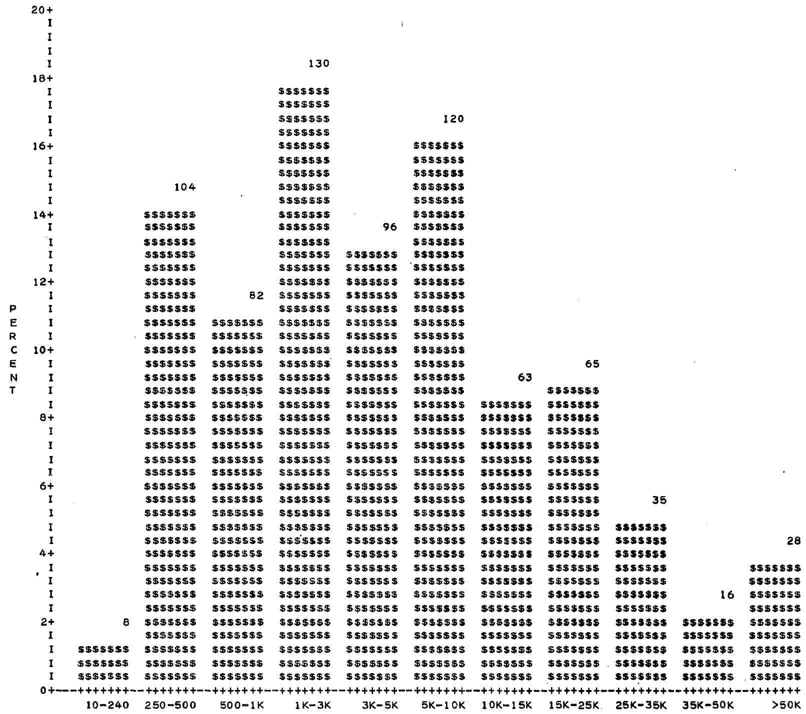
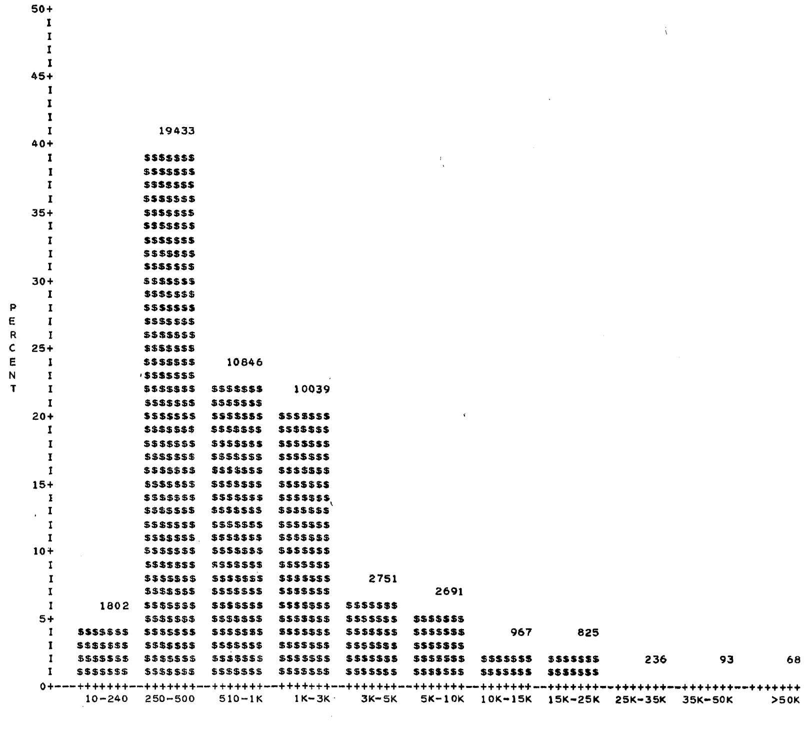


Figure 5-17

NUMBER OF ACCIDENTS VS. PROPERTY DAMAGE PER ACCIDENT
DATA FOR ALL VEHICLES REPORTED, BMCS FILE 1969



between 25 and 34. Figures 5-18 through 5-22 show these distributions in comparable form. Figures 5-23 through 5-35 show the age distribution for drivers of the twelve truck types identified in the Texas data separately.

License status is given on the accident report in Texas, and for all truck drivers taken as a group 1.87% (of those involved in accidents) were unlicensed at the time. Fire truck drivers were never unlicensed, and transit mix drivers seldom (only 2 out of 360). But stake truck drivers reach 2.9%, and tank truck drivers 2.1%. Of the tank and stake trucks in the Texas data more than half are single units, and the invalid licenses tend to be associated with those.

Driver residence is very much a function of the type of truck. In Texas accidents some 25% of the van drivers reside outside the state, very few dump truck drivers, and no one driving a fire or transit mix truck.

One driver characteristic of interest in the Texas data is a record of falling asleep; 188 of 11,839 truck drivers were reported as "fatigued or asleep" in the accident report, none in fire trucks or pole (log) trucks, but over 1 in 40 drivers of float trucks, vans, stake and tank trucks.

Surprisingly truck drivers who are noted as being fatigued or asleep are seldom charged with any violation--only 25% received a citation as compared with 67% of the passenger car drivers in the same situation. This suggests that fatigue is a sort of acceptable occupational hazard for truck drivers, and that the law enforcement fraternity recognizes this.

Truck driving appears to lie in the province of the males. Even in the case of the National Accident Summary, which includes many smaller trucks, the percentage of females is small. The Texas truck data, for 12 large truck types, indicates that fewer than $\frac{1}{2}$% of the drivers in accidents were female. And the BMCS files do not bother to record driver sex, presumably because of the low incidence of females. A brief tabulation of this information is given in Table 5-7.

There are two possible conclusions one might draw from this data: first that there are very few female truck drivers, or second (since this is accident data), that females drive truck very carefully. The correct conclusion may indeed be some combination of the two, but without an independent measure of exposure the question cannot be resolved.

An interesting variation with driver age is shown in Figures 5-36 through 5-39. Pre-accident speed is given for Texas accidents in 10 mile per hour groups, and driver age has been grouped in five year intervals. The several views of this data show this relationship for both truck drivers (taken for the 12 types of trucks from the Texas truck file) and passenger car drivers (taken from the Texas sample file). It can be seen that the large trucks have predominantly low speed accidents, and very few young (age 16-20) drivers. There is a noticeable dip in the speed reporting for 11-20 miles per hour for both cars and trucks which may simply be a

Figure 5-18

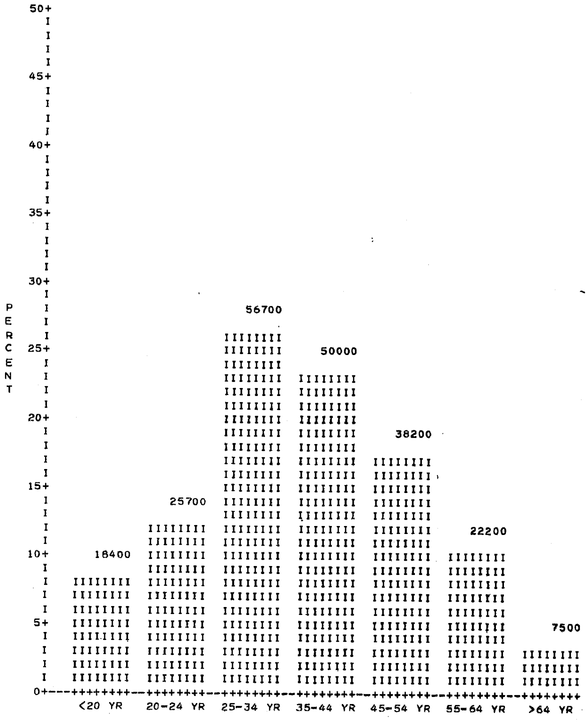

AGE DISTRIBUTION OF TRUCK **DRIVERS INVOLVED** IN ACCIDENTS
NATIONAL ACCIDENT SUMMARY(~~INCLUDES~~ PICKUP TRUCKS)

Figure 5-19

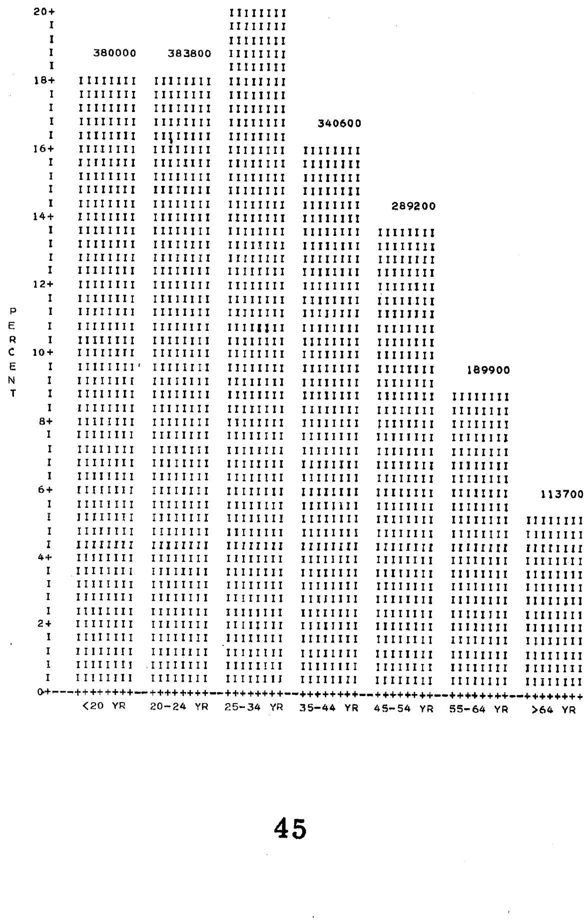

AGE DISTRIBUTION OF DRIVERS
NATIONAL ACCIDENT SUMMARY (PASSENGER CAR DRIVERS)

Figure 5-20

AGE DISTRIBUTION OF TRUCK DRIVERS INVOLVED IN ACCIDENTS
BUREAU OF MOTOR CARRIER SAFETY - 1969
(INCLUDES INTERSTATE VEHICLES ONLY)

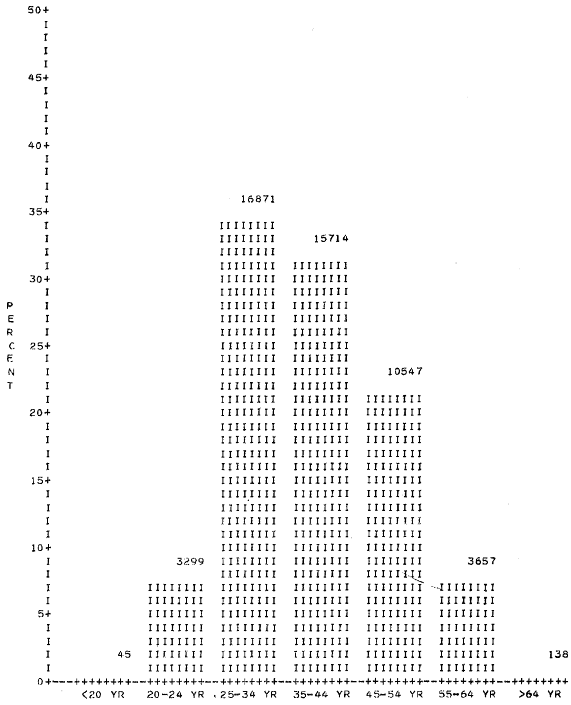


Figure 5-21

TEXAS TRUCK FILES(INCLUDES POLICE REPORTED ACCIDENTS FOR
12 LARGE TRUCK TYPES)

AGE DISTRIBUTION OF TRUCK DRIVERS INVOLVED IN ACCIDENTS

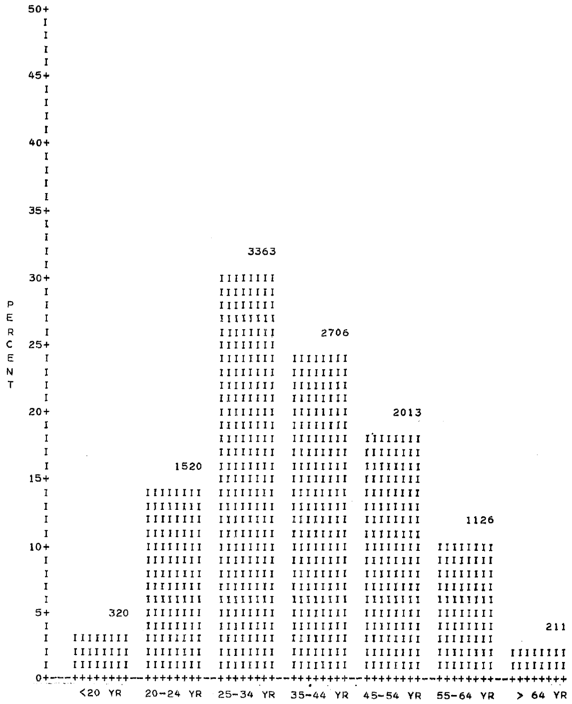


Figure 5-22

AGE DISTRIBUTION OF PASSENGER CAR DRIVERS
INVOLVED IN PASSENGER CAR ONLY ACCIDENTS
TEXAS SAMPLE FILE ,1969

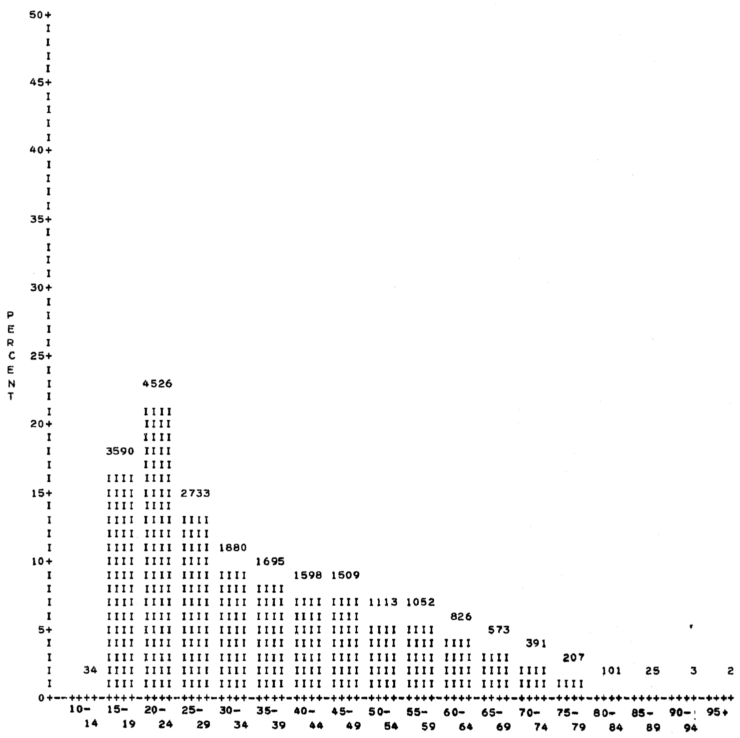


Figure 5-23

ALL TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 1969

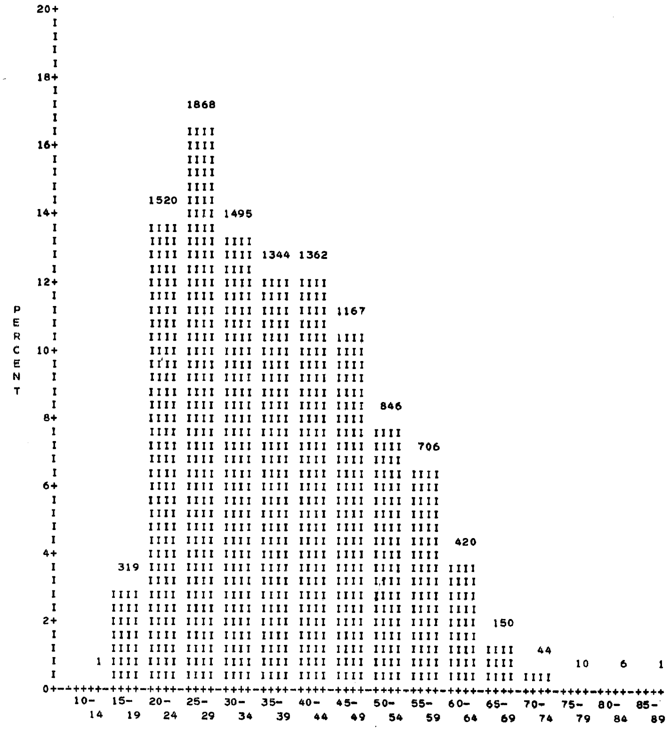


Figure 5-24

BOBTAIL TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 1969

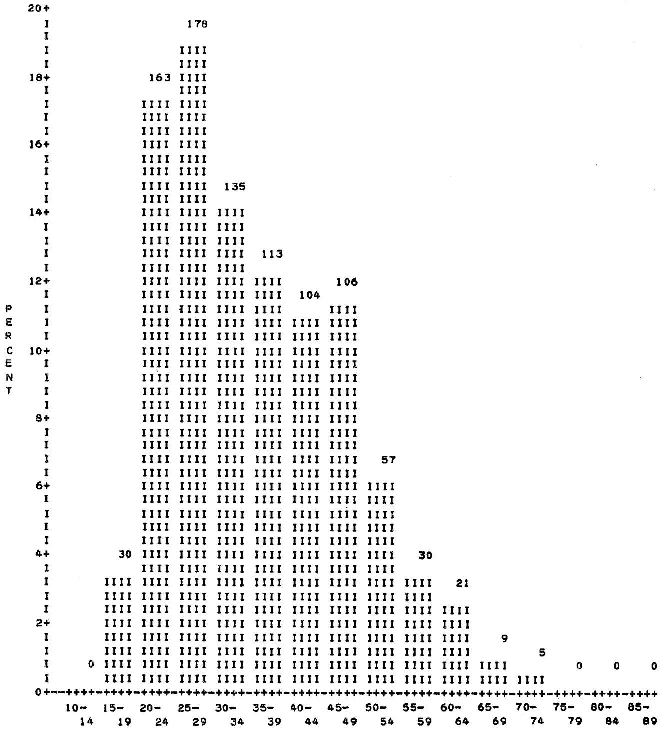


Figure 5-25

DUMP TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 1969

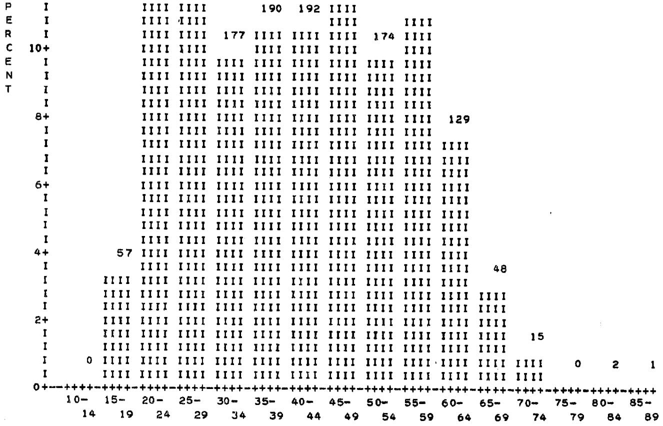


Figure 5-26

FIRE TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 1969

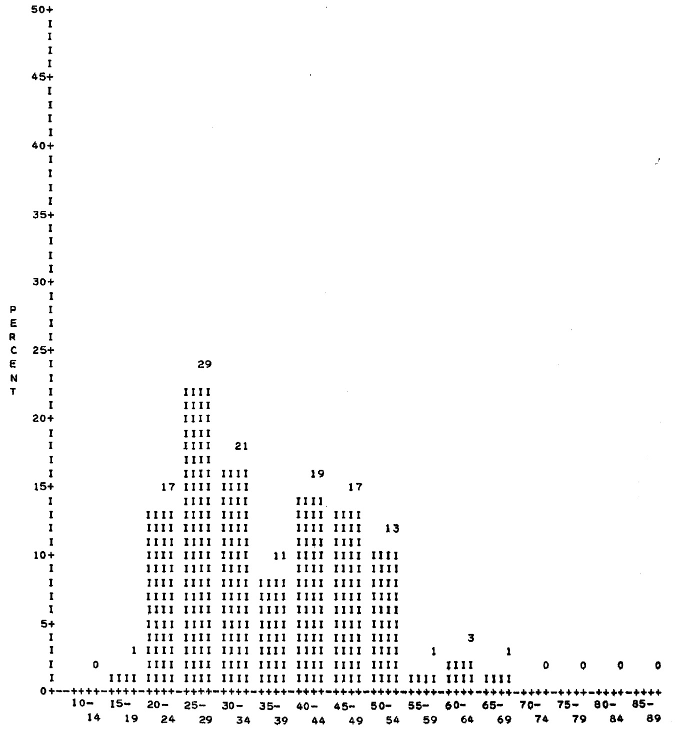


Figure 5-27

FLATBED TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 9169

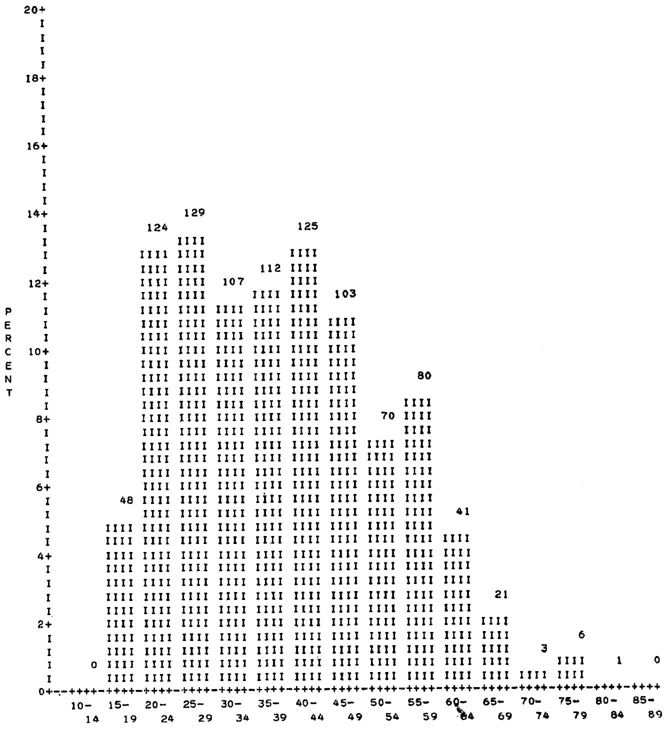


Figure 5-28

FLOAT TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE 1969

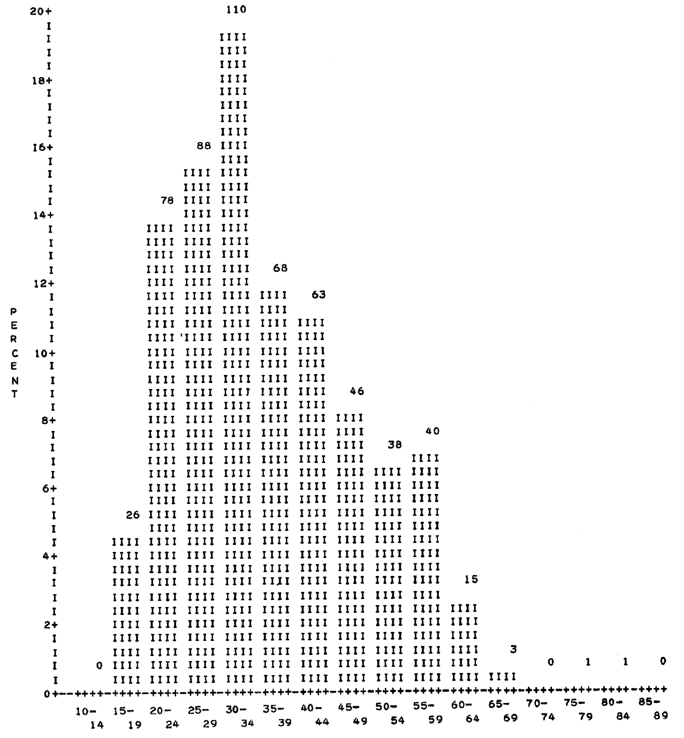


Figure 5-29

TRANSIT TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE 1969

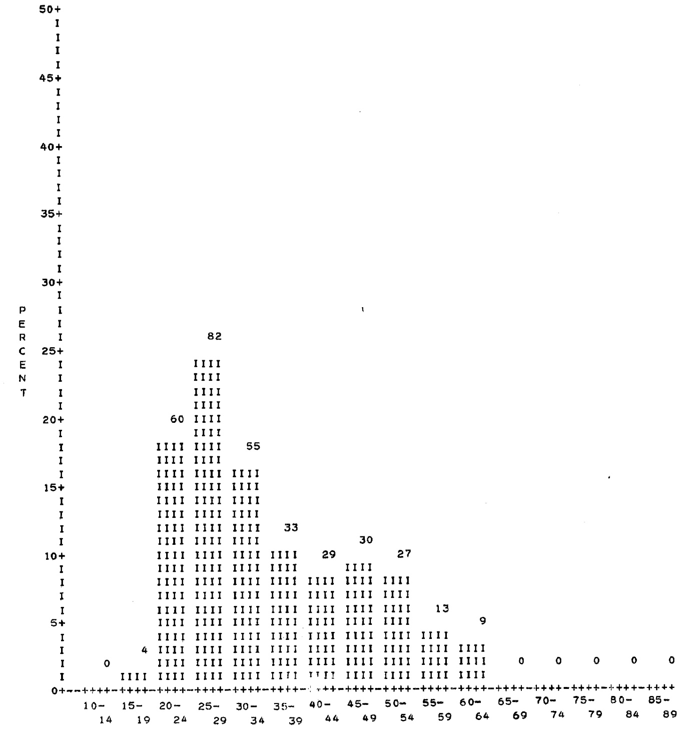


Figure 5-30

POLE TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 1969

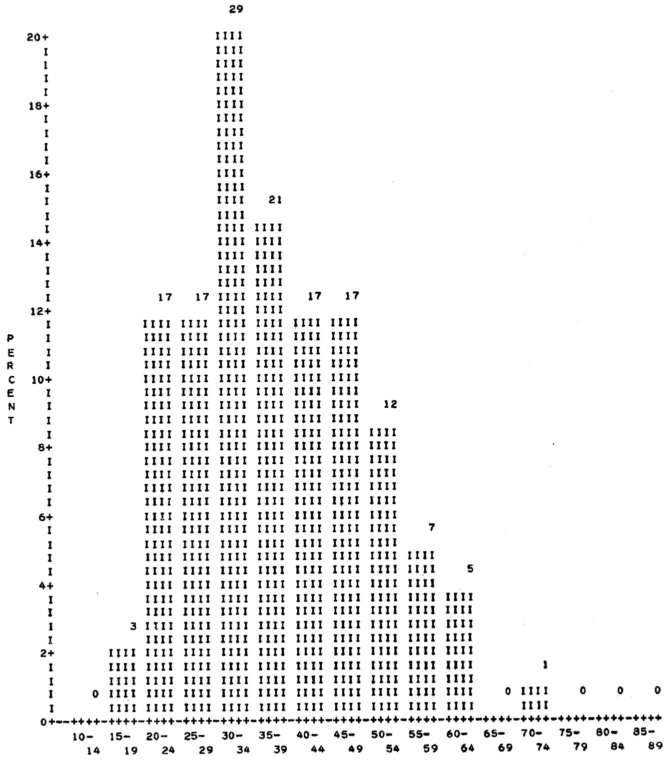
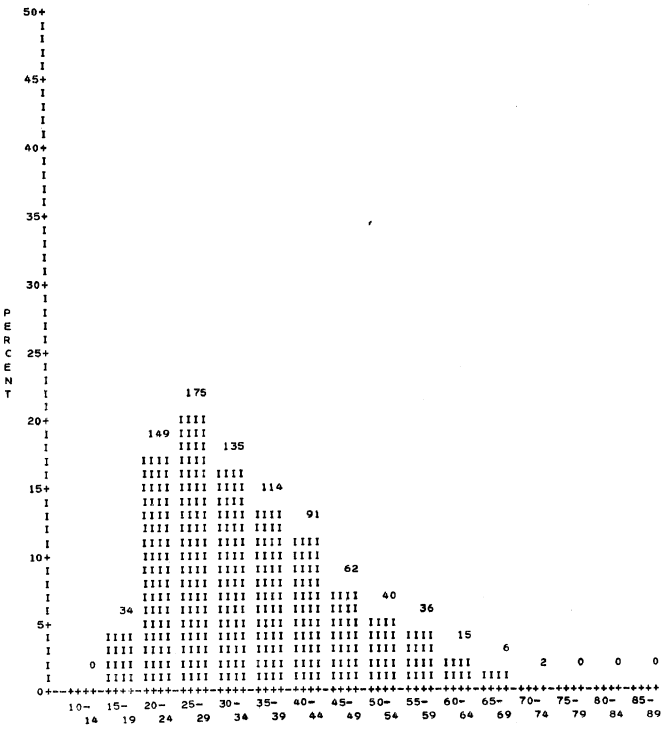
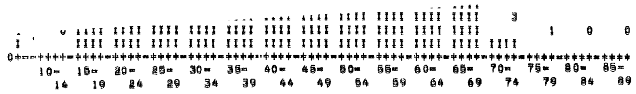


Figure 5-31

REFRIGERATOR TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER
TEXAS TRUCK FILE, 1969



3
1
0
0
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10-14
15-19
20-24
25-29
30-34
35-39
40-44
45-49
50-54
55-59
60-64
65-69
70-74
75-79
80-84
85-89

Figure 5-34

VAN TYPE TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER

TEXAS TRUCK FILE, 1969

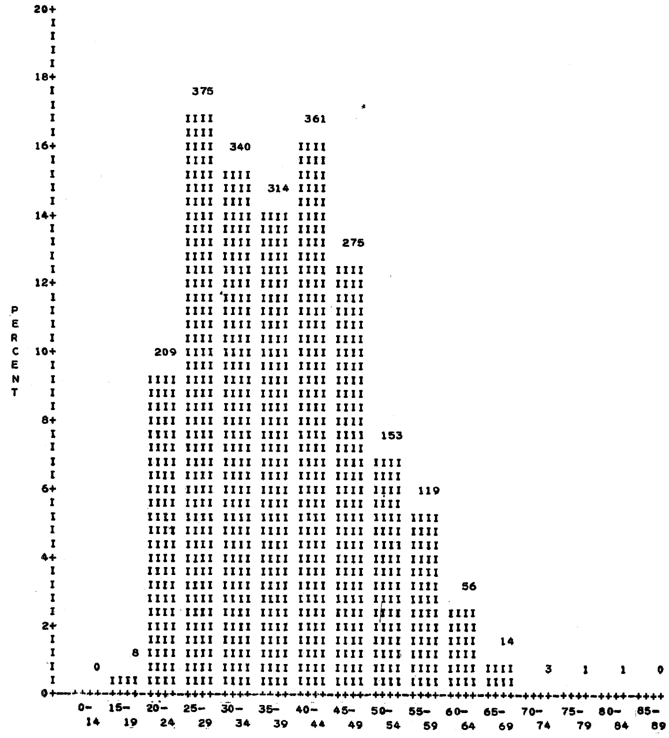
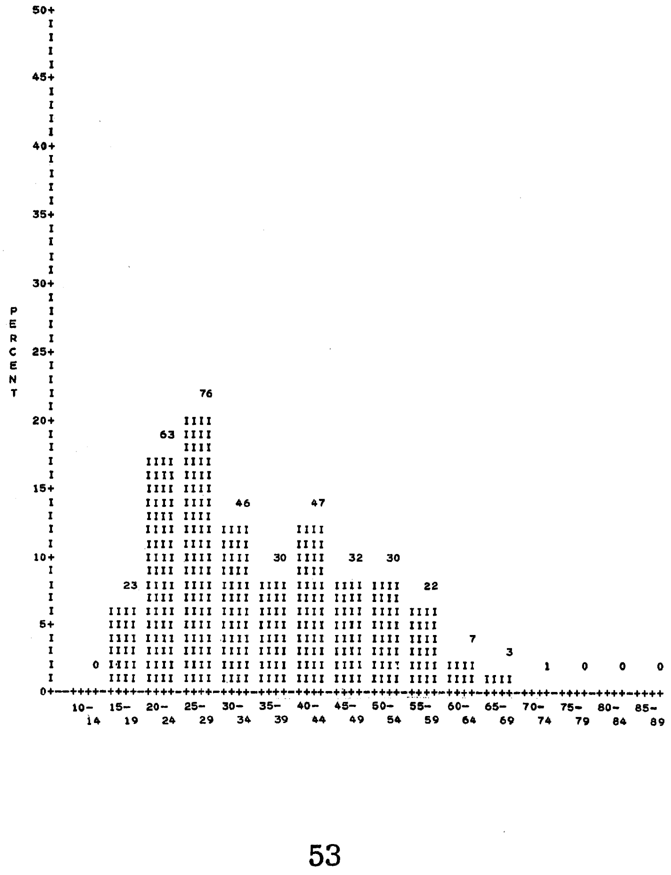


Figure 5-35

WRECKER TRUCK ACCIDENTS DISTRIBUTED BY AGE OF DRIVER

TEXAS TRUCK FILE, 1969



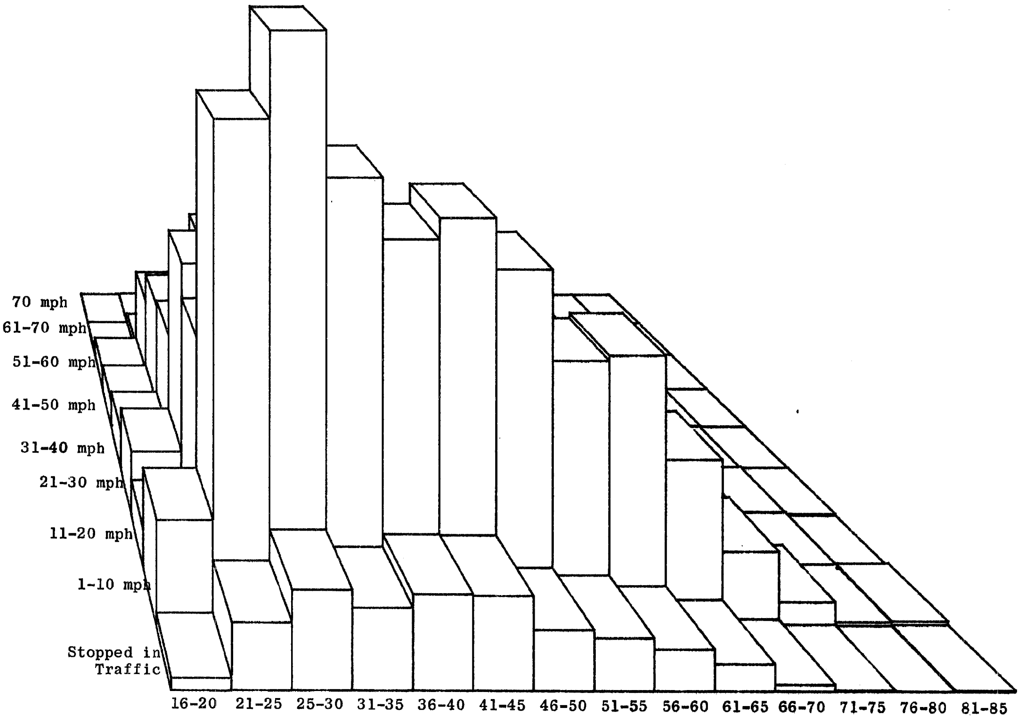


Figure 5-36 Speed of Travel before Accident vs. Age of Driver (View 1), 12 Large Truck Types, Texas Truck File

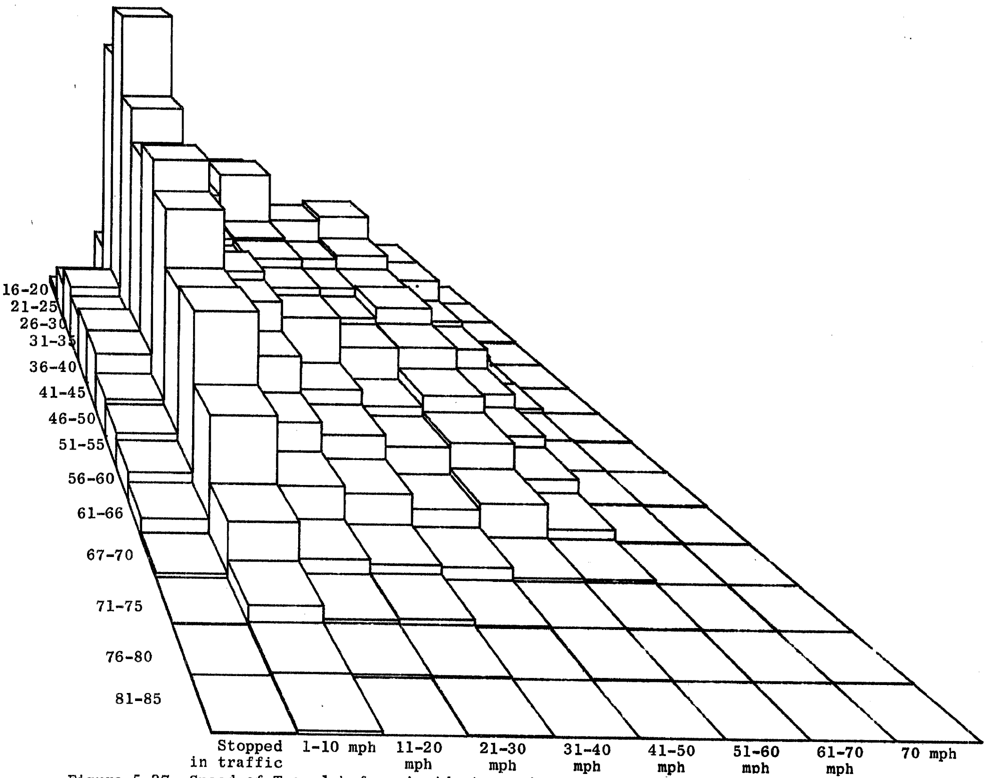


Figure 5-37 Speed of Travel before Accident vs. Age of Driver (View 2), 12 Large Truck Types, Texas Truck File

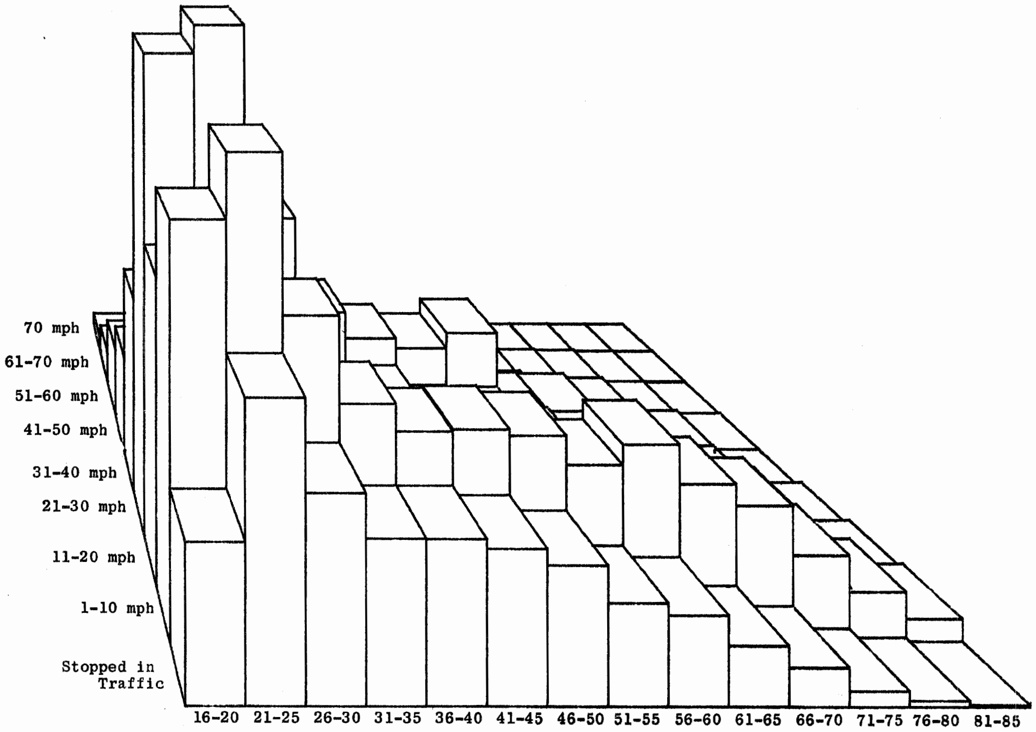


Figure 5-38 Speed of Travel Before Accident vs. Age of Dri (View 1), All Passenger Vehicles, Texas Sample

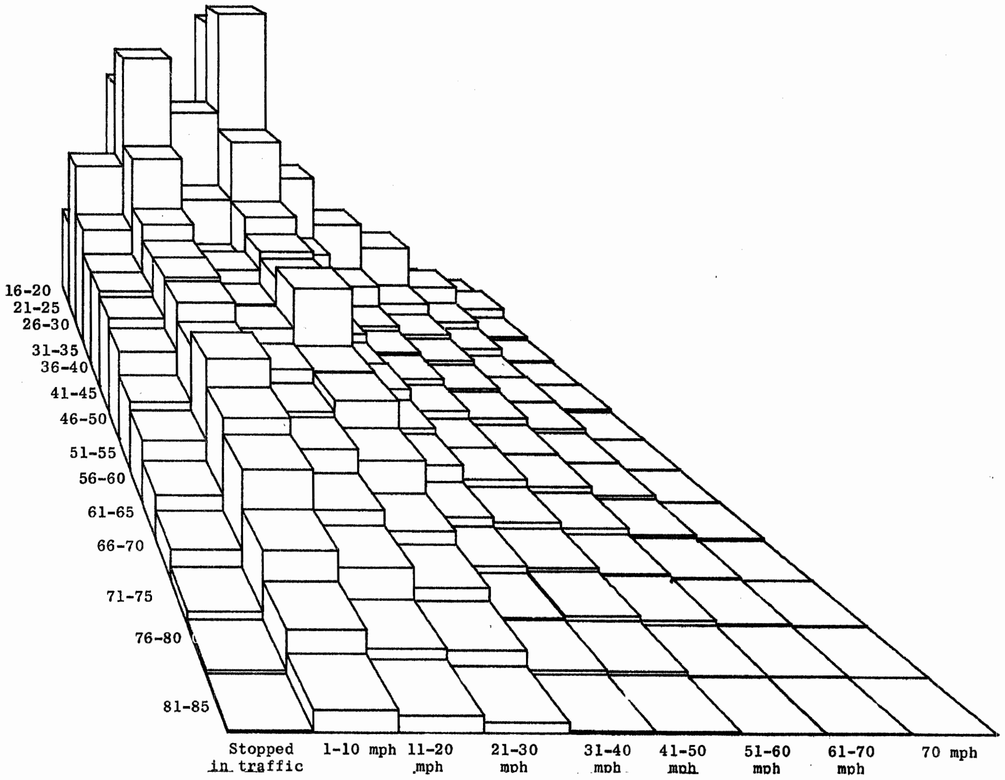


Figure 5-39 Speed of Travel before Accident vs. Age of Driver (View 2), All Passenger Vehicles, Texas Sample

reflection of the exposure situation, i.e., not many vehicles are traveling in that speed range at any time.

Table 5-7

Percent Female Drivers in Accident Data Sources

Source	% Female Drivers
National Accident Summary (passenger cars)	26.7
Texas Sample (pass cars)	33.0
National Accident Summary (trucks)	3.4
Texas Sample (pickup trucks)	7.6
Texas Truck files (12 large truck types)	0.47
Texas Sample (panel trucks)	5.7
BMCS files	not recorded

5.1.4 The Vehicle

What Are the Relative Accident Involvements of Vehicle Types?

As discussed in the introduction to this section, it is exceedingly difficult to compare trucks from one set of data with those from another, as there is little consistency in the categorization. For a small subset of Texas accidents an attempt has been made to identify equivalent vehicles in the National Census of Transportation (op. cit.). This comparison is presented here with the following reservations: The census had tabulated vehicles and vehicle miles by region; the data for the State of Texas alone is not detailed enough for this comparison. So the distribution of trucks and truck miles (by type) for a region of which Texas comprises 55% of the truck population is compared with accident data from Texas itself. Further, there is the possibility that what the one report views as a van, may not be precisely the same as the other. With these cautions, the data is presented in Table 5.8.

The final two columns in this table show the relative involvement ratio, by number of vehicles and by number of vehicle-miles, for these five types of trucks. The reader is encouraged to seek his own explanations of the results, although it is suggested here that dump trucks and cement mixers are generally travelling in congested areas, at peak traffic hours, and have more opportunities per mile for collisions. Vans and tank trucks, on the other hand, would be more likely to be on open highways at off peak hours. Even with the small sample, the transit mix truck may bear further investigation.

Table 5-8

A Comparison of Truck Accidents, Truck Population, and Truck Miles for a Selected Group of Vehicle Types

Sources: Texas Truck accident file, 1969, and U.S. Census of Transportation for 1967

Type of Vehicle	Vehicles Involved in accidents in Texas in 1969		Vehicles Resident in West South Central Region in 1967 Census		Vehicle Miles in West South Central Region in 1967 Census		Relative Involvement Ratio	Relative Involvement Ratio
	Number	Percent	Number (1000's)	Percent	Number (millions of Veh. Miles)	Percent	$\frac{\%\ \text{Accidents}}{\%\ \text{Vehicles}}$	$\frac{\%\ \text{Accidents}}{\%\ \text{Miles}}$
Van	2315	33%	61	39.4%	2252	47.2%	.84	.70
Refrig. truck	891	12.8%	17	11.0%	619	12.9%	1.2	.99
Dump truck	1940	27.8%	27	17.4%	601	12.5%	1.6	2.2
Tank truck	1479	21.2%	43	27.7%	1233	25.7%	.77	.83
Transit mix truck	360	5.2%	7	4.5%	78	1.6%	1.2	3.3
Total	6985	100.0%	155	100.0%	4793	99.9%		

What is the Effect of Vehicle Condition?

Police reports often provide for the listing of equipment factors which may have been involved in the accident. The information for this item may come from the officer's observation (e.g., he can observe that a wheel fell off the vehicle) or from the driver's explanation of the accident ("I put on the brakes, but they wouldn't hold"). There may in fact be some tendency in the reporting system which would overreport failures for trucks as compared with passenger cars. And of course the opposite is possible. Not knowing any better, we propose to treat this data as if it were unbiased--simply warning the reader that the validity is not established.

Texas files list separately defects having to do with the brakes, steering, lights, tires, trailer, stop or turn signals, and "wheel came off". Of the twelve types of trucks studied here the one most frequently exhibiting some defect is the pole or log truck and although the sample size is small, it is significantly worse (at the $\alpha=.03$ level) than the next to worst type. Table 5-9 shows the percent of vehicles by type which were found to be defective in some manner at the time of the accident.

Table 5-9

Percentages of Vehicles Found Defective at Time of Accident
Source: Texas Truck Sample Files

Bobtail	4.8%	*Passenger Cars	1.5%
Dump trucks	8.0%	*Pickup trucks	2.2%
Fire Trucks	2.1%	*Panel trucks	2.4%
Flatbeds	7.6%	12 truck average	6.7%
Float trucks	9.2%		
Transit mix	7.8%		
Pole (log) trucks	14.1%		
Refrigerator	6.8%		
Stake trucks	7.3%		
Tank trucks	5.9%		
Vans	5.5%		
Wreckers	7.1%		

*From Sample File

The most frequently listed defect was brakes, dump trucks leading with 5.3%. Float trucks were next with 4.2% Passenger cars are listed with defective brakes 0.8% of the time. Tires were listed as defective contributing factors in 95 cases (0.8% of 11,839) and "wheels came off" in 79 cases (0.7%). All except the fire trucks shared nearly equally in the problem of having wheels come off. By comparison wheels fell off passenger cars only 9 times in a sample of 25,095 accident vehicles, 0.04% of the time.

In the coding of data for the Indiana Turnpike special note was made of accidents induced by trucks, but not involving the truck itself. Of some 5,744 accidents, 128 could be so identified, about two-thirds of these being tractor trailers. In 23 cases it was a wheel which had fallen from a truck which caused the accident.

Twelve of these were working wheels, and 11 were spare wheels. Although the truck was not otherwise involved in the accident, these 23 incidents represent about 1.5% of the truck accidents on the turnpike.

The loss of a working wheel from a truck suggests a dry or frozen bearing, and thereby implies a need for maintenance or perhaps self-lubricating bearings. This problem of wheels falling off is significantly more frequent in older trucks as shown in Table 5-10.

Table 5-10

Truck Accidents in Which Wheels Fell Off

Vehicle Age	Wheels did not fall off	Wheels did fall off
0 to 3 years old	9,356	55 (.6%)
4 to 10 years old	10,391	97 (.9%)

1. Data from Texas Truck files, 1969-1970 Combined.
2. Chi square significant at .01 level.

What are the Patterns of Damage in Truck Accidents?

Trucks, by virtue of their mass, might be expected to come out of an accident with a passenger car with less damage and fewer injuries. Truck damage in comparison to passenger car damage has been analyzed with reference to accidents occurring in the Denver, Colorado area in 1969.

The State of Colorado accident report form provides for the recording of damage to each vehicle involved in a collision in more detail than most police reporting systems. A somewhat modified TAD rating scale is currently used to record damage to each of 20 areas on the vehicle, as shown in Figure 5-40. The scale bears a direct correspondence to the TAD rating as follows:

Table 5-11

Relationship between Vehicle Damage Scales of TAD and Colorado Accident Report Form

TAD	COLORADO FORM
1,2	1
3, 4, 5	2
6, 7	3

The police officers have been given photographs of accident involved vehicles representing several levels of this scale, and have been instructed to code their reports accordingly.

One year of accident data from the four-county area has been analyzed to provide a damage pattern for each of four types of vehicles--passenger cars, pick-up trucks, straight trucks, and tractor trailers. While the damage diagram is specifically detailed for passenger vehicles (e.g., indicating the degree of damage in the left rear door), the current practice is to code damage to trucks by the same angular position. The data are thus displayed in a series of polar diagrams referenced to the geometric center of the vehicle.

In Figures 5-41 through 5-44 the plotted points indicate the percentage of vehicles (of the given class) which sustained damage of any level (1, 2 or 3) at that location on the vehicle. There is little difference to note between the passenger cars and the pickup trucks, except that these trucks exhibit a slightly lower overall damage. In addition, the right front corners of pickups are relatively more susceptible to damage.

The corresponding protuberance is considerably more pronounced for straight trucks, and a most definite dip at the front of the tractor trailer plot suggests that they are well protected at that point--as opposed to passenger cars. It had been observed in a previous study* that trucks were more frequently damaged on the right side, whereas passenger vehicles received damage more symmetrically. This suggests, at least, a possible visibility problem on the right side of the larger vehicles.

Figure 5-45 shows the patterns for passenger cars and tractor trailers on the same scale; the difference in damage severity between these two types of vehicles is apparent, although the present data can only suggest that the cause of the difference is the relative crushability of the two structures.

The integral of the damage to trucks is noticeably less than for passenger cars. Assuming that all vehicles incur some damage in reported accidents, the integral may still be different because each passenger car may be damaged at many points, whereas each truck may be damaged on only one or two points on the compass scale. It is not possible to put the Colorado data in the same detailed form as is available in Texas--thus the lumping of trucks into the three categories given here.

5.1.5 Use of Accident Files for Special Investigations

Earlier parts of this section addressed the description of truck accidents and compared them to accidents involving passenger vehicles in a general fashion. This information was tabulated with reference to topics thought to be of general interest. A number of specific questions, such as the over/under involvement of commercial vehicles in particular kinds of accidents, or in particular locations were also considered.

A not uncommon experience in beginning a new investigation is to find tabulations in the literature which do not quite fit the problem at hand. Perhaps some other study has provided an age and sex distribution of drivers, for example, but has grouped the ages in a manner not comparable to the original tabulations. Resort to the original data would often answer the question, but it is usually not available. The data sets used in this study program contain so

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* Damage Patterns for Passenger Sedans and Trucks, Robert E. Scott, HITLAB Reports, November 1970.

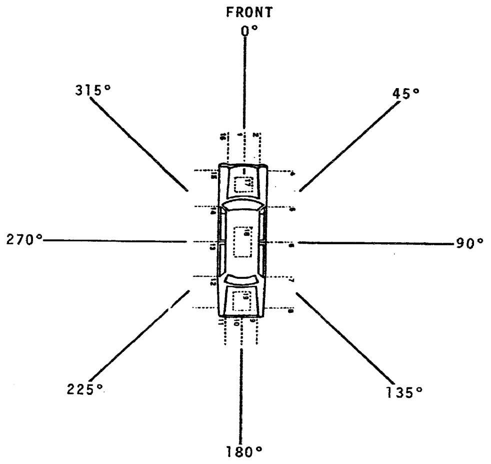

Figure 5-40 Vehicle Damage Areas of Colorado Report Form

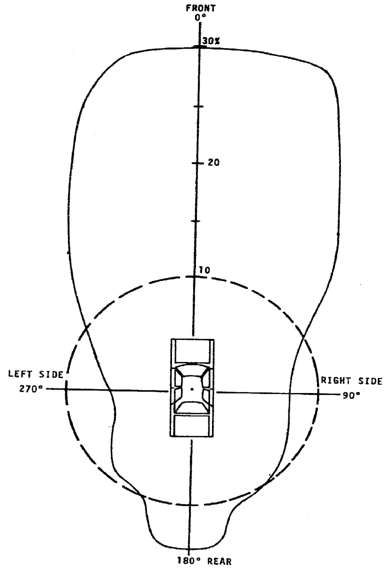

Figure 5-41 Damage Pattern, 54,378 Passenger Cars, Denver 4 County Area, 1969

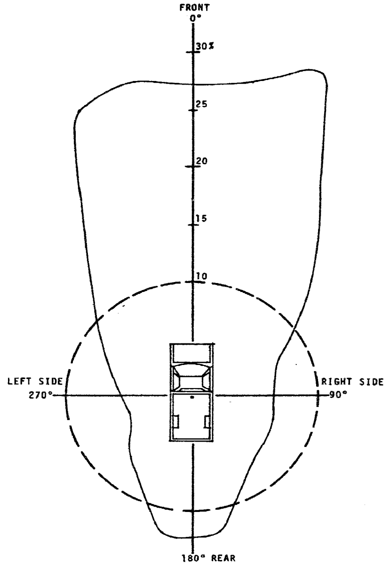

Figure 5-42 Damage Pattern, 4225 Pickup Trucks, Denver 4-County Area, 1969

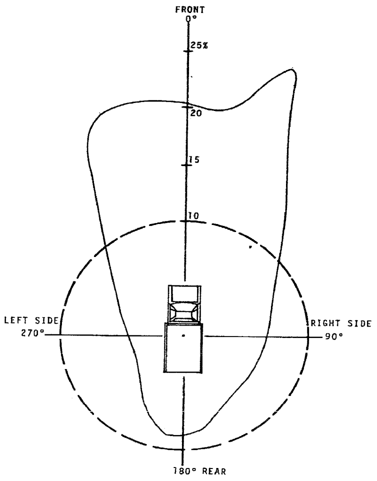

Figure 5-43 Damage Pattern, 1895 Straight Trucks (Excluding Pickups), Denver 4-County Area, 1969

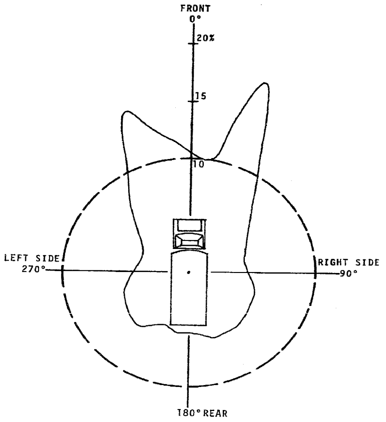

Figure 5-44 Damage Pattern, 399 Tractor Trailers, Denver 4-County Area, 1969

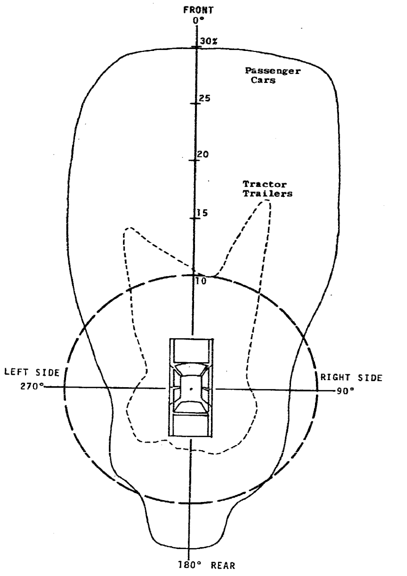

Figure 5-45 Comparison of Damage Patterns to Passenger Cars and Tractor Trailers

many possible combinations of output that only a small percentage can be presented in this report. But the data remain available, and in this section an example of the manipulation of the data will be given--implying that similar analyses can be performed readily in the future.

Analysis of Data Files Relative to Car-into-Truck Rear End Underride Collisions

A set of accidents investigated during the period 1967 to date have been reported on the Collision Performance and Injury Report, commonly known as the General Motors Long Form. This form provides for the detailed tabulation of several hundred factors associated with the accident, most of which are specific to injury determination and to the deformation of the vehicle. The original reports contain fairly comprehensive descriptions of the crash process, and are accompanied by numerous photographs of the vehicle and scene. One group of these accident reports, deriving primarily from work done by UCLA and the University of Michigan, was searched (by computer) to determine how many and which cases involved a passenger vehicle striking the rear of a truck. Of 700 total cases in the file, there were nineteen car-into-truck rear end collisions. By reference to the photographs it could be determined that there were four fatalities. It seems unlikely that this would represent the national frequency of such fatal accidents--i.e., 4 out of 700 cases--but the cases did provide a clear picture of the nature of the underride problem, and evidence of how severe it can be on occasion.

In the 1969 BMCS file are 3,814 cases in which a truck struck a car in the rear (about 1% of which involved a fatality) and 3178 cases in which a car struck a truck from the rear (about 4% of which involved a fatality). Fatalities were 56 and 165 respectively for a total of 221. There is no direct indication of underride or non-underride in these cases. While passenger vehicles (i.e., buses and taxicabs) have been eliminated from this file, it does include some straight trucks in addition to tractor trailers. On the other hand, it does not represent all of the large truck accidents in the country. An analysis presented in Appendix A of this report suggests that the BMCS file may represent about half of the large truck fatal accidents.

In the Ohio Turnpike file of 8,000 vehicle involvements over a period of four years there were 158 cases of car striking truck in the rear (involving 15 fatalities and 114 injuries); and there were 139 cases of truck striking car in the rear (involving 133 injuries and six fatalities). One can conclude that fatalities are somewhat more likely in the car-hits-truck cases, but cannot really identify under-ride other than by the implication of the GM long form file. It was also possible in the Ohio data to look at the estimated collision (differential) speed. There are only five cases in which a truck hit a car with a differential speed of more than 17 miles per hour (out of the 139 truck-car collisions) whereas there were 67 cases of cars striking trucks (of 158) in this speed range.

In the Denver file all reported accidents in a four county area of Colorado were searched--resulting in 73 cases in which a rear-end collision between a tractor-trailer and a car occurred.

Approximately half of these were car striking truck, and half the other way around. There were no fatalities in this set of data, and only ten serious ("A" or "carried from scene") injuries. There were only two cases in which the automobile hood damage was severe--indicating possible underride. The Denver file represents the accidents in an area with a population of slightly more than one million persons ($\frac{1}{2}$% of the U.S. population).

A search was made of the Oakland County, Michigan files for the same thing. It was not easy to differentiate between the two types of accidents, but the total number of accidents was 194 (involving a tractor-trailer and a passenger car-rear-end), and there was one fatality. The population of Oakland County is of the same order as that in the Colorado accident file. The large difference in the total number of truck-car-rear end accidents between Oakland County and Denver may be due to a different reporting method, a different coding scheme, or more truck traffic in the vicinity of Detroit. The latter is suspected as there are two major interstate routes going through Oakland County.

If the BMCS files indeed represented a large percentage of the fatal car to truck rear end collisions in the United States, there would be approximately one fatal accident per year for each million residents of the country. The expected number of such accidents, then, would be about one in Denver and one in Oakland County. So it is not surprising to find a one and a zero. And it is not surprising that UCLA investigators found five such accidents to investigate in the Los Angeles area over a period of several years. In fact, if the BMCS data represents only half of these fatal accidents the likelihood of the results observed in Denver, Oakland County, and Los Angeles would be about the same.

The probability of a year without a fatal tractor-trailer-car rear end collision (within some jurisdiction) can be computed as follows:

$$P(0) = (0.99)^N$$

Where $0.99 = (1 - 0.01)$ and

$0.01 =$ the probability of a fatality, given an accident of this type.

and $N =$ the number of accidents of this type occurring in the jurisdiction in one year.

For Oakland County

$$P\ (0) = (0.99)^{194} = 0.14,$$

the probability of a year with no fatal accidents of this type in Oakland County.

For Denver with 73 accidents, $P(0) = 0.48$.

For Los Angeles, with an estimated population of 8,000,000, the exponent should be about eight times as large as Detroit's. The probability of a year with no fatals of this type in Los Angeles is thus nearly zero.

The available data suggest that the frequency of car-into-truck rear end fatal collisions is of the order of one per million population per year. And the cases reported on the Collision Performance and Injury Report provide evidence that underride does occur (although the sample is too small and perhaps too biased to infer much about the national frequency of this event), and that on occasion fatalities result from the underride.

One is tempted to speculate about the number of fatalities which might be prevented should some form of underride protection be employed on large trucks. It seems likely that this would be fewer than 200, or 1 per million population per year, because the underride protection device would not prevent fatal injuries in every case. Whether this saving is cost effective must be argued by those with a fuller understanding of the costs involved.

5.2 Analysis of Turnpike Data

5.2.1 Turnpike Accident Experience

The accident data in the files from the three turnpikes includes accidents on the main line as well as those in service areas and at toll plazas. Since the service areas are unique to a minor class of limited access highways and are not uniform in frequency or design the analysis of turnpike accidents presented here has been restricted to those incidents that occurred on the main line where travel is at normal highway speeds under conditions that are representative of the Interstate system and most other limited access highways. The three turnpike files contain a total of 23,425 accidents, of which 20,155 or 86% were on the main line. The remaining 3,270 accidents are in general less severe than the mainline crashes because of the lower speeds in service areas. They do include a number of serious accidents however, particularly at toll gates on the mainline at the terminals of the highways. The relative number of these serious crashes was small however, and since they did not occur in circumstances which are representative of most limited access roads, they were not included in the analysis.

The classification of type of vehicles differ slightly in each of the files. Straight trucks (single units), tractor trailers, and trucks with full trailers are identified in all three. Only in the Indiana file can pickup and panel trucks be so identified. In the Ohio and Pennsylvania files these vehicles are included with straight trucks. Smaller trucks(generally those under 20,000 lb. gross vehicle weight) have been omitted from consideration in this study. Emphasis has been placed on categories of vehicles which could be identified as large trucks in all the accident files, thus minimizing the ambiguity of interpretation of traffic data by toll class.[1]

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[1] A description of the toll classes is included in Appendix C.

The distribution of the major classes of vehicles in the three turnpike files is shown in Table 5-12.

Table 5-12

Distribution of Accident-Involved Vehicles by Type
in the Three Turnpike Files
Total Number of Vehicles = 32,700

Vehicle Type	Frequency in Percent
Passenger Cars (including those with trailers)	77.5
Straight Trucks (single units)	4.6
Large Trucks (combination units)	16.5

The vehicles not included in the table are assorted types such as motorcycles, buses, etc. and account for only 1.4% of the total. Single unit trucks represent only 4.6% of the vehicles in the files. In the Indiana file where pickups can be separately identified, they constitute 26% of the straight trucks.

In the early months of the study, considerable interest in recreational vehicles became evident. Since many accident data banks do not identify such vehicles, these vehicles were assigned unique codes in construction of the Indiana Turnpike file with the thought that the data might be of general interest. The numbers of recreational vehicles in the Indiana file are small however, and not sufficient for meaningful analysis. The incidence is given in Table 5-13.

Table 5-13

Recreational Vehicles in the Indiana
Toll Road Accident File

Vehicle	Total Number
Mobile Home/Travel trailer (towed by vehicle other than tractor)	33
Pickup Camper	32
Motor Home	12

The total number of pickups with campers is 20% of all pickups in the file. The number of truck campers sold in 1969 were only 9% of the number of pickups sold.[1] However, the traffic patterns on the turnpikes are typical of recreational travel over much of

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[1] 1970 Motor Truck Facts, Automobile Manufacturers Association, 320 New Center Building, Detroit, Michigan.

the year, and the distribution of the two vehicles in the accident population may not be significantly different than the traffic population.

The total number of passenger cars and large trucks involved in collisions is shown in Table 5-14, for single vehicle and multivehicle collisions.

Table 5-14

Number of Vehicles Involved in Accidents on Mainline of Turnpikes

	Passenger Cars		Large Trucks	
	N	%	N	%
PENNSYLVANIA				
Single vehicle	5352	45.4	563	27.6
Multivehicle	6444	54.6	1477	72.4
Total	11796	100.0	2040	100.0
OHIO				
Single vehicle	2878	50.3	667	42.4
Multivehicle	2848	49.7	905	57.6
Total	5726	100.0	1572	100.0
INDIANA				
Single vehicle	2285	54.4	404	46.7
Multivehicle	1912	45.6	462	53.3
Total	4197	100.0	866	100.0

On all three highways approximately 50% of passenger car involvements were in single vehicle accidents. In the case of large trucks the result is somewhat different. In both the Ohio and Indiana, slightly less than half the truck involvements were single vehicle accidents. In Pennsylvania however, only 28% were single vehicle. The reason for the difference on the latter highway is not yet apparent. In all cases a smaller fraction of trucks were involved in single vehicle than passenger cars. The proportion of all involvements which are single vehicle is considerably higher on the turnpikes than in national experience as reported by the National Safety Council. National figures for all accidents indicate that only about 11% of all motor vehicle involvements are single vehicle.[1] However, about 36% of all accidents are intersection related, and the absence of such conflicts on the toll roads would greatly increase the relative incidence of single vehicle involvements.

When the results of the three highways are combined, the proportion of single vehicle involvements is 36% for large trucks and 48% for cars. Such a combination is difficult to interpret however, because the data was collected over different periods on highways of different lengths. Thus a single combination is a weighted average, with implied weighting factors which are likely inappropriate.

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[1] Accident Facts, 1970 Edition, National Safety Council, Chicago, Illinois

Modification of the weighting is possible, but difficult to accomplish without introducing confounding factors because the highways are not identical in design nor environment, and the annual vehicle miles over each is not the same. Most of the results presented here, particularly those relating to relative exposure, will be given separately for each highway without combination. Combination to simplify presentation is very tempting, but should only be done with caution. Most of the results based on the turnpike files will be given individually for each turnpike, even though the temptation to combine the figures is strong.

The total vehicle miles travelled by the two major types of vehicles in the accident data periods is given in Table 5-15.

Table 5-15

Total Vehicle Miles over the
Accident Data Period

	Passenger Cars	Large Trucks
Pennsylvania	52.98×10^8	10.93×10^8
Ohio	46.84×10^8	9.96×10^8
Indiana	26.26×10^8	5.04×10^8

The distribution of the severity of single vehicle collisions is shown in Table 5-16. With the exception of Ohio, the relative frequency of fatal involvements was slightly higher in truck accidents than in those of passenger cars.

Table 5-16

Severity and Casualty Rates of Single Vehicle
Accidents on the Mainline

		Car			Large Truck	
	Penn.	Ohio	Ind.	Penn.	Ohio	Ind.
Total Accidents	5352	2878	2285	563	661	404
% Fatal	1.31	1.32	1.14	1.96	1.06	2.23
% Injury	31.5	33.4	20.5	27.1	27.2	18.1
% P.D.	67.2	65.3	78.3	70.9	71.7	79.7
Fatalities/Acc.	0.014	0.016	0.014	0.020	0.011	0.022
Injuries/Acc.	0.50	0.57	0.34	0.31	0.31	0.20

The frequency of injury accidents was slightly less for large trucks. The number of injuries per accident was also less, but differed from cars by a greater factor than the frequency of such accidents. This phenomena likely reflects a greater number of occupants per vehicle in cars, thus increasing the number of injuries per injury accident to 1.65 for cars as opposed to 1.13 for trucks. The fraction of occupants injured cannot be examined explicitly because none of the files list the total number of occupants in a vehicle.

Approximately 60% of all large truck involvements on the mainline were in multivehicle collisions. The casualty rates of the major categories of multivehicle accidents are shown in Table 5-17. The accidents in the table have been classified into "collision pairs" by types of vehicles involved. Generally the first vehicle of any pair denoted in the table can be interpreted as the striking vehicle. This representation is most reliable in rear-end and sideswipe accidents of vehicles traveling in the same direction, and collisions with stopped or parked vehicles.

The proportion of the accidents which are fatals is higher for the multivehicle involvements, although the absolute numbers of fatals were small and the proportions are subject to substantial change with a change of only a few fatal collisions. Similarly, the proportion is higher for crashes involving trucks, a subject that will be examined further in later paragraphs.

Injury also occurred more frequently in multivehicle accidents, however, the relative frequency as a function of the collision pairs is not consistent for all turnpikes. Furthermore, many of the differences between columns in the table are not statistically significant.

The number of fatalities per accident was higher for multivehicle accidents than for single vehicle involvements, and was also higher for multivehicle collisions involving trucks when each turnpike is considered separately. Similar consistencies are not apparent in comparisons of the numbers of injuries per collision.

The table does lend some support to the hypotheses that involvement of a large truck results in greater dissipation of energy and more damage with increased likelihood of injury, and that multivehicle involvements increase the number of injuries per accident because the average number of occupants is greater when more than one vehicle is involved. It should be noted however that many of the single vehicle accidents did not involve collisions with attendant high accelerations, but were ran-off-the-road types with gradual and relatively harmless dissipation of energy.

An increase in the number of injuries in multivehicle crashes resulting from truck involvements may be offset somewhat by a lower average total number of occupants in trucks. This is suggested by the small differences between collision pairs in the proportion of accidents that result in injury and the number of injuries per accident.

The hypothesis that involvement of a large truck increases the severity of an accident can also be examined by summarizing the casualty rates for such accidents and comparing the result with crashes in which trucks are not involved.

Table 5-18 compares the rate of both fatalities and injuries (individual victims) in multivehicle accidents involving trucks with those involving only passenger cars. Data from the Texas files has been included to represent a wider class of accident types and highway environments. It should be noted that the number of fatalities per one hundred accidents is higher when a truck is involved for all the data sets. In Texas, the ratio of fatalities for truck and non-

Table 5-17

Severity and Casualty Rates of Multivehicle Accidents on the Mainline

	Car into Car			Car into Lg. Truck			Lg. Truck into Car			Lg. Truck into Lg. Truck		
	Penn.	Ohio	Ind.	Penn.	Ohio	Ind.	Penn.	Ohio	Ind.	Penn.	Ohio	Ind.
Total Acc.	2568	973	765	566	253	161	419	251	106	198	148	70
% Fatal	1.63	2.15	0.52	2.65	5.13	4.34	2.14	4.78	1.89	2.12	2.03	0
% Injury	38.4	52.1	29.3	40.8	46.2	29.8	31.7	46.6	24.5	44.9	46.6	47.1
% P.D.	60.0	45.7	70.2	58.3	52.6	65.8	66.1	48.6	73.6	53.0	51.4	52.9
$\frac{\text{Fatalities}}{\text{Acc.}}$	0.026	0.038	0.006	0.034	0.075	0.068	0.031	0.068	0.019	0.020	0.020	0
$\frac{\text{Injuries}}{\text{Acc.}}$	0.88	1.34	0.61	0.72	0.74	0.60	1.06	0.98	0.56	0.77	0.75	0.70

truck accidents is 2.1, while the turnpikes range from 1.1 in Pennsylvania to 4.5 in Indiana. When all three turnpikes are combined the fatality rates are 4.00 per one hundred accidents involving trucks and 2.48 per one hundred accidents involving passenger cars only, or a ratio of 1.6. The incidence of injury among accidents with and without truck involvement is reversed, with 107 injuries per one hundred accidents involving cars only opposed to 81 per one hundred accidents involving trucks or a ratio of 1.3 for cars over trucks.

Table 5-18

Number of Casualties per One Hundred Accidents

Data Set	Number of Accidents	Number of Fatalities per 100 Accidents	Number of Injuries per 100 Accidents
Texas:			
Truck Involved	12,000	2.39	26.1
No Truck Involved	16,000	1.14	27.5
Pennsylvania:			
Truck Involved	1,183	2.96	84.9
No Truck Involved	2,568	2.60	104
Ohio:			
Truck Involved	652	5.98	83.4
No Truck Involved	973	3.81	133
Indiana:			
Truck Involved	437	2.98	46.6
No Truck Involved	765	0.654	61.4

The difference between fatality rates of truck and non-truck accidents is not as great on the turnpikes as indicated in the Texas data. This may reflect a greater proportion of minor accidents in the general environment represented by the Texas data. On the other hand, the ratio of injury rates for cars over trucks was higher for the turnpikes. Whether this results from a higher average number of occupants in the recreational passenger car traffic on the turnpikes or from some other factor is not evident. Both in Texas, and on the turnpike however, the fatality rate is substantially higher in accidents which involve large trucks than in those which only involve passenger cars.

5.2.2 Turnpike Involvement Rates

The discussion of turnpike accidents in preceeding paragraphs was limited to the relative incidence of accidents by type of vehicles involved and by severity as defined by injury and fatality. These statistics can be derived from nearly any large body of accident data. The outstanding feature of the turnpike data lies in the availability of companion traffic or exposure data. Such data allows computation of absolute rates based on vehicle miles, the most commonly used measure of exposure.

Traffic data was available for all three turnpikes which would allow computation of vehicle miles by toll class for the same periods represented by the accident data. For the analysis presented here, the mileage was computed for a dichotomy of vehicles. The first group is passenger cars, and for this group those toll classes from each turnpike which include all passenger cars and are composed almost entirely of passenger cars were included. The second group is large trucks, primarily tractor trailers. The selection of appropriate toll classes to represent these vehicles is not as straight forward as for passenger cars, and is described in Appendix C.

Use of vehicle miles as a measure of exposure implies that accident experience is somehow, say linearly, related to the distance travelled. When considering a dichotomy of vehicles such as trucks and cars, we might expect that the probability that a vehicle involved in an accident is from either class is equal to the proportion of the total vehicle miles on the highway that is accumulated by that particular class. Thus, if trucks account for a proportion p_t of all vehicle miles on a turnpike, we might expect the probability that a vehicle in a collision is a truck is also p_t. Considering only two-vehicle collisions, namely car/car, car/truck (car into truck and truck into car), and truck/truck involvements, and assuming that the likelihood of involvement as either party to the collision is independent of the vehicle type, the proportion of all accidents in which at least one truck is involved is $(2P_t\text{-}P_t^2)$. The ratio of the proportion of accidents in which trucks are involved to the proportion of all mileage which is due to trucks is then $2(1\text{-}P_t)$. Thus, if trucks travel a small proportion of the mileage they appear to be over represented in the accident population by a factor approaching 2. The same logic can be applied to any dichotomy which includes a minority class of vehicles.

The proportion of all vehicles involved in the two-vehicle accidents considered above that are trucks is P_t. The ratio of the proportion of vehicles involved that are trucks to the proportion of mileage travelled by trucks is P_t/P_t=1, a relative involvement consistent with the assumptions regarding exposure and involvements.

Because of the phenomena described above, rates based on the frequency of accidents in which trucks are involved is a misleading index which tends to overstate the relative involvement of trucks, which are the minority class. Rates based on involvements-where each vehicle counts as a single involvement-is a much more useful index. Furthermore, the use of involvements allows examination of accident configurations by type of vehicles involved. For these reasons, all of the succeeding analyses and discussion of turnpike data are based on involvements rather than accidents.

Involvement rates (in involvements per one hundred million miles) for each of the three turnpikes are given in Table 5-19, for large trucks and passenger cars. The total number of involvements and the total number of vehicle miles is given for each type of vehicle at the bottom of the table. The table is based on both single and multivehicle accidents on the main line, and excludes incidents in service plazas, toll booth areas, etc. On both the Indiana Toll Road and the Ohio Turnpike the involvement rate is higher for trucks than for passenger cars. The ratio of the truck rate to car rate is 1.3 in Ohio and 1.1 in Indiana. The ratio in Pennsylvania on the other hand is only 0.8, with a lower involvement rate for trucks. The last two columns of Table 5-19 give the results for the combination (sum) of the three turnpikes, and indicate that the aggregate involvement rates for cars and large trucks are nearly equal. The same cautions and reservations on interpretation of the combined result which were given earlier apply here, although the figures do indicate lack of a consistent difference in rates for the types of vehicles.

Table 5-19

Involvement Rates on Turnpikes
number of involvements per one hundred million vehicle miles

	Indiana		Ohio		Pennsylvania		Total	
	Cars	Trucks	Cars	Trucks	Cars	Trucks	Cars	Trucks
Involvement Rate								
Single veh.	87.0	80.2	61.4	67.0	101.0	51.5	83.4	63.0
Multi veh.	72.8	91.6	60.8	90.9	121.6	135.1	88.9	109.7
Total	159.8	171.8	122.2	157.8	222.7	186.6	172.3	172.7
Number of Involvements	4197	866	5726	1572	11796	2040	21719	4478
Vehicle Miles (x 10^8)	26.26	5.04	46.84	9.96	52.98	10.93	126.08	25.93

It should also be noted that the differences in rates between Indiana and Ohio for cars and for trucks are as great as the differences between cars and trucks on either. This difference between turnpikes was evident early in the project but has not been explained. It might be hypothesized that the involvement rate on a particular segment of highway is a non-linear function of traffic density, with higher densities resulting in higher rates. Since the traffic on the western portion of the Indiana turnpike is much heavier than on the eastern portion, such a non-linear relation might explain the higher involvement rates on the Indiana Toll Road.

A limited comparison of involvement rate as a function of traffic on each highway failed to substantiate either the hypothesis or distribution of density on the two as an explanation for the differences in involvement rates. A linear regression was obtained of the total involvement rate (trucks and cars) on each segment of the highway (i.e., interval between interchanges) against the aggregate traffic over each segment. Traffic density would have been the appropriate index of traffic but explicit data was not available on density. Instead the count of vehicles which traversed each segment, which is proportional to density, was used as the independent variable in the regression. The results of the regressions with four year traffic counts from 3 x 10^6 to 9 x 10^6 vehicles per segment for both Indiana and Ohio are given in Table 5-20.

Table 5-20

Linear Regression of Involvement Rate Against Segment Traffic Count

OHIO

$IR = 54.4 + 0.0125N$

Correlation = 0.81

Standard Error = 16.6

INDIANA

$IR = 109 + 0.0122N$

Correlation = 0.67

Standard Error = 57.3

where IR = Involvement rate in involvements per hundred million miles, and

N = Number of thousands of vehicles over each segment in four year period.

While the correlations were only moderate, there is no indication that the involvement rates are exponentially related to traffic counts. The modest correlation resulted from scatter rather than a non-linear relation. Furthermore, as implied by the similarity of the slopes, the involvement rates were higher in Indiana than in Ohio throughout the range of traffic. Both of these observations fail to substantiate the hypothesis that the differences between highways is related to geographic distribution of traffic. Although the slopes of the regression lines are nearly the same the standard error of the estimate is large in each case, indicating that little significance should be attached to the similar slopes. The Pennsylvania Turnpike was not included in the computations described above, but similar failure of density as an explanation could be expected there. The passenger car rate was greater in Pennsylvania even though the fraction of vehicle miles by large truck varied only from 16.1% in Indiana to 17.1% in Pennsylvania and 17.5% in Ohio. When the total vehicle miles in each data set is adjusted for the length of each highway and the duration of the measuring intervals, the apparent relative densities vary by less than 37% from highway to highway, with the Pennsylvania density nearly equal to that in Ohio.[1]

The reporting criteria of Ohio and Indiana turnpike data were also considered as a reason for the differences in involvement rates. While all fatal or injury accidents must be reported by statute in both states, the criteria for property damage accidents differs. Ohio requires a report if the damage exceeds 100 dollars while Indiana requires a report of those crashes with over 50 dollars damage. On both turnpikes the agencies policing the highways submit a report for all accidents they cover regardless of the dollar damage. All such reports were included in construction of the Indiana Toll Road file. The punched card data obtained from the Ohio Turnpike Authority, however, excluded all cases in which the total damage was less than 100 dollars. Thus, inclusion of minor damage cases

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[1] Uniformity of both average trip length and average speed is implicit to this statement.

in the Indiana file would be reflected in a higher involvement rate than in the Ohio file. Examination of the incidence of cases with less than 100 dollars damage indicated far too few such cases to account for any significant difference in involvement rate.

While the involvement of trucks relative to cars is quite different on the three highways, the difference is due largely to variation in the rates for cars. The involvement rate for large trucks was more uniform. Table 5-19 indicated that the ratio of the truck rate in Pennsylvania (186.6) to the rate in Ohio (157.8) is only 1.2, with Indiana in the middle (171.8). Passenger car rates however, varied from 222.7 in Pennsylvania to only 122.2 in Ohio, a ratio of 1.8.

The involvement rate data given in Table 5-19 can be compared with two noteworthy studies of the mid 1950's. Computation of rates from data given by Solomon for main rural roads from 1954-1958 (before substantial interstate highway construction) gives 189 involvements per hundred million vehicle miles for trucks and 283 for passenger cars.[1] Data from the New Jersey turnpike from 1952-1957 indicates involvement rates of 300 for trucks and 178 for passenger cars.[2] The rates for cars in both sets of data vary by a factor of over 1.5, a greater factor than was observed in the present study. While the result of Solomon gives a greater involvement rate for passenger cars on main rural roads, trucks had a higher rate on the New Jersey turnpike. The truck involvement rates observed in the present study are similar to those of Solomon and much lower than those of Crosby. This is interesting since we might expect the results reported here to be closer to those of Crosby on the New Jersey turnpike because of the similarity of roadways.

The National Safety Council annually publishes a summary of the accident experience of fleets participating in the Council's National Fleet Safety Contest.[3] Of approximately 2800 fleets reporting in the contest in 1969, some 54 were intercity common carriers; these might represent the truck users on the turnpikes. These intercity carriers reported 382 accidents per hundred million vehicle miles in a total of nearly one billion miles travelled. Presumably few of these accidents would involve more than one truck, so the accident rate would be close to the involvement rate. This rate is over twice the rate experienced by large trucks on the turnpikes. Two factors could explain part of the difference. The accidents reported in the fleet safety contest included all property damage incidents regardless of the amount of damage unless the vehicle was legally parked, and accidents in all locations were included—not just those on limited access intercity routes.

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[1] Solomon, David, Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle, Bureau of Public Roads, Dept. of Commerce, July 1964.

[2] Crosby, J.R., Accident Experience on the New Jersey Turnpike, Traffic Engineering, Vol. 29, No. 5, Feb. 1959, pp. 18-23.

[3] Fleet Accident Rates, National Fleet Safety Contest, National Safety Council, Chicago, Illinois, 1970 Edition.

The involvement rates by severity of accident are given in Table 5-21. Although involvements were counted to compute the rates given, the severity was defined by the total accident. Thus a fatal involvement in the table indicates that at least one fatality occurred in <u>any</u> vehicle involved in the accident.

While Indiana had a higher involvement rate than Ohio for both truck and cars, Table 5-21 indicates that the major difference lies in the property damage accidents, with relatively fewer involvements in injury accidents for both cars and trucks in Indiana. Pennsylvania, which had the highest overall involvement rates, had rates for injury accidents nearly the same as those in Ohio. The rates for injury accident are more stable from turnpike to turnpike for both types of vehicles, with the bulk of the variation in total involvements resulting from property damage crashes.

Table 5-21

Turnpike Involvement Rate by Severity of Accident

	Indiana		Ohio		Pennsylvania	
	Cars	Trucks	Cars	Trucks	Cars	Trucks
Fatal	1.66	4.76	2.73	4.02	3.59	4.39
Injury	38.8	44.6	71.9	61.3	78.2	66.5
Property Damage	119.3	122.4	67.3	92.5	140.9	115.7

5.2.3. Single Vehicle Accidents

The involvement rates of large trucks in single vehicle accidents on the three turnpikes was given in Table 5-19. In Indiana and Pennsylvania the rate for trucks was lower than for passenger cars, 80.2 and 51.5 involvements per hundred million vehicle miles respectively for trucks and 87.0 and 101.0 respectively for cars. While the truck rate was intermediate at 67.0 in Ohio, the car rate, 61.4, was lower than trucks in Ohio and lower than cars in the other two states. Thus, while the results are somewhat mixed, trucks in general had a lower involvement rate than cars in single vehicle accidents.

The distribution of single vehicle involvements among fatal, injury, and property damage accidents was given in Table 5-16. In Ohio, the proportion of truck involvements that result in fatalities is lower than for cars. In Indiana and Pennsylvania the opposite is true. Here too, however, the differences between highways is greater than the difference between vehicle types on a single road, with nearly twice the relative involvement in fatals for trucks than on either other turnpike.

On all three turnpikes, the proportion of trucks in injury accidents was less than for passenger cars. The difference is greater than the proportion of fatal accidents, so it is not explained by the difference in fatals, but is instead the result of relatively greater truck involvement in single-vehicle property damage accidents.

Several factors might account for the lower incidence of injury crashes of trucks. The vehicle itself might provide the occupants more protection in minor and moderate accidents, e.g. ran-off-the-road, without affecting fatalities in the relatively infrequent serious crash. In moderate crashes of cars, their higher occupancy may result in greater probability of at least one occupant sustaining injuries and thus an injury accident. This is very possible even though injuries to several occupants of a single vehicle are not independent events. Since the police reports and accident files do not include the number of uninjured occupants, it is impossible to make explicit correction for occupancy.

The discussion above has related the relative severity of single vehicle truck involvements to those of cars on the basis of injury and fatality, and while differences were observed, they are not great. The relative severities might also be compared on the basis of the amount of property damage. Figures 5-46 and 5-47 give the distribution of property damage in single vehicle accidents of passenger cars and trucks respectively on the Indiana Toll Road. While both figures indicate a mode of less than 500 dollars damage, the trucks have many more cases with high loss, i.e., over 4000 dollars. This is not surprising and merely reflects the relative costs of the two types of vehicles as well as the value of damaged cargo in trucks. The damage information in the turnpike files is derived from police officers on the scene. Since their knowledge of the cost of truck damage and the contents and value of cargo may be limited, the damage data in these files may be less reliable for trucks than for cars. The true loss in truck involvements may well be even higher than indicated in Figure 5-47. The BMCS file, based on carrier reports is probably a more reliable source of quantitative property damage data.

The paragraphs above on single vehicle accidents have presented gross involvement rates based on aggregate vehicle miles and have examined the relative severity of cars and trucks in such involvements. The paragraphs to follow will examine involvement frequency in more detail and then discuss causative factors identified in the turnpike data.

The detailed data obtained on turnpike traffic and described in Appendix C, indicates that the major difference between truck and passenger car travel is in their hourly patterns. Truck mileage is nearly uniform throughout the day while car traffic peaks in mid-day and is much lower during the night. If single vehicle involvements are independent of the relative volume of each vehicle type and temporally related factors, the involvements would be expected to follow a pattern similar to the traffic pattern of each vehicle.

Figures 5-48 through 5-53 give the hourly distribution of single-vehicle involvements of cars and large trucks on each of the three turnpikes. A uniform distribution over twenty four hours would result in a horizontal line at 4.2%. The three figures of truck involvements indicate nearly uniform occurrence, but with slightly higher frequency from midnight to 7 a.m. Passenger cars also have a relatively flat distribution with some increased frequency from about 8 a.m. to 7 p.m. Only Figure 5-52 (passenger cars in Pennsylvania) shows a distribution resembling the distribution of passenger car traffic, but with a considerable attenuation of the difference between the mid-day peak and night lull.

Figure 5-46

SINGLE VEHICLE ACCIDENTS, TOTAL PROPERTY DAMAGE
FOR PASSENGER CARS ON THE INDIANA TOLL ROAD

```
   50+
     I
     I
     I
     I
   45+
     I
     I
     I
     I
   40+
     I
     I
     I
     I
   35+
     I
     I
     I
     I
   30+
     I
P    I                591
E    I
R    I              IIIII
C  25+              IIIII
E    I              IIIII
N    I          469 IIIII   481
T    I              IIIII
     I        IIIII IIIII IIIII
   20+        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
     I        IIIII IIIII IIIII   369
     I        IIIII IIIII IIIII
     I        IIIII IIIII IIIII IIIII
   15+        IIIII IIIII IIIII IIIII
     I        IIIII IIIII IIIII IIIII
     I        IIIII IIIII IIIII IIIII
     I        IIIII IIIII IIIII IIIII
     I    215 IIIII IIIII IIIII IIIII
   10+        IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII   101
    5+  IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII    36
     I  IIIII IIIII IIIII IIIII IIIII IIIII          12
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII           0     0
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
    0+--+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++
         ( 1)  ( 2)  ( 3)  ( 4)  ( 5)  ( 6)  ( 7)  ( 8)  ( 9)  (10)
```

Code	**Dollars**
1	**1-99**
2	**100-249**
3	**250-499**
4	**500-999**
5	**1000-1999**
6	**2000-2999**
7	**3000-3999**
8	**4000-7999**
9	**8000-9999**
10	**10,000 or over**

Figure 5-47

SINGLE VEHICLE ACCIDENTS, TOTAL PROPERTY DAMAGE
FOR LARGE TRUCKS ON THE INDIANA TOLLROAD

```
   20+
     I
     I
     I           67
     I
   18+        IIIII
     I        IIIII
     I        IIIII
     I        IIIII    59    60
     I        IIIII
   16+        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
   14+        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
     I        IIIII IIIII IIIII
     I     45 IIIII IIIII IIIII
     I        IIIII IIIII IIIII    43
   12+  IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII
P    I  IIIII IIIII IIIII IIIII IIIII
E    I  IIIII IIIII IIIII IIIII IIIII
R    I  IIIII IIIII IIIII IIIII IIIII
C  10+  IIIII IIIII IIIII IIIII IIIII
E    I  IIIII IIIII IIIII IIIII IIIII
N    I  IIIII IIIII IIIII IIIII IIIII
T    I  IIIII IIIII IIIII IIIII IIIII                29
     I  IIIII IIIII IIIII IIIII IIIII
    8+  IIIII IIIII IIIII IIIII IIIII             IIIII
     I  IIIII IIIII IIIII IIIII IIIII             IIIII
     I  IIIII IIIII IIIII IIIII IIIII             IIIII
     I  IIIII IIIII IIIII IIIII IIIII    22       IIIII          23
     I  IIIII IIIII IIIII IIIII IIIII             IIIII
    6+  IIIII IIIII IIIII IIIII IIIII IIIII       IIIII       IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII       IIIII       IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII       IIIII       IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII       IIIII       IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII    13 IIIII       IIIII
    4+  IIIII IIIII IIIII IIIII IIIII IIIII       IIIII       IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII    10 IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII       IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
    2+  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
     I  IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII IIIII
    0+--+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++
         ( 1)  ( 2)  ( 3)  ( 4)  ( 5)  ( 6)  ( 7)  ( 8)  ( 9)  (10)
```

Code	**Dollars**
1	**1-99**
2	**100-249**
3	**250-499**
4	**500-999**
5	**1000-1999**
6	**2000-2999**
7	**3000-3999**
8	**4000-7999**
9	**8000-9999**
10	**10,000 or over**

Figure 5-48

SINGLE VEHICLE ACCIDENTS BY HOUR OF THE DAY
FOR PASSENGER CARS ON THE INDIANA TOLL ROAD

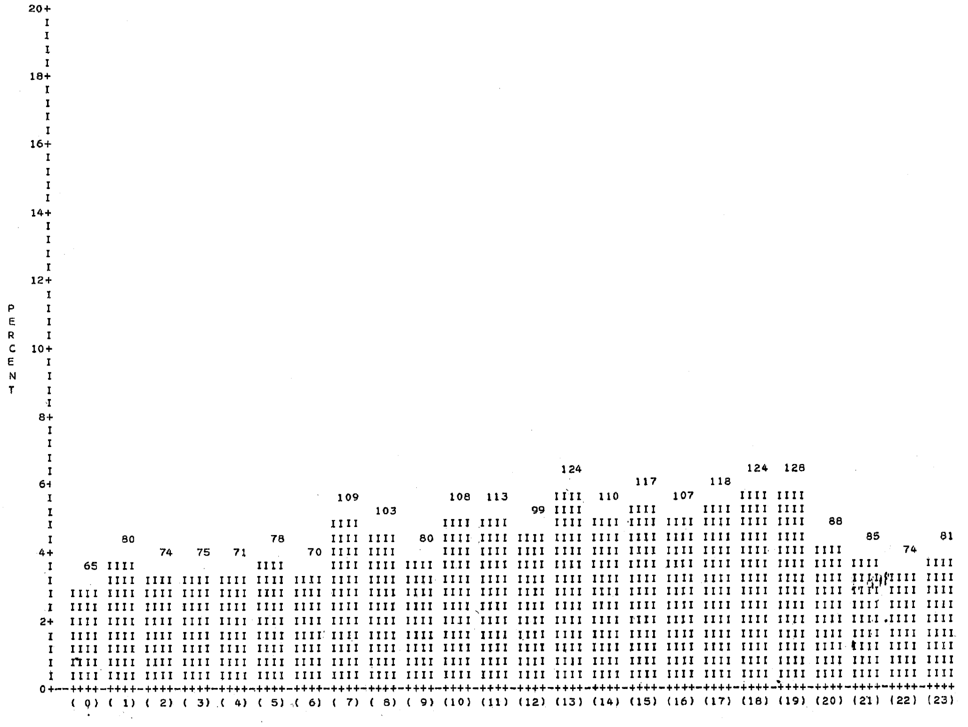


Figure 5-49

SINGLE VEHICLE ACCIDENTS BY HOUR OF THE DAY
FOR LARGE TRUCKS ON THE INDIANA TOLL ROAD

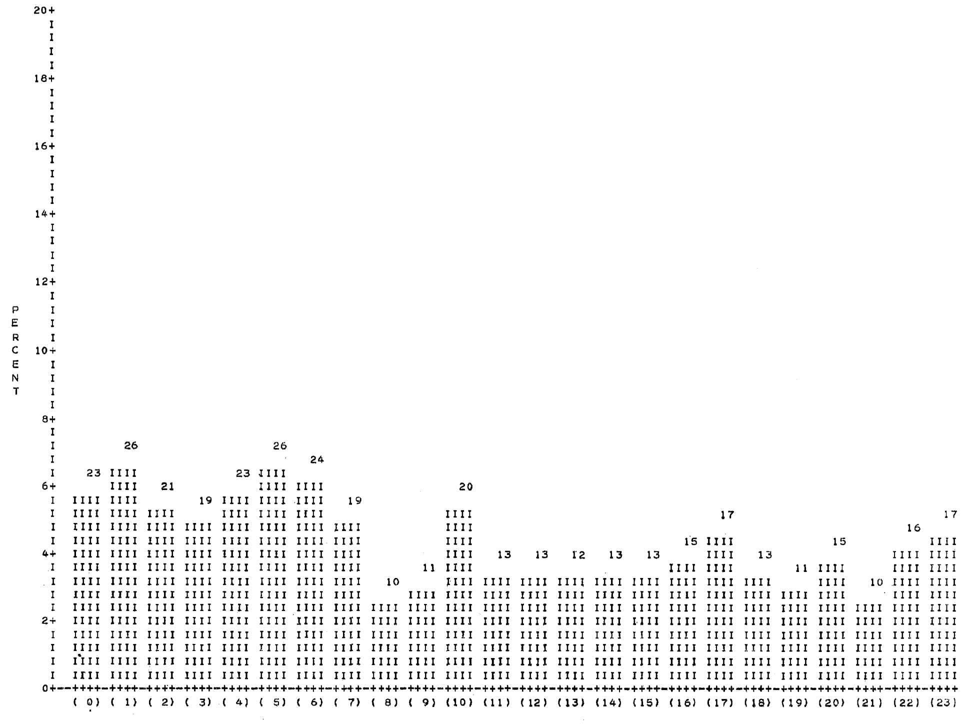


Figure 5-50

HOURLY DISTRIBUTION OF SINGLE VEHICLE ACCIDENTS
OHIO TURNPIKE
PASSENGER CARS - MAINLINE ACCIDENTS

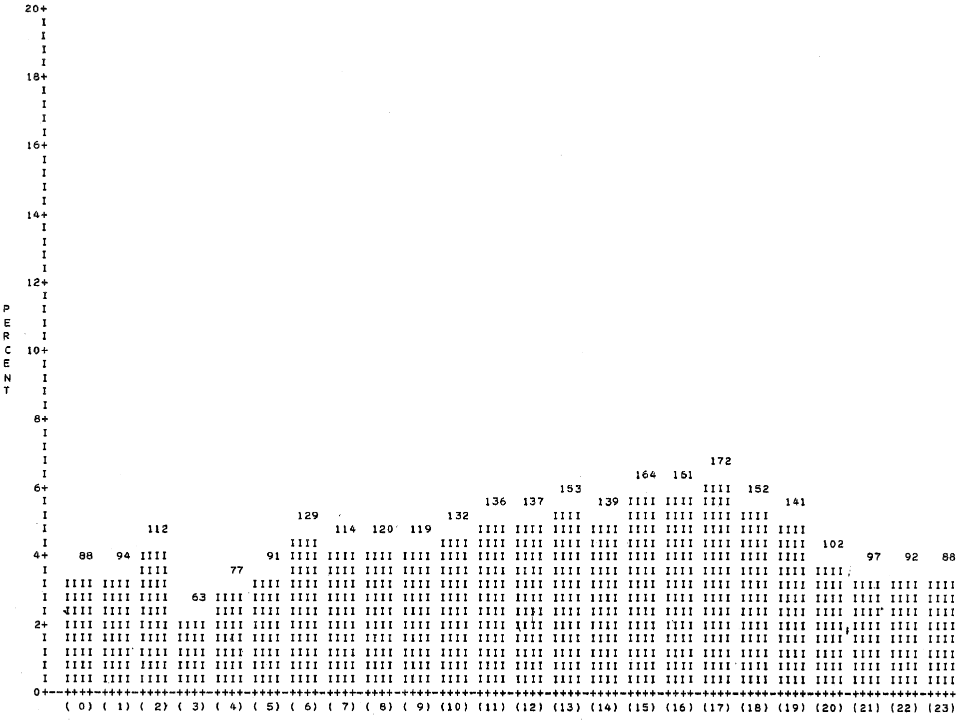


Figure 5-51

HOURLY DISTRIBUTION OF SINGLE VEHICLE ACCIDENTS
OHIO TURNPIKE
LARGE TRUCKS - MAINLINE ACCIDENTS

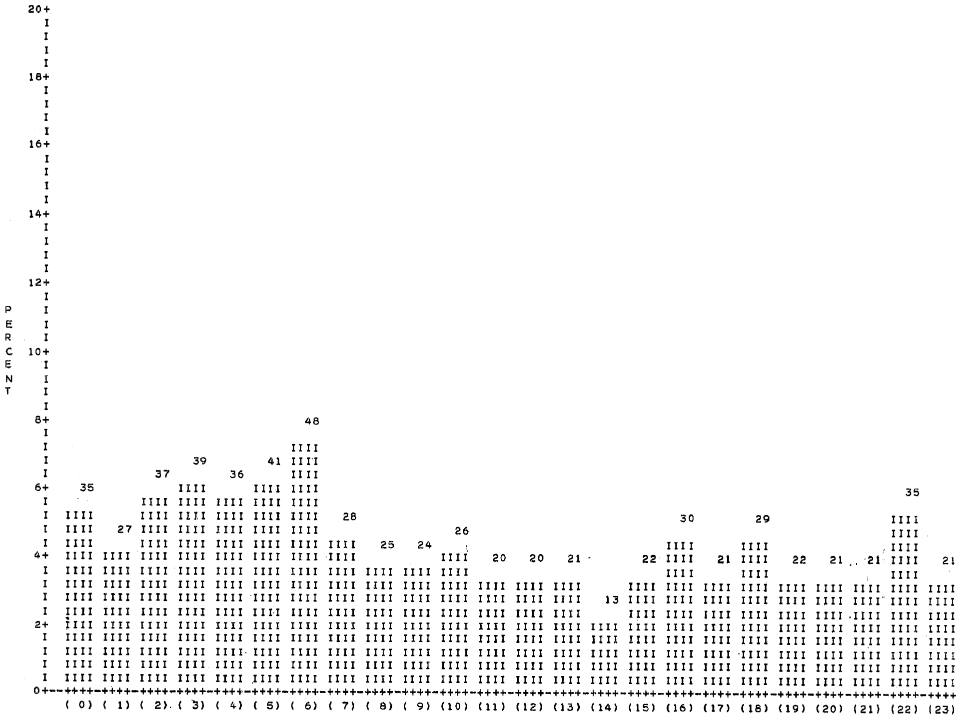


Figure 5-52

HOURLY DISTRIBUTION OF SINGLE VEHICLE ACCIDENTS
PENNSYLVANIA TURNPIKE
PASSENGER CARS - MAINLINE ACCIDENTS

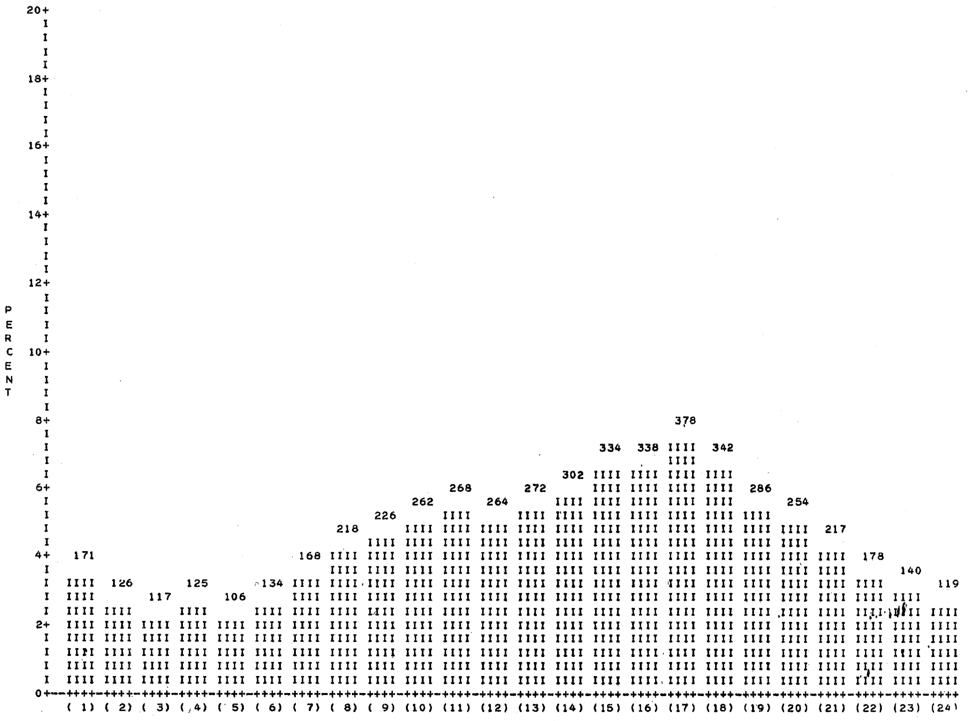
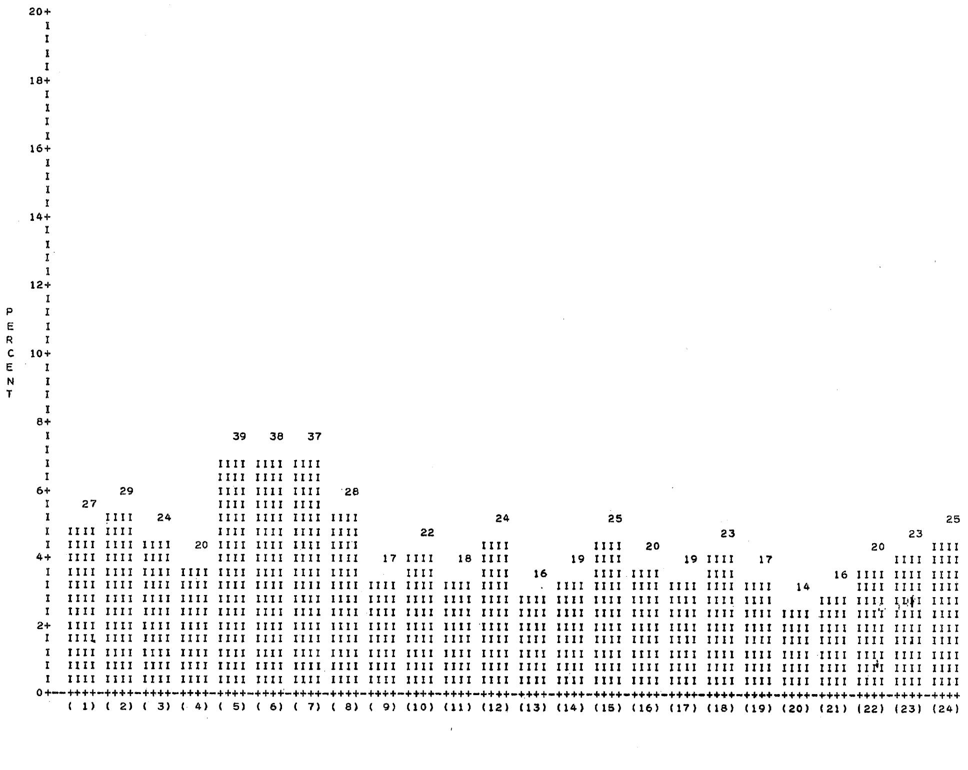


Figure 5-53

HOURLY DISTRIBUTION OF SINGLE VEHICLE ACCIDENTS
PENNSYLVANIA TURNPIKE
LARGE TRUCKS - MAINLINE ACCIDENTS



The slight increase in frequency in early morning hours for trucks and the relative uniformity of the distribution of car accidents suggests some overinvolvement of both types of vehicles in single-vehicle accidents during the night, i.e., overinvolvement relative to other periods of the day based on travel patterns.

To examine this more closely, overinvolvement by time of day has been computed for four equal time intervals. The overinvolvement ratio (OIR) used as an index of overinvolvement is the ratio of the actual number of involvements in a period to the expected number in the same period. The expected number is based on some model of exposure; and vehicle miles was used for single vehicle involvements. The expected number per interval was computed by assuming that the total number of involvements of each type of vehicle occurring in a 24 hour period is expected to be distributed linearly by vehicle miles. Thus, if

A_i = actual number of involvements in interval i

E_i = expected number of involvements in interval i

VM_i = vehicle miles traveled in interval i

the overinvolvement ratio for each of N equal intervals is

$$OIR_i = \frac{A_i}{E_i}$$

where $$E_i = \frac{VM_i}{\sum_{i=1}^{N} VM_i} \sum_{i=1}^{N} A_i$$

The factor $\frac{VM_i}{\sum_{i=1}^{N} VM_i}$ is the proportion of the total vehicle miles which are accumulated in time interval i. These factors were derived for each of four equal periods from data described in Appendix C and are given for cars and trucks separately on each turnpike.

The OIR for single vehicle accidents on each of the turnpikes for time of day is given in Table 5-22. Passenger cars are overinvolved from midnight to 0500 on all three turnpikes, with over three times the involvements that would be expected during this period if the involvements were proportional to vehicle miles. They are slightly underinvolved during other periods of the day. Large trucks were also overinvolved in the early morning hours but to a lesser degree.

The table also includes the results for all three turnpikes combined. These were computed by dividing the sum of the three actual involvements by the sum of the expected involvements. The primary justification for combining the results in this case is the consistency among the three; the result is insensitive to any bias introduced by differences in the amount of data from the three highways. Chi-square tests indicate the differences in the distributions of accidents and vehicle miles with the period of day are significant at the 0.01 level for both cars and trucks on all three turnpikes.

Table 5-22

Single-Vehicle Accidents on Turnpikes: Overinvolvement Rates by Time of Day Based on Vehicle Miles

	Overinvolvement Rate Time of Day			
	0 - 5	6-11	12-17	18-23
Pass. Cars				
Ind.	3.10	0.90	0.70	0.94
Ohio	3.48	0.89	0.77	0.97
Penn.	3.46	0.91	0.89	0.85
All three	3.3	0.9	0.8	0.9
Trucks				
Ind.	1.38	0.97	0.83	0.82
Ohio	1.29	1.03	0.76	0.90
Penn.	1.26	1.04	0.87	0.82
All three	1.3	1.0	0.8	0.8

Vehicle miles has been used as the measure of exposure for deriving expected distributions in the above analysis. One might conjecture that driving time (hours on the road) would be an equally, if not more appropriate measure of exposure for single vehicle accidents. Such a measure can be incorporated in the analysis by adjusting the vehicle miles by speed since driving time is proportional to miles and inversely proportional to speed.

Use of this latter exposure model would introduce changes in the results shown in Table 5-22 of 5% for cars and 7% for trucks using the estimated speeds given in Appendix B. The relative overinvolvements shown for nighttime periods would be reduced by these amounts, with corresponding increases in daylight overinvolvements. These changes are minor and do not represent substantially different results for either model using the parameters selected for this study.

The single vehicle accidents are given by type in Table 5-23. The three accident classifications shown are those that are common to the coding of cases from all three turnpikes. The top row includes all collisions with bridges, bridge piers, or bridge abutments. The second row includes all other fixed objects such as trees, signs, guard rails, median barriers, etc. Since only accidents on the main line are considered in this study, crashes into toll booths, etc. are excluded. The last row includes a small number of collisions with parked vehicles and animals, but largely represents ran-off-road,overturns on and off road, etc.

The rather large differences between highways shown in the table reflect differences in the highway designs. For example 35% of car collisions in Pennsylvania were into median barriers that do not exist on the other two highways. Because of these differences, comparisons of cars and trucks on each highway are more appropriate than comparisons between highways.

Table 5-23

Object Struck in Turnpike Single-Vehicle Accidents

	Object Struck in Percent of Single-Vehicle Acc.					
	Indiana		Ohio		Pennsylvania	
	Cars	Trucks	Cars	Trucks	Cars	Trucks
Bridge/Pier/Abutment	13.8	8.4	4.2	2.6	1.2	0.9
Other Fixed Object	46.1	27.5	5.2	0.8	71.2	73.3
No Fixed Object/Non-Collision	40.1	64.1	90.6	96.6	27.6	25.8
Total	100.0	100.0	100.0	100.0	100.0	100.0

The distributions shown for cars and trucks in Pennsylvania are very similar, while in Ohio and Indiana, truck involvements with fixed objects occurred relatively less frequently than those of cars. It is noteworthy that over 90% of the single-vehicle accidents on the Ohio Turnpike were non-collisions (ran-off-road and non-collision on road), for both cars and trucks. This would seem to indicate that this highway has less furniture in vulnerable locations, although this has not been substantiated.

Single-vehicle involvements with guard rails and median barriers are shown in Table 5-24. Trucks strike guard rails less frequently than cars in Indiana, but with nearly equal frequency in Pennsylvania. Truck involvement with median barriers in Pennsylvania however, is slightly less than for passenger cars. The median barrier was struck by a truck in 14.1% of all truck involvements in Pennsylvania, but by cars in 20.4% of all car involvements. These figures include both single and multi-vehicle accidents.[1] When the barrier was struck by a tractor trailer, it successfully performed its function (prevented intrusion into the opposing lanes) in 90.0% of the involvements. The corresponding figure for cars was 93.6%. While the difference in performance for the two types of vehicles is statistically significant at the 5.3% level (but not at the 5% level), the operational difference is small, i.e., only 27 tractor trailers penetrated the barrier in a two and one-half year period. Change in either vehicle or barrier characteristics to further reduce this number to an amount comparable to the performance for passenger cars may be very difficult.

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[1] Multi-vehicle accidents were included here because the barrier involvement will not be discussed again separately in the section on multi-vehicle accidents on the turnpikes.

Table 5-24

Involvement of Median Barriers and Guard Rails in Single-Vehicle Turnpike Accidents

	Percent of Single Vehicle Accidents			
	Indiana		Pennsylvania	
	Car	Truck	Car	Truck
Struck Guard Rail	37.7	21.3	28.3	29.6
Struck Median Barrier	*	*	35.2	33.3

* The Indiana Toll Road has no median barrier.

5.2.4 Multi-Vehicle Accidents

Multi-vehicle accidents are by far the more important group of accidents involving trucks. This is true from nearly any point of view. Since 62% of all the main-line turnpike accidents involving large trucks were multi-vehicle accidents, 75% of the total number of vehicles involved in the "truck" accidents were in multi-vehicle crashes. These multi-vehicle crashes are much more severe than the single involvements of trucks when fatalities are considered. The fatality rate of single vehicle truck accidents on the three turnpikes was 1.66 fatalities per one hundred accidents. The corresponding rate for multi-vehicle accidents was 4.05 - nearly two and one-half times as great.

The higher fatality rate for multi-vehicle truck involvements results, of course, from two factors. In most of the multi-vehicle truck accidents (81%), the second vehicle is a passenger car, with a higher average number occupants than in the truck. Secondly, the passenger car affords its occupants less protection in such a crash than does the truck.

The above observations would suggest that most of the fatalities in multi-vehicle collisions are occupants of passenger cars rather than the truck driver. Indeed this is the case. The ratio of the number of passenger car occupants killed to the number of truck occupants killed in collisions between these two types of vehicles is sometimes given as a measure of the difference. The ratio computed from the 1969 BMCS file of 50,000 accidents is 33.6. The same ratio from the turnpike data is 21.0, and 21.4 in the Texas data. These ratios are very large and the figure from the BMCS data has sometimes been offered as an indication of the relative consequence of truck accidents. When used in this context, it may appear that trucks are 33 times as dangerous as passenger cars. This is not a correct inference however, and the use of this ratio can be both misleading and unfair. The ratio reflects not only the higher occupancy of cars and the greater total energy available in a collision involving trucks - both of which do indeed increase the severity of such crashes - but also the greater protection given the driver of large trucks by both the strength and weight of his vehicle. He is nearly immune to the effects of the primary impact when struck in the rear by a passenger car. An interesting analogy can be drawn to demonstrate a pitfall inherent in inappropriate use of this figure. If the experimental safety cars now under development are indeed successful in protecting their occupants, they too will demonstrate a high ratio. Obviously the high ratio should not be interpreted as a condemnation of the safety car, but rather as a measure of its success.

A much more appropriate index of truck accident severity, at least to the public traveling in cars, is the relative likelihood of a fatality when a passenger car is involved with a truck instead of another passenger car. Table 5-25 gives the number of fatalities of occupants of each vehicle in accidents involving passenger cars and/or large trucks for each of the four possible configurations. Figures from the Pennsylvania file were not included because that file does not denote in which vehicle casualties occurred. Note that in the 977 collisions in which large trucks were involved on the main line of the Ohio and Indiana turnpikes, only four occupants of the trucks were killed. Table 5-26 gives the average number of passenger car occupants killed per involvement when cars collided with each other and when they collided with trucks. These figures, given in the first two rows, do not differentiate between the striking or struck vehicle. Thus the ratio of average number of fatalities in cars which collide with cars is 10.5, still a large number. In the 1969 Texas data which includes collisions on secondary roads and in urban areas, the ratio was 7.7.

Table 5-25

Fatalities per Vehicle in Multi-vehicle Collisions on Turnpikes

Veh. 1	Veh. 2	Veh. 1 No. Killed	Veh. 2 No. Killed	Number of Collisions
Car into	Car			
	Ind.	1	3	642
	Ohio	8	5	973
Car into	Truck			
	Ind.	9	1	153
	Ohio	18	1	253
Truck into	Car			
	Ind.	0	2	102
	Ohio	0	13	251
Truck into	Truck			
	Ind.	0	0	70
	Ohio	2	0	148

Table 5-26

Relative Fatality Rate of Car Occupants
By Type of Other Vehicle

Collision Configuration	Fatalities per Car Involved [1]
Car and Car	0.00526
Car and Truck	0.0553
Rear End/Side Swipe[2]	
Car into Truck	0.0650
Truck into Car	0.0246

[1] Fatalities of car occupants - Indiana and Ohio

[2] Ohio

On the controlled access turnpikes as on interstate highways, most of the collisions are between vehicles travelling in the same direction and involved in a passing or overtaking situation. These are rear-end collisions or sideswipes in passing. A smaller number are angle collisions (following substantial change of direction) with few if any true intersection types. Relatively few collisions result from median crossings on the turnpikes. Rear end and sideswipe collisions associated with overtaking situations are the most important group on the turnpikes. Table 5-27 summarizes the incidence of fatal collisions of these types involving trucks on the three turnpikes and allows a comparison with corresponding figures from earlier data from the New Jersey turnpike. On the turnpikes studied here, 66% of the fatal accidents involving trucks were multi-vehicle; whereas 90% were multi-vehicle accidents in the New Jersey study. Approximately 72% of the fatal multi-vehicle accidents were rear-end collisions in New Jersey while over 50% were rear-end collisions in the three turnpikes. In this report we have suggested in many places that the turnpike data is likely representative of interstate highways. One exception should be noted here. The Pennsylvania turnpike has a narrow median with a continuous barrier which is apparently quite effective. In spite of the effectiveness there are a number of median crossing accidents that are not representative of interstate or more modern limited access roads. If the median crossing collisions in Pennsylvania were deleted from the tabulations, rear-end (and sideswipe) collisions would account for over 60% of all fatal accidents involving trucks. On the Pennsylvania turnpike, passenger cars crossed the median in about 57% of all multi-vehicle fatal collisions that involved trucks, other than those that were rear-end or sideswipe.

Table 5-27

Comparison of Incidence of Fatal Accidents Involving Trucks on Turnpikes

	Current Turnpike Data	New Jersey Data (1952-1957)
Total Number Fatal Accidents	91	55
Multi-vehicle	65 (66%)	50 (90.9%)
Rear-end	33 (50.7%)	36 (72%)
Into truck	25 (76%)	27 (75%)

Approximately 75% of the fatal rear-end/side swipe collisions with trucks on the three turnpikes were into the rear of the truck. This same proportion was observed by the New Jersey study. Thus the overtaking accident is of particular importance on the turnpikes, and other controlled access highways as well.

The last two rows of Table 5-26 give the relative fatality rates for passenger car occupants when the car strikes a truck in the rear versus being struck by a truck. When a car strikes a truck in the rear, the average number of fatalities per passenger car is 2.67 times as great as when the car is struck in the rear by a truck.

The incidence of rear-end and sideswipe accidents will be examined in particular detail because of their importance and dominance on the turnpikes. The total frequency of such accidents in the turnpike files is given in Table 5-28 along with the total number of fatalities and injuries. The data is given by accident configuration, i.e., car into car, car into truck, etc.

The overall involvement rates of large trucks in collisions on the turnpike have been discussed in earlier paragraphs, and it was shown that while trucks were overinvolved - on the basis of vehicle miles - when compared with passenger cars on the Ohio Turnpike and the Indiana Tollroad, they were underinvolved on the Pennsylvania turnpike. When all three turnpikes are combined by simple aggregation of the data in the files without weighting, the overall involvement rate is nearly identical for both trucks and passenger cars. It is possible to also examine the relative involvement in more detail, i.e., for each collision configuration shown in Table 5-28. It should be noted that the four configurations shown are an exhaustive set of rear end/sideswipe collisions involving passenger cars and/or trucks. Several exposure models will be developed for examination and each will be discussed in detail.

The most commonly used measure of exposure is vehicle miles. We may use this traditional measure to derive an expected distribution of collision configurations. Any computation of expected values based on a priori information has implicit assumptions. In fact, comparison of expected with actual results may be considered a test of the implicit assumptions.

Table 5-28

Frequency of Rear-end and Sideswipe Collisions on Turnpikes

Configuration	Number of Collisions	Number Killed	Number Injured
Indiana			
Car into Car	468	1	266
Car into Truck	98	6	51
Truck into Car	69	1	35
Truck into Truck	52	3	34
Ohio			
Car into Car	634	3	718
Car into Truck	200	15	155
Truck into Car	162	5	160
Truck into Truck	113	3	99
Pennsylvania			
Car into Car	1345	14	1481
Car into Truck	353	6	235
Truck into Car	214	3	160
Truck into Truck	133	2	116

Possibly the simplest - but not necessarily inappropriate - mileage model for accident configuration is based on an assumption that involvement is proportional to mileage (the same assumption implicit in involvement rates based on vehicle miles). We shall also assume that, given a two-vehicle accident, the probability that a vehicle is a truck is equal to the proportion of all vehicle miles that are accumulated by trucks, and similarly for passenger cars. Thus

$$P\left\{ V_1\text{=truck} \;\middle|\; \text{a collision occurred} \right\} = p_T$$

where p_T is the proportion of all vehicle miles that were travelled by trucks. We shall also assume that type of vehicle is an independent event between the two involvements. The proportion of all accidents that are of each configuration would then be

$$p_{C\rightarrow C} = p_C^2$$

$$p_{C\rightarrow T} = p_T p_C$$

$$p_{T\rightarrow C} = p_C\, p_T = p_T p_C$$

$$p_{T\rightarrow T} = p_T^2$$

where $p_T = 1-p_C$, i.e., we are considering a dichotomy of vehicle types. The distribution of configurations given above can be used to compute an expected distribution of the observed accidents. The overinvolvement ratio (OIR) can then be obtained by the method described in the section on single vehicle accidents:

$$\text{OIR} = \frac{\text{Actual number of Involvements}}{\text{Expected number of Involvements}}$$

An example to clarify the development of the OIR by collision configuration is shown in Table 5-29 using the total mileage of cars and large trucks during the accident data period. The first column is the expected distribution, equal to the product of the proportions of the total vehicle miles accumulated by each vehicle type. Since the four configurations are an exhaustive set, the total of the first column is 1.0. The second column is the actual number of each configuration contained in the accident file. The expected number (third column) is the total actual number distributed by the expected proportion. The OIR is then the ratio of the actual number of each configuration to the expected number.

The OIR gives the relative overinvolvement or over representation -which may be less than one-of each configuration relative to the others. The mean OIR when weighted on the expected numbers is equal to one.

Table 5-29

Overinvolvement Ratio by Collision Configuration for Ohio Turnpike

(Based on Total Vehicle Miles)

Configuration	Expected Proportion	Actual Number	Expected Number	OIR
Car into Car	0.680	634	754.4	0.84
Car into Truck	0.145	202	160.3	1.26
Truck into Car	0.145	162	160.3	1.01
Truck into Truck	0.030	113	34.0	3.32
Total	1.000	1109	1109.1	1

Note: On the Ohio Turnpike the vehicle miles of cars and trucks during the $4\frac{1}{2}$ years of accident data were: cars - 82.48%, trucks 17.52%.

The first column of Table 5-30 gives the OIR for each of the three turnpikes. In general trucks are slightly overinvolved as the struck vehicle in rear-end collisions with cars and slightly underinvolved as the striking vehicle. They are considerably overinvolved in collisions between trucks.

If all truck traffic on the turnpikes were at night, and all car traffic were during the day, we would not expect any collisions between the two. While this is an extreme example, it does suggest an unrealistic deficiency of the model using total vehicle miles, namely, that the expectations should include considerations of the temporal distribution of traffic.

Table 5-30

Comparison of Overinvolvement Ratio by Exposure Model

Configuration*	Model Vehicle Miles Annual Vehicle Miles	 Vehicle Miles Daily Traffic Rates	 Interaction Model Annual Vehicle Miles	 Interaction Model Daily Traffic Rates
Car into Car				
Ind.	0.97	0.97	1.12	1.08
Ohio	0.84	0.84	0.97	0.97
Penn.	0.96	0.95	1.10	1.05
Car into Truck				
Ind.	1.06	1.09	0.46	0.50
Ohio	1.26	1.31	0.55	0.59
Penn.	1.22	1.27	0.53	0.60
Truck into Car				
Ind.	0.74	0.78	2.08	2.38
Ohio	1.01	1.05	2.86	3.20
Penn.	0.74	0.77	2.05	2.63
Truck into Truck				
Ind.	2.92	2.00	2.77	1.76
Ohio	3.32	2.59	3.28	1.68
Penn.	2.23	1.66	2.24	1.26

* Collisions between vehicles travelling in the same direction

Details of traffic data were obtained for each turnpike. These included the number of vehicles of each toll class by entry-exit pair for each month of the period over which accident data was available. From this data, vehicle miles were calculated by vehicle class, month, and year. A three month sample of daily traffic counts were obtained from the Indiana Toll Road Commission. An estimate of traffic variation by day of week was derived from this sample. Early in the project it was learned that the hourly variation of passenger car traffic was great, with daytime volumes much higher than nighttime volumes. Thus it became apparent that the effects of monthly or even daily traffic patterns might be overshadowed by hourly patterns. While hourly traffic data is not maintained by the turnpikes, sample vehicle counts by class and hour were obtained from an independent consulting firm for both the Indiana Toll Road and the Pennsylvania Turnpike. These samples were used to derive estimates of hourly patterns. The traffic data and a summary of the patterns mentioned above are discussed in Appendix C, and only a cursory summary will be given here.

Monthly mileage of large trucks was found to be nearly uniform throughout the year, and a uniform distribution by month was used in the analysis.

Approximately 14% of the truck mileage occurred on weekends, with 86% on weekdays. This indicates heavier traffic on weekdays as a uniform distribution would result in 29% of the traffic on weekends. Very similar daily patterns exist in the accident data of the Texas and 1969 BMCS truck files, with weekend accidents representing 13.5% and 14.6% respectively of each file.

Truck traffic on the turnpikes is nearly uniform during the day, with little variation from night to day. For purposes of analysis it was assumed to be uniform. While it should be noted that the uniformity was not present in the Texas truck or BMCS file (Figures 5-8 and 5-9), no reason is offered for the difference except possibly the more restricted type of highway represented by the turnpikes.

Passenger car traffic did not follow the patterns shown by trucks. Definite seasonal factors are evident with traffic increasing in the spring, reaching a peak in August, followed by a sharp decrease in September. This monthly pattern is typical of "recreational" travel. To represent the pattern conveniently for analysis without introducing an unreasonably small sample size in each of a large number of strata, the seasonal variation was represented by two uniform periods, a "summer" level including the months of June through August, and the rest of the year in a "non-summer" level.

Daily data from the Indiana Turnpike indicated that 35% of passenger car mileage occurs on weekends, thus more travel on individual weekend days than on weekdays. This result is also consistent with the distribution of passenger car involvements in Texas shown in Figure 5-2.

Hourly passenger car counts at several interchanges on the Indiana Toll Road and Pennsylvania Turnpike show very pronounced diurnal cycles. Traffic is low during the night, increases gradually during the day and reaches a peak in the afternoon. The ratio of maximum to minimum hourly traffic is as great as ten to one. This pattern is also typical of "recreational" travel. Some of the urban sections of the turnpikes show evidence of some commuter traffic with pronounced peaks of short duration in the morning and late afternoon. The diurnal pattern was represented in the analysis by dividing the day into four periods of equal length with a uniform distribution in each. This procedure incorporates the large, gross features of the traffic pattern without unwarranted stratification of data and minimizes the effects of commuter peaks.

The stratification described above and in more detail in Appendix C results in two seasonal levels, two daily levels and four hourly levels for a total of 16 cells.

The OIR for each collision configuration was computed using the detailed traffic rates described above. The expected proportion of accidents in each of the 16 cells was computed for each configuration. From these proportions, the expected number of accidents was obtained by proportional distribution of the total number of accidents. The OIR for each configuration was then computed by dividing the sum of the actual numbers of accidents by the sum of the expected numbers. The result is given in the second column of Table 5-30. Note that the overinvolvement of trucks into trucks has been reduced in magnitude, although overinvolvement persists. Thus change results primarily from the high daily peak in passenger car traffic and thus a high car-to-truck ratio in the day and a much lower ratio at night. The other results show little change.

The two models described above are both based on vehicle miles the first using total aggregate mileage and the second incorporating details of the temporal traffic patterns. Neither model considers a characteristic of traffic that could markedly affect the distribution of the four collision configurations. Either because of statute or operating characteristics or sometimes both, trucks on interstate highways travel with a lower mean speed than cars. Thus we would expect cars to pass trucks relatively more frequently than trucks would pass cars. The models used above however, predicted both with the same frequency. The observation on relative passing rates is pertinent because collisions between vehicles traveling in the same direction can only occur when two vehicles close on one another, i.e., an overtaking occurs. Although the probability of a collision given an overtaking is extremely low, the overtaking is a necessary prerequisite for a collision. An overtaking, then, defines a conflict situation which may lead to a collision. Since the frequency of overtakings is a function of both traffic density and speed, it offers a much more appropriate exposure model with which to investigate the incidence of rear-end and sideswipe collisions by collision configuration.

An exposure model was developed to incorporate consideration of the difference in operating characteristics of the two vehicle types. The model is based on prediction of overtaking rates for each of the four configurations of Table 5-30. This interaction model allows prediction of overtaking rates as a function of traffic density, and the probability density function of the speed of vehicles. It has been specifically developed to represent a dichotomy of vehicles such as trucks, and cars. However both overtakings of like vehicles and application to a homogeneous population are degenerate cases for which the model provides a solution.

A detailed development and discussion of the model are given in Appendix B, but there are certain restrictions that should be repeated here. The development does not include the formation of queues, and it assumes all overtaking vehicles are free to attempt to pass without altering their behavior. Thus the model would not be applicable to highways in highly urbanized areas with dense rush hour traffic. This would not seem to be a restriction on its applicability to basically rural turnpike traffic however. Although the model has been derived to predict the overtaking rate (overtakings/hour), and hence could be used to predict total overtakings in a time interval, it is not used here to predict the number of overtaking-related accidents. No attempt has been made to evaluate the extremely small conditional probability of a collision given an overtaking. It is used instead to model the relative expectation of collision by configuration. For this purpose, on highways of moderate freely flowing traffic, the interaction model is suggested as a more appropriate exposure model than models based solely on mileage.

The independent variables of the interaction model are the densities of each class of vehicle (usually expressed in vehicles per mile) and the probability density function of the speed of each class. Neither parameter was available directly for either cars or trucks on the turnpikes, so they were estimated from available data. Speed estimates for both classes of vehicles were obtained from measurements taken on interstate highways in Michigan. Traffic densities were estimated using the mileage data described in Appendix C with the speed information described above. The resulting parameters used in the model are listed in Appendix B. It should be noted that use of traffic density allows for the choice between either the average density over the entire data period derived from aggregate mileage, or the temporal characteristics of density. The two possible approaches correspond to the use of annual and daily mileage in the first two columns of Table 5-30.

The third and fourth columns of Table 5-30 give the OIR values derived from both sets of traffic density data using the interaction model. The last column, derived from the interaction model incorporating the detailed temporal structure of traffic patterns, is presented as the most appropriate model for evaluating relative involvement. This is a new departure in representation of exposure, and one that provides a more realistic model than has been used in the past.

The results shown in the last column are quite different than those which are based on mileage only. The ratio for collisions between passenger cars has increased slightly but is still close to unity, indicating little overinvolvement relative to the other configurations. Collisions of cars into trucks are underinvolved, occurring approximately half as frequently as the traffic characteristics would lead us to expect. Truck-into-car collisions, on the other hand, are overinvolved by more than two to one. The actual number of accidents of cars into trucks and trucks into cars are about equal. The interaction model, which includes speed considerations as well as intuition, leads to a lower expected frequency of trucks passing cars than of cars passing trucks. It is this factor which leads to the results shown. While trucks into trucks are still overinvolved, their OIR is less than determined by the earlier model.

The most significant observation, one which was unexpected, is that trucks are overinvolved as the striking vehicle in rear-end and sideswipe accidents, both into cars and into trucks.

The actual frequency of accidents used in the above analysis, shown in Table 5-29, were tested for independence by a 4 x 3 contingency table, and the differences between turnpikes was highly significant. Much of the difference between highways is in the relatively high variation in passenger car involvement rates. When only the accidents involving trucks were included in a 3 x 3 table, the differences were not significant at the 0.05 level, suggesting that the consistency between highways is real.

The discussion of relative involvement by accident configuration presented above has mentioned the importance of the variation of traffic with time and considerable attention has been devoted to the importance of this characteristic to exposure. This suggests that examination of overinvolvement rates relative to time, particularly time of day, might also bear interesting results.

The same technqiues, i.e., employment of the interaction model have been used for examining involvement relative to the four periods of the day. The results are given in Table 5-31. In this table the expected number of accidents were based on row distributions rather than column distributions as used in Table 5-30. Comparisons of overinvolvements should be based on comparisons of row elements of the array, not by column. Comparisons of the three highways in 3 x 4 contingency tables, one for each configuration, failed to indicate significant differences between highways at the 0.05 confidence level. The only exception was cuased by the small samples of truck-into-truck accidents on the Indiana Toll Road from 1200 to 1800 hours and from 1800 to 2400 hours.

All accident configurations are overinvolved in the early morning hours. Crashes of cars into other vehicles are slightly underinvolved in the afternoon hours, while trucks into other vehicles are underinvolved in the evening. We might note that cars into trucks, which were not overinvolved on a 24 hour basis (Table 5-30) are overinvolved in the early evening hours. This overinvolvement in predominantly hours of darkness might be attributed to rear lighting on trucks inadequate to warn the car driver of high closing rates. If insufficient lighting and high speed differentials are accepted as primary contributing factors, one is faced with the dilemma of explaining the even higher overinvolvement rate of cars into cars during the same period.

Table 5-31

Overinvolvement Ratio by Period of Day, Interaction Model

Configuration	Period (Hours) 0000-0600	0600-1200	1200-1800	1800-2400
Car into Car				
Ind.	7.0	0.85	0.76	1.43
Ohio	10.6	0.96	0.75	1.19
Penn.	11.8	0.99	0.89	0.96
Car into Truck				
Ind.	3.96	0.73	0.63	1.23
Ohio	5.82	0.89	0.44	1.04
Penn.	5.53	0.85	0.73	0.87
Truck into Car				
Ind.	2.44	1.08	0.93	0.61
Ohio	2.27	1.15	0.98	0.66
Penn.	1.52	1.38	1.32	0.45
Truck into Truck				
Ind.	1.53	1.85	0.56*	0.45*
Ohio	1.61	1.09	0.81	0.47
Penn.	1.53	0.75	0.96	0.70

* Small sample (less than 10)

It should be noted that the same time period which shows the high overinvolvements in rear-end and sideswipe collisions was also overrepresented in single vehicle collisions of both trucks and cars. This period of the night is also the period of the lowest total traffic density, possibly suggesting that the consistent overinvolvement may be because of driver related factors.

Early in the analysis of the turnpike data, it was noted that a very substantial proportion of the rear-end collisions on the Ohio Turnpike were on upgrades. The indication of vertical alignment was provided by the police on offical report forms. Since reliable standards on the use of this code (how to define an upgrade) are not available, and because of the current interest in the relation between "hill holding" capability, speed differentials, and accident experience, this observation was deemed particularly noteworthy. Consequently, engineering data on vertical alignment was obtained on the Ohio and Pennsylvania Turnpikes. Accident location was given on both highways to the nearest one-tenth mile. The grade of the highway at the point of the accident in tenths of a percent grade was added to the accident file for each of the 17,681 accidents in the files of these two highways.

The maximum grades on the Ohio Turnpike are 2.0% on upgrades and 3.0% on downgrades. The maximum grades on the Pennsylvania Turnpike are 3% on both upgrades and downgrades with the exception of a short segment of the Northeast Extension which has a grade of 3.45%.

If grade is indeed correlated with the incidence of rear-end collisions, an intuitively obvious hypothesis for the causal relation is that grades may affect the speed of climbing vehicles particularly heavy trucks, and thus increase the speed differences in the traffic stream and the overtaking rates. The speed of heavy vehicles which are grade limited is not a function of the grade at the point at which the speed is measured, but the grade over which the vehicle has just travelled, i.e., the grade history.

The effects of grades might be better investigated using an index more closely related to performance than the grade at the point of impact. Such an index could be derived analytically if sufficient information were available on each vehicle, such as weight and horsepower or speed-torque curves at highway loadings. This information is not available from police data. Instead, several studies of truck performance on grades for trucks in use were reviewed, and it was arbitrarily decided that the average grade over the previous half-mile of travel would be an appropriate index for statistical evaluations. This average grade was then computed for each accident location and added to the accident file. It was not calculated for 890 accidents on the Pennsylvania turnpike and 440 in Ohio for which it was not possible to clearly determine either the direction of travel or, in turn, the sign of the grade (+). Fortunately, these cases do not include rear-end or sideswipe collisions which were the only types used in the grade analysis.

The grade at the point of impact was bracketed into 7 intervals for analysis. A histogram distribution of the grade of the highway was obtained by similarly bracketing the grade over the entire length of the highway. An expected number of accidents, by configuration, was obtained for each grade interval by linearly distributing the entire rear-end and sideswipe accident population over the grade distribution of the highway. An OIR was then computed as in previous analyses.

The results for both highways combined are given in Table 5-32. Chi-square tests of the difference between the distribution of grades on the highways and the distribution of grades in the accident file are significant at the 0.05 level. The results given in the table are based on grades at the point of the accident. The results using average grade are nearly identical, possibly because of the physical characteristics of the highway.

Large trucks were indeed overinvolved as the struck vehicle on the steeper upgrades with an OIR=2.09. Cars were also overinvolved as the struck vehicle on upgrades, although to a lesser degree. It should also be noted that cars were overinvolved as the struck vehicle on downgrades. If we hypothesize that the overinvolvement of crashes into trucks on upgrades is in part due to speed differences resulting from insufficient power of trucks, we would expect increased power to reduce the overinvolvement. Yet with the low weight-to-power ratio of passenger cars, which are affected little by 3% grades, there is still some overinvolvement. Table 5-31 also indicated an overinvolvement of trucks as the striking vehicle in turnpike rear-end crashes. It is not clear how an increase in truck power would change this overinvolvement or the total accident experience, if at all.

Table 5-32

Overinvolvement as a Function of Grade,
Rear-end and Sideswipe Accidents on
Ohio and Pennsylvania Turnpikes

	Car or Truck into Rear of:			
	Car		Truck	
Grade (%)	N	Over-Involvement	N	Over-Involvement
+2.5 to +3.5*	300	1.43	155	2.09
+1.5 to +2.4	236	1.09	119	1.56
+0.7 to +1.4	238	0.89	70	0.74
-0.6 to +0.6	692	0.83	230	0.78
-0.7 to -1.4	245	1.02	74	0.87
-1.5 to -2.4	251	1.01	58	0.66
-2.5 to -3.5	246	1.26	74	1.07
Total	2208		780	

* All cases in this interval are in Pennsylvania because the Ohio Turnpike has no upgrades over 2.0%.

Large trucks were overinvolved as the striking vehicle in truck into car collision on the 2.5 to 3.5% downgrades on both turnpikes with an OIR _ 1.7. If the accidents on grades are causally related to speed, we would expect a negative correlation between grade and the speed of the struck vehicle. The correlation between grade and the speed of the struck vehicle before the collision is given in Table 5-33. All the correlations shown are low. The speed of vehicles involved in accidents, as given on accident reports, is difficult for investigating officers to determine with accuracy. This data is an example of subjective or soft information, and may be unreliable. The low correlations indicated by Table 5-33 may only reflect this unreliability. All attempts to use speed as a viable statistic in this study have met with similar lack of correlation or consistency.

Table 5-33

Correlation Between Grade and Speed of Involved Vehicles,
Rear-end Collisions on Pennsylvania Turnpike

Vehicle	Correlation with Speed Before Impact			
	Grade at Impact		Average Grade*	
	Number	Correlation	Number	Correlation
Striking (Rear) Vehicle				
Car	1290	0.0714	1290	0.0448
Truck	293	-0.1264	293	-0.1302
Struck (Forward) Vehicle				
Car	1332	-0.0226	1332	-0.0516
Truck	418	-0.2899	418	-0.3064

* Grade averaged over previous one-half mile of travel.

It is also not clear if the accidents on the higher grades are related to lighting more than accidents on low grades. A check for the significance of the differences in the proportion of accidents in darkness on the highest grades with the same proportion on low grades failed to indicate significance at the 0.05 level. The normal approximation of the binomial distribution for large samples was used for both collisions into cars and collisions into trucks with the same result.

Climbing lanes have been added to both the Ohio and Pennsylvanis turnpikes in locations where a steep grade persists for a relatively long distance. A brief analysis of accidents in climbing lane segments has been conducted using the Pennsylvania Turnpike data. These segments are all at grades of 2.9-3.0 percent, and have been compared with segments of similar grades without climbing lanes. Over a two and one-half year period there was a total of 365 accidents at these upgrades, 59 of which occurred on slopes having a climbing lane. The data is presented in Table 5-34.

Table 5-34

Comparison of Collisions on Climbing Lanes and Other Steep Grades, Pennsylvania Turnpike

Type Collision	Total No. of Acc. at grades of 2.9-3.0%	No. of Acc. in segments with climbing lanes	% of Highway at grade with climbing lanes	% of Acc. occurring within climbing lane segments
Cars into Cars	202	32	14.7	15.8
Cars into Trucks	82	16	14.7	19.5
Trucks into Cars	43	5	14.7	11.6
Trucks into Trucks	38	6	14.7	15.8
Total	365	59	14.7	16.1
Trucks Involved	163	27	14.7	16.6

It can be noted that there is a slightly higher percentage of accidents occurring within the climbing lane segments than might be expected on the basis of their mileage, but this is not statistically significant. What is practically significant is the fact that the 95% confidence interval about the total (16.1%) ranges from 12 to 20%, given the indicated number of accidents, and for the "trucks involved" accidents, from 10% to 23%. Thus one can conclude that there is just not enough data to show that the climbing lane segments are better or worse than the other 3% grade segments. And this is true for a very busy highway with some 11,000 reported accidents in a $2\frac{1}{2}$ year period.

Accident data for the period prior to the installation of the climbing lanes was not available for this study, and it seems likely that the additional lanes were installed because of an unusually high accident frequency in these particular areas. But to discern a difference in performance by looking at the accident statistics would require a change of about a factor of two and a time period of several years. Consequently it is suggested that it may be more appropriate to evaluate the efficacy of climbing lanes by some surrogate measure, such as traffic conflicts. From such measures an inference may be drawn as to the probable effect on accidents.

Traffic count data was not available in a form which permitted an adjustment of the above data for traffic density, although it can be informally observed that the climbing lane segments do not carry much more traffic than other 3% grade portions of the highway.

5.2.5 Double-Bottom Combinations

The turnpike accident files do not in general permit a detailed examination of accident data by size or weight of truck except as they are categorized as tractor-trailer or single unit. The tractor-trailer traffic is predominantly composed of semi-trailers and these units travel the turnpikes in far greater numbers than other truck configurations. However, even for this category, no weight information is given; we do not even know if the rigs involved in accidents are empty or fully loaded. Therefore we cannot examine truck size or weight as independent variables in the files for which we have exposure data.

A single exception to this limitation does exist. In the Indiana file the double-bottom trucks are uniquely identified. The combinations included in this category are tractor-semi trailer-full trailer rigs.

During the five years (1966-1970) for which accident data were available on the Indiana Toll Road, "doubles" were involved in 14 accidents. This number is small but it does allow a worthwhile comparison with the involvement rates of other trucks. In this period approximately 16.6 million miles were travelled by the doubles, for a rate of 84 involvements per hundred million vehicle miles. The involvement rate for large trucks (tractor-trailers) during the same period on the same highway was 171.8 or over twice the rate of the doubles. Since the number of involvements is low, the question of the resulting confidence interval in the involvement rate is pertinent. A confidence interval was obtained by assuming that the infrequent involvements of double bottoms can be represented by a Poisson distribution. The 95% confidence interval on the expected number of events is 7.7 to 23.5, or from 46 to 142 involvements per hundred million vehicle miles. The rate for double bottoms at the upper limit was lower than the observed rate for tractor trailers. Thus we may conclude that double bottoms indeed have a lower involvement rate on the Indiana Toll Road. This does not mean that the sample is necessarily representative of national experience. The Indiana Toll Road Commission may exercise discretion in issuing permits to carriers and drivers for the larger rigs, so the operation may include a bias.

Although the 14 involvements in Indiana are not a large enough sample to allow assessment of relative accident severity, the 1969 BMCS file does contain sufficient numbers of doubles to permit comparison with tractor-trailers. Table 5-35 gives the comparisons for all accidents involving these vehicles, about half of which are single-vehicle accidents, and for those collisions which involve passenger cars. The ratio of the casualty rate of double-bottom accidents to the tractor-semi trailer accidents is also given. The last two rows of the table are particularly noteworthy because they give the relative casualty rates of passenger car occupants for collisions with "singles" and "doubles". The casualties of both severities are slightly greater in double-bottom accidents by 14% for fatalities and 12% for injuries.

The statistical significance of the difference in the rates of the two types of trucks shown in the last column was tested using two techniques with consistent results. Although the number of casualties per accident does not have a normal distribution, the samples are large so the central limit theorem provides justification for testing the difference in the means using the normal distribution. The actual distribution of casualties per collision might be approximated by the Poisson distribution. Based on this assumption, the significance was also checked using the likelihood ratio test for equality of parameters of the Poisson distribution.[1]

5.2.6 Causal Factors

The analysis that has been presented for the turnpike accidents has been restricted to objective i.e., "hard" data, with little dependence on subjective data. This analysis philosophy was adopted to minimize any possible dilution of results from inclusion of subjective data. The objective information, however, contains little direct information on causal factors although inferences are possible and several have been offered.

Reports of police accident investigations often contain causal information and all three turnpike files reflect this in varying degrees. The information of this type contained in the accident files presents several problems in analysis and interpretation. The first and most serious problem results from the subjective nature of the detection of such factors in police investigations. Causal factors are often difficult to detect and evaluate, even in in-depth investigations. Several factors may present themselves without a clear indication of their relative contribution. Even seemingly simple accidents may prove troublesome-did a tire blowout cause the accident, or did the tire damage result from the crash? Did the driver lose control for reasons beyond his control, or from inattention?

Secondly, assessment of causal factors may be influenced by local law enforcement practices and policies, and by motor vehicle codes.

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[1] Wilkes, S.S., Mathematical Statistics, Wiley, New York, 1962, p. 424.

Table 5-35

Comparison of Casualty Rates of Tractor-Semi Trailer and Double-Bottom Accidents, 1969 BMCS File

	Average Number of Casualties per Acc.		Ratio-	Significance Level
	Tractor-Semi	Double-Bottom	Double / Single	
All Accidents*				
Casualties in Accident				
No. Killed	0.044	0.047	1.07	Not Sig.
No. Injured	0.510	0.560	1.10	0.05
Casualties in Other Vehicle				
No. Killed	0.034	0.033	0.97	Not Sig.
No. Injured	0.353	0.354	1.00	Not Sig.
Accidents with Passenger Cars**				
Casualties in Accident				
No. Killed	0.058	0.071	1.22	Not Sig.
No. Injured	0.644	0.745	1.15	0.05
Casualties in Passenger Car				
No. Killed	0.058	0.066	1.14	Not Sig.
No. Injured	0.568	0.638	1.12	0.05

* 39,817 Tractor-Semis, 1507 Doubles

** 18,909 Tractor-Semis, 608 Doubles

Thirdly, the recording and coding practices used in constructing accident data files may contribute to the problem. If multiple responses are not permitted, factors which are present and recognized may not be listed if another factor is perceived to be more important. A single response list may include several factors that are not mutually exclusive, without any provision for indicating more than one.

The turnpike files, as do nearly all accident data files, contain examples of these problems to varying degrees. Nevertheless, they do contain causal data and it would not be appropriate to neglect or omit this information. A summary of the causal variables will be presented in this section. Interpretation will be left to the reader except in those cases where substantial evidence is found consistently. The variables in the individual files which contain these factors are not consistent in structure or content. Rather than present all variables individually from each file, they have been summarized, combined where consistent with exceptions noted, and emphasis has been placed on information that is homogeneous among the files.

The distribution of involvements by weather and surface condition is given in Table 5-36 for the Indiana and Pennsylvania Turnpikes. In Indiana, both cars and trucks have about half of their involvements in inclement weather. In Pennsylvania, 55% of the car involvements but only 40% of the truck involvements were in inclement weather. The average monthly precipitation (by volume) is nearly uniform over the year in this part of the state, so the difference between truck and cars is likely significant. A greater proportion of truck involvements are under conditions of snow or ice on both turnpikes than are those of cars. The ratio of the relative frequency for trucks to cars is 1.4 in Pennsylvania and 1.15 in Indiana. This apparent overinvolvement of trucks in snow might disappear if the exposure data were modified by climatic information, since a much greater fraction of the annual passenger car traffic is in summer. Similar climatological exposure adjustment might increase the overinvolvement of cars in wet weather over that which is indicated in Table 5-36.

Table 5-36

Involvement Frequency by Weather and Surface Condition

	Mainline Involvements by Condition in Percent	
Condition:	Cars	Large Trucks
Clear		
Ind.	51.4	52.4
Penn.	45.3	59.7
Rain		
Ind.	24.6	13.7
Penn.	38.4	21.5
Snow/Ice		
Ind.	18.5	26.0
Penn.	16.0	18.4
Ohter/Missing Data		
Ind.	5.5	7.9
Penn.	0.3	0.4

The "primary" causal factors that are common to all three files are shown in Table 5-37. Speed including "speeding" and "speed too fast for conditions" was listed more frequently for cars than for trucks, although it was by far the most commonly noted factor for both. Defective equipment was listed more frequently for trucks for both single-vehicle accidents and for all accidents but little difference was noted in multi-vehicle involvements. Tests of significance using contingency tables (4x2) for the four factors and cars versus trucks gave significance at the 0.01 level for all three groups of accidents shown. Speed differences contributed heavily. When only the incidence of vehicle defects was tested, the differences were significant only for "single vehicle" and "all" involvements.

The incidence of vehicle defects of trucks in single-vehicle collisions is substantial, both relative to cars and in absolute numbers.

In addition to causal factors, both the Indiana and Ohio files include vehicle defects in two variables. One variable of the Indiana file is devoted exclusively to defects. When all indications of a vehicle defect were included (rather than just those listed as a primary cause) the frequencies of Table 5-38 were found. Over 20% of all trucks in single-vehicle accidents were indicated as defective in some way. The type of defect is given only in the Indiana and and Pennsylvania files, and these are shown in Table 5-39. The columns for the two highways are quite different and should be noted. The Indiana file has a variable for vehicle defects, and indicated responses represent approximately 97% of all involvements. The Pennsylvania file, on the other hand, includes the five defects shown along with ninety-two other possible accident causes. In this file the cause is only given relative to the vehicle identified as the "offending" vehicle. Therefore the responses shown represent 9.5% of the cars and 18.7% of the large trucks in single-vehicle involvements. It should be noted that 80% of all the vehicle defects included in the table are tire problems.

Table 5-37

Primary Causal Factor Noted on Police Report

Distribution by Factor in Percent

	Single Vehicle Accident		Multi Vehicle Accident		All Accident	
Causal Factor	Car	Truck	Car	Truck	Car	Truck
Speed	42.1	30.0	22.3	13.8	34.5	22.0
Defective equipment	11.0	19.3	3.1	2.9	7.9	11.3
Improper Passing or Failure to Yield	2.5	3.0	8.0	8.6	4.6	5.8
Other (Including None)	44.4	47.7	66.6	74.7	53.0	60.9
Total	100.0	100.0	100.0	100.0	100.0	100.0

Table 5-38

Frequency of Notation of Defective Equipment

	Frequency in Percent of Involvements	
	Cars	Trucks
Involvement In:		
Single Vehicle		
Indiana	15.3	17.8
Ohio	22.3	31.1
Pennsylvania	9.5	18.7
All Three	14.3	23.5
Multi-Vehicle		
Indiana	3.3	1.7
Ohio	4.7	5.5
Pennsylvania	2.3	2.1
All Three	3.1	2.9
All Involvements	10.0	13.4

Table 5-39

Type of Vehicle Defect Noted

	Distribution by Defect in Percent					
	Indiana[1]				Pennsylvania[2]	
	Single Vehicle		Multi-Vehicle		Single Vehicle	
	Car	Truck	Car	Truck	Car	Truck
None	83.4	80.2	96.6	98.2		
Brakes	0.5	2.0	0.4	0.7	3.9	10.5
Lights	0.2	0.3	0.6	0.7	0	0
Steering	0.3	1.7	0.1	0	7.1	6.7
Tires	15.6	16.0	2.4	0.5	75.9	55.2
Punc./Blow	8.6	13.8	1.6	0.2		
Bald	7.0	2.2	0.8	0.2		
Other	0	0	0	0	13.1	27.6

[1] From approximately 97% of all accidents

[2] From single vehicle accidents with a defect noted: 510 cars (9.5%), 105 lg. trucks (18.7%)

Indiana and Ohio have specific variables for driver condition. Ohio and Pennsylvania both include several driver conditions as primary causal factors. Indication of the use of alcohol by drivers of large trucks was conspicuous by its absence. The only driver condition which was indicated significantly more frequently among truck drivers was fatigue and sleep. Indications of this condition are summarized in Table 5-40, both for the unique driver condition variables and the causal variables. Sleep was indicated in a substantial proportion of the truck involvements as well as significantly more frequently than for passenger car drivers, as was also noted in the Texas file. Approximately 13% of the drivers of all trucks involved in accidents on the turnpikes were noted as fatigued or asleep in the accident record.

Table 5-40

Indication of Sleep or Fatigue as a Causal Factor or Unsafe Condition of Driver, in Percent

Listed As	Single Vehicle Car	Single Vehicle Truck	Multi-Vehicle Car	Multi-Vehicle Truck
Unsafe Driver Condition				
Indiana	12.1*	16.1*	4.0*	7.9*
Ohio	9.2*	17.1*	9.4	11.6
Primary Causal Factor				
Ohio	9.3*	17.4*	2.7	4.4
Pennsylvania	7.3	9.3	3.6*	5.6*

Notes: (1) Results for Ohio and Indiana are given in percent of all involvements. The Pennsylvania results are in percent of accidents in which the indicated vehicle was deemed responsible.

(2) Car-truck differences indicated by an asterisk (*) are significant at the 0.05 level. The other pairs are not significantly different.

The distribution of drivers asleep in the Ohio Turnpike file are shown in Figures 5-54 and 5-55 by hour for passenger cars and large trucks respectively. Both show a higher density during the early morning hours. The concentration in these hours is even greater for the trucks than for passenger cars in spite of their more uniform distribution of travel through the day. The high peak for passenger cars between 6 and 7 a.m. is not explained. It occurs an hour earlier than most commuter peaks, but whether it is such a peak or is due to a factor associated with sunrise is not known. Since the data is over several years the peak is much more narrow than the distribution of time of sunrise. The overinvolvement ratios based on the hourly distributions of mileage for cars and trucks are

Figure 5-54

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      DISTRIBUTION OF DRIVERS FATIGUED OR ASLEEP IN SINGLE VEHICLE ACCIDENTS
          PASSENGER CARS- OHIO TURNPIKE
              MAINLINE ACCIDENTS

   20+
     I
     I
     I
     I
   18+
     I
     I
     I
     I
   16+
     I
     I
     I
     I
   14+                                  51
     I
     I                                IIII
     I                                IIII
     I                                IIII
     I                                IIII
   12+                                IIII
     I                                IIII
P    I                                IIII
E    I                                IIII
R    I              37                IIII
C  10+                                IIII
E    I            IIII                IIII
N    I            IIII                IIII
T    I            IIII                IIII
     I            IIII   29           IIII
    8+            IIII                IIII
     I    26      IIII IIII           IIII
     I            IIII IIII           IIII   25
     I  IIII      IIII IIII   23   23 IIII
     I  IIII      IIII IIII           IIII IIII
    6+  IIII   20 IIII IIII IIII IIII IIII IIII
     I  IIII      IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII   16   16                       16
     I  IIII IIII IIII IIII IIII IIII IIII IIII
    4+  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII                     IIII        12
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII        11           IIII             11                            11
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII                     IIII   10 IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII    8 IIII           IIII      IIII IIII         8                IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII      IIII    7    7 IIII IIII IIII IIII    7                   7 IIII
    2+  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII           IIII IIII IIII IIII      IIII    4    5      IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII           IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII
    0+--++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++
        ( 0) ( 1) ( 2) ( 3) ( 4) ( 5) ( 6) ( 7) ( 8) ( 9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) (21) (22) (23)
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Figure 5-55

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     DISTRIBTUTION OF DRIVERS FATIGUED OR ASLEEP IN SINGLE VEHICLE ACCIDENTS
          LARGE TRUCKS - OHIO TURNPIKE
               MAINLINE ACCIDENTS

   20+
     I
     I
     I
     I
   18+
     I
     I
     I
     I
   16+
     I
     I
     I
     I
   14+
     I
     I              20
     I
     I            IIII             19
   12+            IIII                  18
     I            IIII           IIII
P    I            IIII   17   17 IIII IIII
E    I            IIII           IIII IIII
R    I            IIII IIII IIII IIII IIII
C  10+            IIII IIII IIII IIII IIII
E    I            IIII IIII IIII IIII IIII
N    I    14      IIII IIII IIII IIII IIII
T    I            IIII IIII IIII IIII IIII
     I  IIII      IIII IIII IIII IIII IIII
    8+  IIII   12 IIII IIII IIII IIII IIII
     I  IIII      IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII
    6+  IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII    7                                                                          7
     I  IIII IIII IIII IIII IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII                                                                       IIII
    4+  IIII IIII IIII IIII IIII IIII IIII IIII                                                                       IIII    5
     I  IIII IIII IIII IIII IIII IIII IIII IIII                                                                       IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII                        4                   4                          IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII    3                        3         3                               IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII                     IIII                IIII                          IIII IIII
    2+  IIII IIII IIII IIII IIII IIII IIII IIII IIII    2         2 IIII IIII      IIII IIII    2                     IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII         1      IIII IIII    1 IIII IIII         1              1 IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII      IIII IIII IIII      IIII IIII IIII                     IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII    0    0 IIII IIII IIII
     I  IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII IIII           IIII IIII IIII
    0+--++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++-++++
        ( 0) ( 1) ( 2) ( 3) ( 4) ( 5) ( 6) ( 7) ( 8) ( 9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) (21) (22) (23)
```

7.7 and 2.4 respectively during the period from midnight to 6 a.m., and 1.1 or less the remainder of the day.

Early in the coding of the five years of Indiana Toll Road accidents, cases were found in which the presence of a truck was noted as a causal factor either directly or indirectly. Since these trucks were not directly involved as either the struck or striking vehicle, they would not normally be coded. These cases were segregated and a supplementary Indiana file was created with six extra variables to describe the indirect involvement of a truck. Forty three percent of the cases involved objects thrown or lost by the truck. Over fifty five percent of the cases were accidents which occurred while, or immediately after, the truck was passed.

Culpability is very tenuous in the passing situations; but the trucks contributed directly to the the accidents when objects were thrown or dropped. Examples of the latter are spare and running wheels lost and struck by another vehicle, and angle iron from mud flaps through the windshield of a following passenger car. A summary of the indirect involvements is given in Table 5-41. A total of 128 such involvements occurred. At least 81 of these involved large trucks. If these are included as "large truck" accidents, they represent 13% of all mainline accidents involving trucks on the Indiana Toll Road.

Table 5-41

Indirect Involvements of Trucks on the
Indiana Toll Road 128 Accidents

Type of Truck Indirectly Involved in Percent		
Tractor-Trailer	25.8	
Single unit	63.3	
Unknown	10.9	
Total	100.0	
Involvement in Percent		
Leaky load	12.5	
Object thrown	5.5	
Lost equipment	25.0	
Wheel		24.5
Spare wheel		22.4
Mud flaps		2.0
Other		51.1
Total		100.0
Being passed/overtaken	55.5	
Wind, vacuum & lost control		27.1
Lost control		25.7
Lost visibility		8.6
Poor visibility		4.3
Other or unknown		34.3
Total		100.0
Unknown	1.5	
Total	100.0	

Appendix A

COMPARISON OF BMCS DATA WITH NATIONAL AND TEXAS TRUCK ACCIDENT DATA

The purpose of this Appendix is to investigate the accuracy and completeness of BMCS data, and its potential for use in estimating characteristics of all truck accidents in the country. Although there are specific rules for reporting of truck accidents to BMCS by motor carriers, there is considerable doubt as to the interpretation of the rules and the number of carriers who follow them. Nevertheless, there are certain similarities between BMCS data and other existing data that suggest the use of BMCS data in estimating some national characteristics of truck accidents.

The data compared here are for the year 1969. The sources are:

1. BMCS file, described in Section 4.
2. National Accident Facts 1970, National Safety Council.
3. Texas Truck accident file, described in Section 4.

Table A-1 presents a summary of the data.

For this comparison the Texas Truck data was subsetted to include only certain types of vehicles--those most likely to be involved in interstate commerce. This included bob-tails, flatbeds, float trucks, pole trucks, refrigerator trucks, tank trucks, and vans. The BMCS file used included only property carrying vehicles. The definition of "truck" in the National Safety Council data is thought to be a very broad one, no doubt stemming from the compilation of state accident data. This would have included (for Texas, for example) pickup trucks and light delivery vans, which are specifically excluded from the other two sets of data here.

Comparison of BMCS Data and National Estimates

While the ratio of BMCS accidents to either the NSC estimates or the Texas Truck file is relatively small, the ratio for fatal accidents is somewhat larger than 0.5--suggesting that a larger percentage of the serious accidents may be included. If this same percentage held throughout the country it would put some credence in the use of BMCS data to compute national estimates--particularly with regard to fatal accident involvement.

As a test of this idea a comparison has been made of the number of fatalities involving trucks from the BMCS data, and the total number of fatalities involving motor vehicles of any kind (as reported by the NSC). Table A-2 shows the state-by-state data

Table A-1

Truck Accidents, Fatal Truck Accidents, and Fatalities in Truck Accidents, from NSC, BMCS and Texas Police Records

Source	No. Truck Accidents	No. truck fatal Accidents	No. fatalities in Accidents
U.S. total (National Safety Council Estimates)	3,075,000[*]	12,400 (all)[*] 4,700 (tractor trailers only)[*]	---------
U.S. total (BMCS)	48,561	1,655	2011
Texas (NSC)	184,000[**]	744 (all)[**] 282 (tractor trailer)[**]	--------
Texas (BMCS)	2,158	90	114
Texas (state police record)	7,450[*]	149[*]	210

[*] Actually these are counts of involvements, and the true number of accidents should be slightly less considering that there are some truck-truck collisions.

[**] These have been estimated by multiplying the national totals by 6%, the estimated Texas proportion of the U.S. population.

Table A-2
Fatalities and Ratios of Fatalities from 1969 BMCS and NSC Data, by State

State	Fatalities		Ratios	
	BMCS	NSC	NSC/BMCS	BMCS/NSC
Alabama	61	1205	20	0.05062
Arizona	30	750	25	0.04000
Arkansas	25	604	24	0.04139
California	71	5080	72	0.01398
Colorado	25	658	26	0.03799
Connecticut	15	404	27	0.03713
Delaware	10	127	13	0.07874
Florida	78	2119	27	0.03681
Georgia	70	1803	26	0.03882
Idaho	8	332	42	0.02410
Illinois	127	2533	20	0.05014
Indiana	142	1676	12	0.08473
Iowa	56	780	14	0.07179
Kansas	52	780	15	0.06667
Kentucky	49	1085	22	0.04516
Louisiana	23	1181	51	0.01948
Maine	6	263	44	0.02281
Maryland	30	799	27	0.03755
Massachusetts	12	898	75	0.01336
Michigan	66	2407	36	0.02742
Minnesota	28	974	35	0.02875
Mississippi	23	822	36	0.02798
Missouri	50	1522	30	0.03285
Montana	10	339	34	0.02950
Nebraska	18	422	23	0.04265
Nevada	10	232	23	0.04310
New Hampshire	3	189	62	0.01587
New Jersey	64	1272	20	0.05031
New Mexico	33	553	17	0.05967
New York	74	3164	43	0.02339
North Carolina	59	1805	31	0.03269
North Dakota	3	182	61	0.01648
Ohio	144	2755	19	0.05227
Oklahoma	25	898	36	0.02784
Oregon	11	706	64	0.01558
Pennsylvania	125	2401	19	0.05206
Rhode Island	8	136	17	0.05882
South Carolina	34	996	29	0.03414
South Dakota	7	297	42	0.02357
Tennessee	52	1348	26	0.03858
Texas	111	3551	32	0.03126
Utah	17	308	18	0.05519
Vermont	7	146	21	0.04795
Virginia	38	1304	34	0.02914
Washington	15	883	59	0.01699
West Virginia	25	538	22	0.04647
Wisconsin	31	1142	37	0.02715
Alaska	11	221	20	0.04977
Wyoming	1	74	74	0.01351
Washington, D.C.	0	127	0	0.00000
Hawaii	0	133	0	0.00000
Puerto Rico	0	0	0	0.00000

on the two fatality figures and their ratios. Table A-3 shows the same data ranked according to the BMCS-to-NSC ratio. Note that there are large states at both ends of the scale--Indiana with a value of .0847 and California with a value of .014--a ratio of seven to one. Texas, a state for which we have more detailed data to consider later lies at .03126, slightly to the low side of the median.

It seems unlikely that such variation would indicate a true difference in the truck fatality involvement in these states, and it is assumed that the difference appears because of biases in the data acquisition method.

The variation in the ratio can be viewed geographically in the map shown in Figure A-1. The range from 0 to 0.084 has been divided into three equal intervals, and the states are distributed as shown on the map. Note the belt of "over-reporting" states in the middle of the country, to which are added only Delaware and New Jersey on the east coast.

The wide variation in the fatality ratio (BMCS to NSC) by state is taken as an indication that the BMCS data are far from complete--at least in some states. It was found in the comparison of Texas data from BMCS and from the State Police that something on the order of half as many fatalities appear in the BMCS files. In this same comparison the Texas police files contained about $3\frac{1}{2}$ times as many non-fatal accidents. This difference may be due to the difference in reporting requirements between the two systems. At any rate it suggests that the BMCS fatality data, while not a complete representation of the truck problem, is large enough to be useful. Further, it would seem that a factor of two applied to Texas BMCS fatalities would lead to a reasonable estimate of Texas large-truck fatalities.

But Indiana's ratio (to the NSC totals) is more than double that of Texas--.085 as compared with 0.031. And this suggests that either Indiana has more than its share of truck fatalities or that it reports more consistently to BMCS or both. Without further information at this point it is difficult to sort this out.

California is conspicuous by its low BMCS to NSC ratio. It is understood that certain metropolitan areas are excused from reporting to BMCS; if Los Angeles is one of these it may account for the low ratio for California.

Comparison of BMCS Data and Texas Data

One of the continually exasperating things about accident data is that so few of the variables are directly comparable. "Kind of truck" in the BMCS data is coded differently than in the Texas police files. "Kind of accident" is somewhat different. But both of these are alike enough that some comparisons can be attempted.

Table A-3

Ranking of States by Ratio of BMCS Fatalities to NSC Total Fatalities

State	BMCS-to-NSC Ratio	Rank	Percentile
Indiana	0.0847	51	99
Delaware	0.0787	50	98
Iowa	0.0718	49	96
Kansas	0.0667	48	94
New Mexico	0.0597	47	92
Rhode Island	0.0588	46	90
Utah	0.0552	45	88
Ohio	0.0523	44	86
Pennsylvania	0.0521	43	84
Alabama	0.0506	42	82
New Jersey	0.0503	41	80
Illinois	0.0501	40	78
Wyoming	0.0498	39	76
Vermont	0.0479	38	74
West Virginia	0.0465	37	72
Kentucky	0.0452	36	70
Nevada	0.0431	35	68
Nebraska	0.0427	34	66
Arkansas	0.0414	33	64
Arizona	0.0400	32	62
Georgia	0.0388	31	60
Tennessee	0.0386	30	58
Colorado	0.0380	29	56
Maryland	0.0375	28	54
Connecticut	0.0371	27	52
Florida	0.0368	26	50
South Carolina	0.0341	25	49
Missouri	0.0329	24	47
North Carolina	0.0327	23	45
Texas	0.0313	22	43
Montana	0.0295	21	41
Virginia	0.0291	20	39
Minnesota	0.0287	19	37
Mississippi	0.0280	18	35
Oklahoma	0.0278	17	33
Michigan	0.0274	16	31
Wisconsin	0.0271	15	29
Idaho	0.0241	14	27
South Dakota	0.0236	13	25
New York	0.0234	12	23
Maine	0.0228	11	21
Louisiana	0.0195	10	19
Washington	0.0170	9	17
North Dakota	0.0165	8	15
New Hampshire	0.0159	7	13
Oregon	0.0156	6	11
California	0.0149	5	9
Alaska	0.0135	4	7
Massachusetts	0.0134	3	5
Hawaii	0.0000	1.5	3
District of Columbia	0.0000	1.5	3

Figure A-1

Map of BMCS to NSC Fatality Ratio

```
>MAP   1
>-------
>RATIO OF BMCS TRUCK FATALITIES TO THE NATIONAL SAFETY
>COUNCIL FATALITY COUNTS--FOR EACH STATE.  THIS DATA IS FOR
>THE YEAR 1969.  BMCS DATA FILTERED TO EXCLUDE PASSENGER VEHICLES

>
>*----+----1----+----2----+----3----+----4----+----5----+----6----+----*
>I  ---------::::::::::::::---------:::                                I
>I -----------:::::::::::::---------::::::::                           I
>I  -----------::::::::::::---------::::::- ----                   --  I
>I  -----------::::::::::::---------:::::-------                  ---- I
>+  ------------:::::::::::---------:::--------  --           -::----  +
>I  ---------------::::::::---------::::::----- ----       ----:---    I
>I ----------------:::::::::::::::::XXXXXXX---  ----     ---------     I
>I  -----::::::::::::::::::::::::::::XXXXXX:::XXXX:   ::::::---::X-    I
>I  -----::::::::::::::::::::::::::::XXXXXX:::XXXX::::::::::::         I
>1   ----:::::::::::::::::::::XXXXXXXX::::::::XXXX::::::::::X:         1
>I    ----::::::::::::::::::::XXXXXXXX::::::::XX:::::::::::::          I
>I    -----:::::::::::::::::::XXXXXXXX::::::::::::::::::::::           I
>I     ------::::::::XXXXXXXX:::------::::::::::::::::::::::           I
>I      -------::::::XXXXXXXX:::------::::::--:::::::::::::            I
>+        -----::::::XXXXXXXX::::::::::::::---:::::::::::              +
>I              :::::XXXXXXXX::::::::::-------:::::::::                I
>I                       ::::::::::::::-------::::::::                 I
>I                         ::::::::::::-----     :::::                 I
>I                          :::::::::               ::                 I
>2  ---- ALASKA                 :::                 :::     ---- D.C.  2
>I                                                   ::                I
>I  ---- HAWAII                                             ---- P.R.  I
>*----+----1----+----2----+----3----+----4----+----5----+----6----+----*
> SYMAP
>DATA VALUE EXTREMES ARE        0.0         0.08
>ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
>      ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)
>  MINIMUM      0.0       0.03      0.06
>  MAXIMUM      0.03      0.06      0.08
>PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
>             33.33     33.33     33.33
>FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL
>  LEVEL         1         2         3
>          ===============================
>  SYMBOLS   ----1---- ::::2:::: XXXX3XXXX
>          ===============================
>  FREQ.        19        27         6
```

Table A-4 compares the number of involvements in these two files by kind of accident. The Texas data has, on the average, 3.3 times as many cases. For single vehicle accidents, there are only 2.1 times as many. A similar comparison by type of vehicle is given in Table A-5. The lowest ratio here is for van bodies.

A grouping of driver ages is shown in Table A-6. BMCS report drivers show much less variance in age, with the mode being in the 30-39 range rather than the 20-29 range of the Texas data. The cutoff on the low end reflects the employment practices of the companies which report to the BMCS, as perhaps the older cutoff does too.

Table A-7 shows the percentages of involvements by day of the week in the two files, and indicates that at least the two truck populations share that characteristic.

The discrepancies in Tables A-4, A-5 and A-6 show that BMCS data for Texas is not adequate for representation of truck-accident distributions within the state.

Table A-4

Comparison of Texas Truck Involvements in BMCS Data and Police Reports, by Kind of Accident

Kind of Accident	Police Reports	BMCS	Police/BMCS
Pedestrian	23	20	1.15
Other Motor Vehicle	5616	1537	3.65
RR Train Street Car	29	21	1.38
Bicycle	8	2	4.0
Single Vehicle	1386	661	2.1
Missing Data	388	---	---
TOTAL	7450	2241	3.3

Table A-5

Comparison of Texas Truck Involvements in BMCS Data and Police Reports, by Type of Truck

Type of Truck	Police Reports	BMCS	Police/BMCS
Bobtail/Tractor	981	80	13.5
Flatbed	1628	263	6.15
Tank	1479	263	5.6
Van	2315	1291	1.8
Other	1057	344	---
TOTAL	7450	2241	3.3

Table A-6

Comparison of Texas Truck Involvements in BMCS Data and Police Reports, by Driver Age

Age in Year Groups	Police Reports	BMCS	Police/BMCS
Under 20	3.8%	0	---
20-29	29 %	23.7%	1.21
30-39	23.6%	32.7%	.72
40-49	22.6%	26.5%	.85
50-59	12.4%	14.3%	.87
60 and over	4.3%	2.6%	1.66
Missing Data	4 %	0.4%	----

Table A-7

Distribution of Texas Truck Involvements in BMCS Data and Police Reports by Day of Week

	Sun.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.
Police	3.9%	17.6%	16.5%	17.0%	16.7%	17.8%	10.4%
BMCS	5.0%	18.3%	16.5%	16.2%	17.0%	17.7%	9.5%

Appendix B

A VEHICLE INTERACTION MODEL: A METHOD FOR DETERMINING EXPOSURE TO SEVERAL TYPES OF ACCIDENT SITUATIONS

Introduction

Exposure is the frequency of occurrence of those traffic events that lead to a possibility of having an accident. For several years researchers have been trying to precisely define exposure and determine how it can be measured. While some argue that the number of miles traveled by the vehicle-driver combination (i.e., the number of vehicle miles) is the most relevant, others argue that such statistics as driving time or traffic volume are the most appropriate. However, vehicle miles is by far the most commonly used measure of this risk of having an accident. Most measures of exposure have concentrated on measuring the risk of having an accident—not necessarily any specific type of accident.

Many of the accidents on turnpikes, or any divided multi-lane limited-access highway, are collisions between vehicles traveling in the same direction. On such highways the incidence of collisions between vehicles traveling in opposite directions is small. The conflicts involving trucks with the greatest potential for injury or fatalities are those between trucks and passenger cars. While vehicle miles as a measure of exposure may be used to examine relative involvement rates by type of vehicle, it does not permit consideration of the performance characteristics, e.g., speed of the vehicles.

The model of exposure developed in this appendix allows examination of the gross effects of vehicle speeds on collisions of several vehicle combinations or pairs.

The major accident situation studied here involves two vehicles traveling in the same direction on the turnpike and the potential conflict between them. The conflict would occur when the projected positions of the two vehicles coincide. This conflict situation is then an exposure event. It is assumed that this type of exposure event occurs in overtaking situations. Further, the model assumes that no queues will form while a vehicle is waiting to pass, nor will the speed of the overtaking vehicle be affected by the fact that it is in an overtaking situation. Thus, if the rate of overtaking can be determined, the measure of exposure naturally follows. The accidents resulting from such a conflict are generally either rear-end or sideswipe accidents. One possible fault with this assumption is the tailgating situation or the panic stop that could lead to an imminent crash.

The Model

The model, then, is a procedure for determining the rate of overtaking. Consider two vehicles on a unit or roadway (e.g., a mile), one vehicle is moving at speed v and the other at speed u, where $u < v$. The rate at which the vehicle moving at speed v overtakes, or approaches, the vehicle moving at speed u is v-u. If the stream of traffic contains n_v vehicles per unit of roadway moving at speed v, the number of overtakings by vehicle at speed v per unit time is $n_v(v-u)$. This is equivalent to a stationary observer counting the number of passings by vehicles traveling at a speed of v-u. In general, the stream of traffic encountering a single vehicle at speed u, will contain vehicles traveling at many different speeds. If D vehicles occupy the unit of roadway, the average total number of overtakings per unit time, or overtaking rate OR, is the integral over all vehicles with speed, v, greater than u or,

$$D_v \int_u^\infty (v-u)h(v)dv$$

where D_v is the density in vehicles per mile, and h(v) is a probability density function that represents the percentage of vehicles at any one speed v, from u to ∞ .

However, this only considers one slow-moving vehicle and only one speed, u. If we assume that on the unit of roadway, we have D_u vehicles which are being passed and that a proportion, h(u), are at each speed u, from 0 to ∞ , then the average rate of overtaking is:[1]

$$D_u \int_0^\infty D_v \int_u^\infty (v-u)h(v)h(v)dv\ du$$

or

$$D_u D_v \int_0^\infty \int_u^\infty (v-u)h(v)h(u)dv\ du \qquad (1)$$

The portion within the integral sign will have units of miles per hour, and the densities (D_u and D_v) will be measured in vehicles per mile. Therefore, the resulting rate is in overtakings per hour per mile. When dealing with speed distributions, it is possible that some vehicles from the slower class might overtake some in the faster class. Therefore, it is conceptually appealing to think of the v's as the passing class and the u's as the class being passed, regardless of which one has the faster distribution of speeds.

---

[1] Miller, A.J. "Queuing in Rural Traffic," in Vehicular Traffic Science, edited by L.C. Edie, R. Herman, R. Rothery. American Elsevier Publishing Co. Inc., New York, 1967, p.123.

If we were interested in collision rates of cars and trucks, we could employ the following analysis. First, for a specified time period, we would obtain the number of rear-end or sideswipe accidents in which: (1) a car strikes a car, (2) a car strikes a truck, (3) a truck strikes a car, and (4) a truck strikes a truck.

The next step would be to gather data concerning the speed distributions of cars and trucks, and their respective densities on the roadway. Given that information, we could then carry out the integration discussed above and determine the exposure for each of the four categories. These numbers could then be used as a normalizing factor for the number of accidents, and from this we could determine which category of the vehicle collision pairs occurs more (or less) frequently than it should based on the number of times that the vehicles are exposed to one another.

Basic Assumptions

One basic assumption underlying this model is that free-flowing conditions exist. Free-flowing means, in this case, that when the driver of a vehicle wants to pass, he can do so without having to wait for traffic to clear. (This implies both that no queues will form, and that the occurrence of an overtaking situation does not affect the speeds of the vehicles involved.) This is a questionable assumption in some cases (such as in metropolitan areas), but it may be generally valid for rural, low-density turnpike traffic. Furthermore, it is assumed that within the range of densities under consideration here, the density of traffic does not affect the free-flowing speed distribution.

Application of the Model

When the speeds of all vehicles on the highway are described by a single density function, the total average overtaking rate is given by

$$OR=D^2 \int_o^\infty \int_u^\infty (v-u)\left[h(v)\right]^2 dvdu$$

This demonstrates that the overtaking rate is proportional to the square of the traffic density, a major difference between the overtaking model and vehicle miles as a measure of exposure. If the normal density function is used, the double integral may be evaluated analytically with the result,

$$OR=0.56\ \sigma\ D^2$$

where σ is the standard deviation of vehicle speeds. It should not be surprising that the rate in this case is not sensitive to the mean speed since overtakings depend only on speed differences between vehicles.

The principal attractiveness of the overtaking model for this study is in its application to a dichotomy of vehicles. Thus h(u) and h(v) may be used to represent any two classes with distinctly different speed patterns, e.g. passenger cars and trucks. However, the double integral in general can only be integrated by numerical methods, even if both density functions are normal.

The integral was evaluated using the Gaussion-quadrature method. Sensitivity of the results to differences in the distributions of speeds for normally distributed speeds, as well as absolute values of overtaking rates, is shown in Figure B-1. Note the normalized rate

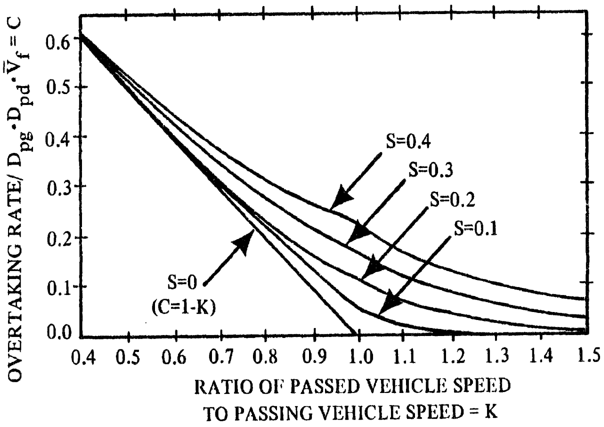
$$C = \frac{OR}{Dpg \cdot Dpd\ \overline{V}f}$$

is given as a function of the ratio of the mean speeds of the passed and passing classes,

$$K = \frac{\overline{V}pd}{\overline{V}pg}$$

In this presentation, v has been replaced by Vpg and u by Vpd. The region to the left of the figure K< 1 represents the rate of vehicles of the faster class passing vehicles of the slower class, for example cars passing trucks. The region to the right, K > 1, represents an occasional slow car passed by trucks, and was obtained by interchanging the role of u and v.

Figure B-1. Overtaking rate for two classes of vehicles



Overtaking rate = $C \cdot D_{pg} \cdot D_{pd} \cdot V_f$. Where: D_{pg} = Density of overtaking vehicle class; D_{pd} = Density of overtakenvehicle class; $\overline{V}_f$ = Mean speed of faster class; K = Ratio of passed vehicle speed to passing vehicle speed = $\overline{V}_{pd}/\overline{V}_{pg}$; S = Percentage of mean speed = $\sigma_{pd}/\overline{V}_{pd} = \sigma_{pg}/\overline{V}_{pg}$; and both speed distributions are assumed to be normal, $N(\overline{V},\sigma)$.]

In Figure B-1, five levels of the standard deviation of the speeds are given. In each case,

$$S = \frac{\sigma pd}{\overline{V}pd} = \frac{\sigma pg}{\overline{V}pg}$$

At K=1.0, the problem degenerates to the case described earlier where the two speed distributions are identical and

$$C = 0.56S.$$

The line for s = 0,

$$C_{s=0} = 1\text{-}K \text{ for } K < 1$$

$$= 0 \text{ for } K > 1$$

is a degenerate case that is a trivial problem to solve analytically. It is noteworthy, however, because it is applicable to any case in which the speed distributions do not overlap. By letting K become minus, it includes the "passing rate" of vehicles traveling in opposite directions.

If the density of all vehicles on the roadway is D_{all}, and passenger cars represent a proportion p_c of D_{all} then trucks represent a proportion p_t of $(1-p_c)$ of D_{all}. The overtaking rate can be derived if we assume a mean speed for the passing vehicle type ($\overline{V}_{pg}$) and an S equal to 0.1 ($\sigma = S \cdot \overline{V}$). Then if we assume a certain ratio K of mean speeds, and

$$D_{all} \cdot p_c = D_c \text{ (density of passenger cars)}$$

and

$$D_{all} \cdot p_t = D_t \text{ (density of trucks)}$$

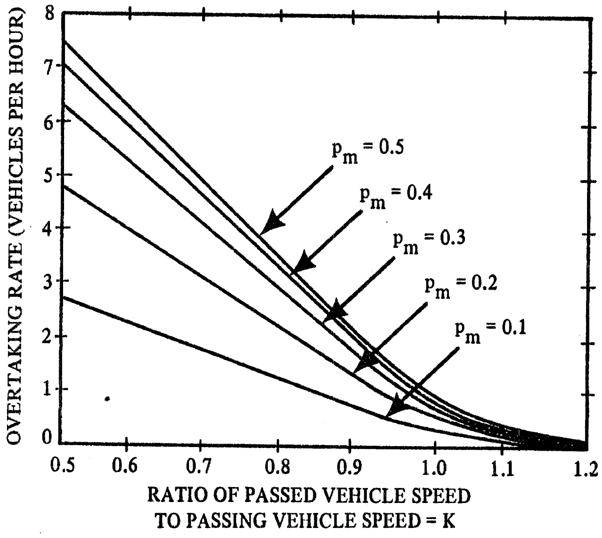
the overtaking rate equals:

$$\text{Overtaking Rate} = D^2_{all} \cdot p_c \cdot p_t \cdot C \cdot \overline{V}_f$$

where C can be found from Figure B-1 since it depends upon K and the level of S.

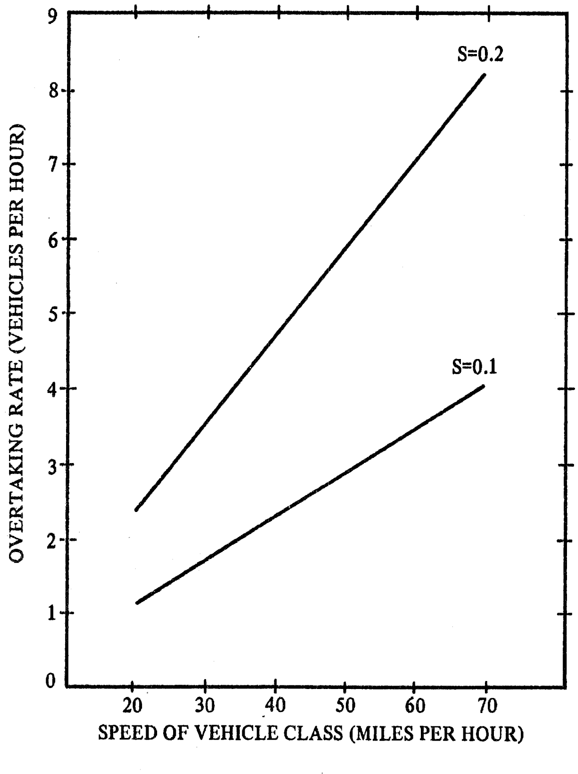
One can assume, for simplicity, that D_{all}=1 and then vary the proportion of the vehicle type in the minority and derive a curve of the overtaking rate as a function of K for each proportion of the total density. This can be seen graphically in Figure B-2. (Again notice the change in slope of the line when K exceeds 1.) These curves allow us to visualize both the relationship between the passing rate as a function of the ratio of mean speeds and the "mix" of vehicle classes on the highway. The curves in Figure B-2 are for the cases where trucks overtake cars or cars overtake trucks. Figure B-3 represents the cases where each is overtaking its own kind. One can then express the passing rate as a function of the mean speed of the vehicle class. In this case, K=1 and curves are plotted for two values of S.

Figure B-2. Overtaking rate for various mixes of two vehicle types



Where: p_m = Proportion of vehicle type in minority; $\overline{V}_{pg} = 60$ mph; and D_{all} = one vehicle per mile.)

Figure B-3. Overtaking rate for cars and trucks overtaking vehicles of the same type.



Where: K = 1; and S = Percentage of mean speed of vehicle class.

The foregoing analysis indicates the critical factors in the determination of the passing rate and shows how the rate changes when different assumptions are made concerning the factors. One can conclude that both speed and density are important factors in the determination of the passing rate.

Other Applications

The previous analyses indicate that the exposure for two types of moving vehicles can be calculated by making the proper underlying assumptions and knowing the densities of the vehicle types and their speed distributions. However, the case where two vehicles are exposed to one another and one of them is parked is nothing more than a special situation within the two-vehicle-both-moving case. In this situation the parked vehicle has a mean speed equal to 0 with a standard deviation equal to 0. The only problem here involves obtaining reliable information on the density of parked vehicles as a function of time.

This model is also applicable to the case where one vehicle hits a fixed object. The passed vehicle in this case will not be a stopped vehicle but a fixed object. The major problem in this case involves obtaining an estimate of the density of fixed objects.

Another possible application would be a two-lane roadway situation in which vehicles meet each other going in opposite directions. If we assume we have free-flowing conditions (a tenuous assumption here), then the number of conflicts can be obtained by changing the variables of integration from v-u to v+u.

Use as Measure of Exposure for Turnpike Accidents

The model developed in this appendix has been used to examine accidents in the turnpike files which are related to conflicts that arise from overtaking situations. These are rear-end and sideswipe accidents involving vehicles traveling in the same direction on the mainline; i.e. omitting crashes in service plazas, etc.

The traffic data for each turnpike in the study is in vehicle miles. Explicit data on vehicle density (the number of vehicles per unit length of roadway at some epoch) was not available. Therefore the densities were estimated from traffic miles and speed. The total vehicle miles traveled on a roadway of length L in time T is

$$VM = D \cdot \overline{V} \cdot L \cdot T$$

where: VM = vehicle miles
D = density (vehicles per mile)
$\overline{V}$ = average speed (miles per hour)
L = length of roadway over which vehicle miles are measured (miles)
T = time period over which vehicle miles are measured (hours)

Thus, the average density may be computed from vehicle miles and speed. Of primary concern here is the relative exposure rate; absolute rates are not necessary. One may look at the problem in this way:

$$D_i \cdot D_j = \frac{VM^2_{all} \cdot P_i \cdot P_j}{V_i \cdot V_j \cdot L^2 \cdot T^2}$$

where i and j indicate vehicle types and P is the proportion of all the vehicle miles accounted for by the appropriate vehicle types. The product of densities may also be expressed as

$$D_i \cdot D_j = Q^2 \frac{P_i \cdot P_j}{\overline{V}_i \cdot \overline{V}_j}$$

where $Q^2 = \dfrac{VM^2_{all}}{L^2 \cdot T^2}$

All of the parameters defined by the size and extent of the data set are then contained in Q, while examination of subsets of the accident data can be accomplished by adjusting the individual proportions and speeds. The rate at which vehicles of type i overtake vehicles of type j is then

$$OR_{ij} = Q^2 \frac{P_i P_j}{\overline{V}_i \overline{V}_j} I$$

where $$I = \int_o^\infty \int_u^\infty (v-u)h_i(v)h_j(u)dvdu$$

Speed data from which $\overline{V}$ and σ_V could be obtained were not available from the turnpikes. Therefore data collected on over 2,000 observations of speeds on Michigan 4-6 lane limited access highways by the Michigan State Highway Department were used to estimate the parameters of the distribution of speeds on highways comparable to the turnpikes and in a similar climate.[2] Normal distributions were assumed with empirical results for the means and variances.

The speeds used for the analysis reported in section 5 are given in Table B-1.

Table B-2 gives the parameters necessary for computing the overtaking rates used in section 5, including the result of the numerical integration (I).

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[2] Speed Report, Report No. 66, Transportation Planning Division, State of Michigan Department of State Highways, July 1971.

Table B-1

Summary of Vehicle Speeds Used in Analysis Using the Interaction Model

Daytime	Mean Speed (MPH)	Standard Deviation (MPH)
Trucks	59.10	5.34
Cars	66.95	6.84
Nighttime		
Trucks	56.36	6.17
Cars	62.58	7.44

Table B-2

Parameters Used for Application of the Interaction Model

1. TURNPIKE PARAMETERS

Turnpike	Length L (mi)	Data Period (months)	Vehicle Miles Cars and Large Trucks (VM_{ALL})	Q^2
Pennsylvania	359.0	30	63.91×10^8	6.602×10^5
Ohio	241.2	54	56.8×10^8	3.560×10^5
Indiana	157	60	31.31×10^8	2.073×10^5

2. INTEGRATION (I)

Collision Pair		Integral	
		Day	Night
Car	Car	3.8596	4.1948
Car	Truck	8.7140	7.7365
Truck	Car	0.8640	1.5165
Truck	Truck	3.0116	3.4805

APPENDIX C

TURNPIKE TRAFFIC PATTERNS

The exposure data used in analysis of turnpike involvements in Section 5, both as measured by vehicle miles and by the interaction model which is developed in Appendix B, was obtained from toll ticket records. The information contained on the toll tickets--and thus the vehicular data which can be derived from them--is in terms of the toll classes that each highway uses for rate schedules. Each turnpike has the same number of toll classes (9), but each defines the classes differently. The definitions of classes on each turnpike also differ from the vehicle descriptions in the accident files.

The toll classes of the three turnpikes are given in Table C-1. The accident vehicle classification common to all turnpikes is passenger car, passenger car with trailer, truck (single unit), and tractor-trailer. The study was addressed to the larger trucks, those with gross vehicle weight ratings of approximately 20,000 lbs. Pickup trucks were excluded from consideration because many of their characteristics are similar to those of passenger cars. In the lower "truck" classes it is impossible to differentiate an empty vehicle with a rating of over 20,000 lbs. from a loaded vehicle of smaller size. Thus the straight trucks present are particularly difficult to define uniquely by toll class.

Table C-1

Definition of Turnpike Toll Classes

Toll Class	Indiana Toll Road	Ohio Turnpike	Pennsylvania Turnpike
1	Light veh. with no more than 4 tires	0-7,000 lb.	2 axle-veh.wt< 7,000 lb.
2	Light veh. with 1-axle trailer under 21 ft.	7,001-16,000 2 axle veh.with trailer & wt.< 16,000 lb.	7,001-15,000
3	Light veh. with 2-axle trailer under 21 ft.	16,001-23,000	15,001-19,000
4	Commercial veh. with 2 axles	23,001-33,000	19,001-30,000
5	Commercial veh. with 3 axles or light veh. with 1 axle trailer > 21 ft.	33,001-42,000	30,001-45,000

Table C-1 continued on following page:

Table C-1, continued:

Toll Class	Indiana Toll Road	Ohio Toll Road	Pennsylvania Toll Road
6	Commercial veh. with 4 axles or light veh. with 2 axle trailer > 21 ft.	42,001-53,000	45,001-62,000
7	Commercial veh. with 5 axles	53,001-65,000	62,001-80,000
8	Commercial veh. with 6 axles	65,001-78,000	80,001-100,000
9	Special oversized or unusual vehicle	78,001-90,000	Over 100,000

The distributions of annual vehicle miles for the Indiana and Pennsylvania turnpikes are shown in Figures C-1 through C-4 where the figures at the top of each bar are the annual number of vehicle miles in millions. Figures C-2 and C-4 give the results with an enlarged ordinate scale, omitting class 1, which masks the truck classes. The Pennsylvania graphs indicate that classes 1 and 4 through 7 dominate. Class 1 is passenger cars and passenger cars with trailers, while the higher group is composed almost entirely of tractor-trailers. This dominance of tractor-trailers over the single-unit trucks is seen more clearly in the Indiana data of Figure C-2. Here classes six and seven dominate. These classes contain those vehicles with four and five axles, nearly all tractor-trailers.

Largely because of the toll class structure, the turnpike study was addressed to large trucks, i.e. tractor-trailers. Passenger cars were defined to include those with and without small (single-axle) trailers. Traffic data for the dichotomy defined thusly was based on the toll class given in Table C-2.

Table C-2

Toll Classes Used in Traffic Analysis

Turnpike	Passenger Car Classes	Large Truck Classes
Indiana	1	1/2 of 5, 6-8, 3/4 of 9
Ohio	1,2	4-9
Pennsylvania	1	4-9

Class five of the Indiana Toll Road is composed largely of 3-axle trucks. Discussion with Toll Road authorities indicated that about half this class is tractor-trailers and about half single units. They also indicated that all of class eight and about one quarter of class nine are double bottoms, while the remainder of

Figure C-1

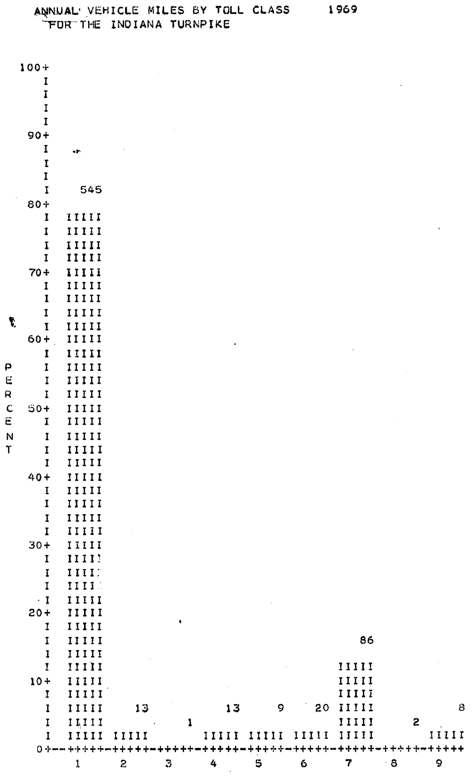

Figure C-2

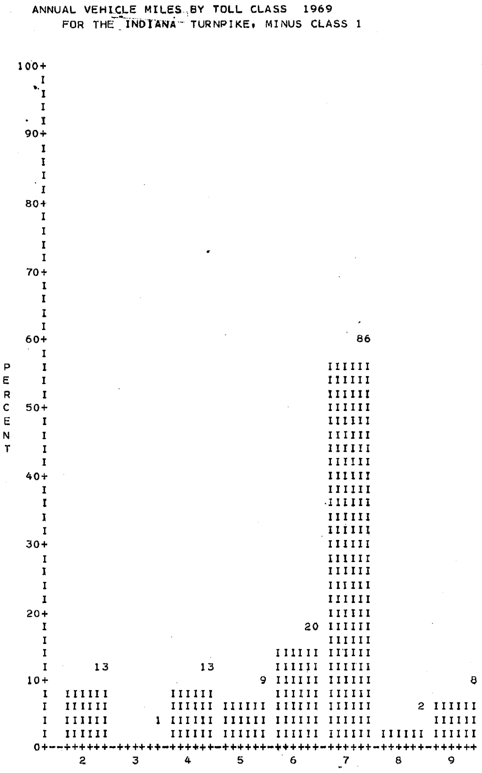

Figure C-3

```
ANNUAL VEHICLE MILES BY TOLL CLASS  1969
     FOR THE PENNSYLVANIA TURNPIKE


  100+
     I
     I
     I
     I
   90+
     I
     I
     I   2226
     I
   80+  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
   70+  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
   60+  IIIII
     I  IIIII
P    I  IIIII
E    I  IIIII
R    I  IIIII
C  50+  IIIII
E    I  IIIII
N    I  IIIII
T    I  IIIII
     I  IIIII
   40+  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
   30+  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
   20+  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
     I  IIIII
   10+  IIIII                                 141
     I  IIIII               107    95   124
     I  IIIII    80                         IIIII
     I  IIIII          16 IIIII IIIII IIIII IIIII     2     0
     I  IIIII IIIII          IIIII IIIII IIIII IIIII
    0+--+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++-+++++
         1     2     3     4     5     6     7     8     9
```

Figure C-4

```
ANNUAL VEHICLE MILES BY TOLL CLASS  1969
       FOR THE PENNSYLVANIA TURNPIKE, MINUS CLASS 1


   50+
     I
     I
     I
     I
   45+
     I
     I
     I
     I
   40+
     I
     I
     I
     I
   35+
     I
     I
     I
     I
   30+
     I
P    I
E    I                                        141
R    I
C  25+                                     IIIIII
E    I                                 124 IIIIII
N    I                                     IIIIII
T    I                              IIIIII IIIIII
     I                   107        IIIIII IIIIII
   20+                              IIIIII IIIIII
     I                IIIIII     95 IIIIII IIIIII
     I                IIIIII        IIIIII IIIIII
     I                IIIIII IIIIII IIIIII IIIIII
     I      80        IIIIII IIIIII IIIIII IIIIII
   15+                IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
   10+  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
    5+  IIIIII     16 IIIIII IIIIII IIIIII IIIIII
     I  IIIIII        IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII      2      0
     I  IIIIII IIIIII IIIIII IIIIII IIIIII IIIIII
    0+--++++++-++++++-++++++-++++++-++++++-++++++-++++++-++++++
          2      3      4      5      6      7      8      9
```

nine is mostly overwidth trailers (mobile homes).

The traffic counts by class were obtained from each turnpike by month for the period covered by the accident files. The Ohio tabulations gave the number of vehicles over each segment (defined by interchanges) and this data was easily converted to vehicle miles by multiplying the counts for each segment by the length of each segment. The Indiana and Pennsylvania counts were for each entrance-exit point. The number of vehicles by class over each segment was computed from the entrance-exit data, then the number of vehicles miles was determined.

The computation of vehicle miles described above provided not only the totals for the accident period but monthly results as well. Figures C-5 and C-6 show the monthly distribution for the Indiana Toll Road and the Pennsylvania Turnpike respectively. Passenger car mileage is indicated by the 0's while truck mileage is shown by the broken horizontal lines.

Two points are noteworthy. The truck traffic is nearly constant throughout the year, while passenger car traffic is seasonal with a peak in the summer vacation months followed by a drop when school starts.

The data from all three highways suggests that truck traffic is nearly uniform and it was taken as such for the analyses. Since passenger car traffic is non-uniform by hour as well as by month, limitations of the quantity of accident data imposed restrictions on the number of strata that could be used to represent the monthly or hourly distributions. Therefore, the seasonal pattern was represented by two levels; a summer level during June through August and a non-summer level the remainder of the year.

Daily traffic information is normally maintained by the turnpike authorities only long enough to compile the monthly summaries. Upon special request, punched cards of Indiana daily counts were made available for the months of December 1970 through February 1971. From this three month's of data, average daily rates were computed as shown in Figures C-7 and C-8 for cars and trucks. Each of the distributions shown in these figures were represented by two uniform levels, one on weekends and one on weekdays. The daily results obtained from the Indiana data were used to represent all three highways.

Hourly traffic data is not collected or maintained by any of the three turnpikes. Since the importance of high variation in the hourly passenger car traffic was recognized early, a great amount of effort was devoted to investigating possible methods of obtaining such information. Finally, a consulting engineering firm was found that had conducted traffic studies for Indiana and Pennsylvania as part of a traffic and rate study.[1] Counts were available from November 1969 of exiting vehicles at each of the interchanges and terminals of the Indiana Toll Road over 24 hour periods for a total of 15 counts. Counts were also available for Pennsylvania from two periods. In August 1968, both the entering and exiting traffic were counted over the same 24 hour period at ten interchanges. In

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[1] Wilbur Smith and Associates, Consulting Engineers, New Haven, Connecticut

Figure C-5

MONTHLY DISTRIBUTION OF CAR AND TRUCK MILEAGE IN 10,000'S
ON THE INDIANA TURNPIKE

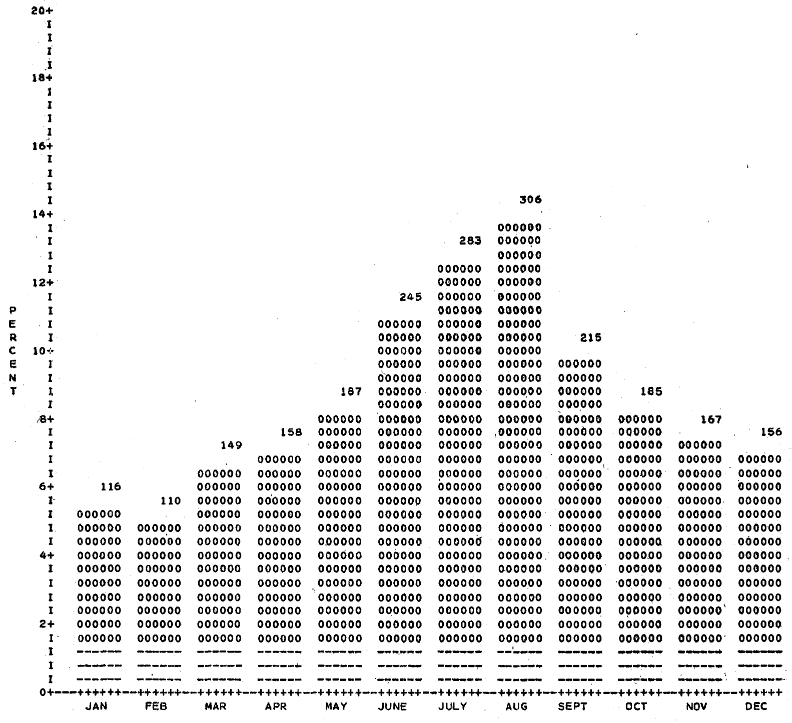


Figure C-6

MONTHLY DISTRIBUTION OF CAR AND TRUCK MILEAGE IN 10,000'S
ON THE PENNSYLVANIA TURNPIKE

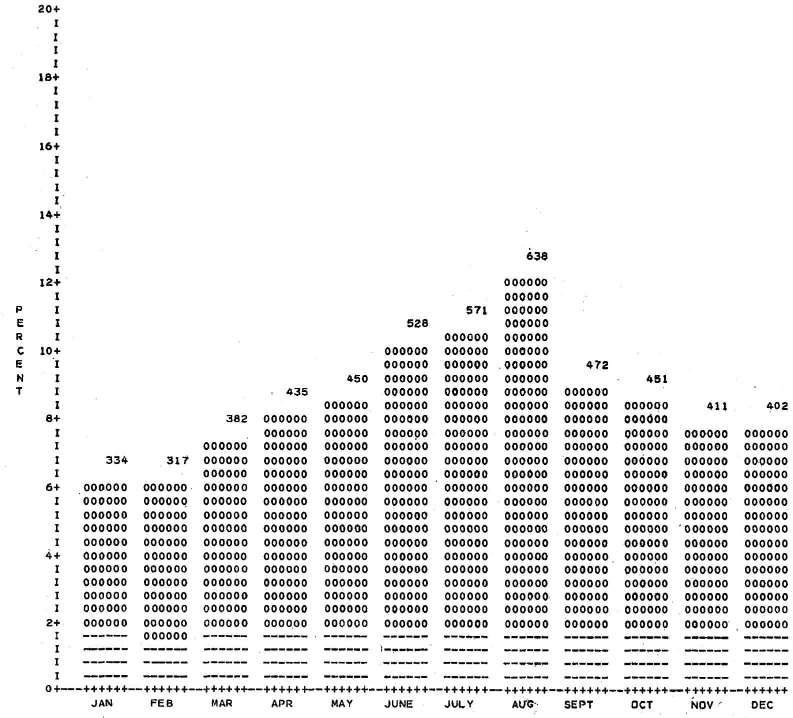


Figure C-7

INDIVIDUAL VEHICLE MILES BY DAY OF THE WEEK
FOR CARS ON THE INDIANA TURNPIKE

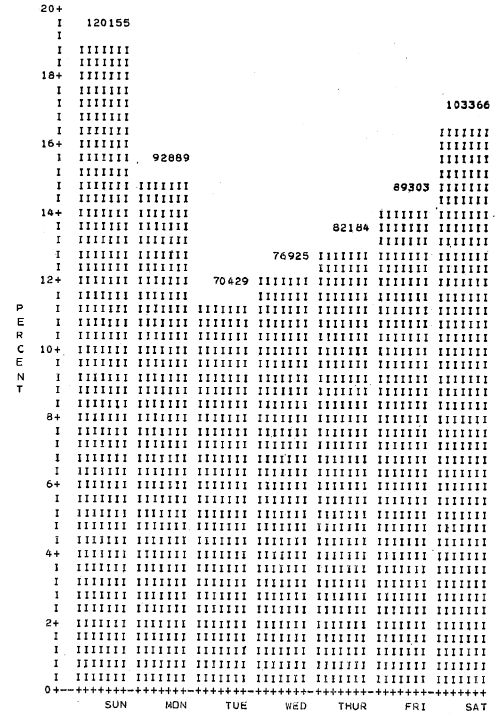
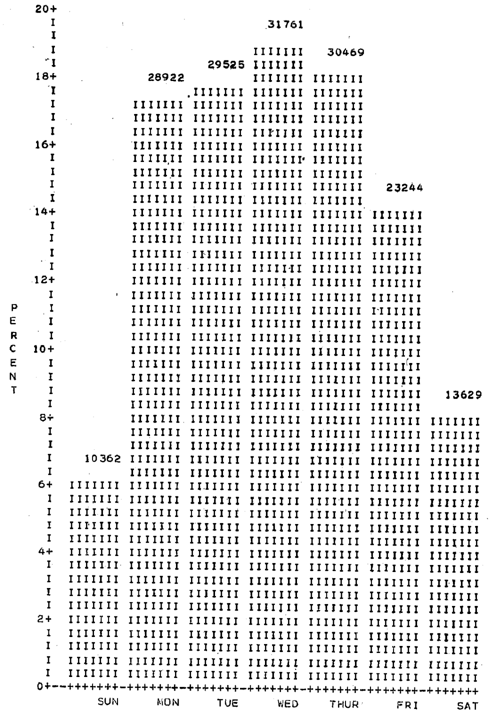


Figure C-8

INDIVIDUAL VEHICLE MILES BY DAY OF WEEK
FOR TRUCKS ON THE INDIANA TURNPIKE



addition, 113 counts of exiting traffic were available for a 24 hour period from each interchange of the entire turnpike in May 1965.

Since the hourly counts are of exiting and entering traffic rather than screen counts (vehicle traveling on the highway), the correlation between the total number of vehicles exiting in a day at each Indiana interchange with the average daily traffic on adjacent segments was computed. This correlation was 0.95.

In general, the passenger-car patterns were typical of recreational traffic. An example of the hourly pattern which shows the recreational characteristics is given in Figure C-9. This figure is representative of a rural interchange in Pennsylvania, and shows traffic low during the night but increasing gradually in the morning until about noon. After 6:00 p.m. the traffic decreases gradually to the nighttime low. Interchanges in urban areas show this basic pattern with commuter traffic superimposed. Figure C-10 is an example with commuter peaks evident in the periods from 7:00-8:00 a.m. and from 5:00-6:00 p.m. A typical pattern from the Indiana Toll Road is shown in Figure C-11. For both Pennsylvania and Indiana, the hourly mileage pattern was represented for analysis by averaging the results for one urban and four rural interchanges. The day was then divided into four equal intervals starting at midnight. Within each interval the traffic was assumed to be uniform, i.e. four levels were used to represent a day.

Since hourly data were not available for Ohio, and the Indiana and Pennsylvania patterns were very similar, the median of the latter two was used to represent Ohio.

Truck traffic was nearly uniform throughout the day in both Indiana and Pennsylvania, with minor hourly fluctuations. Examples for the truck traffic patterns are shown in Figures C-12 and C-13. Since the minor fluctuations are small compared to the major changes in passenger car traffic, and are too rapid to examine with the limited accident data, truck traffic was assumed to be uniform during the day.

The discussion above has briefly described seasonal, daily, and hourly traffic patterns. The distributions of traffic for each of these strata as used in the analysis of Section 5 is given in Table C-3 for each of the three turnpikes. The table effectively summarizes the details of the traffic data for both passenger car and large truck travel.

Figure C-9

HOURLY TRAFFIC FACTORS - RURAL AREAS ON THE PENNSYLVANIA TURNPIKE

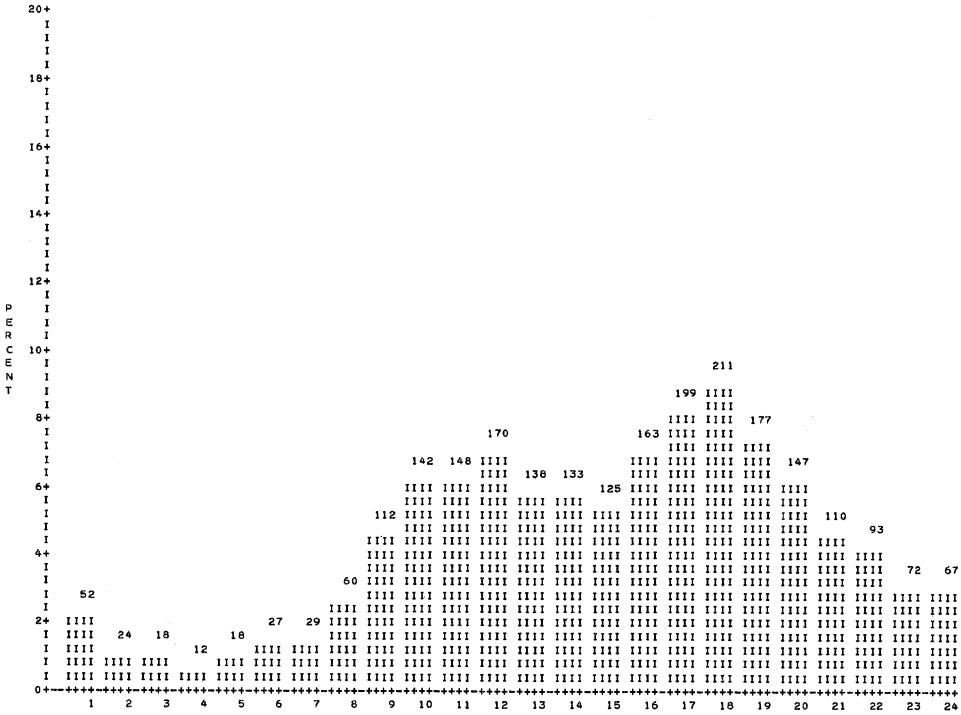


Figure C-10

HOURLY TRAFFIC FACTORS - URBAN AREAS ON THE PENNSYLVANIA TURNPIKE

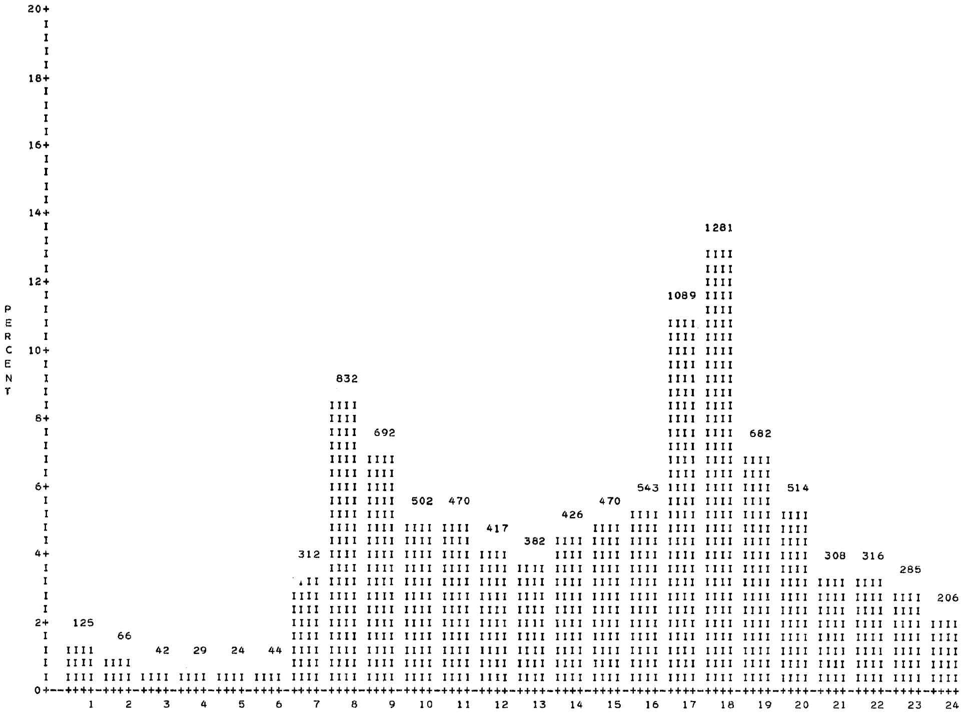


Figure C-11

HOURLY TRAFFIC FACTORS - CARS ON THE INDIANA TURNPIKE

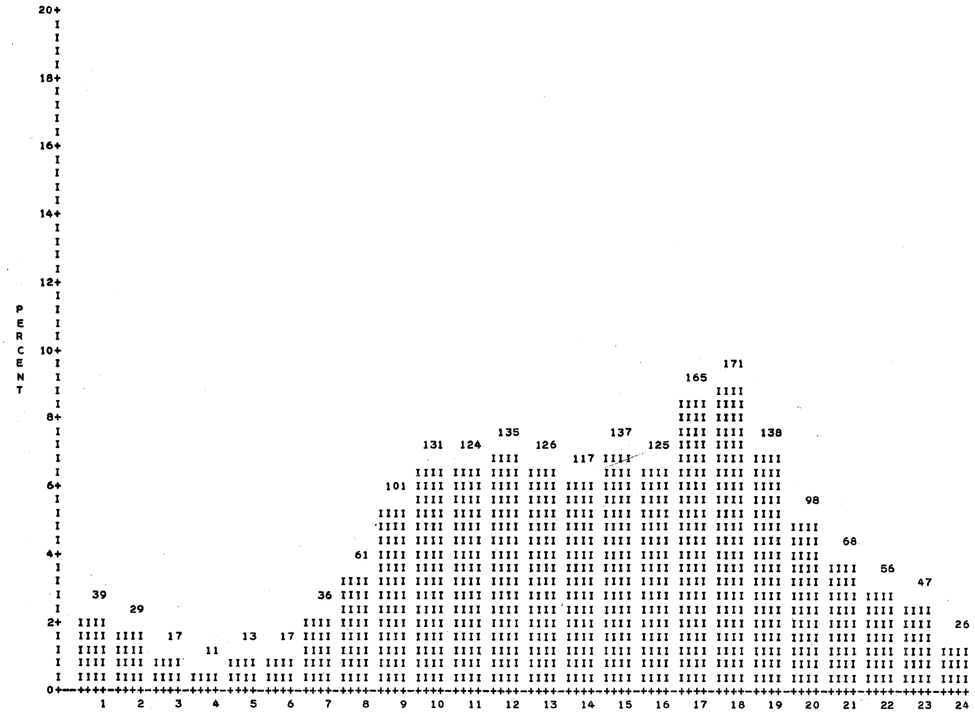


Figure C-12

HOURLY TRAFFIC FACTORS - TRUCKS ON THE PENNSYLVANIA TURNPIKE

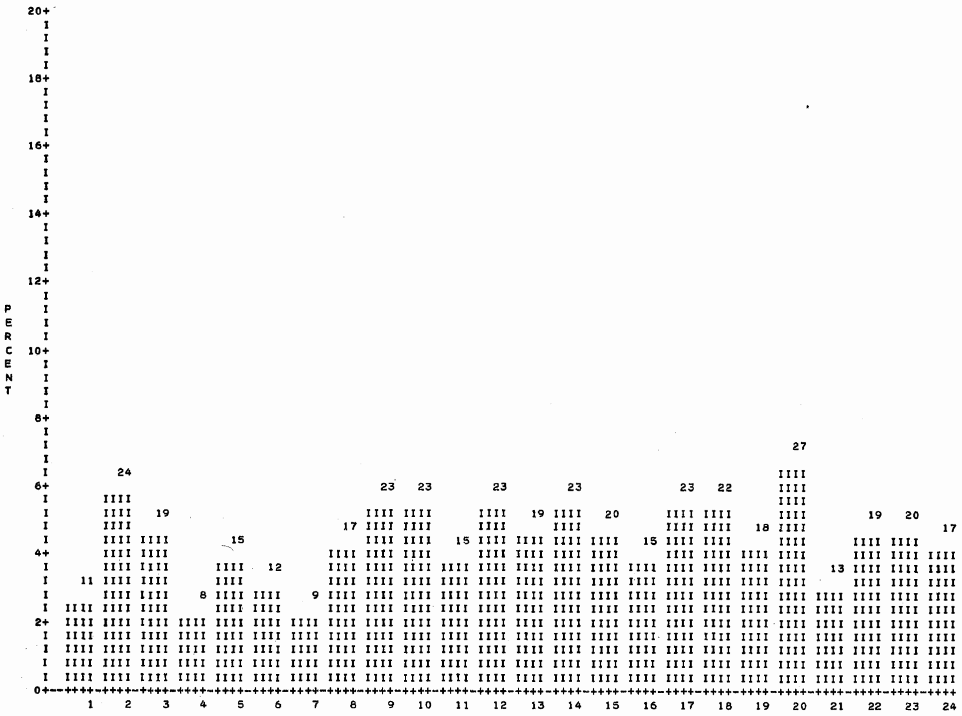


Figure C-13

HOURLY TRAFFIC FACTORS - TRUCKS ON THE INDIANA TURNPIKE

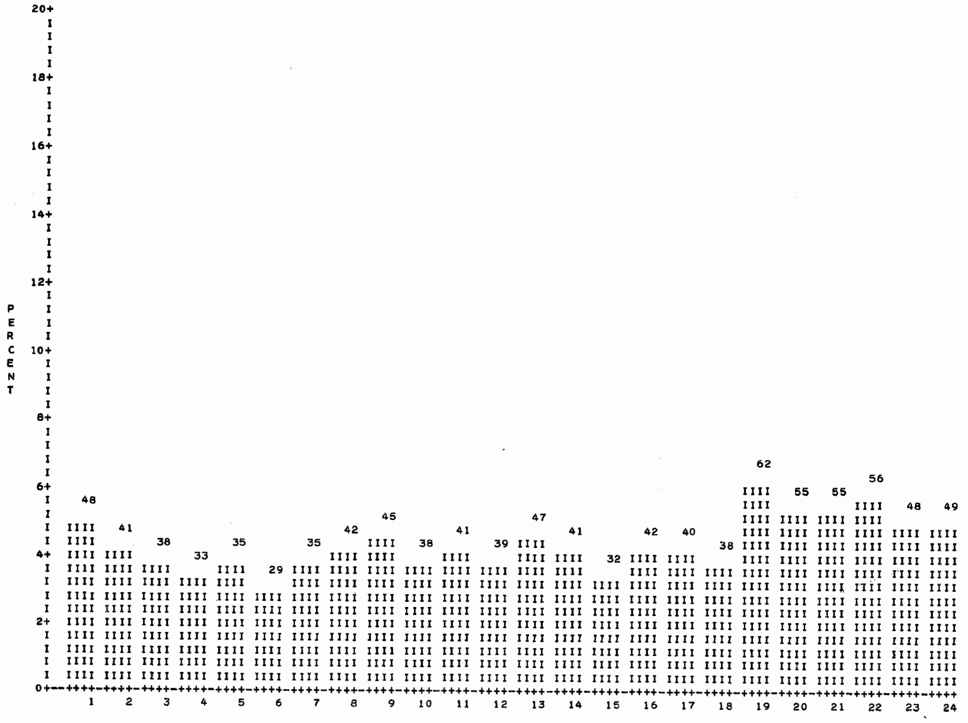


Table C-3

Turnpike Traffic Factors

	Indiana Toll Road		Ohio		Pennsylvania	
	Passenger cars	Large Trucks	Passenger cars	Large Trucks	Passenger cars	Large Trucks
Vehicle Miles ($x10^8$ miles)	26.26	5.04	46.84	9.96	52.98	10.93
in Percent	83.9	16.1	82.5	17.5	82.9	17.1
Traffic Factor in Percent						
(1) Seasonal						
Summer	38.8	25.0	37.0	25.0	33.6	25.0
Non-summer	61.2	75.0	63.0	75.0	66.4	75.0
(2) Daily						
Weekday	64.8	85.7	64.8	85.7	64.8	85.7
Weekend	35.2	14.3	35.2	14.3	35.2	14.3
(3) Hourly						
00-05	6.3	25.0	5.3	25.0	4.2	25.0
06-11	29.6	25.0	29.2	25.0	28.8	25.0
12-17	42.3	25.0	41.6	25.0	40.9	25.0
18-23	21.8	25.0	23.9	25.0	26.1	25.0