AUTOMOBILE-UTILITY TRAILER COMBINATIONS ON RURAL HIGHWAYS IN KENTUCKY

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An analysis of accident records indicated that automobile-utility trailer (AUT) combinations are involved in a disproportionately high number of traffic mishaps. Examination of the history of accidents involving AUT vehicles indicated that differential crosswinds and unanticipated driving maneuvers contribute to the driver's loss of control. AUT combinations contributed to the fatigue loss in pavement life approximately 50 percent as much as single-unit, two-axle, six-tire trucks (per vehicle). In general, AUT vehicles constituted approximately 3 percent of the total traffic stream. Analysis of speed distributions indicated an equivalency factor for AUT combinations equal to that for trucks for similar roadway types and topographical conditions.

•THE Kentucky Bureau of Highways recently completed several studies characterizing traffic on highways within the state. The first of these studies (1) established a methodology for predicting the vehicular composition of the traffic stream as related to significant local variables. A methodology was needed to increase the accuracy of predictions of cumulative equivalent axle loads (EALs). The validity of the proposed procedure depends on the accuracy of vehicle classification and loadometer data used as inputs. A second study (2) was conducted to enhance the validity of the predictive technique of the first by providing data on the lateral distribution of traffic on four- and six-lane limited-access facilities. An analysis of loadometer and classification data of traffic using bridges spanning the Ohio River from Kentucky resulted in a proposed methodology (3, 4, 5, 6) by which the fatigue life of a bridge could be evaluated.

Present methods of classifying vehicle types do not segregate automobile-utility trailer (AUT) combinations. Traffic classification counts merely denote an AUT combination as a passenger car. If a trailer is being pulled by a pickup truck, the combination is recorded as a single-unit, two-axle, four-tire truck. In compliance with this practice, previous studies of traffic characteristics (1, 2, 3, 4) made no special notation of these vehicles. However, a surprisingly large number of automobiles pulling utility trailers were noted by the data collectors. Preliminary observations indicated that during peak periods of traffic flow up to 10 percent of the total traffic stream was AUT combinations.

The present study, therefore, was conceived with the following objectives:

1. To establish the presence of AUT combinations on certain rural Kentucky highways,
2. To ascertain the effect of AUT combinations on capacity (level of service) for various highway types and various dissimilar highway sections (in terms of number of equivalent automobiles),
3. To provide a basic data bank for denoting quantitative trends for this vehicle type in the future,
4. To examine the advisability of counting AUT combinations separately in classification studies,

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5. To consider the effect that AUT axle loads have on the total equivalent axle load accumulation, and
6. To investigate accidents involving AUT vehicles.

ACCIDENT DATA AND ANALYSIS

Preliminary comparisons of accident involvement rates of AUT combinations to percentages of this vehicle type in the traffic stream revealed a glaring disproportionality (Table 1). These data were obtained from toll road records (7) and from available accident reports. Inasmuch as these figures are valuable only for intuitive purposes, it was anticipated that a detailed analysis of accident records would provide additional information.

Extensive accident records (1965-68) of Kentucky highways were available for analysis. The geographical distribution of roadways investigated is shown in Figure 1.

Initially, AUT accident trends were compared with those of accidents in general. The procedure involved examination of all single-vehicle accidents, accidents involving AUT combinations, single-vehicle accidents involving AUT combinations, and traffic volumes by means of a graphical representation of trends by hour of day, day of week, and month of year. Typical distributions of total traffic volume, total accident occurrence, and total AUT accidents are shown in Figure 2. There was no marked difference (except for the smoothness of the curves as a function of sample size) between hourly distributions of AUT accidents relative to traffic volume distribution and hourly distributions of all accidents. The same was true for single-vehicle accidents. During daylight hours, there was a greater percentage of single-vehicle AUT accidents than single-vehicle accidents; at night the opposite trends were evident. It was hypothesized that these trends were caused by the lower volume of AUT traffic at night.

Typical accident and traffic volume distributions by day of the week are shown in Figure 3. Again, similarities were apparent. However, accident and volume distributions of AUT traffic showed marked differences. Tuesday was the lightest day for AUT traffic, yet Tuesday was the third highest day for AUT accident occurrence. A similar situation existed for Friday, whereas for Saturday the opposite was true. Thus AUT traffic and AUT accidents cannot be said to coincide to the degree that was exhibited for all traffic and all accidents. For all single-vehicle accidents, similarities with volume distributions were again evident. Once again, the condition of more accidents than volume for AUT single-vehicle accidents prevailed for Tuesday and Friday; the opposite held true for Monday and Saturday. It may be concluded from these observations that the distribution by day of the week of all accidents, both single-vehicle and total, was not identical to that of similarly classed AUT accidents.

Distributions of accidents and volumes by month are shown in Figure 4. Generally, AUT accidents illustrated the same trends as all accidents. There were, however, some notable exceptions. The percentage of AUT accidents increased markedly in April, whereas the percentage of all accidents dropped significantly. The trends then coincided until October, when AUT accidents rose noticeably over a rather exaggerated September low. At the same time, all accidents decreased slightly from September to October. Again, in November, the percentage of AUT accidents dropped perceptibly while the percentage of accidents in general increased slightly. If we discount exaggerations (again probably caused by small sample sizes), trends in single-vehicle accident and single-vehicle AUT accident distributions seemed to follow similar patterns with the exception of the previously noted differences for October and November. Volume of AUT traffic (as a monthly percentage of the yearly total) increased significantly during the summer months; a corresponding increase in accident proportions was not observed. A relatively high percentage of AUT accident occurrence during December and January was countered by the lowest number of AUT vehicles during these 2 months. This suggests that AUT accidents, like accidents in general, correlate rather highly with periods of inclement weather and reduced visibility. The distribution of single-vehicle AUT accidents shows similar features to all AUT accidents, but the increase in summer accidents corresponding to high summer volumes was more noticeable.

Another manner in which accidents involving AUT combinations can be compared

Table 1. Accident involvement of AUT combinations during 1967 and 1968.

Road	Accidents Involving Combinations (percent)	Combinations in Traffic Stream (percent)	Ratio
Bluegrass Parkway	8.92	2.96	3.01
Kentucky Turnpike	5.72	2.66	2.15
Mountain Parkway	1.54	1.27	1.21
West Kentucky Parkway	4.24	3.85	1.10
US-41	1.23	2.02	0.61
US-27	5.26	1.12	4.70
US-60	2.86	1.26	2.26
I-64	4.47	1.16	3.85
I-65	10.51	2.80	3.75
I-75	8.38	4.21	1.99

Figure 1. Geographical distribution of roadways investigated.

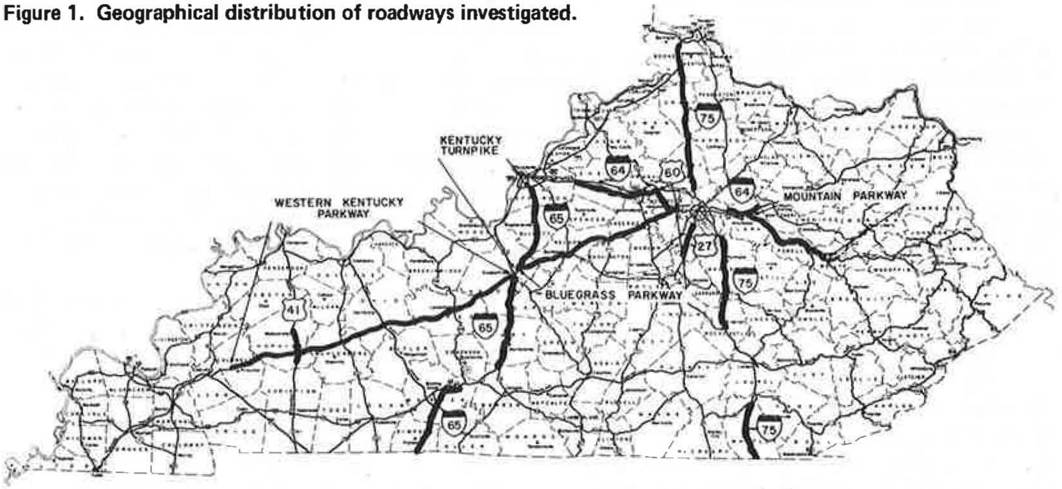
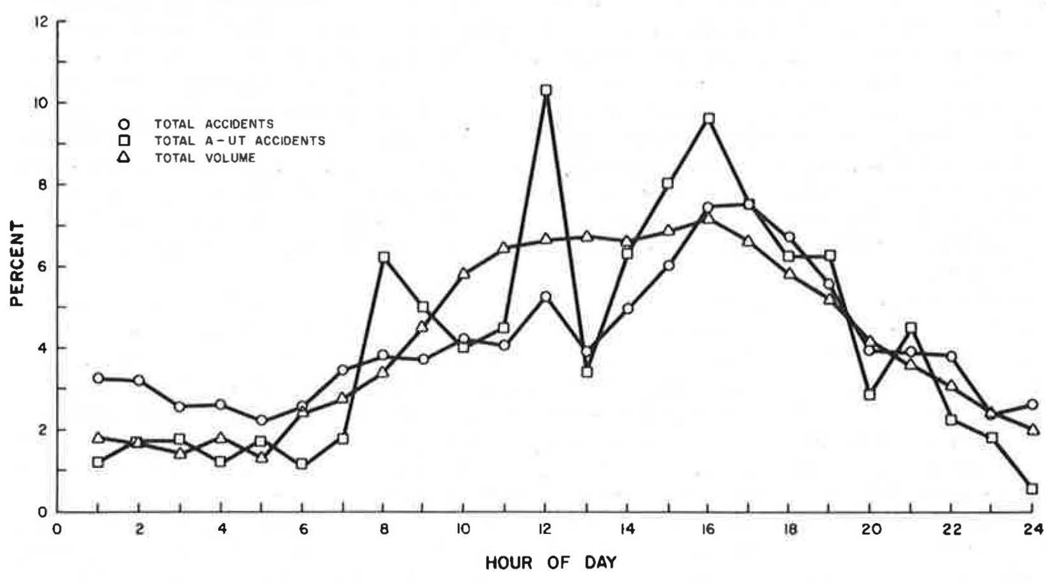


Figure 2. Accident and volume distributions by hour of day for I-75 in Scott County.



with other types of accidents is by distribution in space. It was hypothesized that any location at which the number of AUT accidents was much greater than that of accidents in general could be analyzed for possible contributing factors. A typical spatial distribution of accident occurrences is shown in Figure 5. The methodology to select sites for detailed investigation initially identified all locations at which at least two AUT accidents had been reported. Judgment was then used to ascertain whether the number of AUT accidents represented a disproportionate percentage (60 percent or more) of the total number of accidents reported at that location. It was decided that, although specific accident records at each site could provide insight into probable causes of the problem, they would be best used as a supplement to on-site investigations.

One location was situated on a relatively steep vertical downgrade in relation to several relatively deep rock cuts. Crosswind conditions created by such cuts have been recognized to contribute to accidents. It was hypothesized that crosswinds would affect AUT vehicles more than they would automobiles because of the increased surface area on which wind forces could act. Sudden steering reactions required when a vehicle is subjected to differential crosswind could add to the already difficult task of controlling an AUT combination. Two other locations were similar to the first. At these sites, however, steep grades reduced the speeds of AUT combinations, inducing other vehicles to overtake and pass. The passing of a vehicle also creates a wind loading on both the passing and passed vehicle. Thus these particular accident sites indicated that at least some AUT accidents occur at locations where cuts induce crosswinds or where steep grades lead to wind currents from passing vehicles. These wind factors may be sufficient to affect AUT vehicles although they may not necessarily affect other traffic to such a negative extent.

Another site involving a disproportionate number of AUT combination accidents was a section of six-lane Interstate roadway (three lanes in each direction) with relatively high traffic volumes. Informational signs announcing exit ramps and availability of gas, food, and lodging may precipitate weaving by all traffic and especially AUT traffic. There was also a median crossover at this site; a waiting vehicle within the crossover could induce erratic maneuvers within the traffic stream and thus indirectly create a traffic conflict or a collision. Therefore, the high rate of AUT accidents at this site was probably induced by weaving maneuvers performed during high traffic volume conditions. At another site, the only indicative factor was a blank blue sign panel that previously was lettered REST AREA 2 MILES. It was not known whether the sign message appeared at this site, but there is no subsequent rest area to warrant such a message. Had this sign been erected with such a message, weaving would have been induced. There do not appear to be any contributing conditions, other than some advanced directional signing and the overpass of a county road with its concomitant bridge piers. At a final location, nothing notable in the way of signing appeared in the southbound lanes, but, in the northbound direction, several sign panels preceding an exit (EXIT 1 MILE, GAS-FOOD-LODGING) seemed to present a situation that could induce weaving. In addition, a combination of the cut profile and tree patterns adjacent to the roadway created a situation where wind could be a problem. There was also a crossover located in the area. Specific accident records did not indicate this crossover to be a problem. The primary problem at this site appeared to be a combination of wind and weaving.

A general purview of records of accidents involving AUT combinations seemed to indicate that the primary sources of trouble were trailer hitches becoming loosened while vehicles were in motion and a general loss of control of the AUT combination. There was nothing to indicate that loss of control could be solely attributed to conditions of wet weather. Situations seemed to indicate that more often loss of driver control resulted from wind gusts created by roadway topography or overtaking vehicles. Such situations are difficult if not impossible to correct through modification of the roadway. The apparent difficulty lies with the vehicle itself and not with any roadway disparity. Of course, roadway situations in deep cuts and steep grades, which may contribute to a wind problem, are the result of a desire for economic optimality. Possible elimination or reduction of such situations is necessarily a trade-off against the economic toll of accidents induced by such features. The important factor is that these situations can present problems and may be genuine causes of accidents.

Figure 3. Accident and volume distributions by day of week for I-75 in Scott County.

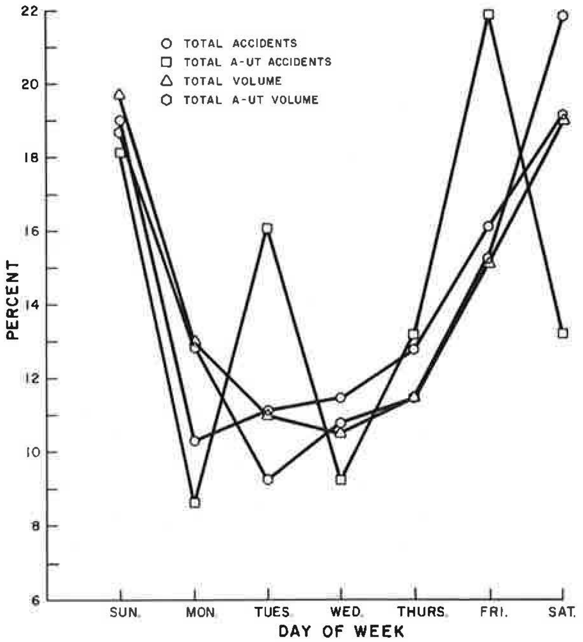


Figure 4. Accident and volume distributions by month of year for I-75.

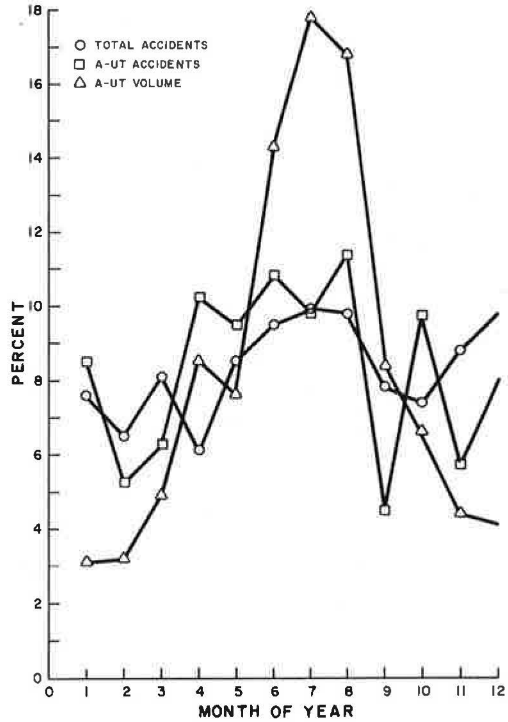
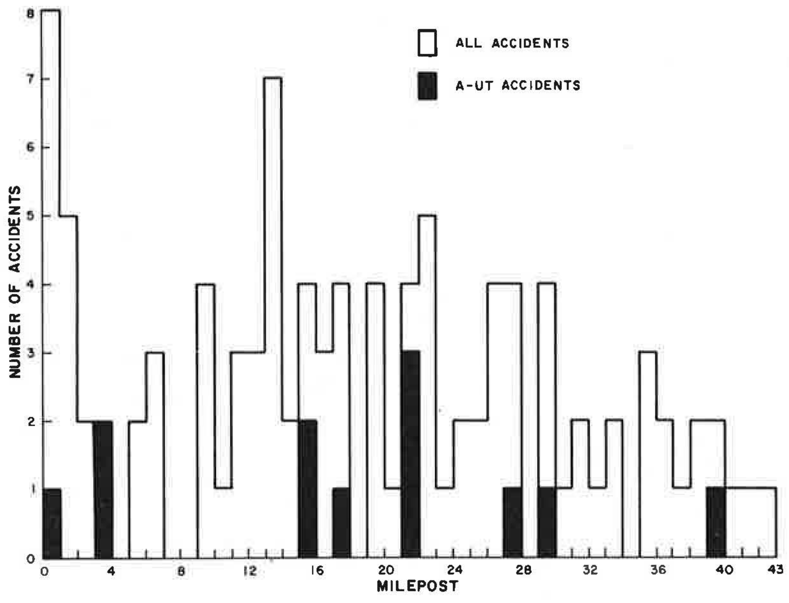


Figure 5. Spatial distribution of accidents on the Bluegrass Parkway.



As a final step in the accident analysis, frequency rates of AUT accidents were compared with the rates of all accidents. The common denominator of this analysis was the accident rate per 100 million vehicle-miles. Reliable measures of such rates were obtained by analyzing accident records, ADT values, and roadway lengths for all accidents. Similarly, rates were computed for AUT accidents by using the number of AUT accidents, the appropriate roadway length, and the volume of AUT traffic. AUT volumes were computed by using data obtained from traffic classification counts and by expanding this information with proper expansion factors. Using the volume of AUT combinations was thought to be a more legitimate procedure than using total volumes and AUT accidents.

Results of the analysis for 10 sections of roadway are shown in Figure 6. The four toll roads are four-lane limited-access highways with attendant toll facilities. US-41 and the three Interstate roadways are four-lane limited-access highways with no toll facilities. US-27 is a two-lane rural highway, and US-60 is a four-lane, no-toll, no access control facility. For the toll roads, the ratio of AUT rates to total accident rates had an unweighted mean value of 0.97. This was markedly different from the unweighted mean value (3.32) for the four toll-free, four-lane, limited-access facilities. This disparity could not be related with any statistical significance to traffic volume, median design, or accidents that occurred on toll facilities. Likewise, no correlation could be established with percentage of AUT vehicles in the traffic stream. Consideration of density did not offer a solution. Finally, this situation was judged to be the result of data sample size. A closer examination of Figure 5 reveals several peculiarities that could most aptly be related to sample size. For instance, the two-lane section of US-27 had the lowest accident rate of all roads considered. This did not conform to intuitive reasoning, for US-27 carried a relatively dense traffic stream. Furthermore, many AUT accident rates were based on a single AUT accident. Undoubtedly, larger accident sample sizes would provide better indications. In general, however, it can still be said that the frequency of AUT accidents was greater than that of accidents involving automobiles alone. The unweighted combination of the statistics shown in Figure 5 indicated that AUT accidents occur 2.35 times more than all accidents.

ANALYSIS OF WEIGHT DATA

To test the hypothesis that the AUT combinations contribute significantly more to accumulated equivalent axle loads on a pavement structure than standard automobiles, we proposed obtaining sample weights of AUT vehicles. No records were available of any previous loadometer data on AUT combinations in Kentucky. A literature search did not reveal any data acquired elsewhere. Principal determinants in selecting weighing sites were compatibility with accident data and availability of facilities for weighing vehicles. Extensive accident records were available for rural, limited-access facilities in the state—both toll roads and Interstate highways. Permanent loadometer stations had been constructed in conjunction with several Interstate facilities, and three of these installations were in operation. The I-75 weigh station was located in Scott County, the I-64 station in Shelby County, and the I-65 station in Hardin County.

Weighing operations were conducted only during the 16-hour period between 6 a.m. and 10 p.m. during the summer of 1970. AUT traffic between 10 p.m. and 6 a.m. did not appear to warrant the inclusion of this time period in the weighing operations. This decision was justified by the number of AUT vehicles finally weighed on I-65 and I-75 (114 and 202 respectively). Thus, a statistically large sample of vehicles in each direction of travel was weighed. However, only 49 vehicles were weighed on I-64. Of these, 21 were eastbound vehicles and 28 were westbound. The relatively smaller number of vehicles weighed was partially attributable to the small daily traffic volumes on I-64 and because of less responsiveness on the part of AUT combination drivers to enter the weigh station area. For each set of data, representing each AUT combination weighed, axle loads, axle spacings, direction of travel, roadway name, and type of trailer being pulled were recorded.

It was desirable to separate the trailers into distinguishable categories so as to evaluate trends for given trailer types. However, it was realized that to obtain statistically significant sample sizes there was a certain practical limit to the number of categories that could be used. As the number of categories increased, the size of each data subset necessarily decreased. Thus, it was decided to categorize the vehicles into three to six classes. A pilot study of vehicle classification was conducted before any data were collected for use in the study to establish procedures and determine classifications of trailers to be used in the actual data collection process.

With the exception of the relatively small amount of data acquired at the I-64 weigh station, the 16-hour weighing period provided statistically sufficient data sample sizes. At the I-64 weigh station, the gross number of vehicles weighed (49) was a significant sample size, but subdivisions of the data into smaller groupings reduced the size of samples below that generally regarded as being statistically large (i.e., 30).

The relationship between vehicle load and contribution to fatigue, whether the fatigue being considered involves structural metallic materials (as in bridge members) or asphaltic or portland cement concrete pavement substances, can best be analyzed by consideration of discrete loading distributions. The initial phase of weight data analysis was to calculate values of selected characteristics. Results of this analysis are given in Tables 2 and 3.

Because the principal intended use of the axle weight data was their application to pavement design techniques, decomposition of these data into subsets of vehicle type, road name, and direction of travel was a necessity if trends peculiar to a certain subset were to be identified (1). However, if certain subsets could be examined with extraneous variables eliminated, the analysis could pinpoint more accurately the source of these trends. To determine whether certain aspects of data subsets were combinable required that appropriate statistical tests be used to examine the equality of means and variances: the Smith-Satterthwaite t-test for equality of means and the F-test for equality of variances. Each of these statistical analyses was performed at the 95 percent level of confidence, with the $\alpha = 0.05$ region divided into two tails.

A rather arbitrary method was necessarily chosen to evaluate results of the statistical comparisons. Four criteria were established. The first was the acceptable statistical combination of three of the four axle loads. The second was the acceptability of combining gross loads. The third examined the combinability of two of the three axle loadings. Statistical lumping of the wheel base was the final criterion. If three of the four criteria were satisfied, it was deemed sufficient evidence of the combinability of the statistical parameter under study. As a result of these tests, the only data lumping deemed proper was that of I-64 eastbound with I-64 westbound and that of I-65 northbound with I-65 southbound.

Pavement design philosophies embody a concept of failure by fatigue in both flexible and rigid pavements and recognize the fatigue-contributing equivalence of a certain number of passages of a standard axle load to a single passage of another weight. The passage of a sufficiently heavy axle contributes to a reduction in the remaining fatigue life. Thus, any unanticipated increase in the number of axle loads from any traffic source could theoretically decrease the useful life of the pavement. Because AUT combinations are categorized merely as automobiles in traffic classification studies, trailer axles are not included in pavement design analyses. If the trailer axles should prove to be relatively heavy, then the damage to the pavement could be significant. When both car axles and trailer axles are considered in a cumulative fatigue analysis for flexible pavement design, the additional EALs accumulated for a 20-year design period for a roadway with significant AUT traffic was approximately 5 percent. AUT combinations contributed to the fatigue loss in pavement life about 50 percent as much as single-unit, two-axle, six-tire trucks (per vehicle).

TRAFFIC COUNTS

Locations for classification studies were restricted from both the aspect of compatibility with available accident records and facilities available for loadometer studies and the aspect of congruity with radar speed study information. Visual classification surveys were conducted in the vicinity of the three loadometer stations. Additional sites were selected to provide data from different classes of roads. One site was

Figure 6. Summary of accident rates.

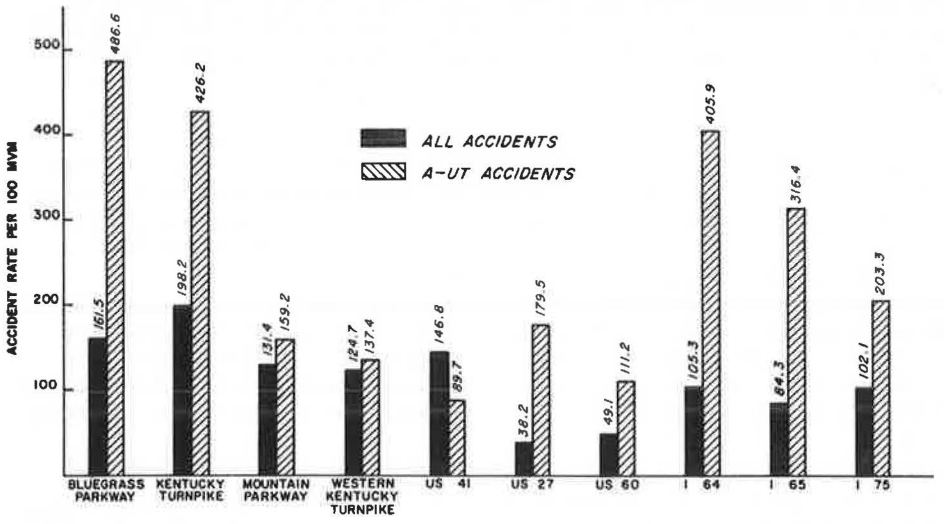


Table 2. Summary of AUT axle weights and spacings by roadway.

	I-75		I-75 Northbound		I-75 Southbound		I-65		I-65 Northbound		I-65 Southbound		I-64		I-64 Eastbound		I-64 Westbound	
Item	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1st axle weight (lbm)	2,270	76	2,233	465	2,303	400	2,338	341	2,360	339	2,325	344	2,258	351	2,301	94	2,224	388
2nd axle weight (lbm)	2,697	112	2,605	308	2,778	337	2,771	177	2,725	588	2,800	499	2,579	485	2,549	455	2,603	515
3rd axle weight (lbm)	1,798	164	1,871	214	1,733	250	1,893	352	1,730	993	1,995	524	1,693	894	1,742	1,165	1,654	820
4th axle weight (lbm)	1,730	642	2,360	781	1,507	419	2,088	669	2,028	867	2,112	617	1,610	750	1,100		1,695	783
Gross load (lbm)	6,949	222	6,856	148	7,032	262	7,325	314	7,041	934	7,502	507	6,756	824	6,643	1,571	6,845	1,573
1st axle spacing (ft)	9.9	0.6	9.8	0.7	9.9	0.5	10.0	0.6	9.9	0.6	10.0	0.6	10.0	0.5	10.1	0.4	10.0	0.6
2nd axle spacing (ft)	14.4	2.6	14.0	2.4	14.7	2.8	14.3	2.8	14.0	2.7	14.5	2.9	13.9	2.4	13.6	2.3	14.1	2.5
3rd axle spacing (ft)	2.5	0.4	2.4	0.6	2.5	0.4	3.2	1.6	3.1	0.2	3.3	2.0	2.8	0.2	2.8	0.4	2.8	0.1
Wheel base (ft)	24.6	3.2	23.9	3.0	25.1	3.4	24.7	3.5	24.2	3.3	25.1	3.6	24.4	3.1	24.0	2.4	24.7	3.3

Note: 1 lbm = 0.45 kg; 1 ft = 0.3 m.

Table 3. Summary of AUT axle weights and spacings by trailer type.

	All Data		One-Axle Trailers		Two-Axle Trailers		Boat Trailers		House Trailers		U-Haul Types of Trailers		Others	
Item	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
1st axle weight (lbm)	2,290	118	2,269	98	2,417	337	2,357	521	2,459	407	2,194	349	2,193	334
2nd axle weight (lbm)	2,704	89	2,657	136	3,014	661	2,788	371	2,781	336	2,538	505	2,713	170
3rd axle weight (lbm)	1,814	117	1,791	56	1,878	649	1,530	704	2,906	394	1,483	454	1,366	298
4th axle weight (lbm)	1,847	681			1,847	681	1,483	418	2,518	520	1,807	647	1,756	733
Gross load (lbm)	7,041	88	6,713	123	9,156	915	6,992	665	8,412	456	6,453	464	6,439	306
1st axle spacing (ft)	9.9	0.6	9.9	0.6	10.3	0.4	10.0	0.9	10.1	0.4	9.8	0.6	9.9	0.5
2nd axle spacing (ft)	14.3	2.7	14.0	2.4	16.1	3.5	17.1	2.1	15.7	2.4	12.6	1.4	13.0	2.0
3rd axle spacing (ft)	2.9	1.1			2.9	1.1	2.3	0.3	2.9	0.1	2.9	0.1	3.3	1.9
Wheel base (ft)	24.6	3.3	23.8	2.6	29.3	3.3	27.7	2.8	26.2	3.1	22.8	2.3	23.3	2.6

Note: 1 lbm = 0.45 kg; 1 ft = 0.3 m.

located on US-41 in Hopkins County. Other locations selected were on US-27 in Jessamine County and on US-60 in Woodford County. It was believed that these six classification study locations, combined with information available from four toll roads, would provide necessary classification information for purposes of this study.

At each site, there was a physical limitation on the number of varying types of information that could be obtained for each count. Some information desired included the lane distribution of total traffic and of AUT traffic and information on whether automobiles had trailer hitches. During any one count period, distribution of traffic by lane or the separation of those vehicles having trailer hitches could be recorded, but not both. A count of cars with trailer hitches was an indicator of the potential of AUT combinations on the roadway. At sites on I-64, I-65, US-27, US-60, and US-41 and the short count on I-75, data concerning trailer hitches were recorded. For the week-long count on I-75, where determination of the presence of a trailer hitch during darkness was difficult, we decided to record the lane distribution of automobiles and of AUT combinations.

A long count (a staggered, week-long study that included each hour of the week) was conducted on I-75 in Scott County. Personnel limitations precluded a 24-hour per day, 7-day continuous count. The remaining counts, which were short, were conducted at locations on I-65, I-64, US-27, US-60, and US-41. The short counts were of 12-hour duration from 8:00 a.m. to 8:00 p.m. These data were supplemented by toll receipts.

Before the classification information was obtained, a method to classify trailer types was chosen. An investigation of the licensing procedure in Kentucky indicated that only "house trailers" and the general class of "trailers" were licensed; a better stratification of trailer type information was needed. During initial counts, data collectors observed that an unusually large number of miscellaneous trailers that could be classified separately as campers were being recorded.

Stratification of trailers by axle configuration was included because this is the type of information needed in an analysis of the effect of axle loads on the pavement. A systematic presentation of loadometer data would of necessity include those types of data needed for the computation of the average numbers of axles in various subsets. Distinction was made between those trailers having two axles closely spaced in tandem and those spaced similar to standard automobiles.

Table 4 gives the average percentages of vehicle types for each of the six roadways at which classification information was obtained. This table also presents a weighted (by volume) average of all data and of data acquired at four-lane, controlled-access facilities. It can be seen that AUT vehicles ranged from 1.12 percent of total traffic on US-27 to 4.24 percent on I-75; the weighted mean value was 2.47 percent on all roads and 3.0 percent on four-lane, controlled-access highways. Thus, the total weighted percentage of recreational vehicles on all roads was 3.48 percent and on all four-lane, limited-access facilities 4.11 percent. The range was a low of 1.75 percent on I-64 to a high of 5.56 percent on I-75.

From data obtained for I-75, it was possible to determine the distribution of vehicle types by hour of day (Table 5) and day of week (Table 6). An analysis of the percentage of AUT traffic as a function of hour of day indicates a good correlation with traffic volume. A similar attempt to relate percentage of AUT vehicles to daily volumes did not produce any significant correlation. It was hypothesized that correlation with volume was significant when day of the week could be incorporated into the percentages, but, when percentage as a function of volume is stratified by day of the week, no correlation was evident. The real meaning of this correlation was not that there was a causative relationship between AUT traffic and traffic volumes but that the increase in AUT traffic during certain periods of time was proportionately greater than the increase in traffic in general. It was obvious this was true for certain days of the week, and the data seem to indicate that this was also true for certain hours of the day.

An analysis was also performed to test the directional equality of vehicle percentages and volume percentages. At the 95 percent level of significance, the percentages of the four vehicle types and of volume were not significantly different by direction of travel.

Furthermore, the following analysis was made of the percentage of non-AUT vehicles that had a trailer hitch:

Road	Vehicles With Trailer Hitches (percent)	Road	Vehicles With Trailer Hitches (percent)
US-41	9.68	I-65	8.16
US-27	11.31	I-64	7.22

The mean percentage of such vehicles was 9.09, and the standard deviation was 1.79. There was no statistically significant difference in the percentages of non-AUT vehicles with trailer hitches. The percentage of this type of vehicle indicated a potential for as much as 10 to 12 percent of the total traffic being AUT vehicles.

Analysis of the percentage of AUT vehicles in the shoulder lane of traffic revealed an unweighted mean percentage of 90.49 when the data were stratified by hour and 88.68 percent when categorized by day. Examination of the hourly percentages revealed that, except for the period between 4 a.m. and 5 a.m. when every AUT vehicle was traveling in the shoulder lane, no particular hour had a statistically significant percentage differential. Similar analysis of percentages by day revealed no significant deviation. It may be concluded that approximately 90 percent of AUT combinations travel in the shoulder lane. Hourly distributions of the percentages of AUT vehicles in the shoulder lane are given in Table 7. Daily distributions were as follows:

Day	Percent	Day	Percent
Sunday	87.39	Thursday	88.45
Monday	90.93	Friday	86.37
Tuesday	91.08	Saturday	89.66
Wednesday	86.90		

The mean was 88.68, and the standard deviation was 1.91. The t-test indicated that Monday, Tuesday, Wednesday, and Friday have significantly different percentages.

The final analysis of traffic classification data was a summary of trailer types. A matrix of five trailer types and three axle configurations was used (Table 8). The distribution of trailer types is dominated by camper trailers; each of the other four trailer types shares an approximately equal percentage of the total. Nearly four-fifths of all trailers had one axle, and less than 1 percent had three axles. Camper trailers were the dominant type of one-axle and three-axle trailers but were the least dominant two-axle trailer. House trailers were the least prevalent one-axle trailer. With the exception of miscellaneous trailer types, house trailers were also the most prevalent two-axle trailer. There were no three-axle boat or U-Haul trailers observed. The largest single trailer type was the one-axle camper trailer.

There was one roadway section, I-75, at which the classification study extended to each hour of the week. It was hypothesized that a calculation could be made to determine the percentage of daily AUT traffic that occurs during each hour of the day and this information could be used to expand a 12-hour count to a full day's count. Similar calculations could then be made for day of the week. Information available from toll road collections could then be used to project the data from the month in which it was taken to the entire year.

There were several assumptions implicit in this numerical manipulation. The distribution by hour of the day was lumped for all days of the week. Therefore, the assumption was that the distribution does not vary within the week. There are several obvious instances in which this assumption is not valid. However, in general, it was

Table 4. Percentage distribution of vehicle types.

Road	Automobiles	AUTs	Campers	Trucks	ADT (vpd)
I-75	85.21	4.21	1.32	9.23	22,988
I-64	80.90	1.16	0.59	18.53	10,586
I-65	77.85	2.80	1.13	18.22	9,860
US-27	90.24	1.12	0.72	7.92	9,740
US-41	79.43	2.02	1.14	17.41	8,510
US-60	86.29	1.26	0.83	11.62	12,000
Weighted avg					
All data	83.59	2.47	1.01	12.93	12,281
Four-lane	81.72	3.00	1.11	14.17	12,986

Table 5. Percentage distribution of vehicle types on I-75 by hour of day.

Hour	Automobiles	AUTs	Campers	Trucks	Average Volume (vehicles/hour)
Midnight to 1	73.72	2.26	1.60	22.02	418
1 to 2	72.96	3.03	1.65	22.36	364
2 to 3	71.87	2.90	1.54	23.69	315
3 to 4	75.97	2.80	0.98	20.25	424
4 to 5	76.19	2.99	1.29	19.53	320
5 to 6	83.36	3.26	0.94	12.44	561
6 to 7	82.75	3.62	1.27	12.36	631
7 to 8	85.22	3.64	1.24	9.90	785
8 to 9	85.77	4.19	1.22	8.82	1,043
9 to 10	86.59	4.70	0.98	7.73	1,334
10 to 11	87.37	4.99	0.99	6.65	1,481
11 to noon	87.12	4.95	1.22	6.71	1,528
Noon to 1	87.64	4.68	1.12	6.56	1,526
1 to 2	87.29	4.89	1.27	6.55	1,517
2 to 3	87.91	4.86	1.33	5.90	1,583
3 to 4	87.19	4.59	2.13	6.09	1,639
4 to 5	88.10	3.93	1.44	6.53	1,513
5 to 6	88.09	4.19	1.28	6.44	1,316
6 to 7	87.11	3.87	1.46	7.56	1,186
7 to 8	84.94	4.07	1.47	9.52	951
8 to 9	81.93	5.35	1.16	11.56	824
9 to 10	83.18	3.34	1.30	12.18	693
10 to 11	80.23	2.92	1.41	15.44	557
11 to midnight	78.69	3.14	1.26	16.91	411

Table 6. Percentage distribution of vehicle types on I-75 by day of week.

Day	Automobiles	AUTs	Campers	Trucks	Volume (vpd)
Sunday	90.21	3.98	1.20	4.61	32,080
Monday	84.99	4.23	1.26	9.52	20,878
Tuesday	81.99	3.57	1.14	13.30	17,589
Wednesday	79.33	4.35	1.13	15.19	16,842
Thursday	80.60	4.24	1.56	13.60	18,369
Friday	85.34	4.18	1.20	9.28	24,589
Saturday	87.92	4.87	1.64	5.57	39,569

Table 7. AUT traffic in shoulder lane by hour.

Hour	Percent	Hour	Percent
0-1	94.87	12-13	87.80
1-2	98.70	13-14	89.21
2-3	93.75	14-15	86.99
3-4	96.39	15-16	86.53
4-5	100.00	16-17	85.58
5-6	95.31	17-18	88.60
6-7	93.12	18-19	85.67
7-8	84.50	19-20	87.82
8-9	92.81	20-21	84.47
9-10	87.47	21-22	89.51
10-11	88.20	22-23	93.86
11-12	89.22	23-24	91.43

Note: Mean = 90.49; standard deviation = 4.44; and largest deviation from mean is not significantly large.

felt that the hypothesis was true. Similarly, the assumption was implicit that the week during which the classification study was conducted was typical of every week of the year. Finally, the assumption was also made that the years for which toll data were acquired were typical. In addition, the assumption was implicit that distributions by hour and by day on I-75 were typical of other roads.

Table 9 gives the percentages of AUT vehicles of the total volume for each hour of the day. It can be seen that the percentage occurring between 7 p.m. and 8 p.m. exceeds that occurring between 7 a.m. and 8 a.m. and that the percentage occurring between 8 a.m. and 9 a.m. and that occurring between 8 p.m. and 9 p.m. were not significantly different. Therefore, it can be concluded that the 8 to 8 shift for the 12-hour count was preferable to a 7 to 7 shift. The percentage of daily AUT vehicles counted between 8 a.m. and 8 p.m. was 77.31 and was distributed as follows:

Day	Percentage of Total	Day	Percentage of Total
Sunday	18.74	Thursday	11.43
Monday	12.94	Friday	15.07
Tuesday	9.21	Saturday	21.86
Wednesday	10.75		

A similar distribution by month of the year is as follows:

Month	Percentage of Total	Month	Percentage of Total
January	3.08	July	17.74
February	3.18	August	16.76
March	4.87	September	8.43
April	8.52	October	6.69
May	7.76	November	4.50
June	14.39	December	4.08

SPOT SPEEDS

The final phase of the study was to determine various spot-speed parameters for different vehicle types. This information could be used to determine AUT combination equivalency factors to be used in capacity analyses. Furthermore, because accident potential on high-speed facilities increases as speed differentials increase, an analysis of speed differential trends might yield a correlation with accident records.

The choice of locations for spot-speed studies was made in conjunction with appropriate criteria for other phases of the study. Specific criteria considered especially relevant to the collection of spot-speed information were relatively straight and level sections of roadway and appropriate possibilities for concealment of measuring apparatus. The requirement that the roadway section be relatively straight and level was derived from the assumption that the most important aspect to be considered is the relative speed between AUT combinations and automobiles, not the absolute speed of either.

At least 3 hours of data in each direction were obtained for each road. Spot speed was recorded for as many vehicles as possible. However, only the first vehicle of a platoon was recorded since this vehicle was the speed determinator of the queue. This limited the data that could be obtained on the two-lane roadway, US-27; however, the greater volume and multilane aspects of the other roads eased the effects of this restriction. Speeds were obtained for automobiles, AUT vehicles, and trucks.

A statistical analysis of speed data indicated a statistically significant difference between AUT combination and automobile speeds at each of the six test sites. Cumulative speed distributions were arrayed according to 85th, 50th, and 15th percentile for automobiles, trucks, and AUT combinations for the six roadway sections. Use of the 85th percentile is consistent with the normal practice used to establish speed limits and gauge the normal running speed of the traffic stream. The 50th percentile is the median speed, a common measure of central tendency. The 15th percentile is used as a lower base for running-speed calculations, sometimes used as the speed below which allowance should not be made in the design of speed-influenced elements. It is also an appropriate statistical symmetry for the 85th-percentile speed.

Based on a symmetry analysis, i.e., a comparison of the difference between the 85th-percentile level and the 50th-percentile level with the difference between the 50th percentile and the 15th percentile, it can be said that automobiles were relatively symmetrical in their speed distribution and exhibited a slightly greater tendency toward dispersion at lower speeds. Trucks were not greatly skewed in their distribution, yet they exhibited a marked trend toward greater variance at lower speeds—more so than automobiles. The speed of AUT vehicles exhibited the greatest variance in distribution in either direction, undoubtedly because of a smaller sample size. However, when the mean difference between upper and lower differentials was computed, the AUT distribution was more heavily skewed downward than the distribution of either automobiles or trucks. By inference, the lower half of the AUT speed distribution was more widely variant than those for automobiles or trucks, indicating that the lower half of the speed range was more extended for AUT combinations.

Equivalency factors can be computed to a remarkable degree of accuracy from speed distributions (8). The process used here to compute equivalency factors for AUT combinations was to compare speed distributions of automobiles, trucks, and AUT combinations. Using established factors for trucks as a base and mean ratio between truck-auto differences and AUT-auto differences as a multiplier, a related figure for AUT combinations was calculated.

Speed-differential ratios for five percentile levels are listed for each road in Table 10. It can be seen that the mean on each of these roads was close to unity. Therefore, the automobile equivalency factor for AUT combinations is essentially the same as the factor for trucks.

SUMMARY AND CONCLUSIONS

The purpose of this discussion has been to consider the influence of AUT combinations on several aspects of highway design and operation. The accident history of these vehicles, the influence of their axle weights on pavement design, the relative proportions of these vehicles in the traffic stream, and the relative speed distributions of these vehicles and other vehicle types are factors that have never before been considered. The purpose of this discussion was not to provide an exhaustive treatise on any of these subject areas but merely to consider all four areas from a general viewpoint.

The following conclusions can be drawn from the results of the study:

1. Accidents involving AUT combinations are disproportionately greater than the prevalence of these vehicles in the traffic stream;
2. Although the size of the data sample was small, several types of locations that seemed to be problem areas for AUT accidents were pin-pointed;
3. Indications at these locations were that AUT accidents are related to wind forces created by either passing maneuvers or cross-sectional configurations or to weaving;
4. Trailer axles, though generally heavier than automobile axles, are relatively light;
5. When both car axles and trailer axles are considered in a cumulative fatigue analysis for flexible pavement design, the additional EALs accumulated for a roadway with significant AUT percentage is approximately 5 percent;
6. Four-fifths of the AUT combinations on the road are one-axle trailers;
7. The camper trailer is the most common type of trailer;
8. The speed distribution of AUT combinations closely resembles that of trucks; and

Table 8. Trailer type percentages.

Trailer Type	Item	One-Axle	Two-Axle	Three-Axle	Summation
House	Mean	11.59	4.28	0.14	16.01
	Std. Dev.	6.04	3.60	0.40	8.80
Boat	Mean	17.54	2.31	0.00	19.85
	Std. Dev.	12.62	3.30	0.00	15.54
U-Haul	Mean	14.57	4.25	0.00	18.82
	Std. Dev.	8.42	4.95	0.00	11.82
Camper	Mean	23.89	0.59	0.53	25.00
	Std. Dev	15.00	0.98	0.03	13.07
Other	Mean	13.01	7.05	0.26	20.32
	Std. Dev.	6.06	4.00	0.73	9.25
Summation	Mean	80.60	18.47	0.93	100.00
	Std. Dev.	8.28	7.99	1.43	

Table 9. Hourly distribution of AUT traffic.

Hour	Percentage of Total	Hour	Percentage of Total
Midnight to 1	1.14	Noon to 1	7.36
1 to 2	1.13	1 to 2	7.61
2 to 3	0.94	2 to 3	7.88
3 to 4	1.22	3 to 4	7.73
4 to 5	0.98	4 to 5	6.10
5 to 6	1.88	5 to 6	5.66
6 to 7	2.35	6 to 7	4.71
7 to 8	2.93	7 to 8	3.98
8 to 9	4.49	8 to 9	4.53
9 to 10	6.44	9 to 10	2.38
10 to 11	7.59	10 to 11	1.67
11 to noon	7.76	11 to 12	1.54

Table 10. Spot speeds and ratios.

		Spot Speeds at Selected Percentiles (mph)					
Road	Vehicle	15	30	50	70	85	Mean
US-27	Automobiles	42	44	48	52	56	
	Trucks	34	39	43	45	50	
	AUTs	38	41	43	45	49	
	Ratio[a]	0.89	0.95	1.00	1.00	1.02	0.97
US-41	Automobiles	56	59	63	66	69	
	Trucks	52	55	58	60	64	
	AUTs	44	52	57	59	61	
	Ratio[a]	1.18	1.08	1.02	1.02	1.05	1.07
US-60	Automobiles	53	57	59	64	65	
	Trucks	47	51	55	58	60	
	AUTs	44	50	53	56	60	
	Ratio[a]	1.04	1.02	1.04	1.04	1.00	1.03
I-65	Automobiles	58	61	64	67	70	
	Trucks	54	56	59	61	63	
	AUTs	50	53	55	60	65	
	Ratio[a]	1.08	1.06	1.07	1.02	0.97	1.04
I-75	Automobiles	61	64	66	69	72	
	Trucks	52	55	58	60	62	
	AUTs	52	55	58	61	65	
	Ratio[a]	1.00	1.00	1.00	0.98	0.95	0.99
I-64	Automobiles	59	62	65	66	70	
	Trucks	54	58	60	63	65	
	AUTs	54	56	58	60	64	
	Ratio[a]	1.00	1.04	1.03	1.05	1.02	1.03

Note: 1 mph = 1.6 km/h.

[a]Ratio of truck spot speed to AUT spot speed.

9. The automobile equivalency factor for AUT combinations is approximately equal to that for trucks.

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