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HIGHWAY SAFETY EFFECTS OF THE ENERGY CRISIS ON U.S. TOLL ROADS -- FINAL REPORT

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16. Abstract

This is a final technical report on a study of the highway safety effects of the energy crisis on selected toll roads in the United States. Data concerning accidents, traffic volumes, and speeds of travel--broken down by vehicle class into passenger cars and large trucks--are analyzed.

It is shown that truck traffic and speeds did not vary much as a result of the energy crisis, but that passenger car traffic was reduced by about 14% and average speeds by about 8 miles per hour. Accident data were analyzed using three adjustment models to permit a better understanding of the processes involved.

Accident rates overall were reduced much more than could be accounted for by travel alone. Accident severity was apparently reduced leading to 47% reduction in fatalities. The number of all casualties, including minor injuries decreased slightly. While both car and truck accident involvements were reduced, large trucks were over-represented in the two-vehicle accident population both before and after the energy crisis.

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1.0 INTRODUCTION

This is a final report on a project entitled "Highway Safety Effects of the Energy Crisis on U.S. Toll Roads" sponsored by the National Highway Traffic Safety Administration under contract DOT-HS-4-00980.

The energy crisis in the United States which began in the fall of 1973 had a number of rather immediate effects on travel characteristics of the population. Both the causes of the changes and the changes themselves are complex. The president asked the populace to institute fuel-saving measures (such as reducing speed); the price of gasoline and diesel fuel increased; gasoline stations were asked to remain closed on weekends to discourage leisure travel. Speeds of travel on highways were visibly reduced, the traffic level decreased, and there was clearly a differential reaction on the part of passenger vehicles (for which mileage went down) and trucks (which remained nearly at the same level).

The general objective of this study has been to estimate the effect of reduced speed limits on motor vehicle accidents, injuries, and fatalities occurring on interstate freeway, and general limited access type roads. With this goal, data on the periods before and after the initiation of the energy crisis have been compared for a selected number of toll road facilities--these toll roads being a sort of surrogate for the general class of interstate roads. Toll roads were prescribed for the study because of the availability of rather precise traffic count data (both number and type of vehicle) and because of the relative uniformity, within a given state, of the accident reporting system. The precision and detail in traffic data available for toll roads is unique, and not generally available for other highway systems. Specific information to be sought about the studied roads included traffic volume, speed, accident or involvement rates, all as a function of time through the energy crisis period. In particular the dichotomy of large trucks and cars has been studied, since it was expected that the response of each of these to the energy crisis might be different.

Data expected to be available from toll roads included the traffic count data (obtained by analysis of the toll records), speed data (obtained either by direct observation or by analysis of toll records), and accident data. A secondary measure of exposure, expected to be determinable on the toll roads, is the passing rate--determined from the observed speed distributions of vehicles. In particular the passing rates of cars vs. trucks was expected to change as these two classes of vehicles tended to operate more nearly at the same mean speed.

In order to study the effects of the crisis two ten-month periods have been selected for comparison. The selection of the exact periods, i.e., January through October of 1973 vs. the same period in 1974, was made mainly to avoid the principal transition time (November and December of 1973). The actual selection of the periods was made after the data had been observed, and the two ten-month periods represent relatively stable and different circumstances.

Toll roads typically report accidents which occur in service plazas, at or near toll booths or ramps, as well as those occurring on the main line of the road. In general for the present analysis, only main line accidents, have been considered since they are the most representative of the "interstate" class of highways. While there are a small number of pedestrian accidents occurring on such roads, these have also been deleted from the present study--largely because there seemed to be no method of determining pedestrian exposure.

Ideally the specific toll roads studied would represent in a statistical sense the nation's population of toll roads, and these would then represent the interstate class. Such precise representation was not possible, the exact choice of roads being determined somewhat by the availability of good accident, speed, and volume data. An attempt has been made to choose toll roads from several parts of the country, although most high-volume facilities are in the northeast. This analysis is based on data from the Kansas Turnpike (deleting data from two end sections where toll counts were unavailable), the New York Thruway (except for a few sections which used barrier toll collection facilities rather than tickets), and all of the Maine, Pennsylvania, and Ohio Turnpike systems.

The analysis is centered on the use of an interaction model to relate speed and volume changes to changes in the accident experience. This model, originally described in "Statistical Analysis of Truck Accident Involvements" (DOT-HS-800-627) defines a concept of exposure to two-vehicle accidents based on the passing rate of vehicles traveling in the same direction. Very briefly, it can be seen that if all cars travelled faster than all trucks on a toll road, there would never be a situation in which a truck passed a car. Consequently there should be essentially no collisions of the truck-into-car from behind type. In fact speeds of both cars and trucks are distributed over a range of several miles per hour, and even if the average speed of trucks is lower, there will be some passings of cars by trucks.

One expected effect of the energy crisis was that cars would slow down in response to the mandated speed limits, but that trucks which were previously limited to a lower speed would stay at about the same speed. Thus the proportion of all passings which result from trucks overtaking cars could be expected to increase. Consequently, the proportion of all accidents which are trucks into cars might be expected to increase with the uniform limits.

As with many mathematical models of social processes it is unlikely that the model will explain all of the observed variation. The intent of such a model is to assist in the understanding of the process. As noted above, the shifts in travel patterns--speed, volume, and mixture--are complex. But to a satisfying extent the basic model used here does help to explain the change.

There are additional factors which may have attended the energy crisis and its effect on the driving public in 1973. The use of automobile travel may have changed with relatively greater reduction in elective or non-essential trips. This could change the hours and location of travel and in turn the "risk" of accidents. Encouragement to establish "car pools" could have increased the occupancy of cars, and in turn the number of persons at "risk" given the occurrence of a crash. At the same time, gradual changes already taking place continued or were accelerated during the crisis. The shift from larger to smaller cars accelerated and substantial changes in occupant restraints in new cars were made with the introduction of the sequential-starter interlock on the 1974 models. Factors such as these are of interest and were considered in the conceptualization and definition of the program. It was found, however, that the data available from the turnpikes in general do not allow examination of these factors. Occupancy, for example, is not included in either the exposure (traffic) or accident data. Injured occupants are listed in accident data, but uninjured occupants are not. Because of these limiations, the analysis concentrated on the effects of changes in travel and speed.

This introduction is followed by a summary of the findings. Included in this are our conclusions and recommendations. The detailed description of the study follows in the remainder of the report beginning with Section 3 which discusses methodology and the data requirements. The next three sections (4-6) present the speed, traffic, and accident data including the findings from each of these. Finally, the analysis results are presented in Section 7. Appendices are included on the interaction model (A), the traffic patterns and elapsed time computations of speed (B), and definitions of individual toll classes (C).

2.0 SUMMARY

Of approximately 25 toll road systems presently in operation in the United States, five were selected for this study. Although it was desirable to have the selected roads be truly representative of their parent population, in fact selections had to be based on (1) the availability of accident data, (2) the availability of traffic data by class (e.g., those roads which used barrier toll collection maintained no record which would provide the detailed traffic counts required), and (3) the availability of speed data. The selected roads represent only 20% of the total toll road miles, but the inclusion of some high volume roads makes the aggregated data representative of about 30% of the U.S. toll road vehicle miles.

For each of the selected roads, sets of accident data were acquired for the years 1973 and 1974. In addition, for each road traffic data were obtained (by month) for the same two-year period. Both the accident data and the traffic data were grouped by vehicle type into cars, straight trucks, and "large" (i.e., tractor-trailer) trucks. (For Maine and Kansas, the distinction between straight trucks and large trucks could not be made.)

Speed data were acquired as available. In general there was adequate speed information for the period after the "energy crisis", but the "before" data were less available. The choice of turnpikes for the study was made in part on the basis of their data being available. But for some turnpikes speed data were taken only once each year, and for some there was inadequate differentiation between trucks and cars. For the Kansas Turnpike, for example, the before data were estimated from information taken on a nearby interstate.

All of the data acquired were placed in computer form for subsequent analysis. This involved a major effort because of the variability of format, but was necessary to get all of the data in a reasonably common form for treatment. The principal purpose of this was to permit the computation of involvement* rates of cars and trucks before and after the initiation of the energy crisis. This also permitted the distribution of the observed vehicle mix in two-vehicle collisions to be compared with distributions predicted by three different models:

(1) An <u>independence model</u> based on the assumption that involvements were proportional to the gross vehicle miles.

(2) A <u>temporal model</u> in which involvements were considered proportional to vehicle miles but with consideration of seasonal, daily, and hourly variation.

*Note the differentiation between involvement rates and accident rates, discussed in more detail in Section 3.1, pp. 27-28.

(3) An <u>interaction model</u> in which the distribution of two vehicle accidents is assumed to be proportional to the passing rates of the vehicles (including the adjustment of the temporal model).

2.1 Findings

The basic comparisons were made between data for two ten-month periods, January through October of 1973 and 1974. Detailed information regarding each road is presented in tabular form. The summary presented below is based on an aggregate of all of the data. General conclusions regarding this aggregation are:

(1) In the after period passenger car traffic was down 14.7% relative to the before period. Truck traffic rose about 1.2%. (See Table 2.1)

(2) The involvement of cars in crashes in the after period was down 45.1%; for trucks involvement was down 16.6%. (See Table 2.2)

(3) The reduction of involvements of cars in two-vehicle crashes was slightly greater than for single vehicle crashes - 47 versus 44%. The involvement of large trucks in single vehicle accidents was down only 3% in 1974, while their involvement in two-vehicle crashes was down 28%. The greater reduction of large trucks in two vehicle collisions is associated with the reduction of cars in two-vehicle collisions, since the "other" vehicle is usually a car. (See Table 2.3 which is the aggregate of Tables 6.2-6.6.)

TABLE 2.1

REDUCTION OF TRAVEL
ON TOLL ROADS IN 1974

The figures give the reduction of January-October travel in vehicle miles in 1974 compared to 1973 in percent.

Type of Vehicle	Toll Road					Aggregate of Five Roads
	Kansas	Maine	New York	Ohio	Pennsylvania	
Passenger Car	18.1	12.1	16.9	13.9	13.1	14.7
Large Truck	4.4*	2.0*	1.9	-4.5	-3.4	-1.2

*The truck figures for Maine and Kansas include all trucks, most of which are large.

TABLE 2.2

REDUCTION OF VEHICLE
INVOLVEMENTS IN ACCIDENTS
ON TOLL ROADS IN 1974

The figures give the reduction of January-October involvements (vehicles) in 1974 compared to 1973 in percent.

Type of vehicle	Toll Roads					Aggregate of Five Roads
	Kansas	Maine	New York	Ohio	Pennsylvania	
Passenger Car	52.4	33.8	33.0	40.2	56.4	45.1
Large Truck	7.1*	31.2*	19.5	6.2	21.2	16.6

*The truck figures for Maine and Kansas include all trucks, most of which are large.

TABLE 2.3

INVOLVEMENTS BY COLLISION TYPE
AGGREGRATE OF FIVE TOLLROADS

Ten Months (Jan.-Oct.)

Collision Type	1973	1974	% Reduction
Single Vehicle Involvements			
Cars	4374	2466	44
Large Trucks	731	707	3
Two-Vehicle Involvements			
Cars	3471	1840	47
Large Trucks	878	632	28
Total Involvements			
Cars	7845	4306	45
Large Trucks	1606	1339	17

(4) Involvement rates (i.e., involvements per vehicle mile) were down 35.6% for cars, 17.6% for trucks. (See Table 2.4)

(5) Car speeds went down 8.2 mph on the average, while truck speeds decreased an average of 4.3 mph. The speed differential between cars and trucks changed drastically only in Ohio where it dropped from 12.8 mph to 1.88 mph. These results are shown for each road in Table 2.5.

(6) The reductions that have been noted in the previous findings are summarized in Table 2.6. Both cars and large trucks are aggregated for all five toll roads. The speed reduction given is the average for cars and large trucks on the five roads weighted by the vehicle miles travelled by each type of vehicle on each road. Obviously the involvements (vehicles) in crashes was down in 1974 much more than the reduction in travel would suggest. The reduction cannot be explained solely, or evenly largely, by travel alone. Hence speed and other factors must account for a major portion of the observed reduction.

(7) Fatalities were down abour 47%, and the fatality rate (fatalities per accident) was down 19.9%. Casualties (injuries of any severity including fatals) were

TABLE 2.4

INVOLVEMENT RATES ON TOLL ROADS IN JANUARY-OCTOBER 1973 and 1974

Involvement rate in involvements per 100 million vehicle miles.

Type of Vehicle	Toll Roads					Aggregate of Five
	Kansas	Maine	Ohio	New York	Pennsylvania	
Passenger Car						
1973	153.3	132.4	116.7	116.2	167.2	136.6
1974	89.2	99.8	81.0	93.7	83.8	88.0
Reduction (%)	41.8	24.6	30.6	19.4	49.9	35.6
Large Truck*						
1973	203.6	313.6	118.7	140.2	139.6	146.5
1974	197.7	220.4	106.6	115.0	106.4	120.7
Reduction (%)	2.9	29.7	10.2	18.0	23.8	17.6

*The truck figures for Maine and Kansas include all trucks, most of which are large.

TABLE 2.5

SPEED CHANGES

Toll Road	Reduction in Speed MPH	Reduction in Speed %	Speed Differential, mph*** Before	Speed Differential, mph*** After
Kansas*				
Cars	8.61	12.6	3.2	1.77
Large Trucks	7.18	11.0		
Maine				
Cars	8.17	12.2	2.48	1.74
Large Trucks	7.43	11.5		
New York				
Cars	8.14	12.4	5.68	3.06
Large Trucks	5.52	9.2		
Ohio				
Cars	10.2	14.3	12.8	1.88
Large Trucks	-0.7	-1.2		
Pennsylvania**				
Cars	5.9	9.0	6.0	2.0
Large Trucks	1.9	3.2		

*Speed surveys were not taken on the Kansas Turnpike before the energy crisis. Speed data from Kansas Interstate roads were used for car speeds. Truck mean speed was subjectively estimated by a member of the Kansas Highway Patrol, Turnpike Division since the Interstate speed limit for trucks was 60 MPH rather than 75 MPH.

**Sufficient speed surveys were not available in Pennsylvania. Mean speeds from a single station on the Turnpike are shown here for comparison.

***The differential is the mean car speed minus the mean truck speed.

TABLE 2.6

REDUCTION OF SPEED, TRAVEL, AND INVOLVEMENTS OF CARS AND LARGE TRUCKS ON TOLL ROADS

Speed Reduction	Vehicle Mile Reduction	Single Vehicle Involvement Reduction	Two Vehicle Involvement Reduction	Total Involvement Reduction
7.1 mph	12.2%	37.8%	43.2%	40.3%

down 37.8%, and the casualty rate was down 6.6%. The reduced fatality rate suggests the accidents of 1974 were less severe than those of 1973. The lesser reduction in the casualty rate is not inconsistent with this, since many minor injuries which could result from minor accidents are included in the casualties. (See Table 2.7)

Given the dichotomy of cars and large trucks, four specific types of two-vehicle crashes predominate on the toll road main lines. These are defined as car front into car rear (CC), car front into truck rear (CT), truck front into car rear (TC), and truck front into truck rear (TT). In the tables presented here we will show the observed frequency distribution of these types of crashes as well as the distributions predicted by the several models.

Table 2.8 presents the aggregated data for 1973 and 1974 with observed information in the left hand columns, and the predicted results from the three models following. Note that total two-vehicle involvements decreased from 3286 to 1926--a 41% change. The percent distributions for the observed data indicate

TABLE 2.7

REDUCTION IN CASUALTIES
Twelve Months

Toll Road	Reduction in 1974 in Percent: Number of Casualties	Reduction in 1974 in Percent: Casualties Per Accident	Reduction in 1974 in Percent: Number of Fatalities	Reduction in 1974 in Percent: Fatalities Per Accident
Kansas	37.8	2.0	-5.0	-65.3
Maine	40.1	17.4	50.0	31.1
Ohio	42.9	24.5	60.0	24.5
New York	22.9	-0.8	58.9	46.0
Pennsylvania	44.9	-2.3	52.2	11.3
Total	37.8	6.6	46.7	19.9

TABLE 2.8

TWO VEHICLE INVOLVEMENTS BY COLLISION TYPE
10 MONTHS (JANUARY-OCTOBER)

	Observed		Predicted					
			Vehicle Miles		Temp. Vehicle Miles		Interaction Model*	
	N	%	N	%	N	%	N	%
1973								
CC	2020	61.5	2290	69.7	2301	70.0	1356	66.9
CT	571	17.4	451	13.7	423	12.9	558	27.5
TC	481	14.6	451	13.7	423	12.9	64	3.2
TT	214	6.5	94	2.9	140	4.3	48	2.4
Total	3286	100.0	3286	100.0	3287	100.1	2026*	100.0
1974								
CC	1008	52.3	1280	66.5	1257	65.3	967	71.5
CT	347	18.0	288	15.0	276	14.3	245	18.1
TC	409	21.2	288	15.0	276	14.3	99	7.3
TT	162	8.4	70	3.6	115	6.0	42	3.1
Total	1926	99.9	1926	100.1	1924	99.9	1353*	100.0

*Pennsylvania is not included in the I.M. results.

that car-car accidents are down, car-truck accidents about the same, truck-car accidents up substantially, and truck-truck accidents up slightly.

The car-car involvements were a lower proportion of all two vehicle involvements than was predicted by any of the three models. This suggests a speed controllability phenomenon not accounted for in any of the models--i.e., cars traveling at lower speeds, even after adjusting for their reduced number, have a lower accident probability than when they were traveling at a higher speed. All three models predicted an increase in the proportion of truck-truck accidents, and this is consistent with the observations.

Neither the independence model nor the temporal model is able to differentiate between car-truck and truck-car collisions. The interaction model is able to distinguish these collision types because the effect of the speed distributions is included. However, the observed changes are much less than the predicted.

The information in Table 2.8 may be used to compute over-involvement rates. For each of the models the over-involvement rate is computed by simply dividing the observed proportions by the predicted proportions for each collision type. These results are presented in Table 2.9 for each model. The consistency between models is striking. The under-representation of car-car involvements and the over-representation of truck-car and truck-truck involvements is indicated by all three models both before and after the energy crisis. Mixed results occur only for the car-truck involvements.

TABLE 2.9

COMBINED RESULTS

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Veh. Mi.	Temporal Veh. Mi.	Interaction Model
1973			
CC	0.88	0.88	0.92
CT	1.27	1.35	0.63
TC	1.07	1.14	4.56
TT	2.24	1.53	2.71
1974			
CC	0.79	0.80	0.73
CT	1.20	1.26	0.99
TC	1.41	1.48	2.90
TT	2.33	1.41	2.71

The interaction model also provides a framework for examining the effects of the speed change. The two-vehicle involvements addressed by the three predictive models were reduced 33%. Assuming a simple linear relation, 13% could be attributed to reduced travel (vehicle miles was reduced by 13%). The number of passings predicted by the interaction model, which include both travel and a speed effect is down 21% (See Table 7.16). The difference of 12% between reduced involvements and reduced predicted passings may in part result from an additional factor of speed. This is a reduction in the probability of a crash in a passing maneuver. If this probability is reduced at lower overall speeds, as seems likely, then speed plays a major role in the reduction of two vehicle crashes on the turnpikes.

2.2 Conclusions

(1) A principal finding is that speeds of passenger cars on toll roads were reduced substantially by the reactions to the energy crisis. This speed reduction was accompanied by a reduction in the number of crashes, injuries, and fatalities far in excess of that expected from a simple volume adjustment. From purely a safety point of view this speed reduction has a significant impact.

(2) The interaction model of traffic flow is intended to help explain a change in the pattern of accidents; and indeed the shift to a higher proportion of truck-into-car collisions is consistent with this model. We must conclude, however, that this model does not predict the observed results fully and that there are other factors not accounted for in the present study which must account for the remainder.

(3) The major part of the variation in accident rate, and perhaps in the pattern as well, should be related to the probability of a collision given a passing maneuver, and data to better define this factor were not available in the present study. Further, the interaction model itself is sensitive to the accuracy and precision of the data used in it.

(4) Even though truck involvements in toll road accidents were reduced as a result of the energy crisis, trucks are still overrepresented in two-vehicle accidents--both of the truck truck and the truck-car variety. The use of the interaction model in the previous report (1) indicated that trucks were over-represented as the striking vehicle in rear-end toll road (and by inference, interstate) collisions--relative to the number of opportunities (passings) for such

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(1) Scott, R.E. and O'Day, J. "Statistical Analysis of Truck Accident Involvement", prepared for NHTSA, DOT-HS-800-627, December, 1971.

collisions. This overrepresentation is still present. Furthermore the proportion of two vehicle collisions in which trucks are involved as the striking vehicle is greater than it was before the energy crisis. Collision rates overall were down, but trucks running into cars while passing is still a problem to be reckoned with.

2.3 Recommendations

(1) In the light of the marked improvement in accident, injury, and fatality rate, continued enforcement of the energy crisis speed limits seems consistent with improved safety. There may have been only a modest conservation of fuel, some inconvenience, and considerable complaint with the reduced speed limits. Nevertheless, the substantial reduction in accident loss shown here should be an important, if not primary, factor to be considered in connection with proposals to return to pre-crisis speed characteristics.*

(2) With respect to the data for a study such as this one, we would recommend that toll roads continue to be used to study traffic phenomena. The availability of relatively good traffic count data, and the uniformity of police accident reporting makes toll facilities superior to other roads. There are certain improvements in data quality which are possible with modest effort: vehicle class designation on the toll records and on the accident records could be made consistent, highly desirable in permitting more precise interpretation of the intersection of these data. Speed measurements, as made by the FHWA, are not regularly conducted on toll facilities; rather the toll facilities have only occasionally measured speeds as a partial measure of their capacity. Speed data acquired frequently, and taken with an eye to subsequent

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* It is interesting to note that the essential features of this recommendation are embodied in the recommendation of AASHTO. "Effects of the 55 mph speed limit" American Association of State Highway & Transportation Officials, November, 1974.

safety evaluations would have been most valuable in this study. It should not be a costly effort, and we recommend that such data taking be instituted on major toll roads to serve as a base for future safety studies.

(3) With respect to traffic flow modeling efforts, we have judged that the interaction model used in this study did not fit the change in the observed distributions of two vehicle collision types. Models of such processes as traffic are useful in that they help to explain effects which may be encountered in the future, and we suggest that further analytical effort toward a better understanding of the relationships of speed, speed variance, type characteristics, road characteristics, etc., are in order. Specifically a better understanding of the elements defining the probability of a collision given a passing maneuver might have led to a model more consistent with the data observed here.

(4) Neither the present report nor the previous one (1) studied the mechanism of the truck-into-car rear-end collisions sufficiently to suggest countermeasures. The reduction in car speeds has made this problem more apparent, and it would be appropriate for better definition of how the maneuvering capabilities or driver actions lead to this overrepresentation. A specific method for study is not proposed, but it is recommended that NHTSA consider methods of further identifying why this overrepresentation exists.

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(1) Scott, R. E. and O'Day, J. "Statistical Analysis of Truck Accident Involvement", prepared for NHTSA, DOT-HS-800-627, December, 1971.

3.0 METHODOLOGY

The general objective of this study is to obtain quantitative estimates of the magnitude of the safety benefits produced by the energy crisis. While it is recognized that a combination of many factors is responsible for the observed safety benefits, this study is concerned primarily with the identification of the role played by changes in traveling speeds. The analysis was restricted to toll roads in the belief that variations in traffic volume could accurately be determined and included in the analysis. The objective of this analysis is the development of an understanding of the roles played by traffic volumes and speeds in the accident experience observed on the selected toll roads during the variety of conditions produced by the energy crisis. Section 3.1 describes the analysis techniques used to study the relationships between changes in speed, volume, and accident experience. The techniques chosen, to a large extent, dictate the data requirements. These requirements and their relation to the selection of toll roads studied is discussed in Section 3.2

3.1 Analysis Techniques

The initial analyses were directed at determining the changes in the three principle variables (volumes, speeds, and accidents) over the two year period. How the combination of events which is referred to as the "energy crisis" produced these changes is beyond the scope of this study. For purposes of analysis the first ten months of 1973 and 1974 were selected for comparison. November and December were omitted because the onset of the energy crisis came during these months. Seasonal variations are not a problem since the same ten months were selected from each year. In general, the two periods represent relatively stable but different conditions of speed, traffic, and accidents for each of the roads.

Another major facet of this analysis is the dichotomy of vehicles on the road. Emphasis is placed on large trucks and passenger cars because these two vehicle types were affected differently by the energy crisis.

Comparisons of the accident experience of trucks and cars have often been based on computation of rates for each in accidents per vehicle mile. When considering a dichotomy of vehicles, such as cars and trucks, with the likelihood of involvement proportional to the amount of travel, the class accounting for the minority of vehicle miles will appear to be overinvolved. If we consider the possible permutations of the two classes of vehicles in two-vehicle accidents, we find that each class is in a greater proportion of the accidents than the proportion of miles travelled by that class. The ratio of two vehicle accidents per vehicle mile for the minority class to the rate for the majority class is $(2-P_m)/(1+P_m)$ where P_m is the proportion of travel which is accrued by the minority vehicle. If trucks were to account for 20 percent of the travel, their two-vehicle accident rate would be one and one-half times as great as the accident rate for cars, assuming each is in equal jeopardy per mile travelled. This apparent magnification of accident rate is avoided if involvement rate is used--counting each individual vehicle involved in a crash--rather than accident rates.

Involvement rates are computed for cars and trucks for each of the ten month periods based on the miles travelled by each. These rates are then compared. The implicit assumption in such a calculation is that accident involvement is proportional to mileage.

Of particular interest are the two vehicle collisions. These are separated into four types:

CC - Car into Car
CT - Car into Large Truck
TC - Large Truck into Car
TT - Large Truck into Large Truck

If one extends the vehicle mileage basis for involvements to two vehicle collisions, then the probability that one of the vehicles is of a particular type is equal to the proportion of the total mileage accumulated by that vehicle type. Under this assumption then, the proportion of the two vehicle accidents of each configuration would be expected to be:

CC - p_C^2
CT - $p_C p_T$
TC - $p_T p_C$
TT - p_T^2

where:

p_C = proportion of car traffic
p_T = proportion of truck traffic

These proportions may be based on the gross mileage for cars and trucks. A refinement of this approach takes into account the temporal distributions of vehicle traffic. For example, the proportion of trucks on the road at night is much greater than in the daytime so that the probability of a truck-into-truck (TT) accident would be higher at night. By breaking the mileage travelled by each class down into the month of the year, day of the week, and time of the day in which it was accumulated, periods may be defined during which the mix of vehicles on the road is constant. The probability of each type of involvement may then be calculated for each of these periods. The distributions from each period can then be combined to generate an aggregate distribution. The combined distribution was computed for purposes of this study by allocating the total two vehicle involvement in each period according to the probabilities computed for that period. The aggregate was formed by simple summing for each configuration.

The methods used so far include only the effects of vehicle mileage. Our primary interest here is in the effects produced by changes in speed. One area where speed effects might be expected to be apparent is in the ratio of car-into-truck (CT) to truck -into-car (TC) collisions. Prior to the energy crisis cars travelled faster than trucks on the average, and consequently one would expect more CT collisions than TC. For the multi-lane limited access divided highways under study here, most two vehicle accidents are of the overtaking nature. Since one effect of the energy crisis was to reduce the speed differential between cars and trucks, one would expect an increase in the proportion of TC collisions and a decrease in the number of CT collisions. Note that the proportion of CT and TC collisions predicted on the basis vehicle miles will always be equal ($p_C p_T = p_T p_C$).

This deficiency in predictions based on vehicle miles alone led to the application of the Interaction Model (1) which incorporates the speed distributions

(1) Scott, R. E. and O'Day, J. "Statistical Analysis of Truck Accident Involvement", prepared for NHTSA, DOT-HS-800-627, December, 1971.

of both vehicle classes as well as the density of each vehicle class on the road. The logic for this model begins with the fact that two vehicles cannot collide unless they are first in close proximity.

In a freeway driving situation the proximity of two vehicles normally arises in a passing situation which occurs as a result of differences in the traveling speeds of the two vehicles. Therefore, the unit of exposure in the interaction model is the overtaking of a slower vehicle by a faster vehicle. If the roadway may be modeled as a one-directional free-flowing traffic stream composed of two vehicle classes having their respective speed distributions and densities, then the overtaking rate (the rate at which the vehicles of one class pass vehicles of the other class) is given by:

$$OR = DvDu \int_0^{\infty} \int_u^{\infty} (v-u)h(v)h(u)\,dv\,du \qquad (1)$$

where:

- Dv - density in veh/mile of the passing class
- Du - density in veh/mile of the class being passed
- v - velocity of vehicles in the passing class
- u - velocity of vehicles in the class being passed
- h(v) - probability density function giving the percentage of vehicles in the passing class traveling in the speed increment ΔV
- h(u) - probability density function for u.

This expression yields the expected number of times vehicles in class v pass vehicles in class u on a one mile segment during a one hour time period. Therefore, the result must be multiplied by the segment length and time period to obtain the predicted number of passings.

The relevant accident configurations are: Car into Car (CC), Car into Truck (CT), Truck into Car (TC), and Truck into Truck (TT). The predicted number of passings for each of these combinations is obtained by carrying out the integration shown in equation (1) four times, each time using the appropriate quantities for Du, Dv, h(u), h(v). This computation is performed using techniques of numerical integration.

A basic assumption of this model is that no queues form, and that the occurrence of a passing situation does not cause either vehicle to alter its speed. Application of this model is appropriate for any increment of roadway and time over which the densities and speed distributions of the two classes do not vary. However, passenger car traffic volume varies considerably. In particular volume is known to follow hourly, weekly, and seasonal trends. Truck traffic also varies, although to a lesser extent. Traffic speed also varies depending on the location, time, density and other factors. Since the interaction model can only be applied to periods of roughly consistent density and speed distributions, it is necessary to know the appropriate monthly, daily, and hourly distributions.

A more detailed description of the application of this model is presented in Appendix A. In summary, however, each segment-month was divided into eight periods defined by a four 6 hour time periods and a division between weekdays and weekends. A segment was the section of road between two interchanges. Speed distributions for cars and truck were obtained for each month, and the vehicle mileage for each vehicle type was allocated to the appropriate periods of the month as in the temporal vehicle mileage calculation. The results of the Interaction Model (I.M.) are aggregated by simply summing the predicted number of passings for each of the four collision configurations.

3.2 Data Requirements

3.1.1 Requirements. Three types of data are required to perform the analyses described in the previous section. The three types are:

(1) exposure (vehicle miles)

(2) accident

(3) speed.

All three are required for the interaction model. The three types will be discussed generally but separately The specific requirements for each type provided much of the criteria for the selection of toll roads for the study.

The primary unit of exposure used in the study is the amount of travel in vehicle miles. Computation of overtaking rates for the interaction model requires the use of average density (vehicles per unit distance). Both vehicle miles and density can be derived from traffic volume (the number of vehicles passing a point in unit time) although the derivation of density also requires knowledge of speed. Thus a traffic measure basic to the study is volume. Over the time intervals used in the basic analysis units (six hours), the volume on a highway is constant over a segment defined by adjacent points of access. Volume may vary from segment to segment. The mix of vehicles, i.e., cars and trucks, which is studied with the interaction model may also vary by segment. Therefore traffic volume is required by vehicle type and by segment.

All toll roads use either of two methods for collecting tolls from which volume can be generated. The most common on roads with long average trips and infrequent access is the use of tickets. On such roads the original data is in the form of origin-destination by toll class. Computation of both volume and vehicle miles is possible from origin-destination data and some roads reguarly compile tabulations of both. The alternative collective technique used is the barrier method in which a toll is collected at one or more points per trip regardless of the destination. This method allows a precise measure of volume at the collection points, but does not permit equally precise computations of vehicle miles since the trip lengths are not necessarily defined, or of volume over individual segments of the road. Thus the ticket collection method provides more suitable exposure data for this study.

In addition to the above, traffic data are necessary to derive volume by segment and toll class in detail sufficient to describe or estimate seasonal, daily, and hourly traffic patterns. The interaction-model is only relevant to the extent that it can reflect the actual mix (by vehicle type) of traffic concurrently using the road. Differences in the patterns for the two types of vehicle can alter the mix substantially.

The accident data used in the study is provided by normal police investigations. The only special requirements were that the data be available in a digital form. The variables essential to the analysis are:

(1) time of day

(2) date or month and day of week

(3) collision type and configuration

(4) type of vehicles involved

(5) location of accident.

The time of the accident—both date and hour--were needed with a resolution adequate to place the occurrence within the appropriate analysis unit and the specific 6 hour period. All police reports provide this data. Some of the roads that were selected code the day of week, which was used to determine if the case occurred on a weekday or weekend. Alternatively, HSRI derived the weekday-weekend variable from the complete date.

The collision type and configuration together with location is necessary to determine which accidents occurred on the mainline rather than in service plazas, entrance-exit ramps, toll booth area, etc. These latter cases were deleted from the study because they are not representative of general interstate highway experience. While the entrance-exit ramps may seem common to both kinds of highways, it is not always possible to determine from digitized accident data, whether a crash in such an area was or was not influenced by the proximity to a toll facility. Furthermore, travel in these areas is not controlled by the general speed limits on the highway. The collision type was also necessary to determine which accidents were single vehicle involvements, and which could be represented by the interaction model.

Information on vehicle type was necessary to determine which were cars and which were large trucks - the dichotomy used for analysis.

Accident location was necessary to determine on which highway segment the crash occurred. Fortunately, the location of all turnpike crashes is documented by milepost. This provides a convenient and adequate basis for determining the specific segment and assigning the appropriate traffic data.

Application of the interaction model requires the probability density function of travel speed for each of the two vehicle types. While complete descriptions of the density function are not given in publications of speed surveys, the empirical distribution can be obtained from the raw field data sheets used in such surveys. The distributions are discussed in more detail in Appendix A. It was found that the usual practice of assuming travel speeds are normally distributed provides an adequate approximation for estimation of passing rates. Thus information allowing estimates of the mean and variance of speed are sufficient. The speeds of both vehicle types and both before and after the intervention of the energy crisis are required. Speed surveys have not been conducted on many toll roads routinely in the past, however, and this requirement presents one of the more difficult data problems. Since the energy crisis, many more surveys have been conducted, but data on traveling speed before the crisis was one of the more difficult data requirements to resolve.

3.1.2 Toll Road Survey. The selection of toll roads included in the study was based on several factors. These included: availability of suitable traffic and accident data, existence of speed data for 1973 and 1974, geographic representation of toll roads, and quantity of data. The project was structured to include analysis of approximately five to seven roads. A mail survey of each toll road in the United States was conducted to determine the availability and suitability of the necessary data from each. A list of the toll roads is given in Table 3.1, and includes all such roads in the continental United States except several short roads in Florida and the West Virginia Turnpike. The latter was included in the survey but was dropped from consideration early because it is a two-lane, undivided highway. Toll roads in Texas and Delaware were dropped because they are short. Many of the toll roads collect tolls at barriers located such that volume (and in turn vehicle-miles) cannot be determined on each segment, or do not use a toll rate structure that allows differentiating the type of vehicle. These roads include those in Connecticut, Delaware, Illinois, Kentucky, Maryland, the Garden State Parkway in New Jersey, and Virginia. New Hampshire and Massachusetts do not have accident data automated in a manner compatible with the hardware at HSRI. The New Jersey Turnpike Authority was conducting their own study and could not participate in this project until too late for inclusion.

Florida was considered a desirable road because it is the only toll road in the south. The accident data for 1974 was not automated in time for inclusion in the study, however. The Indiana Toll Road was eliminated because it would add only a small amount of data to the Pennsylvania-Ohio axis. The Oklahoma and Kansas roads share many common geographic and climatic characteristics. Since traffic by segment is available on only a portion of the Oklahoma Turnpike(s), Kansas was selected.

TABLE 3.1

CANDIDATE TOLL ROADS

Toll Road	1 Length Miles	2 Traffic 10^8 Miles	3 No. Fatal Acci- dents	4 No. Acci- dents	5 Speed Limit Car/ Truck
Connecticut Turnpike	129	19.0	37	2631	70/65
Delaware(JFK)	11	2.1	5	249	60/60
Florida Turnpike	307	15.9	34	2112	70/70
Illinois Tollway	256	23.2	28	3191	70/55
Indiana Toll Rd.	157	6.7	17	967	70/70
Kansas Turnpike	233	5.5	18	860	75/75
Kentucky (All)	673	12.6	27	923	70/70
Maine Turnpike	100	4.6	9	621	70/55
Maryland (JFK)	42	5.2	12	555	70/60
Massachusetts Turnpike	134	12.4	24	1252	65/50
New Hampshire	78	5.0	7	338	70/70
Garden St. Pkwy	173	25.6	25	2154	60/60
New Jersey Turnpike	131	27.5	47	2306	60/60
New York Thruway	496	43.2	72	6098	65/55
Ohio Turnpike	241	16.5	22	1902	70/55
Oklahoma (All)	420	8.6	20	530	70/60
Pennsylvania Turnpike	469	28.2	38	3148	65/55
Dallas-Ft.Worth	30	4.7	2	878	70/60
Richmond-Petersburg, Va.	35	4.9	6	799	65/55

TABLE 3.1 (continued)

1. Road length taken from 1974 Rand McNally Road Atlas.
2. 1973 Traffic provided by the International Bridge, Tunnel and Turnpike Association, Inc., Washington, D.C., given in 100 million vehicle miles.

3,4. National Safety Council 1973 annual figures.
5. Daytime speed limits prior to energy crisis taken from Rand McNally Road Atlas and "Trucking Safety Guide" published by J.J. Keller and Associates, Inc.

The remaining five roads were included in the study. These are the Kansas Turnpike, Maine Turnpike, New York Thruway, and the Ohio and Pennsylvania Turnpikes.

Speed data by vehicle type is available for periods after the intervention of the crisis on many roads, but for only a few for the "before" period in 1973. On the roads deleted from the project, only the Connecticut and New Hampshire Turnpikes could provide pre-crisis speed surveys. Before and after speed data was used from Kansas, Maine, Ohio, and New York, and is discussed in detail in a later section.

Table 3.2 presents a brief physical description of the project toll roads for those wishing to compare their general features with interstate highway practice.

The annual travel in vehicle-miles on the five roads included in the study is 29 percent of the total travel on all toll roads in the United States.

TABLE 3.2

PROJECT TOLL ROADS
PHYSICAL DESCRIPTION (2)

Toll Road	Length (mi.)	Dividing Strip (ft.)	No. Lanes (each dir.)	Width Lanes (ft.)	Width Shoulders (ft.)	Max. Grade (%)	Maximum Curvature	Design Speed (mph)
Kansas Turnpike	236	20(grass)	2	12	4-10	3	3°	75
Maine Turnpike	106	18(grass)	2	12	4-8	5	5730'	70
New York Thruway	426	44(grass)	2-3	12-13	4-9	3	2800'	70
Ohio Turnpike	241	40(grass)	2	12	8-10	3	2292'	--
Pennsylvania Turnpike	470	4-10	2	12	10	3	6°	70

(2) Survey of Toll Road Construction and Design, International Bridge, Tunnel, and Turnpike Association, Revised 1975, Washington, D.C.

4.0 SPEEDS

This section describes the speed data which were utilized. Sufficient amounts of speed data were obtained for all of the roads except Pennsylvania. In general there was much more data available for the post-energy crisis period than for the pre-crisis period. The first part of this section discusses the general trends observed in these data. This is followed by a road by road presentation of the data and a discussion of the interpretation of the surveys for each road.

4.1 General Trends

The speed changes were summarized in Table 4.1 of the Summary. The average decrease in car mean speed is 8.2 mph and the average decrease in truck mean speed 4.3 mph. For truck mean speed this average is the result of three roads, Kansas, Maine, and New York having a 6-7 mph decrease while Ohio and Pennsylvania showed essentially no change in truck mean speeds. The decreases in standard deviations of car speeds found in other studies[3] were not found here.

The issue of speed differential is somewhat clouded. In Kansas and Maine the differential was only

(3) For example, "Effects of the Speed Limit". American Association of State Highways and Transportation Officials, November, 1974.

TABLE 4.1

SUMMARY OF SPEEDS

Toll Roads	1973 Daytime Speed Limits	Results of Available Speed Surveys					
		Before		After		Speed Differential***	
		Mean Speed	Standard Deviation	Mean Speed	Standard Deviation	Before	After
KANSAS							
Cars	75	68.20*	7.38*	59.59	5.16	3.2	1.77
Large Trucks	75	65.00*	6.50*	57.82	5.19		
MAINE							
Cars	70	67.19	5.89	59.02	4.89	2.48	1.74
Large Trucks	55	64.71	4.37	57.28	4.00		
NEW YORK							
Cars	65	65.45	5.89	57.31	5.11	5.68	3.06
Large Trucks	55	59.77	5.33	54.25	4.61		
OHIO							
Cars	70	71.48	5.69	61.28	6.07	12.8	1.88
Large Trucks	55	58.68	4.21	59.40	4.52		
PENNSYLVANIA**							
Cars	65	65.4	--	59.5	--	6.0	2.00
Large Trucks	55	59.4	--	57.5	--		

*Speed surveys were not taken on the Kansas Turnpike before the energy crisis. Speed data from Kansas Interstate roads were used for car speeds. Truck mean speed was subjectively estimated by a member of the Kansas Highway Patrol, Turnpike Division since the Interstate speed limit for trucks was 60 MPH rather than 75 MPH.

**Sufficient speed surveys were not available in Pennsylvania. Mean speeds from a single station on the Turnpike are shown here for comparison.

***The differential is the mean car speed minus the mean truck speed.

about 3 mph before the energy crisis. This differential decreased to approximately 2 mph. New York and Pennsylvannia showed a decrease in the speed differential of about 3 mph in going from a 6 mph differential to a 2-3 mph differential. The Ohio Turnpike is the only road which showed an appreciable change in the speed differential between cars and trucks. Before the energy crisis this differential was nearly 13 mph. After the imposition of 55 mph speed limits this differential decreased to approximately 2 mph.

While it is of interest to summarize the results for the pre- and post- energy crisis periods, those roads which collected speed data on a regular basis provide sufficient information to reveal considerable variation in speeds beginning with the energy crisis in November and continuing through all of 1974. To some degree these variations arise from the particular chronology of speed limits and enforcement on each road. In general the two year period (1973-1974) can be discussed in three segments. During the first ten months of 1973 speeds were stable, although different from road to road. Beginning in November with the President's call for a voluntary 50 mph speed limit, a transition period began which continued until adoption and enforcement of the 55 mph speed limit. Little information is available during this period to address the variability of speeds on a given road, but there was variability road to road in the response. In general, the reduction in car speeds under the voluntary 50 mph was about half the reduction obtained under the enforced 55 mph limit. Commencing with the beginning of enforcement of the 55 mph limit the two roads which conducted surveys on a periodic basis (Kansas and New York) showed a steadily progressing trend of increasing speeds throughout the remainder of 1974. As far as is known, at the beginning of the enforced 55 mph limit, car and truck speeds were both close to the limit for all of the roads. By the end of the year car speeds approached 60 mph with truck speeds about 2 mph less.

All of these results must be tempered by a knowledge of the manner in which these speed surveys were conducted. Historically, speed surveys are carried out to aid transportation officials in planning. Their objective is to measure "free flowing" speeds intended to represent the speeds at which people would prefer to drive in the absence of any restrictions such as traffic or weather conditions. Consequently surveys are usually limited to low volume periods (mid-morning and mid-afternoon) with clear skies and dry pavement. If their is any queuing in the traffic stream, only the front vehicle of the queue is recorded on the presumption that the others are being impeded. As toll road officials began conducting speed surveys after the energy crisis with the intention of monitoring typical speed conditions, these survey techniques were adhered to in varying degrees. Although attempts were always made to conceal the speed detecting equipment, measurements were made from parked cars in some states and the influence of CB radio use by truckers may have influenced the results obtained.

4.2 Speed Data by Road

This section describes in more detail the speed data received from each road. The manner in which the data were combined and extrapolated is unique to each road because of the variety of data received. For each road a monthly plot of car and truck speeds is also presented.

4.2.1 Kansas Speed Data. Speed data for the Kansas Turnpike were furnished by the Kansas Highway Patrol, Turnpike Division. No speed surveys were conducted prior to November, 1973. Starting in November, 1973 a total of 105 surveys were conducted over the period ending December, 1974. For the Kansas Turnpike the legal speed limit was 75 mph day and 70 mph night for cars and trucks. Fifty-five became the legal speed limit on March 6, 1974 in Kansas, but enforcement did not begin until April 1. As of July 1, 1973, it became legal on other roads in Kansas for trucks licensed for a gross vehicle weight of less than 12,000 lbs. to observe passenger car speed limits. The previous limit was 8,000 lbs. For purposes of the speed survey then, only speeds of trucks appearing to weigh more than 12,000 lbs. were recorded. Passenger cars with trailers, pickup trucks, and panel trucks were recorded as cars. These surveys were conducted without regard to weather conditions, during the night, as well as the day, on all days of the week, on most segments, on weekends as well as weekdays, and during all of the months in this time period except May, 1974. In summary, the speed data obtained through the Kansas Turnpike Authority were far more suitable for this project than those obtained from other states.

These data were built into a file containing mean speeds, standard deviations, and number of observations for cars and trucks plus the information available defining the time and location of the survey. Normally 100-200 cars would be observed in each survey along with the trucks (20-40) which passed during that time period. In general, the number of observations decreased during periods of reduced volumes indicating some constraint on the period of observation also.

This file was then used to evaluate several factors in relation to the mean speeds. No significant differences (either statistical or practical) in mean speed were found across the segments of the road. However, monthly variations were significant and these were retained. Mean speeds and standard deviations were computed for each month by combining the data from the separate surveys. The mean speeds were weighted by the sample size and a pooled variance was calculated. Variations in mean speed by time of day and day of week were also evaluated. Time of day was coded as either day or night, and day of the week was grouped into week days and weekend days. The differences in mean speeds were generally less than 1 mph. One exception was the day/night difference for cars which was 1.5 mph. Although some of these differences were statistically significant, they were judged not to be of practical significance.

Speed surveys from Kansas Interstate rural highways were used to represent passenger car speeds on the turnpike during the first ten months of 1973. These surveys were conducted during the months of July and August.using concealed radar equipment, by the Planning and Development Department of the State Highway Commission. However, truck speeds from these surveys were not appropriate for the turnpike because the daytime speed limit on the interstate for trucks was 60 mph. As a last resort, a member of the Kansas Highway Patrol Turnpike Division was persuaded to estimate the average daytime speed for trucks prior to the energy crisis. His estimate was 65 mph and a 10% standard deviation was assumed. It was his impression that the relatively high speed limit on the turnpike resulted in a some dispersion of truck speeds. The mean speeds for cars and trucks are shown graphically by month in Figure 4.1. The connecting lines indicate the interpolation which was done. The appropriate data from the interstate surveys is also shown for comparison.

4.2.2 Maine Speed Data. Speed data for the Maine Turnpike were obtained from the Maine Department of Transportation. A total of 26 surveys were taken at three locations. Approximately 200 cars and 20-50 trucks were observed in each survey. Surveys were conducted in October of each year plus June and August of 1974. Speed limits prior to the energy crisis were 70 mph for cars and 55 mph for trucks. Fifty-five became the legal speed limit in March, 1974. In the surveys, truck speeds were obtained for mostly combination units with some single units with dual tires. Speeds in Maine are shown by month in Figure 4.2. There is considerable fluctuation in truck speeds. Conversations with the Maine State Police Troop assigned to the Turnpike revealed a high usage of CB radios by truckers. Trucks were often able to drive 65 mph without interference. In spite of the variations shown, speeds for each month were estimated by interpolating between the available data points.

Figure 4.1

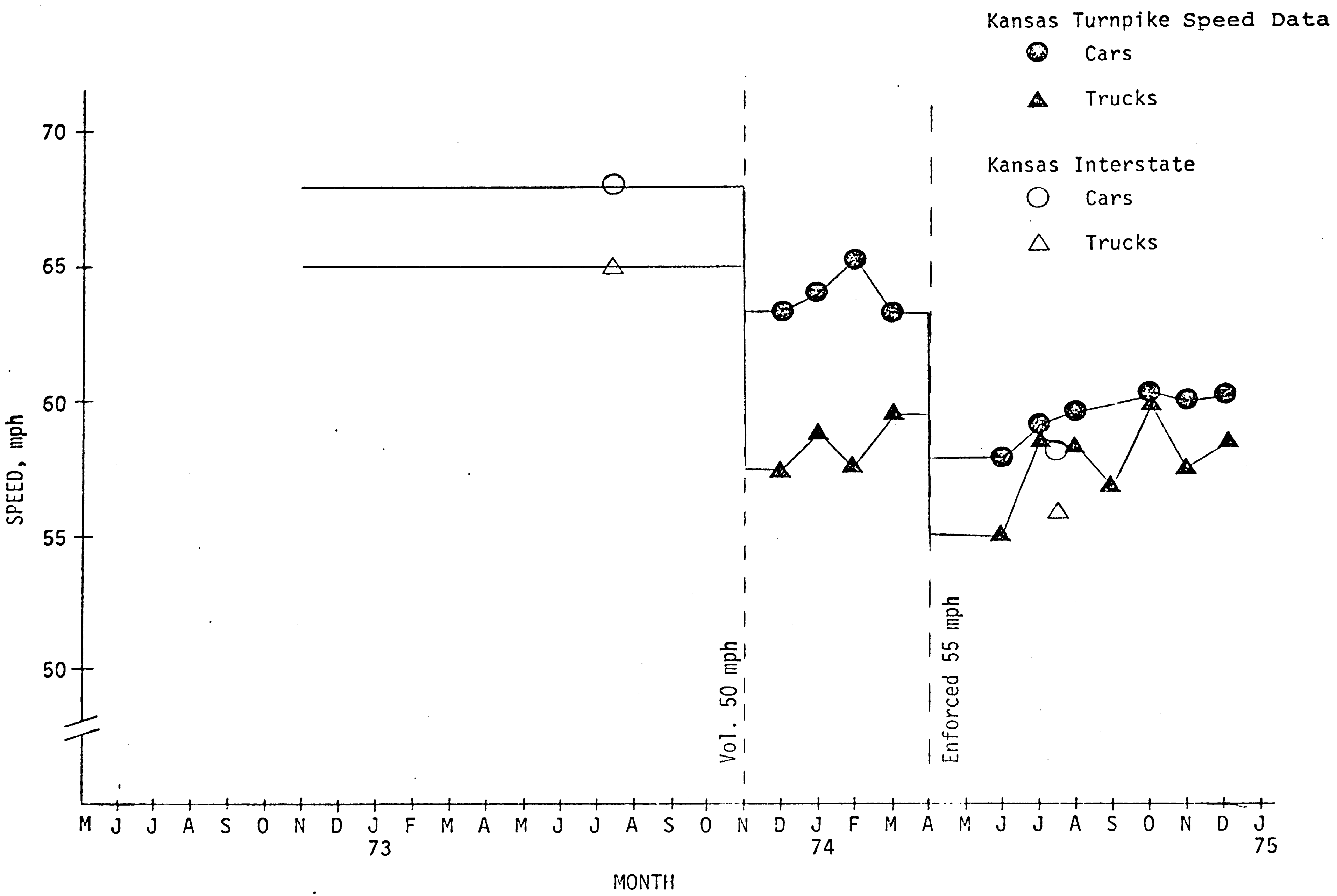
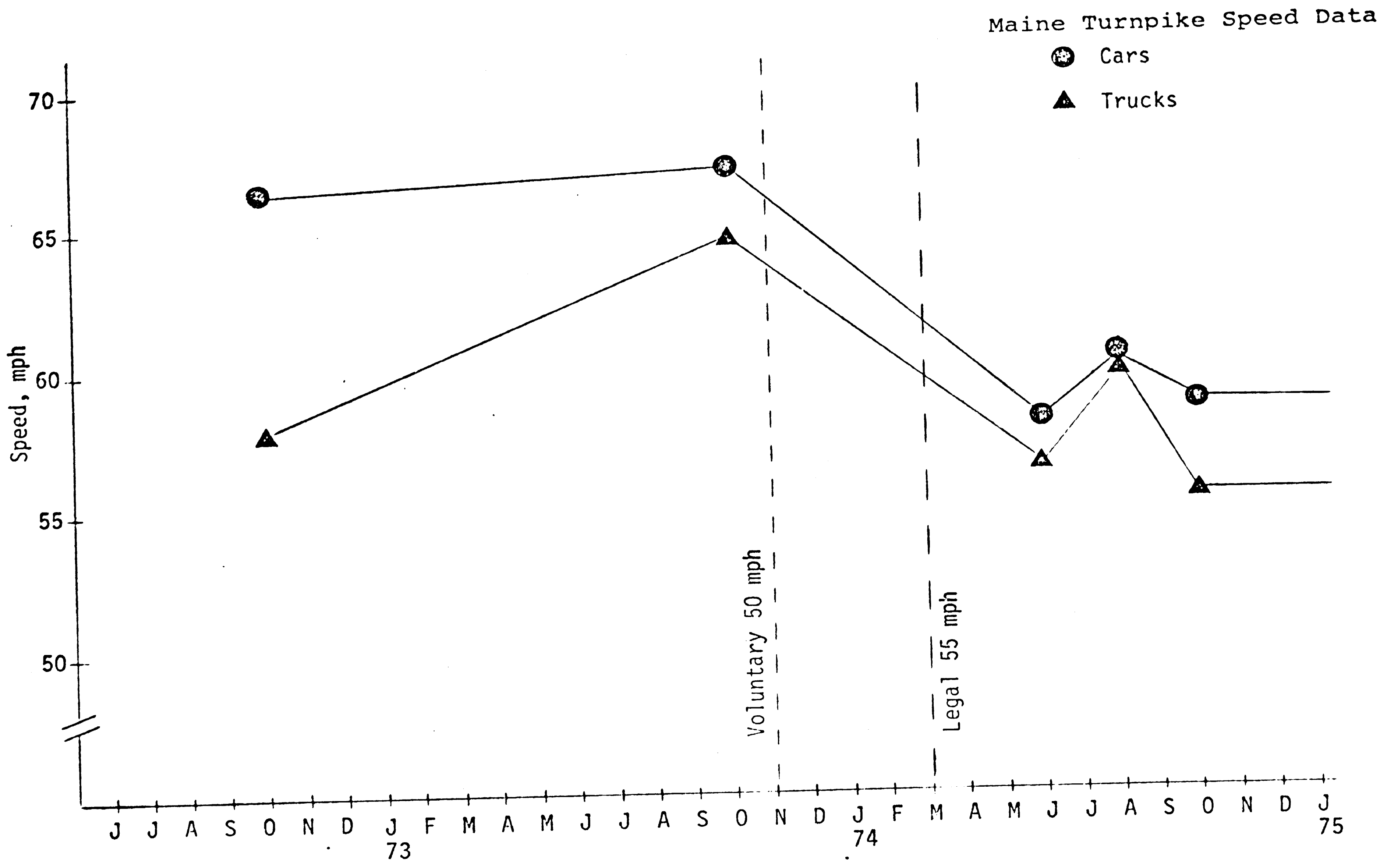

Kansas Turnpike Speed Data
Cars
Trucks
Kansas Interstate
Cars
Trucks
70
65
60
55
50
SPEED, mph
Vol. 50 mph
Enforced 55 mph
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
73
74
75
MONTH

Figure 4.2



Maine Turnpike Speed Data
Cars
Trucks
70
65
60
55
50
Speed, mph
Voluntary 50 mph
Legal 55 mph
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
73
74
75

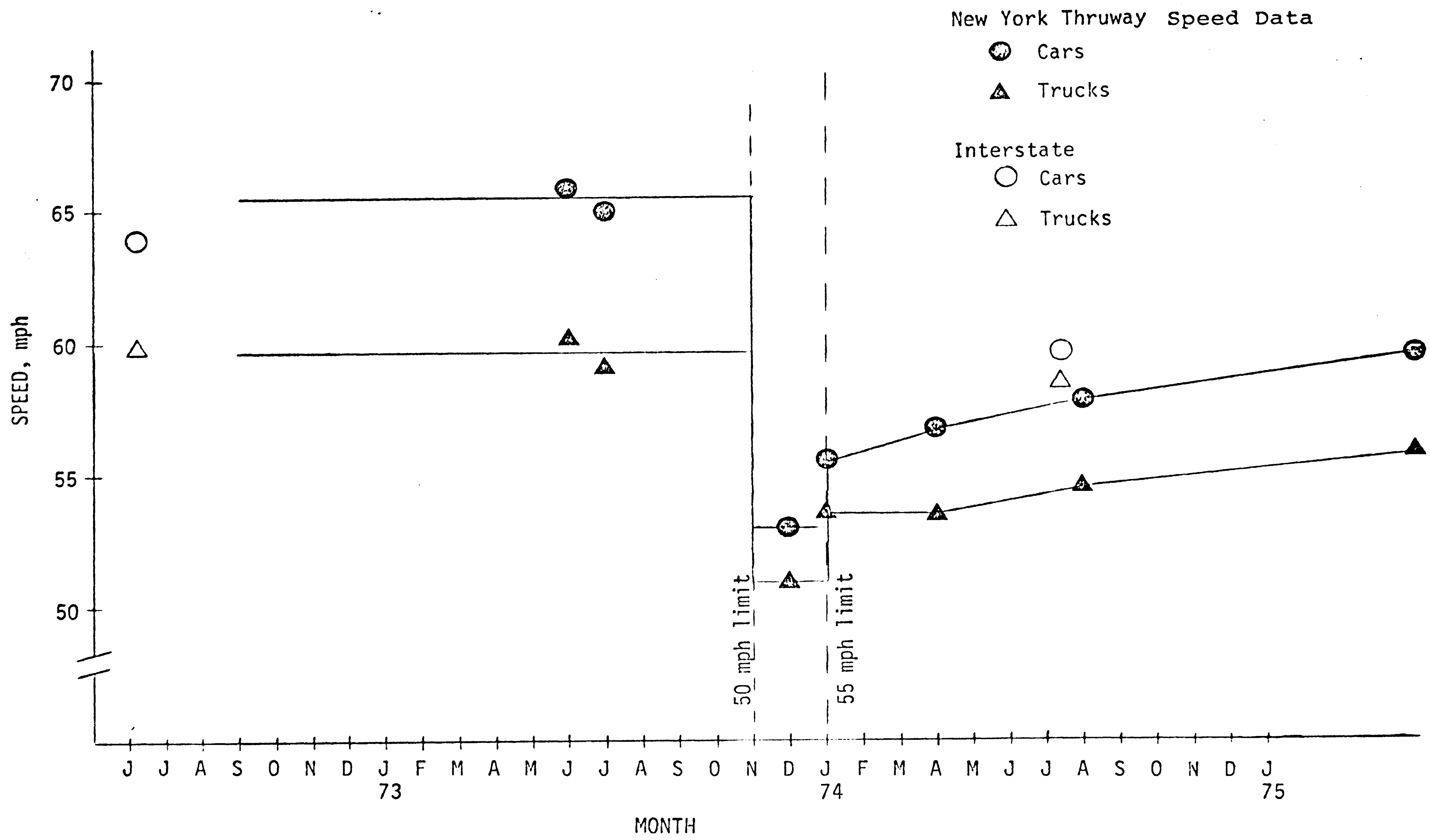
4.2.3 New York Speed Data. Speed data for the New York thruway were obtained from the Thruway Authority. These surveys were taken at four locations spread over the length of the road by state troopers in a concealed parked car using radar units. Surveys were conducted at each of the four sites in June, July, and December, 1973 and January, April, and August, 1974. There were a total of 33 surveys, each involving 500-600 cars and 100-200 trucks.

In response to the President's request, the legal speed limit in New York became 50 mph on November 12, 1973. The limit was raised to 55 mph in January in response to the Federal Emergency Highway Energy Conservation Act which was signed on January 2, 1974. Prior to these changes the legal speed limits on the New York Thruway were 65 mph for cars and 55 for trucks. The truck speed limit applied to combination units and mobile homes.

The speed data from New York are plotted by month in Figure 4.3. Also included are the results of surveys conducted in May, 1975. Of interest is the steady growth in speeds beginning in early 1974. Speed for the months without surveys in 1974 were estimated by interpolating along the solid line shown. Some speeds measured on New York interstate highways are also shown for comparison.

4.2.4 Ohio Speed Data. Speed data for the Ohio Turnpike were furnished by the Turnpike Commission. These data were collected in November of 1972, 1973, and 1974 at each of four locations on the Turnpike. Speeds were recorded separately for car and truck by direction. The data were collected on weekdays during

Figure 4.3



New York Thruway Speed Data
Cars
Trucks
Interstate
Cars
Trucks
70
65
60
55
50
SPEED, mph
50 mph limit
55 mph limit
J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J
73
74
75
MONTH

the mid-morning and mid-afternoon under good weather and dry pavement conditions. All of the speed checks were performed using a speed meter from an overhead structure, with the meter powered by a storage battery. No turnpike vehicle was parked at the site.

November is not an optimum month for speed data since the 1973 surveys fall in the transition period of the energy crisis. At this time the oil embargo had begun and a voluntary 50 mph speed limit had been called for. Legal speed limits had not changed. For these reasons the November, 1972 speed survey was felt to be more representative of conditions during the first ten months of 1973. The November, 1973 survey was used to characterize the transition period from November, 1973 through February, 1974. On March 2, 1974, 55 mph became the legal speed limit in Ohio. The November, 1974 survey was used for the remainder of 1974.

It seemed likely that speeds for the months immediately following imposition of the 55 mph limit would be a little lower than in November, 1974 when fuel shortages had subsided. Speed data from Interstate Roads in Ohio were available for the July-August period of 1972, 1973, and 1974. These speed data are compared with the Turnpike Data in the Figure 4.4. Prior to the energy crisis the Interstate speeds are about 4 mph below the Turnpike. After the energy crisis the Interstate speeds are about 3 mph below those on the Turnpike. The consistency of this difference does not support the premise that Turnpike speeds were significantly lower in July and August of 1974 than indicated by the survey conducted in November, 1974.

Figure 4.3

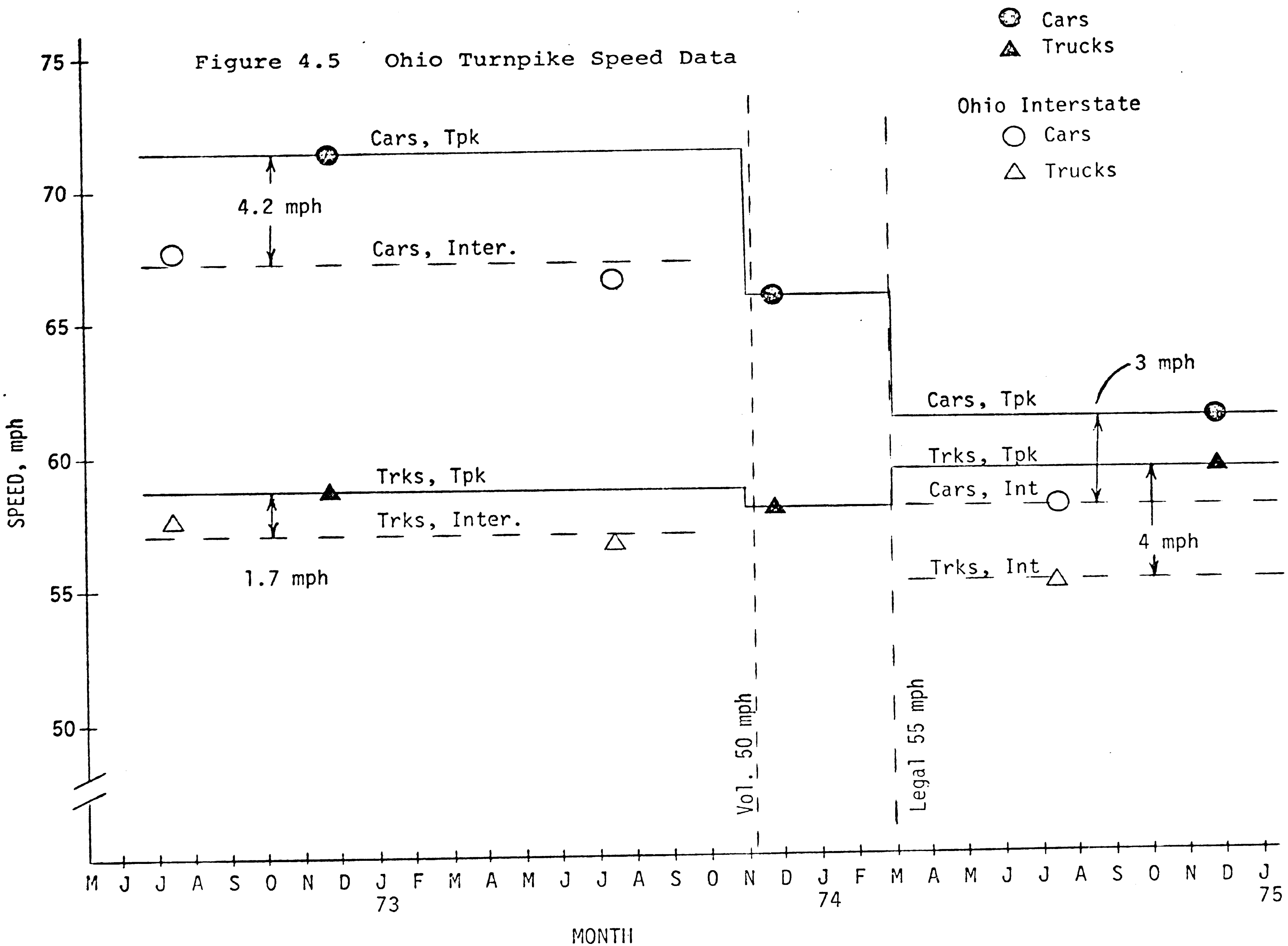


Figure 4.5 Ohio Turnpike Speed Data

For the initial construction of the analysis file, the turnpike was divided into 16 segments defined by the interchanges. The data for east and westbound traffic were tabulated separately for each segment. The speed surveys were conducted in four of the 16 segments (3, 5, 8, and 14). The speed surveys were somewhat arbitrarily assumed to be representative of the adjacent segments in the following groupings: 1-3, 4-7, 8-11, and 12-16. It was observed that the variations in traffic volume approximately followed these groupings.

4.2.5 Pennsylvania Speed Data. The only speed data available for the Pennsylvannia Turnpike were from a single station which was operated for one day in August of each year. Mean speeds obtained from this station were presented in the summary of speeds table in Section 2. The legal speed limit on this road prior to the energy crisis was 65 mph for cars and 55 for trucks.

5.0 TRAFFIC

5.1 Toll Classes

The basic traffic data from all turnpikes were obtained in the form of either origin-destination or "density" reports. The latter form is actually a tabulation of volume by segment. In either case, the data were obtained by month over the two year period. The methods which were used to represent daily and hourly patterns are discussed in Appendix B.

All turnpikes using the ticket method of toll, structure the collection and thus the traffic data, on the basis of toll class roughly defining vehicle size. The data were obtained for each toll class for New York, Ohio, and Pennsylvania, and all three turnpikes define nine toll classes. The traffic data for Kansas and Maine were obtained already collapsed into a dichotomy of cars and all trucks.

Although toll data provide a precise census of travel, its use as a measure of exposure for accident research on specific types of vehicles is not without problems. Agencies which collect and maintain accident data on these roads do not identify vehicles by toll class. Accident files universally identify vehicles by classification such as passenger car, truck (single unit), tractor-semi, truck-trailer, or by similar such characterizations. Toll classes on the other hand, are defined by weight (as in Ohio and Pennsylvania), axle count (as in Indiana), etc.

The New York Thruway uses a very complex classification based on both the number of axles and the specific vehicle configuration. Thirty-six specific configurations are defined in the toll schedule. In addition, double bottoms are given two tickets, one for class five and a second which depends on the combination of units making up the double bottom.

The vehicle types coded in accident data do not all correspond uniquely to specific toll classes. The three-level vehicle categorization used in this study (passenger cars, tractor-trailer combinations, single unit trucks) present such a problem. In particular, single unit trucks may be in a toll class with passenger cars, or if heavily loaded they could be in a class with empty tractor-trailers. Fortunately, the vast majority of the traffic on the toll roads is comprised of passenger cars and tractor-trailers. Errors from contamination of the passenger car classes and tractor-trailer classes by small trucks can be minimized by examining the distribution of classes for low frequency classes representing light trucks.

The distribution of travel by toll class for the toll roads in Ohio, New York, and Pennsylvania are shown in Figures 5.1 to 5.3. The preponderance of passenger cars in class 1 compared to other toll classes is evident on all three roads and even masks variations between the other classes. Because of this, the same information is presented in Figures 5.4 to 5.6 with classes occupied predominately by passenger cars excluded. Class 3 in Ohio contains vehicles of gross weight from 16,001-23,000 lb., with less than half the travel of the next heavier class. Since most single unit trucks are lighter than the vehicles of class 4, class 3 is assumed

FIGURE 5.1

OHIO TURNPIKE
VEHICLE MILES BY TOLL CLASS
1973-1974

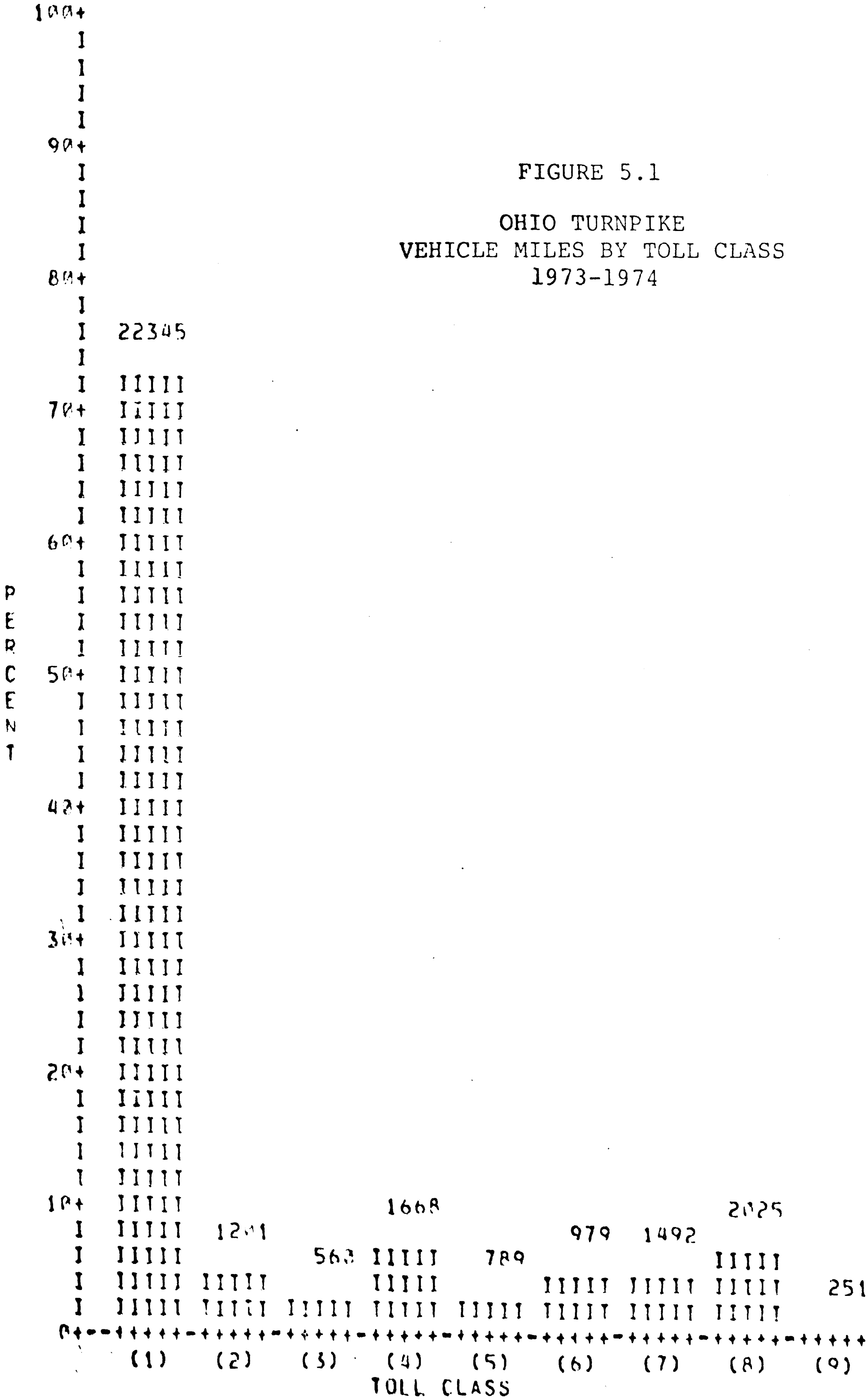


FIGURE 5.2

NEW YORK THRUWAY
VEHICLE MILES BY TOLL CALSS
1973-1974

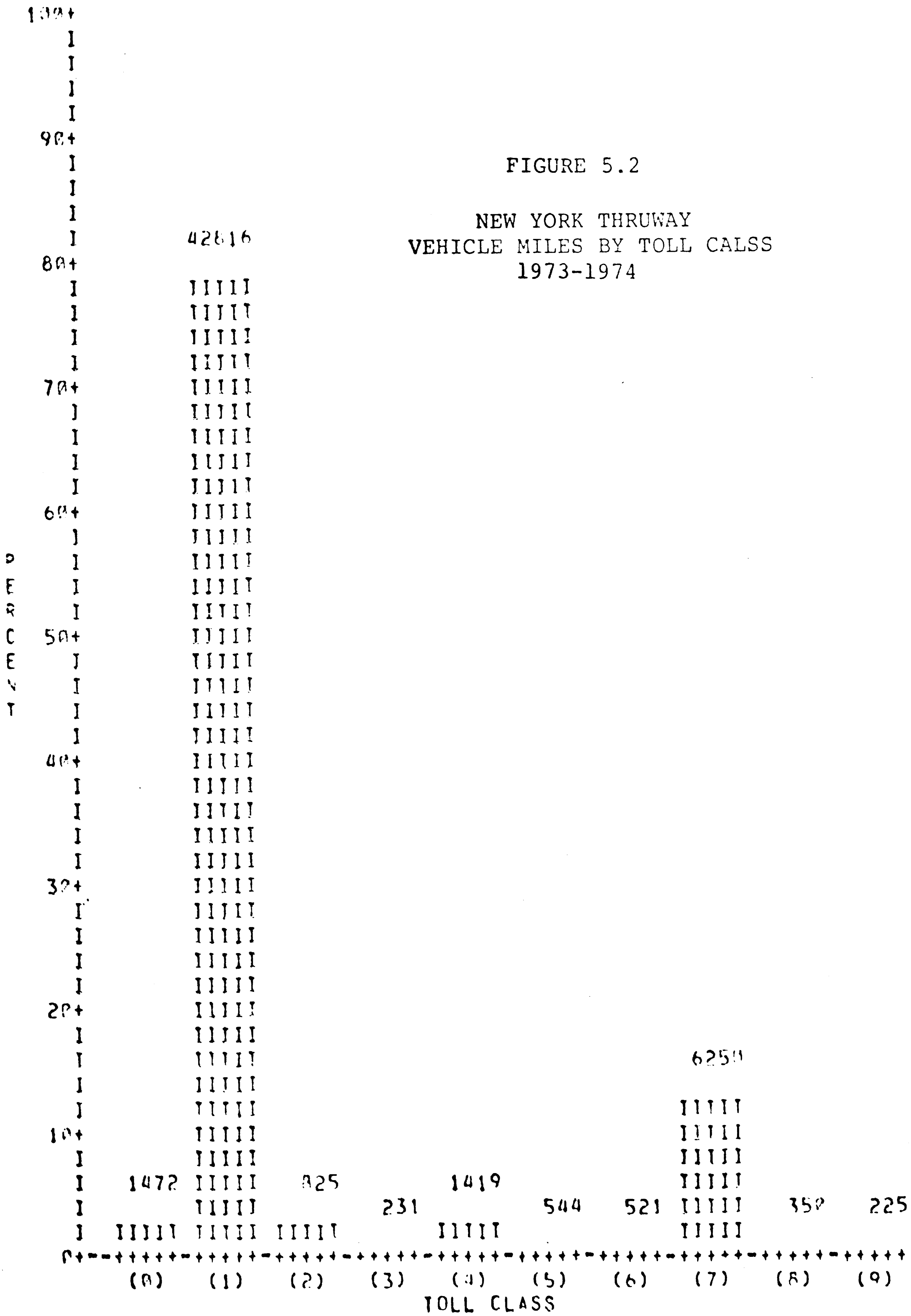


FIGURE 5.3

PENNSYLVANIA TURNPIKE
VEHICLE MILES BY TOLL CLASS
1973-1974

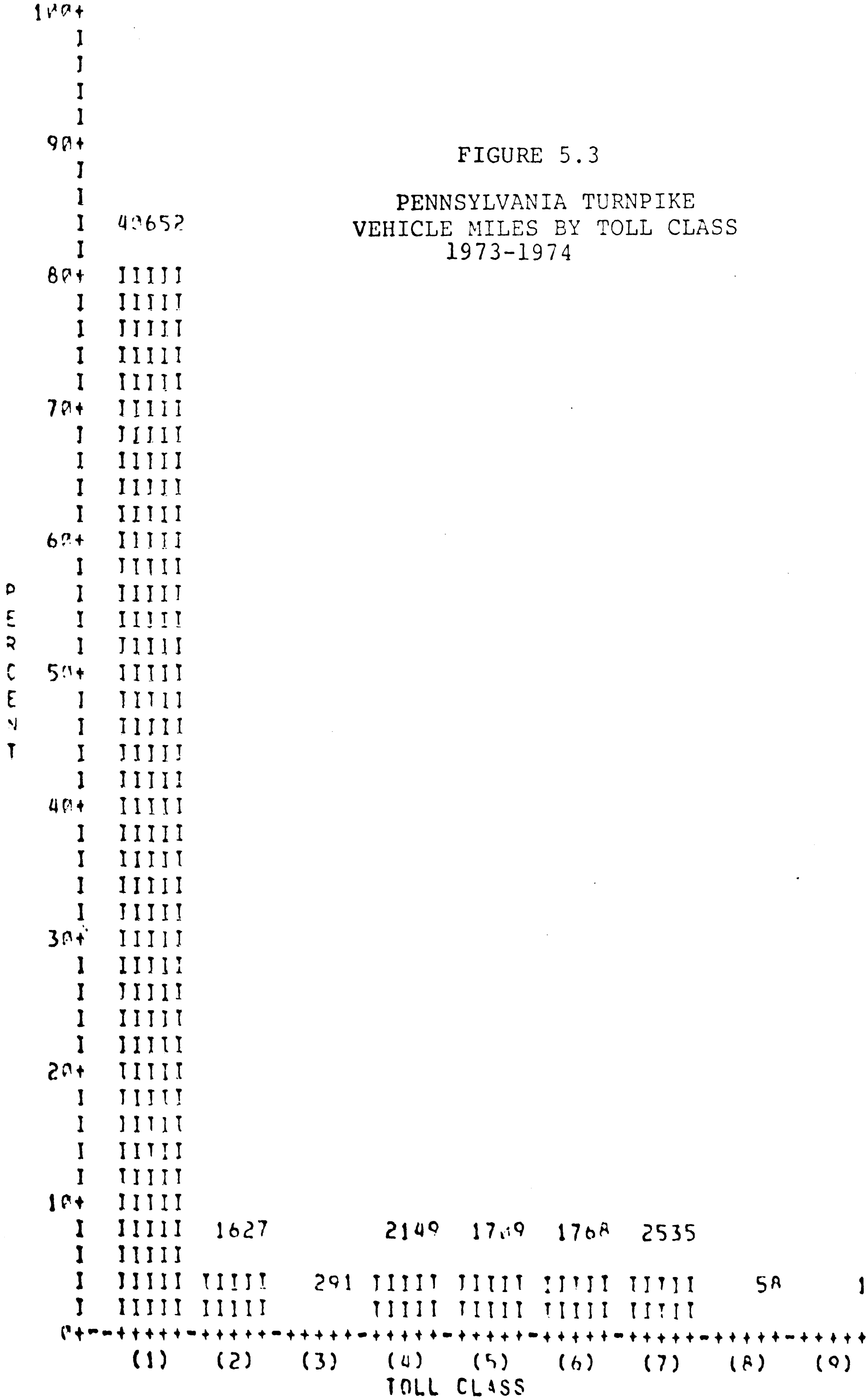


FIGURE 5.4

OHIO TURNPIKE
VEHICLE MILES BY TOLL CALSS
PASSENGER CARS EXCLUDED
1973-1974

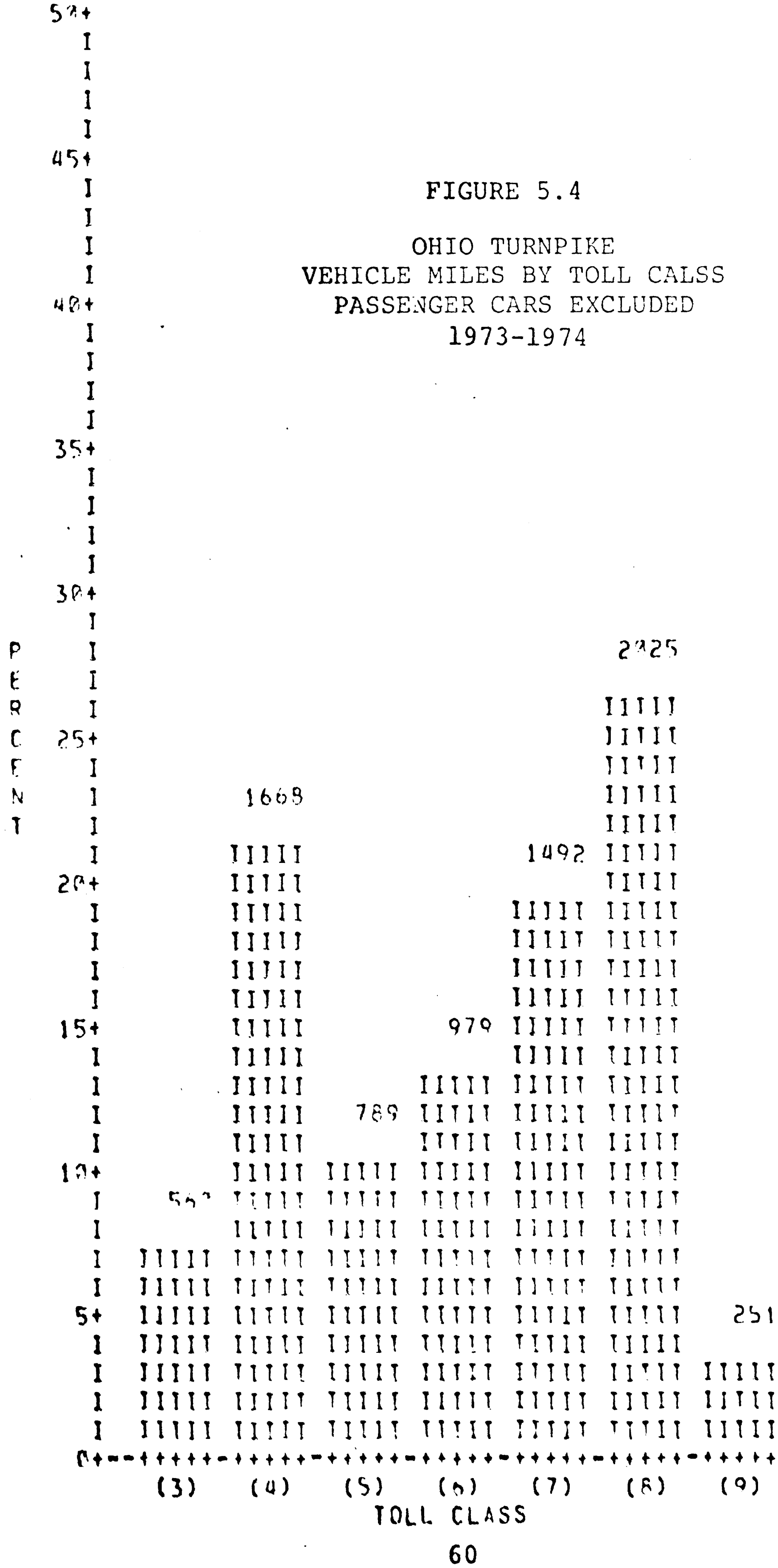


FIGURE 5.5

NEW YORK THRUWAY
VEHICLE MILES BY TOLL CLASS
PASSENGER CARS EXCLUDED
1973-1974

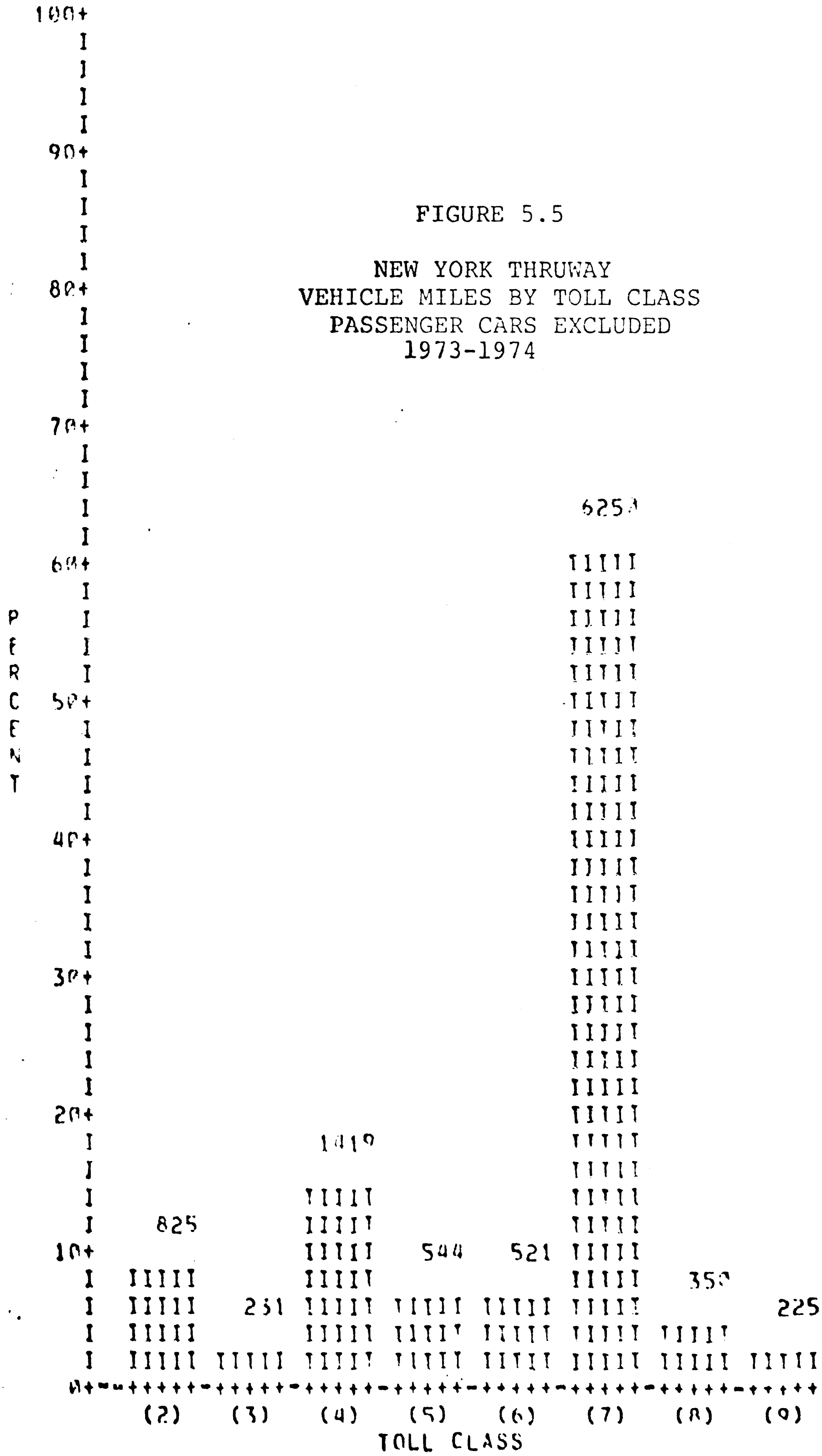
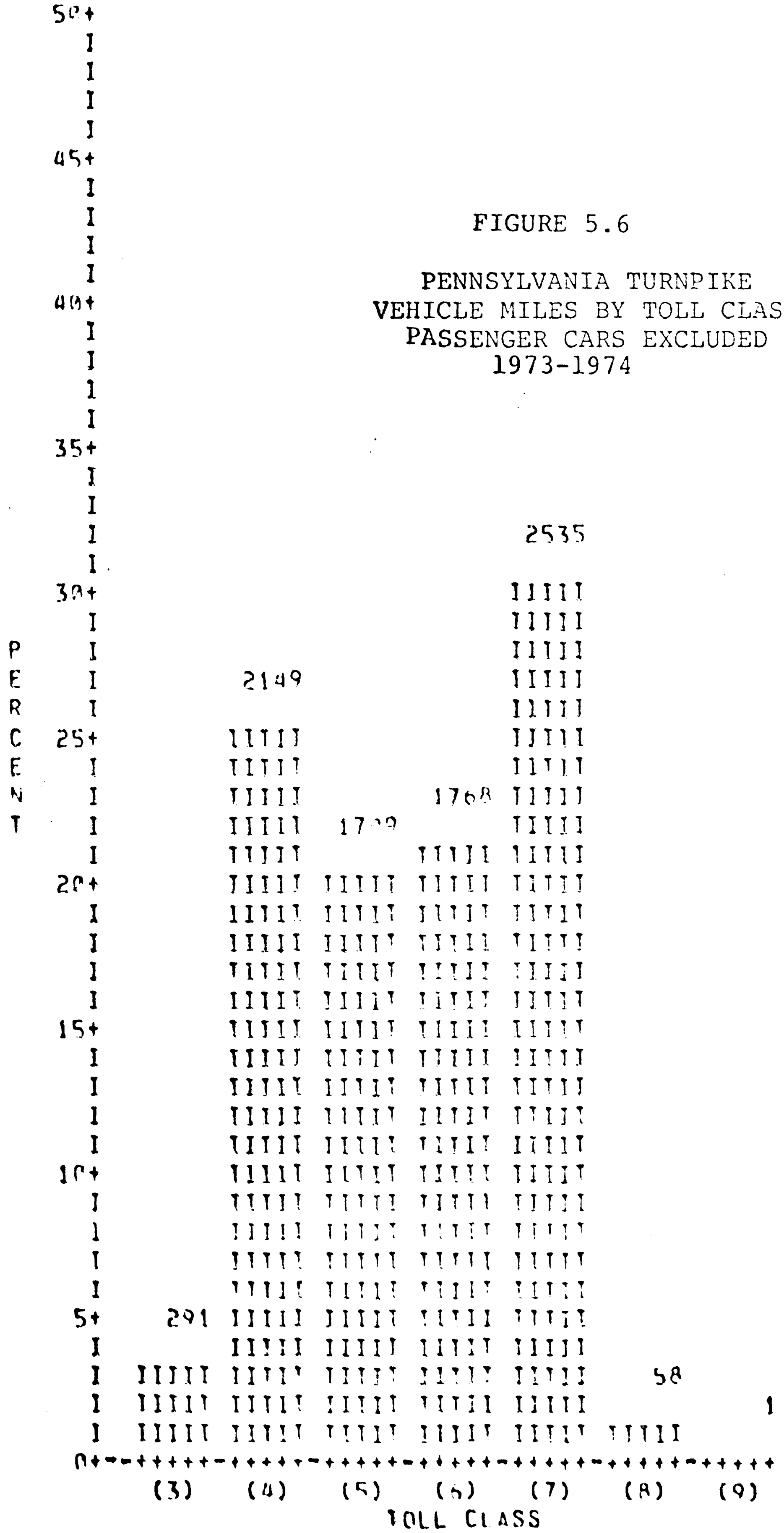


FIGURE 5.6

PENNSYLVANIA TURNPIKE
VEHICLE MILES BY TOLL CLASS
PASSENGER CARS EXCLUDED
1973-1974



to contain those single unit trucks not in class 2, and some lightly loaded or empty tractor trailers. The grouping of toll classes in Ohio used in the study is passenger cars (with or without a trailer) - class 1; large trucks, classes 4-9 plus two-thirds of class 3; single unit trucks and other miscellaneous vehicles - class 2 and one-third of class 3.

The toll classes in New York are much more complex than those based solely on weight. Figure 5.5 indicates that class 7 accounts for most truck traffic. This class includes, among others, tractor-trailers with four or more axles and a single trailer. However, there is no clear division between all combination units and single units. Discussion with personnel of the Thruway Authority lead to the following grouping for New York:

Passenger Cars - Classes 0, 1

Single Unit Trucks/Others - Classes 2, 4, 6, 8

Large Trucks - $\frac{\text{Class 3}}{2}$, $\frac{\text{Class 5}}{2}$, Class 7

Classes 3 and 5 were divided by two because of the use of multiple tickets for a single user in these classes.

The toll structure in Pennsylvania is similar to that in Ohio except that class 4 begins at 19,000 lbs. rather than at 23,000 lb. as in Ohio. We assumed that all combination units would be in class 4-9 therefore, with all single unit trucks in class 3. Class 2 (7,000-15,000 lb.) could contain light straight trucks, but would also contain many passenger cars with trailers and was therefore included with passenger cars. Since class 2 is only four percent as great as class 1, the small number of trucks in class 2 results in only a small error in the computed passenger car travel.

With the grouping of toll classes described above, the travel by vehicle can be obtained. The resulting distributions of travel by vehicle type are shown in Figures 5.7 through 5.11 for the five toll roads. The figures at the top of each column are 10^5 vehicle miles of travel in 1973 and 1974 combined. The distributions are listed in Table 5.1.

5.2 Results

Passenger car travel on the toll roads was lower, as expected, in 1974. However, the large truck travel changed very little. The travel of these two types of vehicles are shown in Figures 5.12-5.16 by month for each toll road. The figures are very similar for all five roads. The car traffic shows the typical summer peak of recreational travel, with nearly three times as much travel in August as in January on the Ohio Turnpike. The reduction in car travel in 1974 is nearly uniform throughout the year on all roads, with the exception of December which has more travel in 1974. This reversal in December is partly the result of the onset of the effects of the energy crisis causing a reduction of travel in December 1973. The curves representing large truck travel are noteworthy. The truck travel is nearly uniform throughout the year, and changes very little from 1973 to 1974. Furthermore the small variations from month-to-month which might appear to represent a random component are also duplicated in both years. This is particularly apparent in Ohio, New York, and Pennsylvania.

The reduction in travel in percent are given in Table 5.2 by month for passenger cars and in Table 5.3 for large trucks. The results for passenger cars (Table 5.2) are plotted in Figure 5.17. This figure also

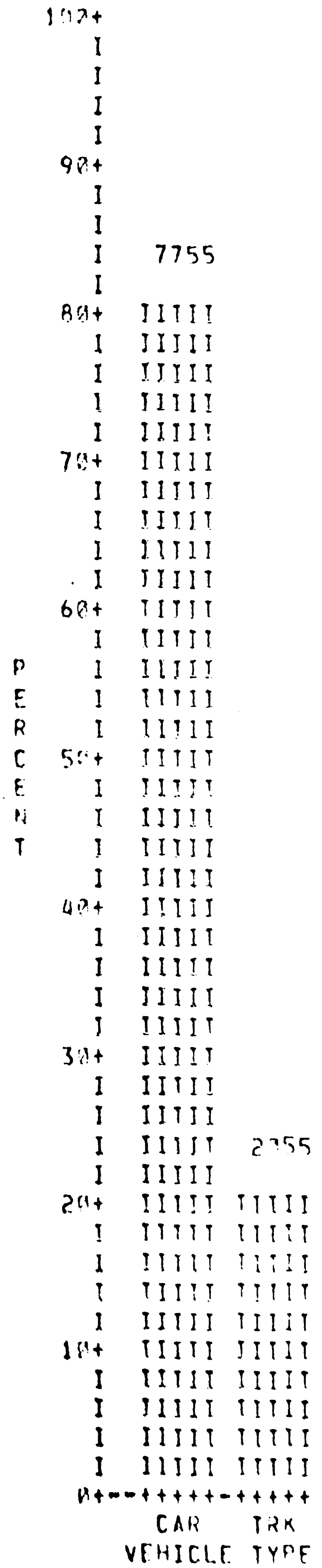


FIGURE 5.7

KANSAS TURNPIKE
VEHICLE MILES BY VEHICLE TYPE
1973-1974

FIGURE 5.8

MAINE TURNPIKE
VEHICLE MILES BY VEHICLE TYPE
1973-1974

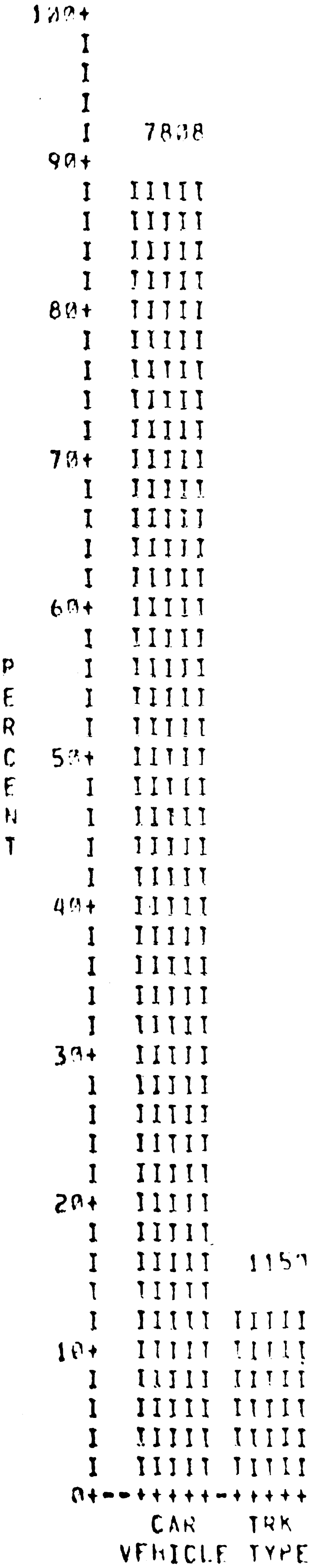


FIGURE 5.9

NEW YORK THRUWAY
VEHICLE MILES BY VEHICLE TYPE
INDICATING CONTRIBUTION BY TOLL CLASS
1973-1974

```
      100+
         I
         I
         I
         I
       90+
         I
         I   44288
         I
         I   11111
       80+   11111
         I   11111
         I   11111
         I   11111
         I   11111
       70+   11111
         I   11111
         I   11111
         I   11111
         I   11111
       60+   11111
         I   11111
   P     I   11111
   E     I   11111
   R     I   11111
   C   50+   11111
   E     I   11111
   N     I   11111
   T     I   11111
         I   11111
       40+   11111
         I   11111
         I   11111
         I   11111
         I   11111
       30+   11111
         I   11111
         I   11111
         I   11111
         I   11111
       20+   11111
         I   11111
         I   11111           7025
         I   11111
         I   11111          77777
       10+   11111   3115   77777
         I   11111          77777
         I   11111  66666   77777
         I   11111  44444   77777
         I   00000  22222   55555
         0+--+++++-+++++-+++++
              CAR    STK    TRK
              VEHICLE TYPE
```

FIGURE 5.10

OHIO TURNPIKE
VEHICLE MILES BY VEHICLE TYPE
INDICATING CONTRIBUTION BY TOLL CLASS
1973-1974

```
      100+
         I
         I
         I
         I
       90+
         I
         I
         I
         I
       80+
         I
         I  22345
         I
         I  11111
       70+  11111
         I  11111
         I  11111
         I  11111
         I  11111
       60+  11111
         I  11111
  P      I  11111
  E      I  11111
  R      I  11111
  C    50+  11111
  E      I  11111
  N      I  11111
  T      I  11111
         I  11111
       40+  11111
         I  11111
         I  11111
         I  11111
         I  11111
       30+  11111         7577
         I  11111
         I  11111        99999
         I  11111        88888
         I  11111        88888
       20+  11111        88888
         I  11111        77777
         I  11111        77777
         I  11111        77777
         I  11111        66666
       10+  11111        55555
         I  11111  1388  55555
         I  11111        44444
         I  11111 22222  44444
         I  11111 22222  33333
        0+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
             CAR    STK    TRK
              VEHICLE TYPE
```

FIGURE 5.11

PENNSYLVANIA TURNPIKE
VEHICLE MILES BY VEHICLE TYPE
INDICATING CONTRIBUTION BY TOLL CLASS
1973-1974

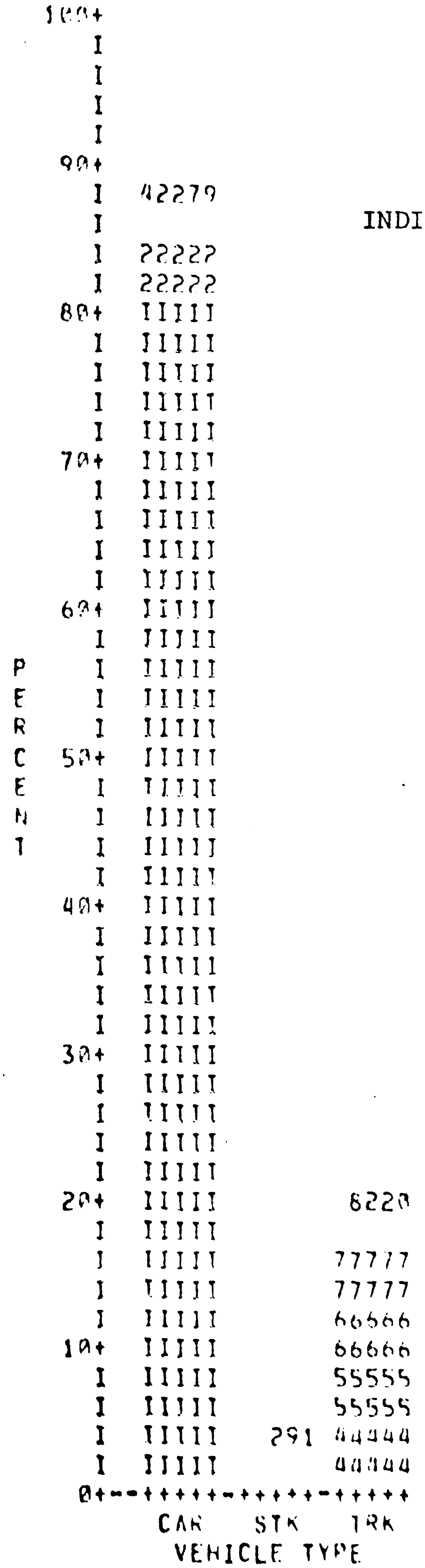


TABLE 5.1

RELATIVE TOLL ROAD TRAVEL BY
TYPE OF VEHICLE 1973-1974

Toll Road	Proportion of travel in percent		
	Passenger Cars	Straight Trucks Others	Large Trucks*
Kansas	79.1	---	20.9*
Maine	87.2	---	12.8*
Ohio	71.4	0.6	28.0
New York	81.3	5.7	12.9
Pennsylvania	83.2	0.6	16.2

*All trucks was included as one group in the data for Kansas and Maine.

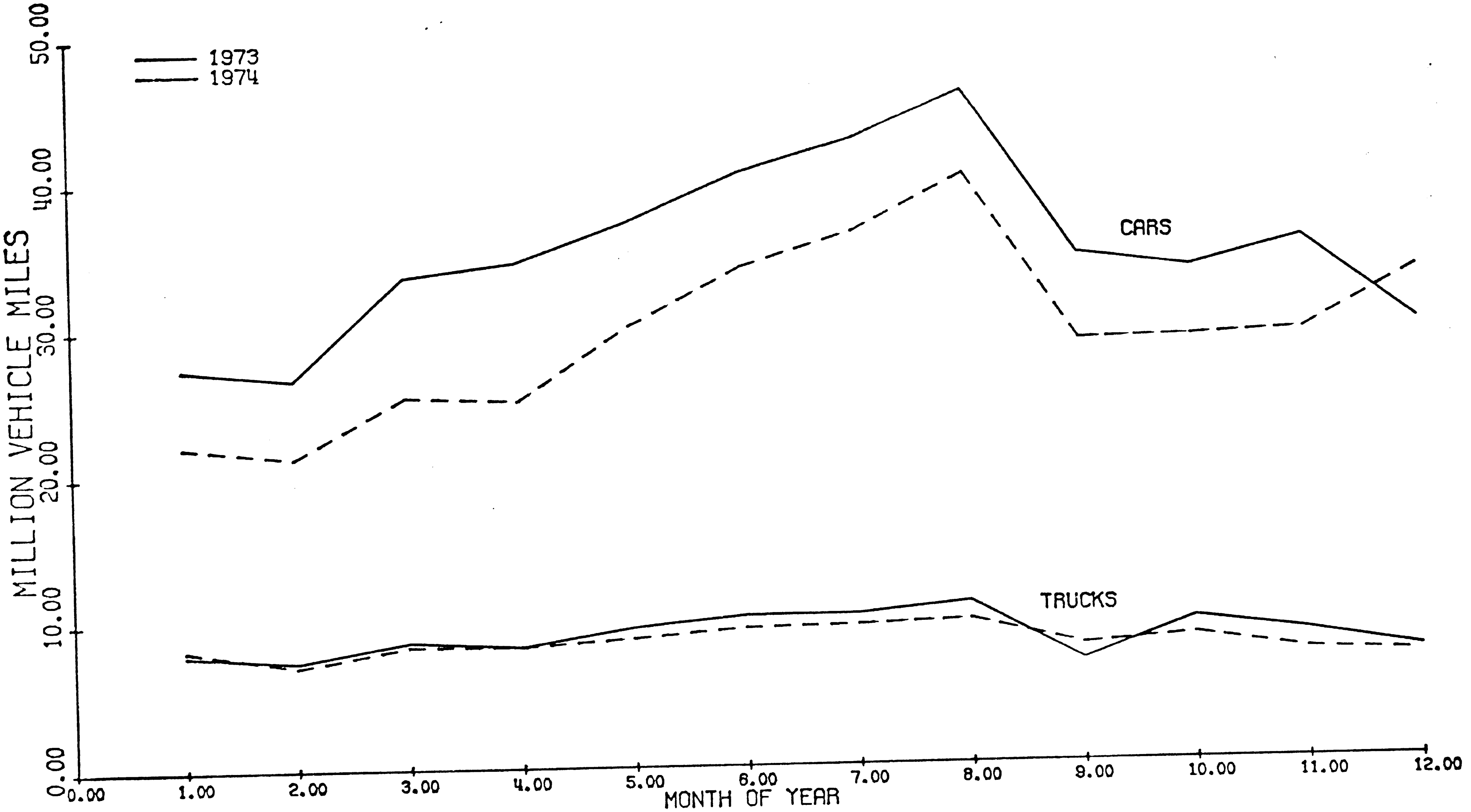


FIGURE 5.12
KANSAS TURNPIKES
VEHICLE MILES BY MONTH
1973, 1974

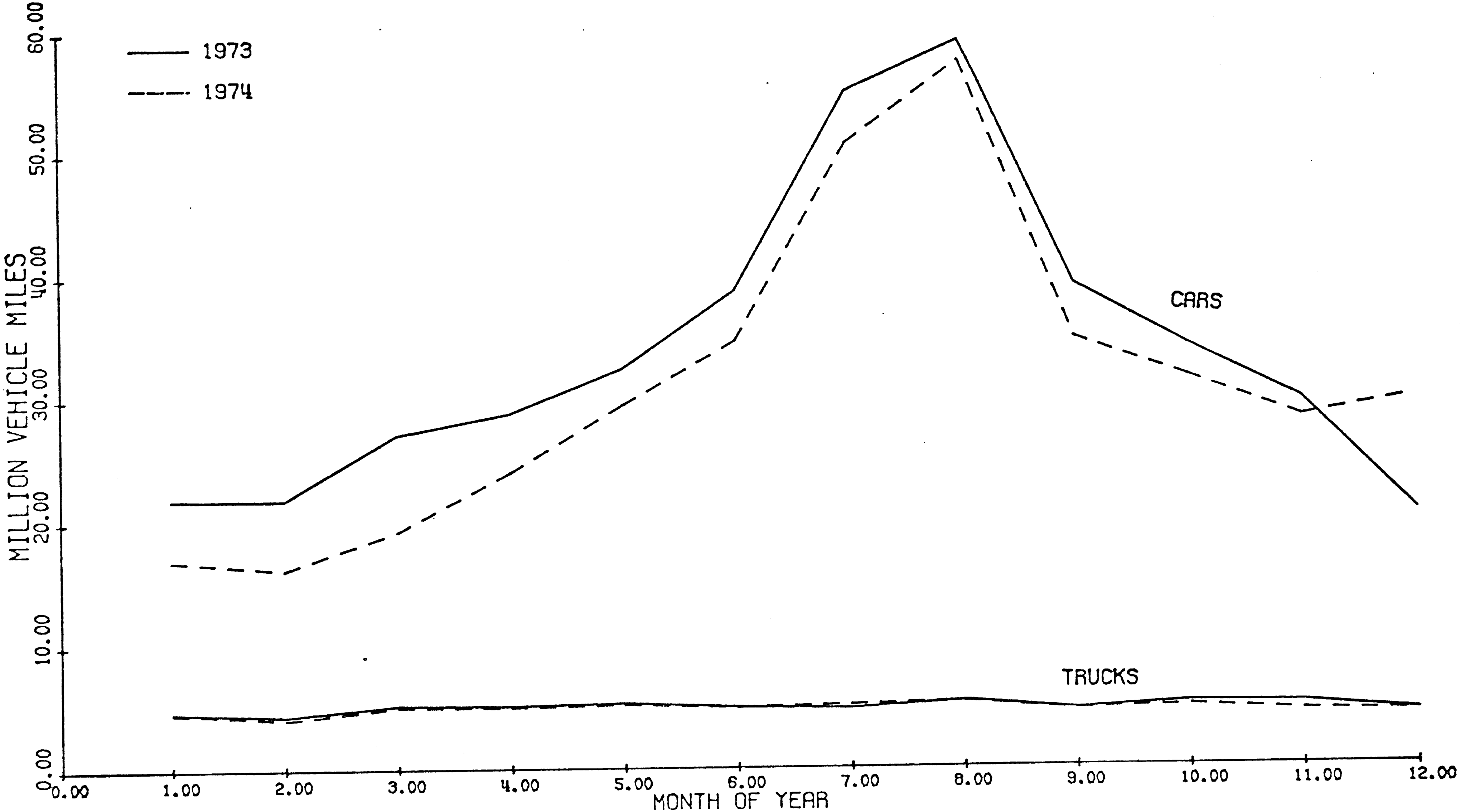


FIGURE 5.13
MAINE TURNPIKE
VEHICLE MILES BY MONTH
1973, 1974

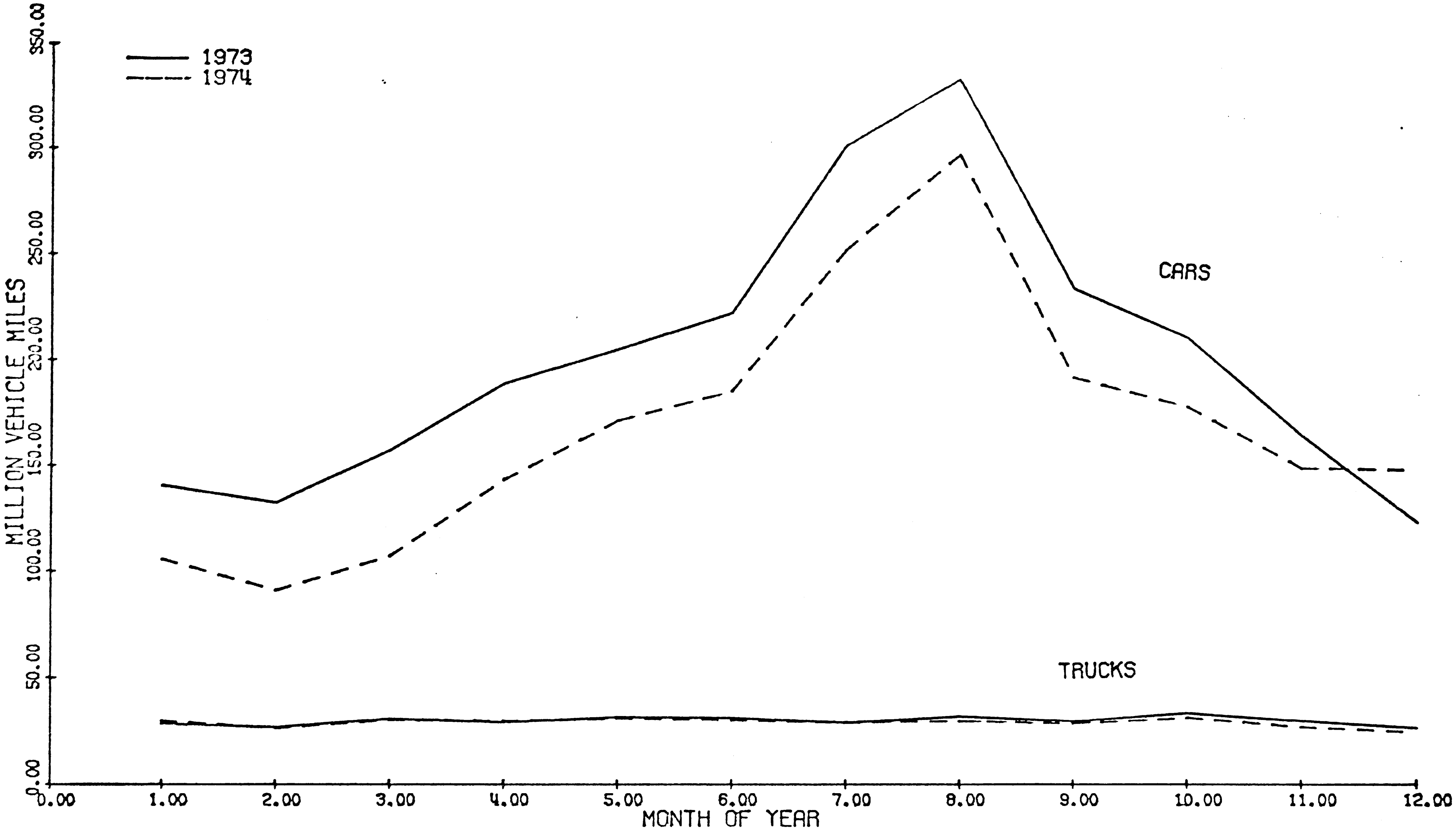


FIGURE 5.14

NEW YORK THRUWAY
VEHICLE MILES BY MONTH
1973, 1974

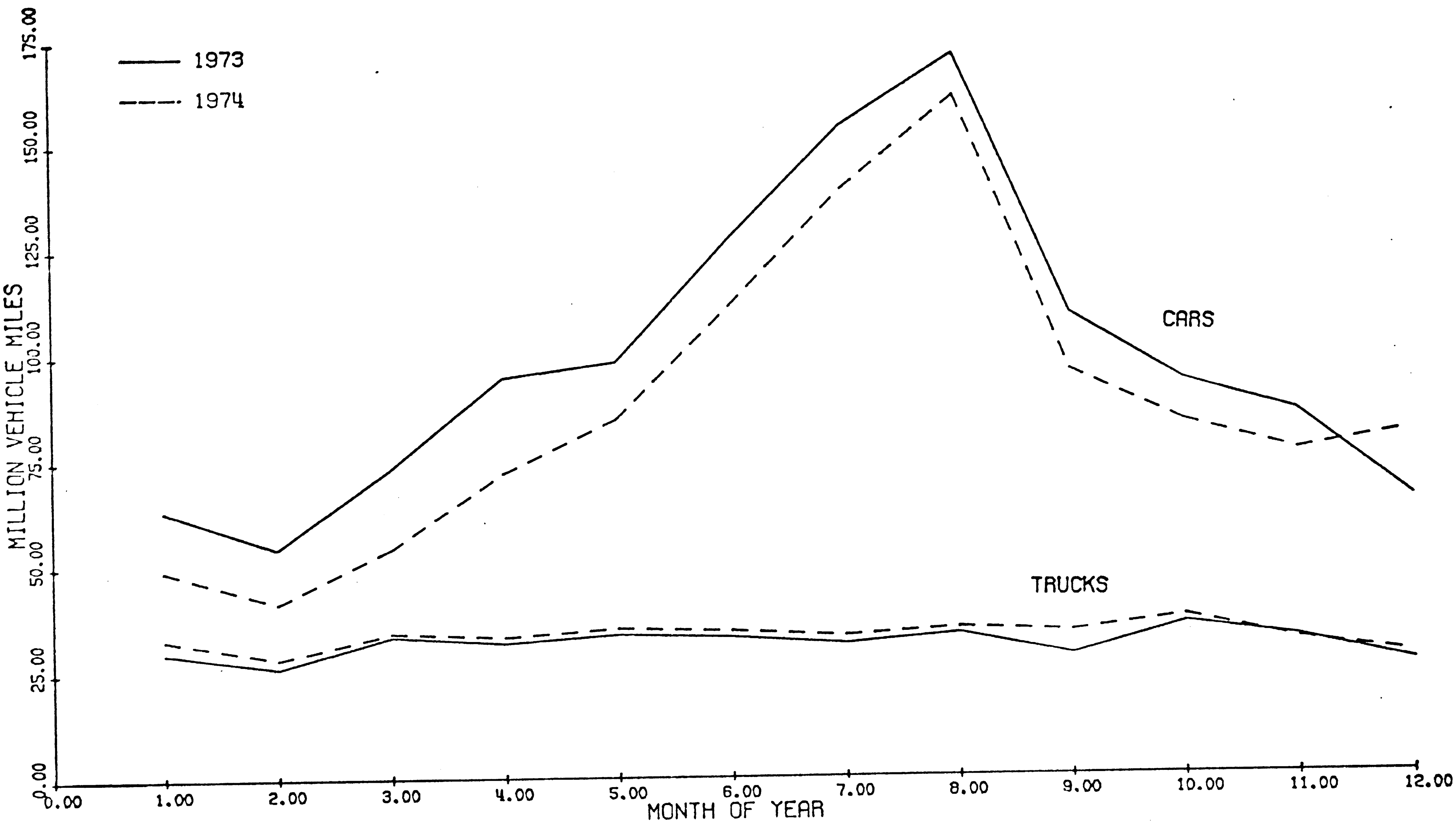


FIGURE 5.15
OHIO TURNPIKE
VEHICLE MILES BY MONTH
1973, 1974.

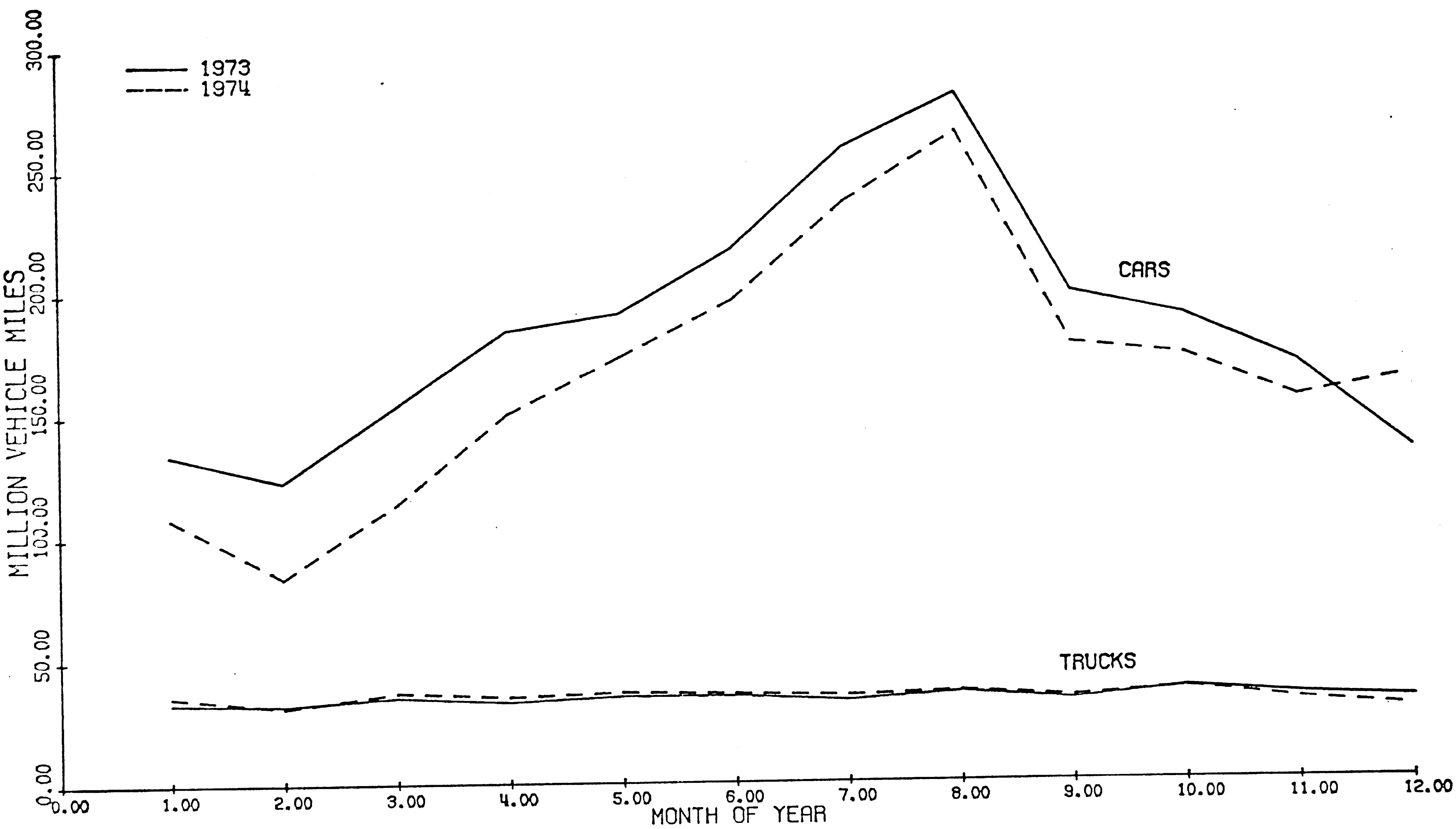


FIGURE 5.16
PENNSYLVANIA TURNPIKE
VEHICLE MILES BY MONTH
1973, 1974.

TABLE 5.2

REDUCTION OF PASSENGER CAR VEHICLE MILES IN 1974
COMPARED WITH 1973 BY MONTH

Reductions in Percent

Month	Toll Road				
	Kansas	Maine	New York	Ohio	Pennsylvania
January	19.3	22.7	24.8	22.5	19.4
February	20.1	26.0	31.4	23.7	32.0
March	24.5	29.1	31.8	26.0	26.0
April	27.4	16.7	24.1	23.8	18.4
May	19.2	9.2	16.4	13.8	9.4
June	15.9	10.5	16.7	12.4	9.6
July	14.8	7.7	16.4	9.9	8.7
August	12.4	2.8	10.8	5.9	5.7
September	16.9	11.1	18.0	12.4	10.7
October	14.0	7.6	15.5	10.6	8.6
November	17.7	5.0	9.4	10.8	8.5
December	- 11.9	- 45.3	- 19.9	- 24.1	- 22.1

Note: A negative sign indicates an increase in 1974

TABLE 5.3

REDUCTION OF LARGE TRUCK VEHICLE MILES IN 1974
COMPARED WITH 1973 BY MONTH

Reduction in Percent

Month	Toll Road				
	Kansas*	Maine*	New York	Ohio	Pennsylvania
January	- 4.5	2.0	- 4.9	-10.1	- 8.1
February	4.6	6.9	2.3	0.0	3.0
March	3.9	3.5	2.1	- 2.8	- 5.5
April	0.1	3.1	- 1.7	- 4.9	- 6.7
May	7.9	3.7	2.4	- 3.6	- 4.6
June	8.1	0.8	4.7	- 3.1	- 2.9
July	7.2	- 6.7	0.2	- 4.8	- 0.9
August	10.9	0.8	7.2	- 3.9	- 0.9
September	-15.2	1.3	4.2	- 7.5	- 3.7
October	11.7	5.8	6.3	- 4.3	0.7
November	15.0	13.2	9.9	2.0	6.1
December	4.2	1.5	8.0	- 5.5	11.7

Note: A negative sign indicates an increase in 1974

*The truck figures for Maine and Kansas include all trucks, most of which are large.

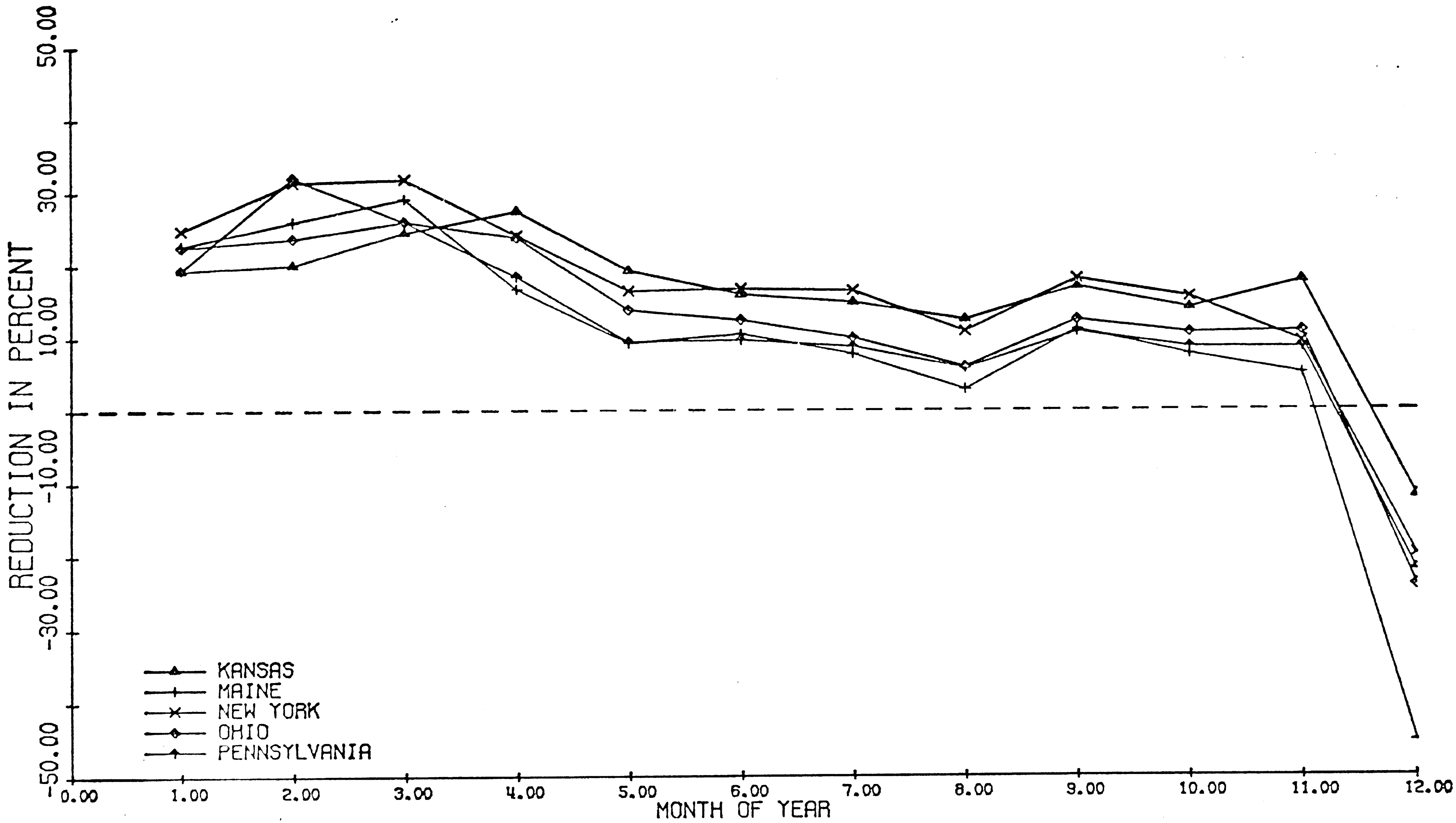


FIGURE 5.17

REDUCTION OF PASSENGER CAR TRAVEL IN 1974 indicates very similar patterns for all five roads with duplication of month-to-month variations.

The annual travel for each road each year is given in Table 5.4. Figures are given for the full year, and for the first ten months of 1973 and 1974. The ten-month figures provide the basis for computation of involvement rates in Section 7.

TABLE 5.4

VEHICLE MILES IN 1973 AND 1974 BY VEHICLE TYPE

Travel in Million Vehicle Miles

	Toll Road				
	Kansas*	Maine*	New York	Ohio	Pennsylvania
TWELVE MONTH *(Jan. - Dec.)*					
1973					
Passenger Car	421.3	408.2	3241.1	1185.8	2233.2
Large Truck	105.5	58.4	355.2	371.4	408.1
1974					
Passenger Car	354.1	372.7	2011.5	1048.8	1994.7
Large Truck	100.0	56.6	344.7	386.3	413.9
Percent Reduction					
Passenger Cars	16.0	8.7	14.1	11.6	10.7
Large Trucks	5.2	3.0	3.0	-4.0	-1.4
TEN MONTH *(Jan. - Oct.)*					
1973					
Passenger Car	356.1	358.0	2062.5	1035.1	1926.6
Large Truck	89.4	49.1	299.6	314.3	341.6
1974					
Passenger Car	291.6	314.7	1714.8	891.7	1675.9
Large Truck	85.5	48.1	293.8	328.3	353.3
Percent Reduction					
Passenger Cars	18.1	12.1	16.9	13.9	13.1
Large Trucks	4.4	2.0	1.9	-4.5	-3.4

*The truck figures for Maine and Kansas include all trucks, most of which are large.

6. ACCIDENTS

6.1 Data Processing

Accident data for each road were obtained on magnetic tape or punched cards from the tollroad authority or statewide accident data center. Documentation explaining the format and meaning of the data was also provided and used to create an OSIRIS (4) type dictionary and data file. All variables from the original data were retained for up to seven vehicles per accident. Any necessary recoding of missing data or alphabetic characters was also done at this time. Then selected variables were read into MIDAS (5) and used to determine the location, time, and classification of the accidents as explained below.

All accidents that occurred off the mainline of the toll road were excluded. Most of these accidents occurred at toll plazas or ramps, with some at service plazas or other sites unique to toll roads. Accidents occurring at overpasses or underpasses on the mainline were included if they were on the toll road. Pedestrian and pedalcycle accidents on the mainline were also deleted at this point in the analysis. All accidents on the mainline were assigned to the appropriate road segment by the use of milepost or equivalent information. When it was included in the accident, the direction of the lane of the accident was also preserved.

(4) OSIRIS III; Vol. 1-System and Program Description Institute for Social Research, The University of Michigan, 1973 Library of Congress Card Number 73.620113.

(5) Daniel Fox and Kenneth Guire, Documentation for MIDAS, Michigan Interactive Data Anlysis System, The Statistical Research Laboratory, The University of Michigan, Ann Arbor, Sept. 1973.

The major data processing tasks in determining the number of involvements for analysis consisted of the following:

(1) Recoding vehicle type into passenger car, large truck, other (straight trucks, buses, etc.)

(2) determining which multi-vehicle crashes would be represented by the interaction model, and which would not.

(3) identification of the striking (overtaking) and struck (overtaken) vehicle in crashes used in the model.

Determination of class of vehicle type is straightforward from the original coding in each data set. Accidents involving straight trucks were not considered for the analysis by accident configuration, but the number of cars involved in these same crashes were preserved for later inclusion in overall involvement rates for cars independent of collision configuration. Straight trucks were not separated for Kansas or Maine. For these two roads the resulting vehicle classes are (1) cars, and (2) all trucks.

Determination of which crashes are suitable for representation by the interaction model was not straightforward. These crashes are those that involve moving vehicles traveling in the same direction, and involved in rear-end or sideswipe crashes. The remaining multi-vehicle crashes included stopped or parked vehicles, median crossings (opposite direction), crashes involving a backing vehicle, etc. The stopped vehicles make up the majority of cases in the "non-modeled" group. Although they are not identified and described uniformly in the separate data sets, they appear to result from disabled vehicles and vehicles involved in previous accidents. Identification of the "non-modeled" accidents was only possible for Ohio, New York, and Pennsylvania. On all three data sets, a number of variables were examined to make the identification. These included variables such as collision or involvement type, directional anlysis, driver action, object struck, and causal actions.

Identification of the striking and struck vehicles is not explicitly given in any of the original data sets. It was not possible in the case of Maine. In the other data sets a determination was possible by again examining a number of related variables. The specific variables and logic required varied from road to road, but the method was generally analogous to that used for identifying which crashes were represented by the model.

6.2 Involvements

The total number of accidents on each toll road are shown in Table 6.1. All accidents on the mainline except pedestrian and pedalcycle cases are included, regardless of the number and type of vehicles involved or the collision configuration. The results are for twelve months and are presented for calculation of total accident rates. Although the study presented here is based primarily on involvements, the gross accident results are given simply because they are a typical way of giving a brief over-view, and might be useful for comparison with other reports. The total number of accidents on the five roads went down by 33 percent in 1974 compared to 1973, a very substantial reduction.

6.3 Collision Configuration

The number of vehicles involved in crashes is shown by vehicle type in Tables 6.2-6.6 for the two

TABLE 6.1

TOTAL ACCIDENTS ON

FIVE TOLL ROADS

	Number of accidents in twelve months 1973	1974
Kansas	699	444
Maine	572	415
Ohio	2918	2232
New York	1603	1212
Pennsylvania	3548	1912
Total	9340	6215

TABLE 6.2

KANSAS TURNPIKE

INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan.-Oct.)

Collision Type	1973	1974	% Reduction
SINGLE VEHICLE INVOLVEMENTS			
Cars	328	166	49
Trucks	102	111	-9
TWO VEHICLE INVOLVEMENTS			
Cars	218	94	57
Trucks	80	58	28
TOTAL INVOLVEMENTS			
Cars	546	260	52
Trucks	182	169	7

Note: The truck figures for Kansas include all trucks, most of which are large.

TABLE 6.3

MAINE TURNPIKE

INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan.-Oct.)

Collision Type	1973	1974	% Reduction
SINGLE VEHICLE INVOLVEMENTS			
Cars	244	173	29
Trucks	82	51	38
TWO VEHICLE INVOLVEMENTS			
Cars	230	141	39
Trucks	72	55	24
TOTAL INVOLVEMENTS			
Cars	474	314	34
Trucks	154	106	31

Note: The truck figures for Maine include all trucks, most of which are large.

TABLE 6.4

OHIO TURNPIKE

INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan.-Oct.)

Collision Type	1973	1974	% Reduction
SINGLE VEHICLE INVOLVEMENTS			
Cars	680	401	41
Large Trucks	172	194	-13
TWO VEHICLE INVOLVEMENTS			
Cars	528	321	39
Large Trucks	201	156	22
TOTAL INVOLVEMENTS			
Cars	1208	722	40
Large Trucks	373	350	6

TABLE 6.5

NEW YORK THRUWAY

INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan.-Oct.)

Collision Type	1973	1974	% Reduction
SINGLE VEHICLE INVOLVEMENTS			
Cars	1473	968	34
Large Trucks	234	197	16
TWO VEHICLE INVOLVEMENTS			
Cars	923	638	31
Large Trucks	186	141	24
TOTAL INVOLVEMENTS			
Cars	2396	1606	33
Large Trucks	420	338	20

TABLE 6.6

PENNSYLVANIA TURNPIKE

INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan.-Oct.)

Collision Type	1973	1974	% Reduction
SINGLE VEHICLE INVOLVEMENTS			
Cars	1649	758	54
Large Trucks	141	154	-9
TWO VEHICLE INVOLVEMENTS			
Cars	1572	646	59
Large Trucks	336	222	34
TOTAL INVOLVEMENTS			
Cars	3221	1404	56
Large Trucks	477	376	21

ten-month comparison periods. The two vehicle types included in these tables and all others to follow in this section are cars and large trucks except for Kansas and Maine. In the latter two states all truck sizes are grouped together and thus included in the tables. The involvements in two-vehicle crashes given in tables 6.2-6.6 for cars and large trucks include all such involvements regardless of the type of the "other vehicle". Thus, the involvements for cars includes their involvements with straight trucks.

The involvements of cars were reduced by 33-56 percent on the five roads, while the involvements of large trucks were reduced by 6 to 33 percent. The reduction of involvements of cars was approximately the same in both single and multi-vehicle crashes.

The involvements in multi-vehicle accidents by collision configuration are given in Tables 6.7 and 6.8 for cars and large trucks. Table 6.7 gives the involvements which are used with the interaction model, while Table 6.8 gives the much smaller number of crashes which do not "fit" the model. The figures given are the number of involvements (or vehicles), and thus twice the number of accidents. The convention used for the denoting of the configurations here and subsequently in the report is:

C-C -- car into car
C-T -- car <u>into</u> large truck
T-C -- large truck <u>into</u> car
T-T -- large truck into large truck
C/T -- car and large truck without identification of striking/struck.

TABLE 6.7

TWO-VEHICLE INVOLVEMENTS:

MOVING VEHICLE, SAME DIRECTION COLLISIONS

JAN.-OCT.

	Number of Involvements (vehicles)				
	Kansas*	Maine*	Ohio	New York	Pennsylvania
1973					
#C - C	164	174	308	560	814
C - T	70	-	111	115	214
C/T	-	112	-	-	-
T - C	38	-	111	97	184
T - T	26	16	70	52	50
1974					
#C - C	62	100	171	382	292
C - T	38	-	54	101	116
C/T	-	82	-	-	-
T - C	26	-	142	81	116
T - T	26	14	50	24	48

*The truck figures for Maine and Kansas include all trucks, most of which are large.

TABLE 6.8

TWO-VEHICLE INVOLVEMENTS:
NOT SAME DIRECTION ACCIDENTS
OR ONE VEHICLE STOPPED

JAN.-OCT.

	Number of Involvements (vehicles)		
	Ohio	New York	Pennsylvania
1973			
C - C	58	168	394
C - T	2	2	40
T - C	18	34	30
T - T	10	10	16
1974			
C - C	16	102	152
C - T	6	10	24
T - C	10	22	14
T - T	0	10	14

6.4 Casualties

Casualties in the two years, or casualty rates, are of interest for two reasons. Casualty rates serves as a surrogate for accident severity and might be an indicator of the change of severity with travel speed. Furthermore casualties, particularly fatalities, are of paramount interest in themselves.

Casualties and fatalities are tabulated for each entire year in Table 6.9. The figures given for casualties include the number injured and killed in mainline, non-pedestrian accidents regardless of the severity of injury. The reduction in casualties is slightly greater than the change in the number of accidents. The average number of casualties per accident for the five roads is down 6.6 percent, and this change is significant at the 0.025 level.

The reduction in the number of fatalities is 46.7 percent, a dramatic decrease. The fatality rate (fatalities per accident) is down 19.9 percent in 1974. This change is not statistically significant however, because of the small number of fatalities on the five roads.

Although the number of fatalities on the five roads is too small to attach statistical significance to the changes, the reductions are nonetheless very important. The reductions in fatalities on these high-speed highways-comparable to "interstates" are about 2.7 times as great as the reduction nationwide on all roads.* The reduction on all turnpikes in 1974,

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*The National Safety Council in "Accident Facts", 1974 and 1975 editions, gives 55,800 motor vehicle deaths in 1973 and 46,200 in 1974. The National"Highway Fatality Statistics Monthly Estimates Based on Early Reports" Dec. 1974, published by the National Highway Traffic Safety Administration gives 55,658 motor vehicle traffic fatalities in 1973 and 46,078 in 1974. Both sets of figures indicate a reduction of 17.2 percent in 1974.

TABLE 6.9

CASUALTIES ON TOLL ROADS
TWELVE MONTHS

	Toll Road					
	Kansas	Maine	Ohio	New York	Pennsylvania	Total
Accidents						
1973	699	572	1603	2918	3548	9340
1974	444	415	1212	2232	1912	6215
Reduction (%)	36.4	27.4	24.4	23.5	46.1	33.5
Casualties						
1973	458	307	913	1184	1765	4627
1974	285	184	521	913	973	2876
Reduction (%)	37.8	40.1	42.9	22.9	44.9	37.8
Fatalities						
1973	20	10	15	46	46	137
1974	21	5	6	19	22	73
Reduction (%)	-5	50.0	60.0	58.9	52.2	46.7

given by the National Safety Council (Accident Facts, 1975 edition) is 43.3 percent, very close to the results for the five study roads. This suggests that the experience on these five roads is truly representative of the nations' turnpikes.

The 19.9 percent reduction in fatality rate suggests that the accidents in 1974 were less severe than those of 1973. The lower reduction in the casualty rate (6.6 percent) is not inconsistent with this observation. Casualty counts include injuries of all severities recorded by police. Many are very minor injury such as bruises, stiffness, etc., which can result from even minor collisions. Even elimination of all truly dangerous collisions might result in only a small change in the casualty rate.

Casualty rate by type of vehicle and involvement is shown in Tables 6.10-6.14. The multi-vehicle accidents shown include those that "fit" the model and those that don't. The rates are given in injuries per accident. Chi-square contingency tables (2x2) of the incidence of injury per accident in 1973 compared with 1974 indicate only two comparisons out of the total of 25 on the five roads are significant at the $p=0.05$ level. These two are C/Lg. truck in Ohio with an 18 percent reduction in the injury rate, and Lg. truck/Lg. truck in Pennsylvania with an <u>increase</u> of 99.6 percent. The reason that only these two groups should be significant is not apparent. Even more perplexing is the fact that the changes are not in a consistent direction.

The same data with all five roads pooled is shown in Table 6.15. None of the comparisons in the aggregate are significant of the 5 percent level. The lack of significance is probably because of mixed results and insufficient data with which to examine subsets of the casualty experience.

TABLE 6.10

CASUALTIES IN ACCIDENTS BY COLLISION TYPE
JAN. - OCT.

KANSAS

	1973			1974		
	Acc.	Cas.	Rate	Acc.	Cas.	Rate
Single Vehicle						
Car	328	222	0.677	166	109	0.657
Truck	102	67	0.657	111	60	0.541
Multi-Vehicle						
Car/Car	82	48	0.585	31	27	0.871
Car/Truck	54	36	0.667	32	29	0.906
Truck/Truck	13	18	1.385	13	10	0.769

Note: The truck figures for Kansas include all trucks, most of which are large.

TABLE 6.11

CASUALTIES IN ACCIDENTS BY COLLISION TYPE
JAN. - OCT.

MAINE

	1973			1974		
	Acc.	Cas.	Rate	Acc.	Cas.	Rate
Single Vehicle						
Car	244	125	0.512	173	73	0.422
Truck	82	39	0.476	51	14	0.275
Multi-Vehicle						
Car/Car	87	59	0.678	50	33	0.660
Car,/Truck	56	44	0.786	41	20	0.488
Truck/Truck	8	6	0.750	7	3	0.429

Note: The truck figures for Maine include all trucks, most of which are large.

TABLE 6.12

CASUALTIES IN ACCIDENTS BY COLLISION TYPE
JAN. - OCT.

NEW YORK

	1973			1974		
	Acc.	Cas.	Rate	Acc.	Cas.	Rate
Single Vehicle						
Car	1473	573	0.389	968	356	0.368
Large Truck	234	33	0.141	197	41	0.208
Multi-Vehicle						
Car/Car	364	269	0.739	242	170	0.702
Car/Lg. Truck	124	64	0.516	112	71	0.634
Lg. Truck/Lg. Truck	31	12	0.387	17	7	0.412

TABLE 6.13

CASUALTIES IN ACCIDENTS BY COLLISION TYPE
JAN. - OCT.

OHIO

	1973			1974		
	Acc.	Cas.	Rate	Acc.	Cas.	Rate
Single Vehicle						
Car	680	365	0.537	401	182	0.454
Large Truck	172	56	0.326	194	64	0.330
Multi-Vehicle						
Car/Car	254	153	0.602	94	52	0.553
Car/Lg. Truck	121	110	0.909	106	53	0.500
Lg. Truck/ Lg. Truck	40	39	0.975	25	20	0.800

TABLE 6.14

CASUALTIES IN ACCIDENTS BY COLLISION TYPE
JAN. - OCT.

PENNSYLVANIA

	1973			1974		
	Acc.	Cas.	Rate	Acc.	Cas.	Rate
Single Vehicle						
Car	1649	763	0.463	758	359	0.474
Large Truck	141	66	0.468	154	63	0.409
Multi-Vehicle						
Car/ Car	604	418	0.692	222	162	0.730
Car/Lg. Truck	234	136	0.581	135	65	0.481
Lg. Truck/Lg. Truck	33	16	0.485	31	30	0.968

TABLE 6.15

CASUALTIES IN ACCIDENTS BY COLLISION TYPE
JAN. - OCT.

FIVE TOLL ROADS

	1973			1974		
	Acc.	Cas.	Rate	Acc.	Cas.	Rate
Single Vehicle						
Car	4374	2048	0.468	2466	1079	0.438
Large Truck	731	261	0.357	702	242	0.342
Multi-Vehicle						
Car/Car	1391	947	0.681	639	444	0.695
Car/Lg. Truck	589	390	0.662	426	238	0.559
Lg. Truck/Lg. Truck	125	91	0.728	93	70	0.753

Note: The truck figures for Maine and Kanasa include all trucks, most of which are large.

7.0 ANALYSIS RESULTS

In the previous three sections the results obtained from speed, traffic, and accident data were presented. In this section, results which were obtained from a combination of these data are presented. In Section 7.1 accident and involvement rates are presented. The observed and predicted distributions of two vehicle collisions are shown in Section 7.2.

7.1 Involvement Rates

Table 7.1 presents total mainline accidents by year on the segments of the roads studied excluding pedestrian accidents. These accidents are divided by the total vehicle mileage in 100 million vehicle miles to get an overall accident rate for each road. Reductions in percent are shown for each road in addition to the aggregate. Substantial reductions (12.6% - 40.9%) are shown on all roads.

Table 7.2 and 7.3 show involvement rates for cars and large trucks for each road. In Table 7.2 these are computed for the twelve month periods whereas Table 7.3 presents the same information based on the ten month periods. Percent reductions are shown for mileage, involvements, and the involvement rate. The fact that involvement rates are substantially down indicates that the reduction in vehicle miles does not completely explain the observed decrease in involvements.

TABLE 7.1

ACCIDENT RATE
ACCIDENTS PER 100 MILLION VEHICLE MILES
ALL TYPES OF VEHICLES - 12 MONTHS

		Acci-dents	100 Million Vehicle Miles	Accident Rate
Kansas	1973	699	~~4.667~~ 5.268	~~149.8~~ 132.7
	1974	444	~~4.293~~ 4.541	~~103.4~~ 97.8
	Reduction			~~31.0%~~ 26.3%
Maine	1973	572	~~5.268~~ 4.667	~~108.6~~ 122.6
	1974	415	~~4.541~~ 4.293	~~91.4~~ 96.7
	Reduction			~~15.8%~~ 21.1%
New York	1973	2918	28.580	102.1
	1974	2232	25.019	89.2
	Reduction			12.6%
Ohio	1973	1603	16.292	98.4
	1974	1212	15.019	80.7
	Reduction			18.0%
Pennsylvania	1973	3548	26.563	133.6
	1974	1912	24.227	78.9
	Reduction			40.9%
All Roads	1973	9340	81.370	114.8
	1974	6215	73.099	85.0
	Reduction			26.0%

TABLE 7.2

INVOLVEMENT RATES FOR CARS AND LARGE TRUCKS BY ROAD 12 MONTHS

	1973 Number Involved	1973 Vehicle Miles ($x10^8$)	1973 Involvement Rate ($inv/10^8VM$)	1974 Number Involved	1974 Vehicle Miles ($x10^8$)	1974 Involvement Rate ($inv/10^8VM$)	Percent Reduction in 1974 Inv.	Percent Reduction in 1974 Vehicle Miles	Percent Reduction in 1974 Rate
Ohio									
Passenger Cars	1446	11.858	121.9	1026	10.488	97.8	29.0	11.6	19.8
Large Trucks	455	3.714	122.5	432	3.863	111.8	5.1	-4.0	8.7
Pennsylvania									
Passenger Cars	3903	22.332	174.8	1900	19.947	95.3	51.3	10.7	45.5
Large Trucks	584	4.081	143.1	437	4.139	105.6	25.2	-1.4	26.2
New York									
Passenger Cars	2858	23.411	122.1	2085	20.115	103.7	27.0	14.1	15.1
Large Trucks	523	3.552	147.2	424	3.447	123.0	18.9	3.0	16.4
Kansas									
Passenger Cars	652	4.213	154.8	344	3.541	97.1	47.2	16.0	37.3
Trucks	219	1.055	207.6	197	1.000	197	10.0	5.2	5.1
Maine									
Passenger Cars	566	4.082	138.7	393	3.727	105.4	30.6	8.7	24.0
Trucks	184	0.584	315.1	137	0.566	242.0	25.5	3.0	23.2
Total									
Passenger Cars	9425	66.596	141.5	5748	57.880	99.3	39.0	13.1	29.8
Trucks	1965	13.009	151.0	1627	13.019	125.0	17.2	0.0	17.2

TABLE 7.3

INVOLVEMENT RATES FOR CARS AND LARGE TRUCKS BY ROAD
10 MONTH (JAN.-OCT.)

	1973			1974			Percent Reduction in 1974		
	Number Involved	Vehicle Miles ($x10^8$)	Involvement Rate ($inv/10^8VM$)	Number Involved	Vehicle Miles ($x10^8$)	Involvement Rate ($inv/10^8VM$)	Inv.	Vehicle Miles	Rate
Ohio									
Passenger Cars	1208	10.351	116.7	722	8.917	81.0	40.2	13.9	30.6
Large Trucks	373	3.143	118.7	350	3.283	106.6	6.2	-4.5	10.2
Pennsylvania									
Passenger Cars	3221	19.296	166.9	1404	16.759	83.8	56.4	13.2	49.8
Large Trucks	477	3.416	139.6	376	3.533	106.4	21.2	-3.4	23.8
New York									
Passenger Cars	2396	20.625	116.2	1606	17.148	93.7	33.0	16.9	19.4
Large Trucks	420	2.996	140.2	338	2.938	115.0	19.5	1.9	18.0
Kansas									
Passenger Cars	546	3.561	153.3	260	2.916	89.2	52.4	18.1	41.8
Trucks	182	0.894	203.6	169	0.855	197.7	7.1	4.4	2.9
Maine									
Passenger Cars	474	3.580	132.4	314	3.147	99.8	33.8	12.1	24.6
Trucks	154	0.491	313.6	106	0.481	220.4	31.2	2.0	29.7
Total									
Passenger Cars	7845	57.413	136.6	4306	48.949	88.0	45.1	14.7	35.6
Trucks	1606	10.959	146.5	1339	11.093	120.7	16.6	-1.2	17.6

In those states where straight trucks were omitted, the car and large truck involvements shown include the collisions with straight trucks. Only the tabulation showing the number of times straight trucks were involved with all other vehicles is omitted.

7.2 Two Vehicle Collisions

Three methods of predicting the distribution of two vehicle collision types were used. The resulting distributions are compared with the observed distribution for each road in Tables 7.4-7.8. In the Maine Turnpike accident data CT accidents could not be distinguished from TC accidents. These two categories are grouped for that reason. No interaction model results were computed for the Pennsylvania Turnpike because sufficient speed data were not available. Only those two vehicle collisions which were determined to fit the models are shown in these tables as explained in Section 6. In general the predicted distributions do not agree well with the observed distributions. Table 7.9 presents X^2 values for the comparison of each of the predicted distributions with the observed distribution. At the bottom of the table the observed distributions are compared for the two ten month periods. The only two distributions which are not significantly different are the observed distributions in Maine. The predicted and observed involvements were combined to produce Table 2.5 which was presented in the summary.

In general, none of the models predicted the reduction in CC collisions. The distributions based on vehicle miles also failed to predict the shift from CT to TC accident. This limitation was known previously

TABLE 7.4

KANSAS TURNPIKE

TWO VEHICLE INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan. - Oct.)

	OBSERVED		PREDICTED					
			Veh. Miles		Temporal Veh. Miles		Interaction Model	
	N	%	N	%	N	%	N	%
1973								
CC	164	55.0	190	63.9	194	65.2	201	67.6
CT	70	23.4	48	16.0	45	15.0	60	20.0
TC	38	12.8	48	16.0	45	15.0	26	8.8
TT	26	8.7	12	4.0	14	4.8	11	3.6
TOTAL	298	99.9	298	99.9	298	100.0	298	100.0
1974								
CC	62	40.8	91	59.8	88	57.6	95	62.6
CT	38	24.7	27	17.5	27	17.8	34	22.5
TC	26	17.4	27	17.5	27	17.8	15	10.1
TT	26	17.1	8	5.1	10	6.9	7	4.8
TOTAL	152	100.0	153	99.9	152	100.1	151	100.0

Note: The truck figures for Kansas include all trucks, most of which are large.

TABLE 7.5

MAINE TURNPIKE

TWO VEHICLE INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan. - Oct.)

	OBSERVED		PREDICTED					
			Veh. Miles		Temporal Veh. Miles		Interaction Model	
	N	%	N	%	N	%	N	%
1973								
CC	174	57.6	234	77.3	227	75.3	242	79.9
CT/TC	112	37.0	64	21.2	68	22.6	57	19.0
TT	16	5.3	4	1.5	7	2.2	3	1.1
TOTAL	302	99.9	302	100.0	302	100.1	302	100.0
1974								
CC	100	51.0	147	75.2	140	71.5	157	80.6
CT/TC	82	41.8	46	23.0	50	25.6	35	18.0
TT	14	7.1	3	1.8	6	3.0	3	1.3
TOTAL	196	99.9	196	100.0	196	100.1	195	100.0

Note: The truck figures for Maine include all trucks, most of which are large.

TABLE 7.6

NEW YORK THRUWAY

TWO VEHICLE INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan. - Oct.)

	OBSERVED		PREDICTED					
			Veh. Miles		Temporal Veh. Miles		Interaction Model	
	N	%	N	%	N	%	N	%
1973								
CC	560	68.0	602	73.1	624	75.7	638	77.4
CT	115	14.0	102	12.4	89	10.8	150	18.2
TC	97	11.8	102	12.4	89	10.8	25	3.0
TT	52	6.3	17	2.1	22	2.7	12	1.4
TOTAL	824	100.0	823	100.0	824	100.0	825	100.0
1974								
CC	382	65.0	429	72.9	434	73.8	453	77.0
CT	101	17.2	74	12.5	68	11.6	95	16.2
TC	81	13.8	74	12.5	68	11.6	30	5.1
TT	24	4.1	12	2.1	17	2.9	11	1.8
TOTAL	588	100.0	589	100.0	587	99.9	589	100.1

TABLE 7.7

OHIO TURNPIKE

TWO VEHICLE INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan. - Oct.)

	OBSERVED		PREDICTED: Veh. Miles		PREDICTED: Temporal Veh. Miles		PREDICTED: Interaction Model	
	N	%	N	%	N	%	N	%
1973								
CC	308	51.3	353	58.8	350	58.2	275	45.8
CT	111	18.5	107	17.9	102	17.0	301	50.2
TC	111	18.5	107	17.9	102	17.0	3	0.5
TT	70	11.7	32	5.4	47	7.8	22	3.6
TOTAL	600	100.0	599	100.0	601	100.0	601	100.1
1974								
CC	172	41.1	223	53.4	218	52.2	262	62.6
CT	54	12.9	82	19.7	77	18.4	93	22.2
TC	142	34.0	82	19.7	77	18.4	42	10.0
TT	50	12.0	30	7.2	46	11.0	21	5.1
TOTAL	418	100.0	417	100.0	418	100.0	418	99.9

TABLE 7.8

PENNSYLVANIA TURNPIKE

TWO VEHICLE INVOLVEMENTS BY COLLISION TYPE
Ten Months (Jan. - Oct.)

	OBSERVED		PREDICTED			
			Vehicle Miles		Temporal Veh. Miles	
	N	%	N	%	N	%
1973						
CC	814	64.5	911	72.2	906	71.6
CT	214	17.0	162	12.8	153	12.2
TC	184	14.6	162	12.8	153	12.2
TT	50	4.0	29	2.3	50	4.1
TOTAL	1262	100.1	1264	100.1	1262	100.1
1974						
CC	292	51.0	390	68.2	372	66.8
CT	116	20.3	82	14.4	79	13.6
TC	116	20.3	82	14.4	79	13.6
TT	48	8.4	17	3.0	36	5.9
TOTAL	572	100.0	571	100.0	571	99.9

TABLE 7.9

COMPARISON OF
TWO VEHICLE COLLISION TYPE
DISTRIBUTIONS

Comparison	X^2 by Toll Road Kansas	Maine	New York	Ohio	Pennsylvania
73					
Veh. Mile	137	87.4	76.9	51.6	45.2
Temp.	29.9	56.4	55.8	17.9	39.9
I.M.	34.5	128.5	358	4117	---
74					
Veh. Mile	54.3	83.5	27.7	78.9	109
Temp.	37.8	42.6	27.6	72.2	55.6
I.M.	71.6	124.1	114	326	---
73 vs. 74	11.6	2.3*	7.0	34.2	36.5

*This is the only comparison for which the distributions are not significantly different at least at the .02 level.

of course. The temporal calculation of the vehicle miles predictor did better in predicting the TT involvements as expected. While the interaction model predicts a shift in the distribution towards TC collisions, the observed shift is not nearly as big.

Over-involvement rates are computed by dividing the observed number of involvements by the predicted number. The results of this division are shown by road in Tables 7.10-7.14, and in aggregate in Table 7.15. The vehicle miles predictors indicate that trucks are overinvolved in all collision types. However, when the relative speeds are included as in the interaction model, the CT collision type is no longer over-involved. For each road the TT collision type is indicated to be over-involved by each prediction method. In the aggregate the TC collision type is also over-involved.

The interaction model provides a conceptual framework for interpretation of these results. The factor not included in the interaction model, as applied here, is the probability of an involvement given a passing. The finding that car-car involvements are under-represented may be interpreted as a finding that the probability of an involvement given a car-car passing is lower than the overall probability for all two-vehicle passings. Similarly, the over-representation of trucks as striking vehicles may be interpreted as a higher probability of involvement for truck-car passings.

TABLE 7.10

KANSAS TURNPIKE

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Veh. Mi.	Temporal Veh. Mi.	Interaction Model
1973			
CC	0.86	0.84	0.82
CT	1.46	1.56	1.17
TC	0.80	0.86	1.46
TT	2.17	1.83	2.36
1974			
CC	0.68	0.71	0.65
CT	1.41	1.39	1.12
TC	0.99	0.98	1.73
TT	3.33	2.49	3.71

Note: The truck figures for Kansas include all trucks, most of which are large.

TABLE 7.11

MAINE TURNPIKE

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Veh. Mi.	Temporal Veh. Mi.	Interaction Model
1973			
CC	0.75	0.77	0.72
CT/TC	1.75	1.65	1.96
TT	3.64	2.41	5.33
1974			
CC	0.68	0.71	0.64
CT/TC	1.78	1.64	2.34
TT	4.07	2.41	4.67

Note: The truck figures for Maine include all trucks, most of which are large.

TABLE 7.12

NEW YORK THRUWAY

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Veh. Mi.	Temporal Veh. Mi.	Interaction Model
1973			
CC	0.93	0.90	0.88
CT	1.13	1.29	0.77
TC	0.95	1.09	3.88
TT	3.06	2.36	4.33
1974			
CC	0.89	0.88	0.84
CT	1.36	1.49	1.06
TC	1.09	1.19	2.70
TT	2.00	1.41	2.18

TABLE 7.13

OHIO TURNPIKE

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Veh. Mi.	Temporal Veh. Mi.	Interaction Model
1973			
CC	0.87	0.88	1.12
CT	1.04	1.09	0.37
TC	1.04	1.09	37.00
TT	2.19	1.49	3.18
1974			
CC	0.77	0.78	0.65
CT	0.66	0.70	0.58
TC	1.73	1.84	3.38
TT	1.67	1.09	2.38

TABLE 7.14

PENNSYLVANIA TURNPIKE

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Vehicle Miles	Temporal Veh. Mi.
1973		
CC	0.89	0.90
CT	1.32	1.40
TC	1.14	1.20
TT	1.72	1.00
1974		
CC	0.75	0.78
CT	1.41	1.47
TC	1.41	1.47
TT	2.82	1.33

TABLE 7.15

COMBINED RESULTS

OVER-INVOLVEMENT RATES FOR TWO VEHICLE COLLISIONS
Ten Months (Jan.-Oct.)

Collision Type	Veh. Mi.	Temporal Veh. Mi.	Interaction Model
1973			
CC	0.88	0.88	0.92
CT	1.27	1.35	0.63
TC	1.07	1.14	4.56
TT	2.24	1.53	2.71
1974			
CC	0.79	0.80	0.73
CT	1.20	1.26	0.99
TC	1.41	1.48	2.90
TT	2.33	1.41	2.71

Note: The truck figures for Maine and Kansas include all trucks most of which are large.

This section is concluded with some information on the degree to which vehicle miles and predicted passings predict the observed reductions in involvements. The previous analysis looked solely at the distribution of two vehicle collision types. The results of this comparison are shown in Table 7.16. In general the reduction predicted on the basis of passings is closer to the observed result than the reductions predicted on the basis of vehicle mileage alone. For example, on the Kansas Turnpike two vehicle collisions are down 49%, total mileage is down 15% and the total number of predicted passings is down 28%. Overall mileage decreased 13%, predicted passing decreased 21%, and two vehicle involvements decreased 33%. Clearly the interaction model predicts more of the observed decrease than vehicle mileage alone does. Although both models do not handle volume in exactly the same manner, it is appropriate to conclude that the difference between the two is primarily due to the inclusion of speed distributions in the interaction model. On this basis the inclusion of the speed distributions would appear to account for 8 (21 minus 13) of the 33% reduction observed in two vehicle involvements.

Looking at the ratio of involvements to predicted passings, a 15% reduction is observed. This may be interpreted as a decrease in the probability of an involvement given a passing. It is possible to subjectively relate this change to many factors. Clearly this probability varies both by road and time. However one possible interpretation is to relate the change in the probability of an involvement given a passing to the lower mean speed at which the passings are now occurring. (For distributions with fixed standard

TABLE 7.16

COMPARISON OF VEHICLE MILES AND PREDICTED PASSINGS (I.M.)
AS PREDICTORS OF ACCIDENT INVOLVEMENTS

TEN MONTHS (JAN.-OCT.), 1973 VS. 1974

Reductions in Percent

Involvements, Predictors and Rates	Toll Roads				Net Reduction
	Kansas	Maine	New York	Ohio	
INVOLVEMENTS					
CC	62	43	32	44	41
TT	0	13	54	29	30
Two Vehicle	49	35	29	30	33
Total	41	33	31	32	33
MILEAGE					
Car	18	12	17	14	16
Large Truck	4	2	2	-4	0
Total	15	11	15	10	13
PREDICTED PASSINGS (PP)					
CC	33	18	22	- 8	15
TT	3	1	-2	-13	-8
Two Vehicle Total	28	19	22	21	21
INVOLVEMENT RATES					
CC Inv/Car Miles	53	35	18	36	29
CC Inv/CC PP	43	30	12	48	30
TT Inv/Truck Miles	-5	11	53	32	31
TT Inv/TT PP	-3	12	55	37	36
Two Veh. Inv/Tot. Mi.	40	27	16	23	23
Two Veh. Inv/Tot. PP	29	20	9	12	15
Total Inv/Total Miles	30	25	19	25	23
Total Inv/Total PP	18	18	12	14	14

Note: The truck figures for Maine and Kansas include all trucks, most of which are large.

deviations and a given difference between the mean speeds, the interaction model yields the same result regardless of the absolute value of the mean speeds.) The interpretation being suggested here is that the probability of an involvement given a passing is lower when the passing occurs at a lower mean speed.

The point here is that two conclusions can be derived from Table 7.16. The first is that the speed distributions, as incorporated in the interaction model, appear to account for eight of the observed 33% reduction in two vehicle involvements. The second is that the probability of an involvement given a passing was also decreased. It seems reasonable to presume that the speed changes may also have played a role in this reduction. It is not possible to estimate the magnitude of this effect. Future improvements in this model as a predictor would have to address the variation in the probability of an involvement given a passing as a function of such things as type of passing, mean speed, traffic density, etc.

APPENDIX A

APPENDIX A

INTERACTION MODEL

The interaction model is specifically concerned with the turnpike situation, in which there is a four-or-more-lane roadway with extremely limited access and lanes divided by direction of travel.

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. 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, 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 the vehicle moving at speed u is v-u. If we have more than one vehicle moving at speeds greater than u, say, D vehicles, in that unit section of roadway (e.g., the mile), then one must integrate v-u over all possible speeds, v, greater than u in order to determine the average rate of overtaking:

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

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]

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

or

$$D_u D_v \int_0^\infty \int_u^\infty (v-u)h(v)h(u)dv\ du \qquad \text{eq.A.1}$$

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.

Density is computed from the following expression:

$$D= \frac{VM}{\bar{V}\cdot L\cdot T} \qquad \text{eq. A.2}$$

where:

VM=vehicle mileage

$\bar{V}$=mean speed, mph

L=segment length, mile

T=time period, hours

The double integral is computed numerically using a normal distribution. Field data sheets were obtained from the speed surveys showing number of vehicles observed in 2 mph increments of speed. The mean and standard deviation of these observations were computed. For convenience the double integral was computed from the mean and standard deviation under the assumption that the speed distributions are normal.

In many cases the speed distributions were not particularly normal. Trucks often had a very flat distribution for example. To evaluate the influence of the normality assumption on the double integral computation, a program was written to compute the integral from the raw data directly. In general the differences were 1-2% with the normal approximation tending to be higher. One exception was the TC rate in Ohio prior to the energy crisis when the differential in mean speeds was large. Here the overtaking rate is very small (.02-.06) and the differences between the integral computed using the normal assumption and the raw data were large (20-60%). However, there was no systematic bias in these differences. For this reason the results obtained under the assumption of normality were presumed to be as good as those obtained from the raw data. In all cases the double integral was evaluated using the assumption that the speed distributions were normal.

Each road was broken down into segments defined by the interchanges. The hourly and daily traffic distributions described in the next appendix were used to allocate the monthly traffic by class (cars and large trucks) into 8 periods. These periods were defined by four 6-hour periods of the day and a weekday/weekend split. The interaction model calculations were carried out separately in each of these periods. Speed data were not available to this level of detail. In general the same speed distributions were used in each of the 8 periods.

APPENDIX B

APPENDIX B

TRAFFIC PATTERNS AND ELAPSED TIME

As explained earlier one of the needs of this study was the determination by vehicle type of traffic patterns by time of day and day of week. One of the presumed advantages of studying toll roads was the fact that toll tickets could be used to obtain time of entry and exit. This would permit derivation of the "overlap" in usage patterns for vehicles of different classes, and would hopefully also provide an independent measure of the speed distribution for vehicles of each class.

Unfortunately in all but one state the necessary information was not available from the toll road. The time on or off was seldom punched on the ticket. Some states printed the time on but not the time off. In states where both times were recorded the data was not usable for a variety of reasons: the time off was only printed to the nearest hour, the tickets had been discarded or recycled, the clocks at the different stations were not synchronized, or not working at all. Officials from the toll roads generally explained that the tickets were designed for accounting and other administrative purposes and were not intended to monitor traffic patterns or travel time.

The Ohio Turnpike did record entry and exit times for vehicles during a several month period beginning in November, 1974. (They have subsequently stopped recording this information.) This data was provided for us on three magnetic tapes, two covering a 17 day period in November, 1974 and one tape for March, 1975. The November data was extensively analyzed as explained below and formed the basis of hourly and daily traffic distributions used for the other toll roads.

From the original tapes a 2% random sample was taken of all vehicles on the road between 00:01 Tuesday, November 12 and 11:59 Monday, November 25 that had no missing data for time on and off, and location on and off. Based on its class and number of axles each of the 14197 vehicles was assigned to one of four groups as explained below:

1. 10229 were "cars." They had a class 1 ticket and 2 axles (or if towing a trailer the car plus trailer weighed less than 16,000 pounds).
2. 580 were "other." This group included straight trucks, passenger cars with heavy trailers, and tractors without trailers.
3. 3322 were "large trucks" having four or more axles.
4. 56 vehicles in the sample (less than 1%) were excluded from further analysis because of an impossible combination of variables, e.g., two axles and weight greater than 65,000 pounds.

The distribution for distance traveled, elapsed time, and miles per hour were examined for groups 1-3. These are described in Table B.1. Histograms of the miles/hour variables grouped into 5 miles/hour intervals, are given in Figures B.1 to B.3. Remembering that the miles/hour variable is not equivalent to traveling speed

TABLE B.1

DISTANCE TRAVELED, ELAPSED TIME, AND MILES/HOUR FOR
PASSENGER CARS, "OTHER" VEHICLES, AND LARGE TRUCKS*

DESCRIPTIVE MEASURES <1> NEWCLASS:1 Passenger Cars

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
50.DISTANCE	10229	0.	241.20	54.825	53.665
410.ELAPSED	10229	.16667 -1	23.867	1.0857	1.2767
411.MILES/HR	10229	0.	110.85	53.351	9.3615

DESCRIPTIVE MEASURES <2> NEWCLASS:2 Other Vehicles

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
50.DISTANCE	580	0.	241.20	63.707	60.649
410.ELAPSED	580	.10000	16.467	1.5345	1.4576
411.MILES/HR	580	0.	85.200	46.772	13.016

DESCRIPTIVE MEASURES <3> NEWCLASS:3 Large Trucks

VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
50.DISTANCE	3332	0.	241.20	67.009	65.062
410.ELAPSED	3332	.33333 -1	23.850	2.2736	2.4554
411.MILES/HR	3332	0.	78.000	45.981	12.830

---

*From the Ohio Turnpike Transaction Tape -- November 12, 1974 to November 25, 1974.

FIGURE B.1

HISTOGRAM OF MILES/HOUR FOR PASSENGER CARS

```
HISTOGRAM/FREQUENCIES  <1> NEWCLASS:1

MIDPOINT      COUNT  FOR 411.MILES/HR   (EACH X= 70)

 0.              49  +X
 5.0000          14  +X
 10.000          19  +X
 15.000          23  +X
 20.000          40  +X
 25.000          58  +X
 30.000         116  +XX
 35.000         202  +XXX
 40.000         519  +XXXXXXXX
 45.000        1008  +XXXXXXXXXXXXXXX
 50.000        1929  +XXXXXXXXXXXXXXXXXXXXXXXXXXXX
 55.000        2798  +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 60.000        2223  +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 65.000         979  +XXXXXXXXXXXXXX
 70.000         145  +XXX
 75.000          32  +X
 80.000          61  +X
 85.000           2  +X
 90.000           0  +
 95.000           7  +X
 100.00           1  +X
 105.00           2  +X
 110.00           2  +X

 TOTAL        10229  (INTERVAL WIDTH= 5.0000)
```

FIGURE B.2

HISTOGRAM OF MILES/HOUR FOR "OTHER" VEHICLES

```
HISTOGRAM/FREQUENCIES  <2> NEWCLASS:2

MIDPOINT     COUNT FOR 411.MILES/HR   (EACH X= 4)

 0.            11 +XXX
 5.0000         5 +XX
 10.000         3 +X
 15.000         9 +XXX
 20.000         6 +XX
 25.000        11 +XXX
 30.000        16 +XXXX
 35.000        28 +XXXXXXX
 40.000        65 +XXXXXXXXXXXXXXXXX
 45.000       101 +XXXXXXXXXXXXXXXXXXXXXXXXXX
 50.000       114 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 55.000       123 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 60.000        66 +XXXXXXXXXXXXXXXXX
 65.000        15 +XXXX
 70.000         3 +X
 75.000         0 +
 80.000         3 +X
 85.000         1 +X

 TOTAL        580   (INTERVAL WIDTH= 5.0000)
```

FIGURE B.3

HISTOGRAM OF MILES/HOUR FOR LARGE TRUCKS

```
HISTOGRAM/FREQUENCIES  <3> NEWCLASS:3

MIDPOINT      COUNT FOR 411.MILES/HR   (EACH X= 19)

 0.             28 +XX
 5.0000         26 +XX
 10.000         39 +XXX
 15.000         80 +XXXXX
 20.000         77 +XXXXX
 25.000         87 +XXXXX
 30.000        116 +XXXXXXX
 35.000        170 +XXXXXXXXX
 40.000        282 +XXXXXXXXXXXXXXX
 45.000        542 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 50.000        735 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 55.000        714 +XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 60.000        365 +XXXXXXXXXXXXXXXXXXXX
 65.000         66 +XXXX
 70.000          2 +X
 75.000          1 +X
 80.000          2 +X

 TOTAL       3332  (INTERVAL WIDTH= 5.0000)
```

because of the possibility of stops, these histograms give very reasonable results. Note the substantially greater portion of large truck travel in the 0-35 miles/hour range. This is due to the greater number of long stops made by large trucks. Along the Ohio Turnpike there are several rest areas and service plazas but no motels or other facilities intended for an extended stop by passenger car drivers. However, there are areas at some interchanges where truckers can stop and sleep in their cab., without leaving the toll road.

An effort was made to isolate a group of vehicles whose miles/hour results could be interpreted as actual traveling speed. There are a few portions of the Ohio Turnpike with no rest areas or other stopping places. However, the amount of traffic entering the road immediately before these short stretches and exiting immediately after was a tiny fraction of the total traffic, and was felt to be unrepresentative. For those vehicles whose trip included a segment with a stopping place it was not possible to identify those that stopped.

After the 56 invalid vehicles were deleted the mileage traveled by all the other vehicles was "integrated" over the two week period. This was done by assuming each vehicle traveled at a constant rate of speed the entire time that it was on the road. The number of miles traveled by cars and large trucks were separately summed for each of the 336 hours. These were then combined for the weekdays and weekends and the results are presented in Table B.2.

The first column is the hour of the day with the first hour from 12:01 am to 1:00 am. The second through fourth columns are the percentages of car miles traveled during this time period during the total week, weekdays,

TABLE B.2

PERCENTAGE OF CAR AND LARGE TRUCK MILEAGE BY HOUR: TOTAL, WEEKDAY, AND WEEKEND

	9. CAR%	10. CWDAY%	11. CWEND%	12. TRUCK%	13. TWDAY%	14. TWEND%
1	.13614 -1	.71424 -2	.64711 -2	.34262 -1	.27875 -1	.63366 -2
2	.95004 -2	.50768 -2	.44236 -2	.36046 -1	.28971 -1	.72690 -2
3	.78796 -2	.44869 -2	.33926 -2	.33577 -1	.27117 -1	.64604 -2
4	.70194 -2	.42494 -2	.27691 -2	.34719 -1	.28074 -1	.61149 -2
5	.78960 -2	.54448 -2	.24511 -2	.35987 -1	.28439 -1	.65496 -2
6	.99707 -2	.67835 -2	.31872 -2	.34196 -1	.27635 -1	.65611 -2
7	.16513 -1	.11773 -1	.47398 -2	.35041 -1	.28914 -1	.61269 -2
8	.31971 -1	.24519 -1	.74519 -2	.35799 -1	.29717 -1	.60326 -2
9	.43093 -1	.31602 -1	.11296 -1	.36037 -1	.32172 -1	.58637 -2
10	.52077 -1	.35458 -1	.16619 -1	.39546 -1	.33393 -1	.61471 -2
11	.60028 -1	.38249 -1	.21778 -1	.45976 -1	.38819 -1	.72671 -2
12	.63350 -1	.37323 -1	.26127 -1	.48884 -1	.41614 -1	.72805 -2
13	.64540 -1	.39377 -1	.25162 -1	.46136 -1	.40939 -1	.71856 -2
14	.66249 -1	.41631 -1	.24618 -1	.47876 -1	.41029 -1	.68457 -2
15	.70741 -1	.46905 -1	.23836 -1	.47266 -1	.41153 -1	.61043 -2
16	.75403 -1	.51821 -1	.23582 -1	.48974 -1	.43176 -1	.57976 -2
17	.79867 -1	.55234 -1	.24633 -1	.46587 -1	.39077 -1	.66107 -2
18	.76456 -1	.52370 -1	.24185 -1	.43258 -1	.37145 -1	.61132 -2
19	.63637 -1	.41113 -1	.22523 -1	.46851 -1	.40026 -1	.68252 -2
20	.51967 -1	.32285 -1	.19682 -1	.46937 -1	.38323 -1	.86132 -2
21	.43231 -1	.26653 -1	.16578 -1	.45359 -1	.37196 -1	.61713 -2
22	.35222 -1	.21636 -1	.13586 -1	.43160 -1	.36176 -1	.69841 -2
23	.28252 -1	.17803 -1	.10449 -1	.43097 -1	.35378 -1	.76246 -2
24	.21522 -1	.13727 -1	.77951 -2	.40558 -1	.32930 -1	.76262 -2

and weekends. Similarly the next three columns are the percentages of large truck miles traveled during the total week, weekdays, and weekends.

Each of the numbers consist of a fraction and an exponent of 10, so that the fraction of car mileage in the first hour or weekdays is 0.13614×10^{-1} or 1.36%. (No further use was made of the detailed information from this table. However, it is being included here for possible use by other investigators.)

This data was then combined into the four six-hour time periods (12:01 am - 6:00 am, 6:01 am - noon, 12:01 pm - 6:00 pm, 6:01 pm - midnight) and the results are given in a simpler format in Table B.3.

Information from traffic counters in Kansas was compared with the distribution from Ohio. Table B.4 gives the percentage of total traffic on the rural state highways for each of the eight time periods during the week. Note that the percentage of traffic in period 1 (12:01 am - 6:00 am) is much smaller than that for Ohio. Other analyses of the Kansas data indicated that this was primarily due to much less large truck traffic during their early morning hours. The distribution of large truck traffic from Ohio was modified by reducing the percent at that time and distributing it among the rest of the day. The distribution for cars was in basic agreement and was left unchanged. The final distributions of car and large truck mileage which were applied to all toll roads in this study are given in Table B.5.

TABLE B.3

PERCENTAGE OF CAR AND TRUCK MILEAGE IN EACH TIME PERIOD

Time Period	CARS		
	Weekday	Weekend	Total
1	3.3	2.3	5.6
2	17.9	8.8	26.7
3	28.7	14.6	43.3
4	15.3	9.1	24.4
TOTAL	65.2	34.8	100.0

Time Period	TRUCKS		
	Weekday	Weekend	Total
1	17.0	3.9	20.9
2	20.4	3.9	24.3
3	24.3	3.9	28.2
4	22.0	4.6	26.6
TOTAL	83.7	16.3	100.0

TABLE B.4

PERCENTAGE OF TOTAL TRAFFIC ON KANSAS RURAL HIGHWAYS*

Time Period	1973		
	Weekday	Weekend	Total
1	3.4	1.9	5.3
2	22.6	8.1	30.7
3	30.0	12.3	42.3
4	14.6	7.1	21.7
TOTAL	70.6	29.4	100.0

Time Period	1974		
	Weekday	Weekend	Total
1	3.3	2.0	5.0
2	22.1	7.7	29.8
3	30.1	12.0	42.1
4	15.4	7.4	22.8
TOTAL	70.9	29.1	100.0

*From Continuous Traffic Court Data and Traffic Characteristics on Kansas Highways, 1973, p. 48; 1974, p. 56.

TABLE B.5

FINAL PERCENTAGE OF CAR AND TRUCK MILEAGE IN EACH TIME PERIOD

Time Period	CARS		
	Weekday	Weekend	Total
1	3.3	2.3	5.6
2	17.9	8.8	26.7
3	28.7	14.6	43.3
4	15.3	9.1	24.4
TOTAL	65.2	34.8	100.0

Time Period	TRUCKS		
	Weekday	Weekend	Total
1	9.0	2.1	11.1
2	23.5	4.3	27.8
3	27.3	4.5	31.8
4	24.0	5.3	29.3
TOTAL	83.8	16.2	100.0

APPENDIX C

APPENDIX C

TOLL ROAD TOLL CLASSES

The distributions of toll classes and explanation of grouping of classes into the categories of car, large truck, others, are given in Section 5.1. The specific definitions of each toll class are given here.

The toll data for Kansas and Maine were obtained from the turnpikes in a dichotomy of vehicles - cars, trucks-and individual toll classes were not used. These turnpikes did not maintain the data in a computerized form that would allow derivation of travel over each segment by individual class. Data from these two roads was tabulated for the dichotomy by hand from summaries regularly maintained for each road. Therefore, the individual toll classes were not used in the project and are not defined here. The definitions for the New York Thruway, Ohio Turnpike, and Pennsylvania turnpike are given below.

Both the Ohio and Pennsylvania Turnpikes define toll classes basically by gross vehicle weight. The toll classes used by the Ohio Turnpike are listed in Table C.1. The classes are defined solely on the basis of weight except that all 2-axle vehicles with trailers and a gross combined weight of 16,000 pounds or less are class 2 - even those weighing less than 7,000 pounds.

The classes used on the Pennsylvania Turnpike are listed in Table C.2. Weight alone is used in Pennsylvania.

The toll class structure used on the New York Thruway is considerably more complicated. The toll classes are defined not by weight, but by a combination of number of axles and vehicle configuration. The classification is shown in Figure C.1. In addition to the 9 numeric categories shown, vehicles using permits are coded PO in the computerized toll data, and were combined with class 1 in this study. Certain combination-vehicles are given two tickets. These are shown at the bottom of the figure.

Table C.1

OHIO TURNPIKE

TOLL CLASSES

Class	Gross Weight (lb.)
1	0-7,000
2	7,001-16,000*
3	16,001-23,000
4	23,001-33,000
5	33,001-42,000
6	42,001-53,000
7	53,001-65,000
8	65,001-78,000
9	78,001-90,000

*Class 2 includes all 2-axle vehicles with trailers if the total gross weight does not exceed 16,000 pounds.

Table C.2

PENNSYLVANIA TURNPIKE

TOLL CLASSES

Class	Gross Weight (lb)
1	0-7,000
2	7,001-15,000
3	15,001-19,000
4	19,001-30,000
5	30,001-45,000
6	45,001-62,000
7	62,001-80,000
8	80,001-100,000
9	GVW > 100,000 By special permit only

FIGURE C.1

NEW YORK THRUWAY

TOLL CLASSES

TA-63124 (1/72)

Vehicle Classifications on the Thruway System

(Except Grand Island Bridges)

Class		Axles STD.	Axles VAR.
Permit	Passenger car, suburban or motorcycle with Permit	2	0
1	Passenger car, taxi, suburban, ambulance, motorcycle, hearse	2	0
	Light truck, 2 axles, 4 tires	2	0
	Tractor, 2-axle	2	0
	Motor home, 2 axles, 4 tires	2	0
2	Car or 4-tire truck with 1-axle trailer	3	0
	Tractor, 3-axle	3	0
	Car or light truck with mounted 1 axle camper	3	0
3	Tandem trailers (see box)	2	-1 +1,2
4	Truck, 2 axles, 6 tires	2	0
	Motor home, 2 axles, 6 tires	2	0
	Bus, 2 axles, 4 tires	2	0
	Car or 4-tire truck with 2-axle trailer	2	+2
5	Tandem trailers (see box)	3	-1 +1,2
6	Tractor-trailer, 3-axle	3	0
	Auto transporter, 3-axle	3	0
	Car or 4-tire truck with 3-axle trailer	3	+ 2
	Tractor mobile home comb. with 4 axles	3	+ 1
	Truck, 2 axles, 6 tires with 2-axle trailer	3	+ 1
	Bus with 3 axles	3	0
	Tractor, 2 axle, with double saddlemount	3	+ 1

Class		Axles STD.	Axles VAR.
6 (continued)	Tractor, 3 axle, with single saddlemount	3	+ 1
	Truck, 2 axles, 6 tires with double saddlemount	3	+ 1
7	Tractor-trailer, 4 or more axles (Controlled System only)	4	+1,2
	Tractor-trailer, 4 axles (Fixed-toll barriers)	4	0
	Auto transporter 4 or more axles	4	+1,2
	Tractor mobile home comb. with 5 or more axles	4	+1,2
	Truck, 2 axles, 6 tires, with 3 or more axle trailer	4	+1,2
	Truck, 3-axle, with 1 or more axle trailer	4	+1,2
	Bus with 4 or more axles	4	+1
	Tractor, 3-axle with double saddlemount	4	+1
	Truck, 3-axle, with single saddlemount	4	0
	Truck 3 axle with double saddlemount	4	+1
8	Truck, 3-axle	2	+1
	Tractor, 2-axle with 1-axle mobile home	2	+1
	Motor home, 3 axles	2	+1
	Truck, 2 axles, 6 tires, with 1-axle trailer	2	+1
	Bus, 2 axles, 6 tires	2	0
	Tractor, 2-axle with single saddlemount	2	+1
	Truck, 2 axles, 6 tires with single saddlemount	2	+1
	Truck, 2 axles, 6 tires with mounted 1 axle camper	2	+1
0	Tractor-trailer with 5 or more axles (At fixed-toll barriers only)	5	+1

TANDEM TRAILERS Trailers over 28 feet are Class 5. Trailers 28 feet and under are Class 3

Tractor with two large trailers (Two Class 5 tickets)	Utility trailer with 2 axles 4 tires (Class 3 ticket)
Tractor with 1 large, 1 small trailer (Class 5 ticket and Class 3 ticket)	Dolly and semi (over 55 ft. total) hauled by single unit truck (Class 5 ticket plus proper ticket for truck)
Tractor with 2 small trailers (Two Class 3 tickets)	