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Traffic Accident Analysis and Application of Systems Safety

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Identification of High-Hazard Locations in the Baltimore County Road-Rating Project

DAVID L. RENSHAW AND EVERETT C. CARTER

One objective of the Baltimore County road-rating project was to identify problem sections of county-maintained roadway. A safety rating was determined for each roadway section in the county inventory; sections vary in length and average daily traffic (ADT) as well as in physical and environmental aspects. Two problems in rating roadway sections are the determination of an adequate number of years of accident data and the choice of clear measures of hazardousness. Short sections that have low ADT often produce rates that indicate high hazard, but with low certainty that they are high-hazard sections; however, the use of a longer sample period may involve many changes in the roadway's physical characteristics, which may invalidate results. The study team attempted to determine which roadway sections were most hazardous and represented the most critical needs. The relationship of the exposure available for analysis on each roadway section, the required exposure for the level of analysis, and the years of accident data required were studied and summarized in a nomograph. A three-year accident data sample was selected by using this nomograph. High-hazard sections were first identified with accident-number and accident-rate measures, and then they were ranked. More sophisticated measures were used to rate and rank sections for hazardousness, and all rankings were compared. Finally all sections were reevaluated, and those that were hazardous with a high level of certainty were identified.

The road-rating project for Baltimore County used several factors based on the county maintenance function, including physical (cross section, present serviceability rating, etc.), capacity, and safety factors, to rate road sections defined by the county. Safety evaluation of sections required that the occurrence of accidents be identified with a particular roadway section. The number and type of accident occurring on each roadway section are the most important measures of roadway hazardousness.

Physical characteristics were measured in the field, for the most part, and compared with the existing inventory provided by the county. Calculations of capacity were made based on the physical features and traffic characteristics observed in the field or provided by the county. Accident data, on the other hand, came from state files maintained by the University of Maryland for research purposes.

The accident data are maintained in a file in which each accident is represented by an accident record. Several times each year, accidents occurring in the state of Maryland are entered into a single file consisting of approximately 100 000 records; the data are therefore more or less in chronological order and grouped by county.

Completing the safety analysis with maximum accuracy and thoroughness required that the accident records be correctly matched with the roadway sections. Variation in the data tapes was found depending on which hardware had been used to generate magnetic data tapes and depending on the year. Different compilers had to be used in the several processing steps to take advantage of available software features and packages.

Sample size had to be determined to provide adequate data for reliable analysis and to stay within the confines of project resources. The use of many years of data involves the risk that significant physical changes in the roadway may affect the analysis. For example, accidents may appear to be related to physical elements that were not present at the time when the accident occurred. The result of using too little data is that some hazards may not be caught. Also, a short sample period and consequently a small sample are disadvantageous when using accident rates. A long-enough study period was sought to allow hazards existing on the roadway network to have generated accidents and thus to have been analyzed in the scope of this road-rating project.

A thorough analysis requires great care in selecting the appropriate measure of hazardousness. Several measures are available; each has advantages. More importantly, each has its proponents. Unfortunately, none satisfies all the concerns of any study or group of decision makers. Some studies have attempted to use several of the available measures, and individual measures have been weighted based on surveys of the importance of each measure. In some cases a measure of hazardousness is selected because it has been much used in the past. Simplicity and ease of understanding are important, but the potential for misleading decision makers must also be considered. This concern tends to lead the analyst to use several measures and to develop rankings based on several points of view. This study focused on a single measure but included several others for discussion and perspective. Determination of composite scores based on weighted measures was left to subsequent analysis.

The measures of hazardousness and their suggested use are critiqued in this paper. Recommended procedures and a different use of the measures are also given.

DATA-PROCESSING PROCEDURES

We first determined what data were available. This paper describes the safety evaluation and the scope of the Baltimore County road-rating project with regard to safety analysis. Accident data are maintained by the county. The Transportation Studies Center has been receiving accident data on magnetic tape directly from the state for the past eight years. With changes in the hardware used to generate tapes, some variations were required in the procedures used to read the tapes for various years. Additional problems occurred because of tape degradation with age and because of the hardware and software idiosyncrasies associated with different manufacturers. Some data tapes for particular years were EBCDC (recent) and some were ASCII (older). The University of Maryland computing system (Univac) required that all EBCDC data be translated to ASCII or field data. This was readily done but represented a processing step. Nevertheless, this data source was far more readily usable than basically hard-copy data from Baltimore County.

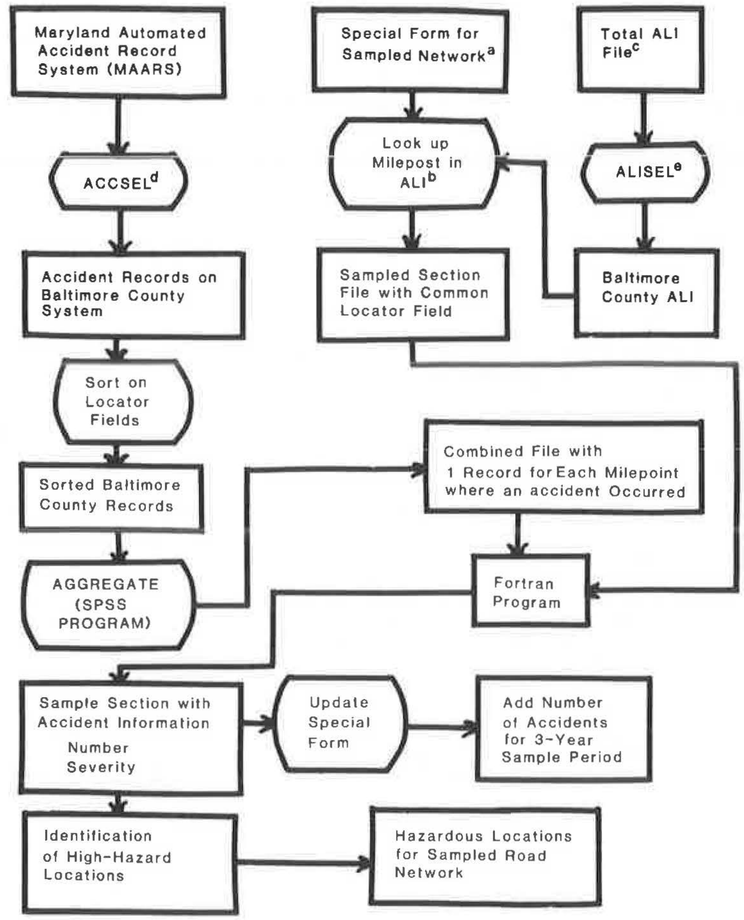
All state data are written with COBOL programming. Both SPSS (Statistical Program for Social Scientists) and BMD (biomedical package) require FORTRAN-generated data files. Neither the standard FORTRAN compiler (FOR) nor the special University of Maryland FORTRAN compiler (RALPH) read COBOL-generated files directly. Similarly, the standard COBOL compiler (ACOB) does not read or write FORTRAN data files.

One alternative that enables use of the state data files requires the generation of card images by using a COBOL program and reading these card images with a FORTRAN program. This would establish a FORTRAN-readable data file suitable for use with SPSS. The other alternative uses a special COBOL compiler (ACOB74) that contains an option for directly outputting data to FORTRAN-readable data files. The second alternative was more used and was more direct and less cumbersome than creating 80-column card images even if this was done entirely in mass storage (no hard copy).

Accident data consisted entirely of digits and letters, so that special characters, which are a concern with IBM-generated files (EBCDC), were no problem.

The first step in preparing the accident data for use in the road rating was to select the Baltimore County accident records for each study year and put all these records into one file. The Baltimore County inventory is developed

Figure 1. General process for safety rating.



a. Accident data is a void
b. Route prefix, route number, milepost
c. ALI: Accident Locator Index File
d. Cobol Program for accident selection
e. Cobol Program for Locator Record selection

around a route-numbering system generated by the state in which each route is assigned a unique six-digit number. For a county-maintained route the first two digits are always 03. The last four digits are a systemically generated unique number. On the accident records, the route number listed is this same four-digit number, and the route prefix CO is equivalent to the code 03. Accidents were therefore selected if they were associated with a CO route. For the three-year period studied (1975-1977), 33 091 accident records from the Maryland Automated Accident Record System (MAARS) were found that had occurred on routes in Baltimore County.

The Baltimore County inventory road sections are developed around intersections and landmarks, whereas the accident files have milepoints to locate accidents. An inventory road section begins at the intersection of the subject route with a specific route or at some distance from an intersection. Similarly, the end point is a physical landmark or intersection and has no relation to the state accident-milepoint system. Consequently, milepoints had to be determined for each inventory-record landmark.

The accident locator index (ALI) file was used to find the milepoint associated with each landmark, since this file lists each intersection and other landmarks together with their milepoints. Since landmarks have no code number, computer processing was not convenient. Finding each landmark in the ALI was very time consuming; intersecting route numbers could be used to some extent, but this resulted in no significant time saving. The 33 091 accidents needed to be matched to the sections with regard to route prefix, route number, and milepoint; the result was the number of accidents occurring on each section.

The overall safety-rating process is shown in Figure 1. Three data sources were used: accident records (MAARS), identification and detailing of the sample section, and common locator indexing by using the ALI file. With these data, the accidents could be matched to the roadway sections, and then the safety analysis was performed.

Computer programming was used to perform most of the steps. COBOL programs were written to select pertinent accident records and ALI records. Programs from the SPSS such as Aggregate were used to combine certain of the data records. A small FORTRAN program was written and used to analyze and to provide a relative rating of the sections.

When several accidents had occurred at a single milepoint, milepoint totals were compiled by using the SPSS program Aggregate. The output from Aggregate was a condensed file that had one record for every milepoint where an accident had occurred. This combined SPSS (FORTRAN) file was then merged with the FORTRAN-file record for the section that contained the section milepoint limits and geometric inventory. These two files were sorted so that the accident record was compared with the section record until the accident record exceeded the milepoint limits of the section record. When a section-record limit was exceeded, it was discarded because all subsequent accident records would also have exceeded the section limit.

Accident records were initially selected by county. Where sampling did not include the entire route, corresponding accident records were discarded. Records of accidents that occurred on a boundary or section limit were associated with the section that had that milepoint as a leading boundary.

Accidents found to have occurred on the network sections were written and stored on magnetic tape, along with pertinent information. The matching-process results were checked for accuracy.

The aggregate statistics, by functional classification, were compiled after the matching process was completed. The accident rate was computed for each section. The sections were then ranked and sorted by accident rate for each functional classification.

METHOD OF ANALYSIS

One objective of the Baltimore road-rating project and the basis for safety analysis was to identify those road sections that were more hazardous than others, i.e., to determine the relative hazardousness of each section being considered. The hazardousness depends on the general characteristics of accidents and the road systems. The primary task in determining the relative hazardousness of locations in the sample network was the choice of the most appropriate measure of effectiveness. The common measure of relative hazardousness is the accident rate, expressed as accidents per million vehicle kilometers. This accident rate measure is used when the road sections are very short or have little traffic or both.

The accident rate expressed as accidents per kilometer was found to be a good measure when the volumes over the road sections were relatively uniform. When there was a significant difference in average daily traffic (ADT) among sections, the accident rate expressed as accidents per million vehicle kilometers was a better measure. Accidents per kilometer were reported as well as a ranking based on this measure for each section.

Sections that have fewer than five accidents per year may be removed if a sufficient number of more-hazardous locations exists. For this study, sections that had fewer than five accidents per year were not considered in depth, although all statistics were reported. If more than five accidents per year had occurred on a road section, section length was considered.

The boundary of an individual road section was determined by the change in some cross-sectional element. A very short section of bituminous (or concrete) curb on one side of the road was represented in the physical inventory by a separately identified and defined roadway section and inventory record. When geometric characteristics remained unchanged, adjacent sections were combined. However, the combination had to specifically avoid very short roadway sections, even when they were defined in such a way as to have homogeneous geometric and cross-section characteristics.

Although accidents may occur because of the presence of a 16-m (0.01-mile) section of bituminous curb, they require space to happen. A vehicle traveling at 48 km/h (30 mph), requiring 6 s to maneuver (although unsuccessfully) to avoid collision and 6 s to come to rest, has potentially used up 152 m (500 ft) of roadway. The cause may have been a lane drop or other such physical element 152 m upstream of the accident-point location listed in the accident record. Our approach to the accident analysis and hazardousness rating was undertaken with this idealized scenario in mind.

Where roadway sections were long and had adequate traffic, the accident rate was simply computed. Where sections were short or had too little traffic, some sections were merged with other sections to avoid production of very large but possibly unrealistic accident rates. The threshold where too little exposure exists had to be defined in order to determine how many years of accident data would allow retention of individual road sections as defined without combination and still have adequate exposure.

Several types of data were required, including the distribution of road section lengths; ADT had to be determined or estimated; and the average accident rate also had to be estimated. From these an estimate was made of how many sections would have too little exposure for accurate evaluation based on a proposed number of years of accident data.

The comparison of the safety of two roadway sections with exactly the same physical and traffic characteristics should be made based on the number of accidents occurring on the two sections. The hazardousness must be measured in increments of one accident. The comparison or measurement is discrete based on an integer number of accidents.

In such a comparison, the analysis should consider the relative effect of the independent variables on the dependent variables. Suppose that the two sections were identical except that one had one more driveway than the other. What difference (percentage) would this make on the relative hazardousness of the two sections? Further suppose that the section with the extra driveway had one more accident. How much more hazardous is the section with the extra accident? The relative hazardousness of the sections can be given by

$$R_1 = A_1/EX \tag{1}$$

$$R_2 = (A_1 + 1)/EX = A_2/EX \tag{2}$$

$$R_2 - R_1 = (A_1 + 1 - A_1)/EX = 1/EX \tag{3}$$

where

A_1 = number of accidents on section 1,
A_2 = number of accidents on section 2, and
EX = exposure (equal for both sections).

If EX is 161 million vehicle-km (100 million vehicle miles), ΔR = 1 accident/161 million vehicle-km = 0.006 accident/million vehicle-km (0.01 accident/million vehicle miles). This result would seem reasonable in that an additional driveway is associated with an increase in accident rate of 0.006 accident/million vehicle-km. If the average accident rate were 3 accidents/million vehicle-km (5 accidents/million vehicle miles), 0.006 accident/million vehicle-km would represent a 0.2 percent increment.

Most importantly for the above situation, the fineness of the analysis is 0.2 percent, and it is measurable. Had the exposure been only 16 million vehicle-km in each of the sections, the difference of one accident would represent a relative fineness of hazardousness of 2 percent. If the sections differ by only one driveway, suggesting that (hypothetically) one driveway causes a 2 percent increase in the accident rate may cause some objection to be raised depending on other factors. For a hypothesis that the driveway accounts for a 2 percent increase in the accident rate, the exposure of 16 million vehicle-km may be marginally adequate, but 161 million vehicle-km would be much better, and possibly 81 million vehicle-km (50 million vehicle miles) would be a preferred minimum.

The outset of the analysis required a general statement about how fine the detectable differences should be. For road sections precisely identical in all physical and traffic attributes, what relative hazardousness should be detectable? The detection level was initially put at 8 percent, assuming a 3-accident/million vehicle-km average accident rate. The 8 percent detection level (error) corresponds to 0.25 accident/million vehicle-km (0.4 accident/million vehicle miles). That is, one accident divided by the exposure must equal 0.25 accident/million vehicle-km. The required exposure therefore was

EX = 1/0.25 = 4.0 million vehicle-km (2.5 million vehicle miles).

For county road sections averaging 152 m (500 ft), the number of vehicles required for the study period is given by

N_v = 4.0 million vehicle-km/0.15 km = 26.6 million vehicles, where N_v is the number of vehicles. For an ADT of 2500 vehicles/day, the required sample period S_y is given by

S_y = 26.6 million vehicles/(365 x 2500) = 29.2 years.

This is an infeasible period.

Some sections are shorter and have less traffic. Many are longer and have more traffic. A substantially traveled section that has 15 000 ADT and a length of 0.8 km (0.5 mile) requires number of vehicles (N_v) and years of sample (S_y) as follows:

N_v = 4.0 million vehicle-km/0.8 km = 5.0 million vehicles.
S_y = (5.0 million vehicles ÷ 10^6)/(365 x 15 000) = 0.913 year = 1 year.

This example can be concluded by stating the minimum volume for which a three-year sample period will yield an 8 percent fineness for an 0.8-km section length:

$ADT_{0.08}$ = 5.0 million vehicles/(365 x 3 years) = 4566.2 vehicles/day.

Realizing that many of the sections in the sample (even after combinations were made) were well under both 0.8 km and 4566 ADT, we examined the results and excluded or segregated those sections in which exposure was very low. Comparing shorter, low-volume sections with longer, higher-volume sections would be statistically unsound, since the sections with low exposure would have a very much higher error associated with them. The error (detection level) is the change in the accident rate produced by the incremental change of one accident; that is,

$$\Delta R = 1/EX \quad (4)$$

where ΔR is the permissible error in the rate or the detection level. For the exposure of 4.0 million vehicle-km

ΔR = 1/4.0 = 0.25 accident/million vehicle-km.

This error can be stated as a percentage of the accident rate. The typical accident rate value for the county road system is 3 accidents/million vehicle-km. The effect of the change of 1 accident/4.0 million vehicle-km on the typical accident rate is

ΔR = (1/4.0)/3 = 0.25/3 = 0.08 or 8.0 percent.

Finally, if the error in the accident rate can be 10 percent, what exposure is required?

$\Delta R/R$ = 0.10 = (1/EX)/3;
EX = 3.3 million vehicle-km (2 million vehicle miles).

The issues discussed above are covered in the Transportation and Traffic Engineering Handbook by using the number-rate method (1, p. 390). The number-rate method requires that hazardous locations have both a high number of accidents and a high accident rate. This almost ensures that the critical sections will be longer and have higher ADT, since short sections generally produce high accident rates but low numbers of accidents.

The nomograph shown in Figure 2 was constructed to assist in determining sample size. Use of this nomograph first requires the estimation of the average accident rate for the subject sample set or subset and location of point P_a on line A. The analysis fineness $\Delta R/R$ multiplied by 100 is then selected, and point P_b is located on line B. The intersection of the line joining P_a and P_b with line C is the point of minimum detection level (P_c). Line C is constructed from lines A and B.

Similarly, the minimum section length is determined, and point P_d is located on line D. The minimum ADT for the minimum-length section is determined, and point P_e is located on line E. The intersection of the line joining P_d and P_e with line F is the minimum exposure (point P_f). Line F is constructed from lines D and E. The line joining the point of minimum exposure (P_f) with the point of minimum detection level (P_c) is extended to intersect the line of family G, corresponding to point P_c (see Figure 2).

The point of intersection of line $\overline{P_c P_f}$ and line G is located in a region, and this shows the required number of years in the sample. Reducing the number of years in the sample means that the minimum exposure must be raised to maintain the desired detection level. Trade-offs in terms of detection level, sample years, minimum section length, and ADT are possible.

The procedure described above has several applications. For example, if the effect on the accident rate of adding 60 cm (2 ft) of shoulder is the subject of analysis, the analytical procedure usually results in obtaining several pieces of information that should have been determined

Figure 2. Accident-sample-exposure nomograph.

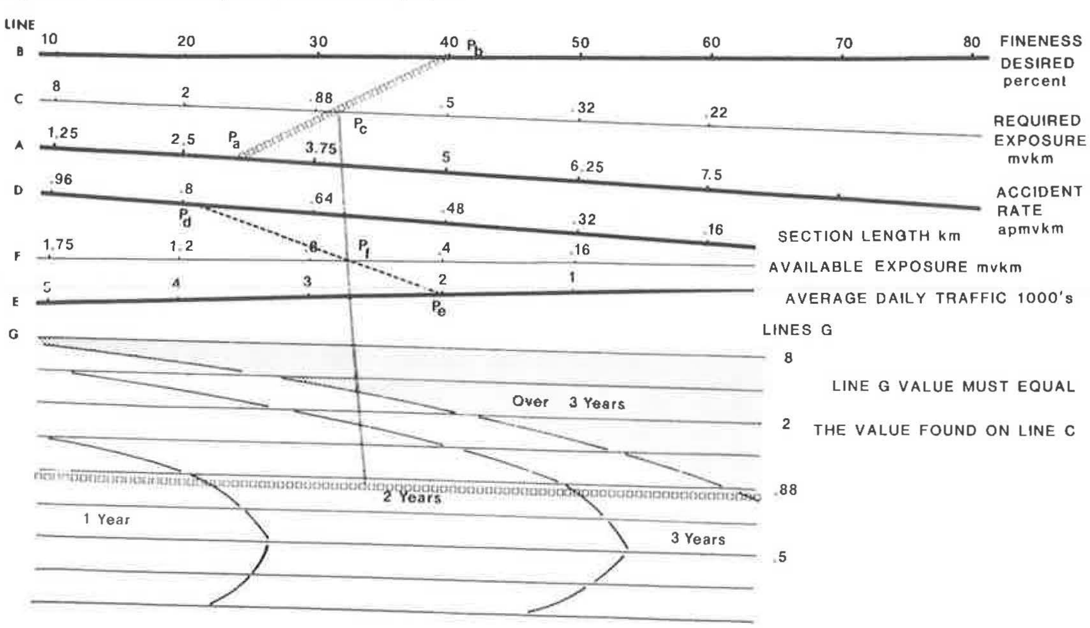


Table 1. Initial safety criteria.

Functional Classification	Accidents in Three Years	Sample Road (km)	Accident Rate [accidents/(km/year)] Three Years	One Year	Twice Three Years	Twice One Year	Accidents per Million Vehicle-km Initial Rate	Twice Initial Rate
Major arterials	3604	56.20	64.1	21.4	128.2	42.7	3.46	6.92
Minor arterials	7219	281.62	25.6	8.5	51.2	17.1	2.93	5.86
Collectors	4002	236.43	16.9	5.7	33.8	11.3	3.02	6.04
Local roads	798	117.99	6.8	2.2	13.6	4.5	4.21	8.42

Note: 1 km = 0.6 mile.

before. The average accident rate on roads with a narrow or no shoulder had not been determined, and we now considered it to be of interest. The data set or subset to be used should have been found to have some general characteristics such as either short sections or low volumes or both. In addition, it should have been determined that the set of roadway sections with a narrow or no shoulder had an accident rate that was not unusual or of unusual variance compared with the rest of the data.

Now the effect on accident rates of adding shoulder width to roads may be analyzed by using another set of data points in which all other characteristics are the same or very similar. The analyst then estimates the change in accident rate or the $\Delta R/R$ (fineness) caused by the added shoulder width. The above procedure can be used to estimate the study period required for each roadway section in the data set where it is desired to compare a series of pairs of roadway sections with and without the incremental shoulder width. Once these pairwise comparisons are based on adequate exposure, any one of a number of statistical tests can be applied.

The same procedure can be applied to the identification of high-hazard locations. The comparison of an apparently high-hazard location with an average location or roadway section should be made with a certainty that the high-hazard section is generating accidents. Apparently high-hazard sections that have few accidents and little travel must be put into a separate category from those that have many accidents and great exposure, just as the proverbial apples and oranges must be separated. With this in mind, the application of this technique to Baltimore County for identification of high-hazard locations by using the entire data set becomes a cluster analysis on different degrees of certainty that some sections are more hazardous than the average and further that they are more hazardous than any other individual section.

DISCUSSION OF ANALYSIS

The general safety characteristics are shown below for the Baltimore County sample network. The total average accident rate, 3.11 accidents/million vehicle-km (5.01 accidents/million vehicle miles), is not particularly high (1 km = 0.6 mile):

Functional Classification	Exposure (vehicle-km 000 000s)	Accidents	Section Length (km)
Major arterials	1041	3 604	56.20
Minor arterials	2460	7 219	281.62
Collectors	1326	4 002	236.43
Local roads	190	798	117.99
Total	5017	15 623	692.24

Baker suggested the number rate for analyzing the safety problems in areas similar to Baltimore County roads (1, p. 390). The number-rate combination was cited as a subsequent step in determining relative hazardousness of locations with about the same number of accidents. The first step was to look at the number of accidents per kilometer per year and to discard those that were less than twice the average. The second step was to discard locations that had less than twice the accident rate as given by

$$\text{Accident rate} = (\text{accidents} \times 10^6)/(\text{ADT} \times \text{days} \times \text{kilometers}) \quad (5)$$

where the accidents correspond to the days (one year, two years, etc.) in the sample. Table 1 contains initial safety criteria for Baltimore County data.

The quality-control technique was adopted from industry and is primarily for sections that have fairly uniform volumes. A critical rate is calculated for each location based on the average for all locations in the group (1, p. 390). If the actual accident rate is greater than the critical rate, the deviation is probably not due to chance but to an unfavorable characteristic of the location, and this warrants study.

The Baltimore County road-rating program was designed to identify deficient road sections in the county system. Deficiencies with regard to safety are those that involve the risk of human life directly and continuously. How hazardous an individual roadway section is and its relation to other sections is often controversial, especially when capital expenditures are at stake. For this reason, it was necessary to evaluate safety deficiencies by means of several measures in order to be comprehensive. Initial measures were total accidents (measure 1) and accident rate (measures 2 and 3). Subsequent consideration was given to three other measures, which involve quality control and variation in the sample for each functional classification. Measure 4 is the upper control limit of the quality-control formula:

$$\text{UCL} = \overline{\text{AR}} + t_i\sqrt{(\overline{\text{AR}}/\text{EX})} + (0.5/\text{EX}) \quad (6)$$

where

UCL = upper control limit,
$\overline{\text{AR}}$ = average accident rate for class, and
t_i = statistic of confidence (1.645 = 95 percent confidence).

Measure 5 is the difference, or amount above the rate limits of the average plus (2 * standard deviation):

$$\text{Difference} = \text{ACCRAT} - (\overline{\text{AR}} + 2 * \text{SD}) \quad (7)$$

where ACCRAT = accident rate for sample section and SD = standard deviation of sample-section accident rate.

Measure 6 is the ratio of the normalized rate to the standard deviation:

$$\text{Ratio} = (\text{ACCRAT} - \overline{\text{AR}})/\text{SD} \quad (8)$$

The average accident rate for the system and the functional classification groupings determines whether many very hazardous sections are ignored (high average accident rate in general) or whether some apparently hazardous sections are actually relatively safe (low average accident rate in general).

There were no standard accident rates found to be applicable and appropriate for this study. Consequently, criteria for the analysis were developed from the sample for comparison with other experiences, either nationwide or statewide.

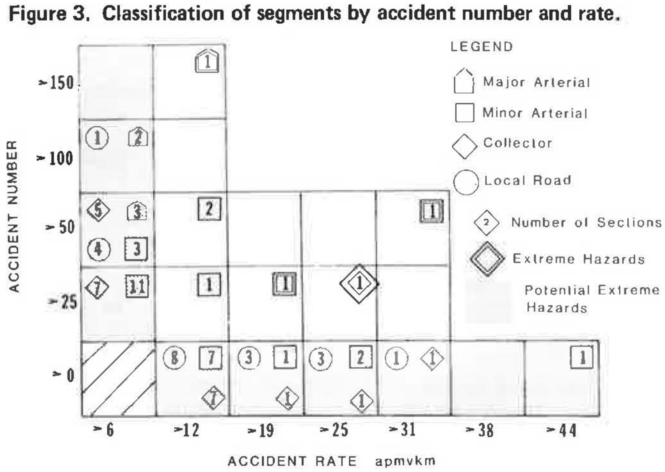
The number of suggested high-hazard locations based on the cutoff values of average rate and twice-the-average rate are shown below for both accidents per kilometer per year (A) and accidents per million vehicle kilometers (B). The numbers of sections having rates beyond these values are given.

Functional Classification	Average Accident Rate		Twice-Average Accident Rate	
	A	B	A	B
Major arterials	31	35	15	13
Minor arterials	147	147	77	54
Collectors	126	125	71	57
Local roads	54	64	36	31

Those sections for each functional class that have an accident rate greater than twice the average are given, as well as those that have rates greater than the average for each measure. For example, 31 major arterial sections had a rate of accidents per kilometer per year greater than the average. Thirty-five sections from that functional class had a rate of accidents per million vehicle kilometers greater than the average. These sections are not necessarily the same. Some may be in both groups (as would be expected); however, it would be possible for them to be totally different groups of sections. Using the cutoff values of twice-the-average rate in accidents per million vehicle kilometers yielded the number of suggested locations shown in the last column above. This is a total of 155 suggested sections from a total of 798 sections.

The number-rate method was then employed. Subsequently, sections that had a rate greater than or equal to 6 accidents/million vehicle-km (10 accidents/million vehicle miles) and an accident number greater than or equal

Figure 3. Classification of segments by accident number and rate.



to 25 were identified. The total number within the range of these values was 80.

Finally, those sections that had a rate greater than or equal to 12 accidents/million vehicle-km (20 accidents/million vehicle miles) and an accident number greater than or equal to 25 were identified. This resulted in eight high-hazard locations. The upper limit of the quality-control curve for those sections was checked for each. All were more than 5 SD above the mean.

The average accident rate ($\overline{AR}$) for all sections in each functional classification was computed, along with a range of two standard errors (LL = lower limit, UL = upper limit) for the purpose of comparing averages. The standard deviation (section) and standard error of the average were also computed. For the standard deviation, the average ±2 SD should encompass 99 percent of the sample. A determination was made whether each section lay within 2 SD of the average accident rate for each functional classification.

Functional Classification	$\overline{AR}$	LL	UL
Major arterials	3.46	3.37	3.55
Minor arterials	2.93	2.90	2.97
Collectors	3.02	2.98	3.05
Local roads	4.21	4.13	4.29

As can be seen above, local roads have an average accident rate that is much higher statistically than that of major arterials; major arterials are higher than minor arterials and collectors. Statistically, minor arterials are not very different from collectors, but collectors are significantly higher, nevertheless.

The average accident rate for each functional class was used as the standard for the safety analysis in the Baltimore County road-rating project. The justification for this is that little in the way of applicable standard accident rates, by functional classification, was available as a guide. These averages are based on an adequate sample and are drawn from the system in question. Use of the average rates derived from the sample facilitates the comparison of sections, and determination of relative hazardousness appears very logical. This procedure is not affected by the magnitude of the average accident rate.

RESULTS

Figure 3 displays the number of sections classified by accident number and accident rate for major arterials, minor arterials, collectors, and local roads examined in the sample network. Sections that had an accident number of 0 to 25 and an accident rate of 0 to 6 accidents/million vehicle-km (0 to 10 accidents/million vehicle miles) were excluded from the sample in Figure 3. The number inside the geometric shape shows the number of roadway sections that occurred in the number-rate category for that functional classification. An example of the correct interpretation is that one minor arterial section had a rate of more than 33 accidents/million vehicle-km (53

Table 2. Rankings of high-hazard sections.

Functional Classification	Measure 1		Measure 2		Measure 3		Measure 4		Measure 5		Measure 6	
	Accident Number	Rank	Accident Rate	Rank	Accident Rate	Rank	Quality Control	Rank	Amount over 2 SD Above Average	Rank	Ratio	Rank
Major arterials	154	1	341.8	3	13.20	8	8.91	8	4.31	5	2.54	4
Minor arterials	74	2	766.4	1	34.30	1	29.68	1	22.40	1	5.76	1
	28	6	217.5	4	19.34	3	14.41	3	7.44	3	3.01	3
	72	3	43.0	7	16.72	4	12.54	4	4.82	4	2.53	5
	55	5	117.9	5	15.73	6	11.44	6	3.84	7	2.35	7
	26	7	115.4	6	14.85	7	10.07	7	2.95	8	2.19	8
Collectors	25	8	40.9	8	24.89	2	19.52	2	14.60	2	4.95	2

accidents/million vehicle miles) and had an accident number of more than 50 for the three-year study period (or 16.67 accidents/year). The shapes in Figure 3 that have double boundaries represent the most hazardous sections with regard to accident number and rate.

Table 2 gives rankings of high-hazard sections. The choice of rate measures is accidents per million vehicle kilometers (measure 3) rather than accidents per kilometer (measure 2). Cutoff values for hazardous locations begin at twice the average.

The most hazardous section with regard to accident number is a major arterial. One major arterial section had an accident number of more than 150 accidents for the three years, with a rate of more than 12 accidents/million vehicle-km (20 accidents/million vehicle miles), compared with the average of 3.5 accidents/million vehicle-km (5.6 accidents/million vehicle miles) for major arterials.

The most hazardous section with regard to accident rate was a minor arterial that had a rate of more than 31 accidents/million vehicle-km (50 accidents/million vehicle miles), compared with the average of 2.9 accidents/million vehicle-km (4.7 accidents/million vehicle miles), and an accident number of more than 50. This section had a rate 10 times the average.

One collector section had a rate of more than 25 accidents/million vehicle-km (40 accidents/million vehicle miles), compared with the average of 3.0 accidents/million vehicle-km (4.8 accidents/million vehicle miles), and an accident number of more than 25. No local roads had both a rate of more than 12 accidents/million vehicle-km and an accident number of more than 25. However, several had either a high rate or a high number.

The general locations of eight high-hazard sections are shown in Figure 4. The numbers in the geometric shapes stand for the rank of hazardousness of each section (see Table 2).

Figure 4. General locations of high-hazard sections.

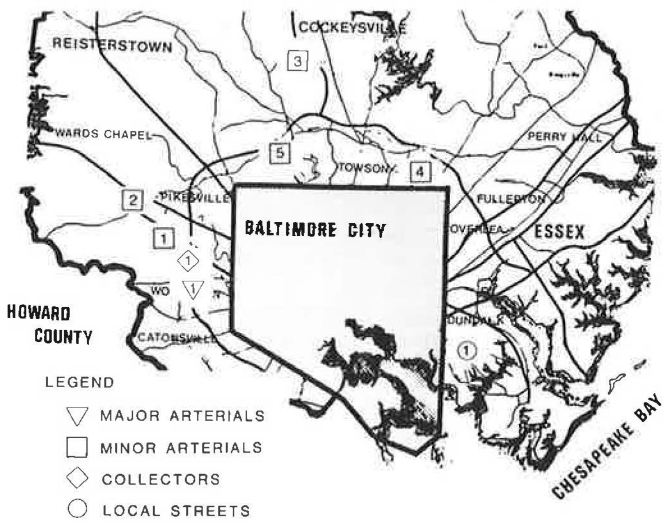


Table 3. Selection of high-hazard sections for which there is certainty.

Functional Classification	$\bar{R}$	$2\bar{R}$	ΔR	EX (vehicle-km 000 000s)	Number of Sections Above $2\bar{R}$ (hazardous)	Number Hazardous with Required Exposure	Total Number of Sections
Major arterials	5.57	11.14	0.56	2.88	13	7	72
Minor arterials	4.72	9.44	0.47	3.43	54	18	307
Collectors	4.86	9.72	0.49	3.28	57	12	256
Local roads	6.77	13.54	0.68	2.37	31	1	163

Note: 1 km = 0.6 mile.

Figure 5. Measures of hazardousness for major arterials.

BALTIMORE COUNTY ROAD RATING SURVEY

ROUTE NO	NODE A	NODE B	F C	SECTN LEN	ADT	ACC NO	ACCIDENT RATE ACC/MVM	ACCIDENT RATE ACC/MI/YR	QUALITY CONTROL	2 STD DEV ABOVE AVG	STD DEV RATIO
35560	7081	8669	2	1.44	29000.	287	6.28	66.44	.121	-8.080	.132
31400	8379	5902	2	.13	24300.	22	6.36	56.41	-1.447	-8.000	.147
32000	6321	6320	2	.28	7350.	15	6.66	17.86	-1.723	-7.700	.203
32000	8154	8155	2	.06	13760.	6	6.64	33.33	-3.572	-7.720	.200
31400	8484	8486	2	.68	21840.	111	6.83	54.41	.262	-7.530	.235
31700	8124	5641	2	.12	25750.	23	6.80	63.89	-1.033	-7.560	.230
31400	8486	8372	2	.36	21840.	60	6.97	55.56	.014	-7.390	.261
30438	5375	8727	2	.04	23000.	7	6.95	58.33	-2.990	-7.410	.258
31153	8333	5910	2	.64	17270.	86	7.11	44.79	.378	-7.250	.288
32000	8144	6568	2	.18	19850.	29	7.41	53.70	-.255	-6.950	.344

ROUTE NO	NODE A	NODE B	F C	SECTN LEN	ADT	ACC NO	ACCIDENT RATE ACC/MVM	ACCIDENT RATE ACC/MI/YR	QUALITY CONTROL	2 STD DEV ABOVE AVG	STD DEV RATIO
32000	8151	8152	2	.46	19320.	73	7.50	52.90	.630	-6.860	.361
31400	8372	8378	2	1.17	23700.	233	7.67	66.38	1.375	-6.690	.392
35460	7080	8648	2	.53	34000.	152	7.70	95.60	1.226	-6.660	.398
35212	8667	7112	2	1.13	20200.	205	8.20	60.47	1.829	-6.160	.492
32000	6660	8140	2	.18	11340.	19	8.50	35.19	.104	-5.860	.548
31153	5922	8333	2	.28	19010.	51	8.75	60.71	1.481	-5.610	.595
35248	7089	8608	2	.06	3170.	2	9.60	11.11	-6.885	-4.760	.754
35248	8608	7092	2	.29	5800.	18	9.77	20.69	1.063	-4.590	.786
31400	8378	8379	2	.46	24300.	120	9.80	86.96	3.075	-4.560	.791
32400	9269	6619	2	.69	19260.	172	11.82	83.09	5.193	-2.540	1.169

Figure 5 continued.

ROUTE NO	NODE A	NODE B	F C	SECTN LEN	ADT	ACC NO	ACCIDENT RATE ACC/MVM	ACCIDENT RATE ACC/MI/YR	QUALITY CONTROL	2 STD DEV ABOVE AVG	STD DEV RATIO
32000	6568	8145	2	.26	19850.	74	13.09	94.87	5.794	-1.270	1.407
31400	5999	8482	2	.05	14670.	12	14.94	80.00	4.410	.580	1.754
35460	8648	8647	2	.19	34000.	106	14.99	185.96	7.885	.630	1.763
32000	6569	8144	2	.05	19850.	17	15.64	113.33	5.880	1.280	1.885
32000	8155	6563	2	.06	15050.	16	16.18	88.89	6.194	1.820	1.986
35212	8664	8667	2	.18	20000.	66	16.74	122.22	9.083	2.380	2.091
35212	7081	8664	2	.16	20000.	60	17.12	125.00	9.328	2.760	2.162
31400	5902	8380	2	.04	24300.	19	17.85	158.33	8.042	3.490	2.298
32400	6601	9267	2	.16	23590.	77	18.63	160.42	11.025	4.270	2.444
32000	8150	8151	2	.11	10260.	24	19.42	72.73	9.948	5.060	2.592
ROUTE NO	NODE A	NODE B	F C	SECTN LEN	ADT	ACC NO	ACCIDENT RATE ACC/MVM	ACCIDENT RATE ACC/MI/YR	QUALITY CONTROL	2 STD DEV ABOVE AVG	STD DEV RATIO
35248	7092	8609	2	.11	3810.	9	19.61	27.27	7.213	5.250	2.628
32400	6602	6601	2	.28	23590.	154	21.29	183.33	14.203	6.930	2.942

REFINEMENTS OF THE ANALYSIS

To identify sections that were definitely hazardous, i.e., those sections for which there is a high level of certainty that the hazardousness was not a statistical quirk, longer section lengths and higher ADTs were required. For those sections with low certainty, the proper disposition would be that, based on the data, no conclusion can be drawn concerning the relative hazardousness of the section.

The cutoff value stated earlier was used for this phase of the analysis. The section accident rate (accidents per million vehicle kilometers) had to exceed twice the average for its functional classification. The additional criterion was that the fineness had to be 10 percent. The required exposure is based on the average accident rate by functional classification ($\overline{R}$). Fineness in percent (F percent) was defined to be ($\Delta R/\overline{R}$) x 100 percent.

The detection level (ΔR) is thus determined by solving for R, given fineness and $\overline{R}$. Required exposure (EX) is determined, since R is given by $\Delta R = 1$ accident/EX. The computed requirements are given in Table 3.

The eight most hazardous locations were chosen with somewhat arbitrary limits of 25 or more accidents and 12 accidents/million vehicle-km or greater. A breakdown by functional class of these eight and of those that were found to be hazardous with certainty is as follows:

Functional Classification	Original Sections	Hazardous with Certainty: Original	New	Total
Major arterials	1	1	6	7
Minor arterials	6	3	15	18
Collectors	1	0	12	12
Local roads	0	0	1	1

All sections on major arterials that had more than twice the average accident rate for the functional class are shown in Figure 5.

REFERENCE

1. J. S. Baker. Traffic Accident Analysis. In The Transportation and Traffic Engineering Handbook (J. Baerwald, ed.), Prentice-Hall, Englewood Cliffs, NJ, 1976.

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Comparison of Accident Data for Trucks and for All Other Motorized Vehicles in Michigan

S. KHASNABIS AND ALI ATABAK

A two-stage study was undertaken to analyze historical accident data for trucks versus all other motorized vehicles in the state of Michigan. In the first stage, a comparison of accident data categorized into three groups of severity and corrected for exposure factors was made between trucks and all other vehicles. In the second stage, truck accident data were further classified into three categories: pickups, panels, and vans (PPVs); straight trucks (dumps, stakes, etc.); and truck tractors. Separate comparisons were made between each truck category and all other vehicles and among the truck categories themselves. The conclusions of the first-stage analysis were that, for fatal and property-damage accidents, trucks had a higher accident rate than did all other vehicles; for injury accidents, trucks had a lower rate; and for all accidents together, there is no significant difference among the accident rates. The second-stage analysis indicated that, in almost all accident categories, PPVs and straight trucks had a higher accident rate than did all other vehicles, whereas truck tractors had a higher rate for fatal accidents only. In all other categories of severity, truck tractors had a lower rate than did all other vehicles. Further, a comparison of accident rates among the three truck categories indicated that straight trucks had the highest accident record, followed by PPVs and truck tractors. Truck tractors, however, had a higher fatal-accident rate then did PPVs.

The prime users of roadway facilities in the United States may be divided into such vehicular categories as passenger cars; trucks, buses, and other commercial vehicles; and motorcycles. Of these, passenger vehicles account for the largest share of total travel, followed by trucks. Approximately 75 percent of all travel by motorized vehicles in the state of Michigan, expressed in vehicle miles of travel (VMT), is generated by passenger vehicles. Trucks account for another 15 percent, and the remaining 10 percent is attributable to all other motorized vehicles.

Truck-related accidents are believed to account for a sizable portion of all highway accidents. As an example, during 1977, 374 751 highway accidents were reported in the state of Michigan, of which 84 640 involved trucks (22.5 percent). Although 631 259 motorized vehicles were involved in such accidents, 91 000, or 14 percent, were trucks. Last, of 1741 fatal accidents reported in Michigan in 1977, as many as 492, or 28 percent, can be considered to be related to trucks.

The increasing number of truck accidents in recent years has caused researchers to question the relative roles of trucks and all other vehicles in the incidence of traffic accidents. It has been suggested by some groups that trucks are involved in a disproportionately large number of accidents compared with all other vehicles. Others have argued that there are no significant differences between accidents experienced by these two vehicular categories when the accident data are duly adjusted for their corresponding exposure factors. The purpose of this paper is to investigate this question by an analysis of factual data on accident and highway travel with the state of Michigan as the experimental site. The study was conducted from September 1978 to March 1979.

OBJECTIVES

The specific objectives of the research reported in this paper are as follows:

1. To collect (from available data files, inventories, and other reports) historical accident and exposure data for trucks and all other motorized vehicles for the state of Michigan,
2. To compare the historical accident data for these two vehicular categories and to draw conclusions about the role of trucks in highway accidents, and
3. To further classify the data on truck accidents and exposure into various categories and to analyze the accident experiences of these categories as they are compared among themselves and with all other vehicles.

METHOD

A two-stage analysis of the accident and travel data was performed. In the first stage, a comparison of accident data (categorized into three classifications of severity and corrected for exposure factors) was conducted between all trucks and all other vehicles. The research approach consisted of collecting historical accident and exposure data for the state of Michigan, developing accident rates, and comparing these rates by using appropriate statistical techniques. The results provide insights about the general role of trucks in the incidence of traffic accidents.

In the second stage, truck data were further classified into (a) pickups, panels, and vans (PPVs); (b) straight trucks (dumps, stakes, etc.); and (c) truck tractors (semitrailers). A separate and independent comparison of accident rates was made between each truck category and all other vehicles and among the three truck categories themselves. The second-stage analysis provided information on the type of truck that has a higher or lower accident rate when compared with all other motorized vehicles.

The scope of this study did not include the collection of any new field data. Rather, the emphasis was to maximize the use of information from different published documents, in-house reports, etc.

Collection of Accident Data

The accident data for the analysis were collected from publications of the Michigan Department of State Police (1), the U.S. Department of Transportation (2,3), and other sources (4-6). In addition, the Motor-Vehicle Accident Tape Inventory, prepared by the Michigan Department of State Police, constituted a prime data source.

Collection of Travel Data

Traffic exposure data were estimated indirectly from a number of sources. Data on total VMT for all motorized vehicles in the state were available from the records of the Michigan Department of Transportation (MDOT). Information on gasoline tax receipts and traffic data collected by the agency as a part of the regular traffic-updating procedure constitute the two primary sources for such VMT data (1). The VMT data obtained from MDOT served as the control total for the state for a given year. These control totals were apportioned into different vehicular categories by using approximate estimating techniques. The reports published by the U.S. Bureau of the Census on the five-year census of transportation (truck use and inventory survey) for 1967 and 1972 (4) were used to conduct an independent check of the reasonableness of the VMT data generated by different estimating techniques.

Statistical Analysis

The statistical analysis—t-tests concerning the difference between means—was conducted for testing the significance of the difference between mean accident rates of the two vehicular categories. Annual accident rates for each combination of vehicular category and accident type were developed from the data compiled; these rates were compared by using a statistical package entitled MIDAS developed by the Statistical Research Laboratory at the University of Michigan (7).

The null hypothesis tested with the accident data was as follows: There is no significant difference between the mean accident rates as compared between trucks and all other vehicles (stage 1) and between each of the three truck categories and all other vehicles, as well as among the three truck categories themselves (stage 2).

The hypothesis testing was conducted by computing the t-statistic where t is a measure of the difference between the two mean accident rates compared. The calculated t-value was then compared with an appropriate critical t-value obtained from the standard statistical tables for the corresponding df and confidence interval used (90 percent). If the calculated t-value was smaller than the critical t-value, the hypothesis was accepted. A higher t-value resulted in the rejection of the null hypothesis. The implications of the acceptance or rejection of the hypothesis are as follows:

1. Acceptance of the null hypothesis signifed that threhere was no real difference between the accident rates of the two vehicular categories. Whatever small difference might have been observed between two data sets was indeed attributable to random chance.
2. Rejection of the hypothesis implied that there was a significant difference between the mean accident rates of the two vehicular categories.

Table 1. Number of accidents involving trucks and all other vehicles and corresponding VMT data, 1970-1977.

Year	Type of Accident: Fatal	PI	PD	Total	VMT (000 000s)
Accidents Involving Trucks					
1970	363	9 620	22 935	32 918	7 301
1971	354	11 183	29 884	41 421	7 726
1972	390	15 245	39 792	55 427	8 948
1973	420	16 146	42 874	59 440	9 119
1974	345	14 837	43 408	58 590	9 225
1975	363	15 932	45 108	61 403	9 616
1976	433	19 125	54 801	74 359	10 644
1977	492	21 939	62 209	84 640	11 335
Accidents Involving All Other Vehicles					
1970	1500	92 258	187 039	280 797	45 894
1971	1536	89 264	181 794	272 594	47 848
1972	1607	98 428	204 283	304 318	48 896
1973	1529	94 139	195 756	291 424	49 328
1974	1306	80 536	184 331	266 173	46 522
1975	1248	82 305	188 604	272 157	46 644
1976	1297	87 938	202 006	291 241	50 993
1977	1249	87 670	201 192	290 111	53 518

Table 2. Number of trucks involved in accidents in Michigan and corresponding VMT data, 1966-1977.

Year	Type of Accident: Fatal	PI	PD	Total	VMT (000 000s)
1966	352	11 068	29 400	40 828	5 560
1967	324	11 237	29 335	40 896	5 978
1968	360	13 502	32 377	46 239	6 591
1969	412	16 076	39 006	55 494	6 963
1970	384	15 383	36 281	52 048	7 301
1971	392	13 502	35 841	49 735	7 726
1972	422	16 223	42 021	58 666	8 948
1973	454	17 296	45 365	63 115	9 119
1974	365	15 879	46 052	62 296	9 225
1975	381	17 019	47 945	65 345	9 616
1976	469	20 608	58 450	79 527	10 644
1977	532	23 744	66 818	91 094	11 335

RESULTS: STAGE 1

Estimation of Exposure Data

Truck VMT Data

Neither truck VMT data nor the average travel rates for trucks in the state of Michigan were available directly. However, two primary sources were available for estimating truck VMT data: Highway Statistics (2) and American Trucking Trends (5). For each of these two sources, total annual VMT was calculated as a function of the number of trucks registered in the state of Michigan and the average annual travel rate in miles per truck, computed from nationwide data.

It was assumed that the travel generated in Michigan by out-of-state trucks was balanced by travel generated outside the state by Michigan-registered vehicles. No explicit effort was thus made to account for truck travel generated in the state by out-of-state trucks or to discount travel generated by Michigan trucks outside the state boundaries.

The data were then compared with a third independent data source, namely, the five-year census of transportation prepared by the U.S. Bureau of the Census (4). These data were available only for 1967 and 1972. The relative closeness of the VMT data developed from these independent sources indicated that the information was realistic.

VMT Data for All Other Vehicles

Total VMT generated in the state of Michigan by all motorized vehicles (trucks, passenger cars, buses, motorcycles, etc.) is regularly computed by the state highway department from gasoline tax receipts. This information was thus directly available from Michigan Traffic Accident Facts, prepared by the Michigan Department of State Police (1). The difference between the total VMT and the truck VMT was calculated as the VMT for all other vehicles.

Accident Data Analysis

The major source of accident data was the accident inventory files maintained by the Michigan Department of State Police, in which all reported accidents in the state are recorded. As such, the data base used in the analysis is considered the most comprehensive. Accident data were collected in four categories—fatal, personal injury (PI), property damage (PD), and total. The data collected from the accident files included information on number of accidents as well as number of trucks involved in accidents. The latter figure, although not used in the first-stage analysis, was used in the second stage to categorize truck accidents into subgroups.

Table 1 shows data on number of accidents in which trucks and all other vehicles were involved in any one of the four accident categories and the corresponding VMT data, Table 2 shows the data on the number of trucks involved in accidents, and Table 3 shows the VMT data for trucks, other vehicles, and passenger cars obtained from different sources. The relative closeness of the truck VMT data from the three sources is worth noting. Table 1 indicates that, during 1970, there were 363 fatal accidents in which at least one truck was involved and 1500 fatal accidents in which at least one other type of vehicle was involved. It must be noted that these numbers are mutually exclusive; the sum of these two figures represents the total number of fatal accidents in the state in which at least one motorized vehicle was involved during 1970. An accident that involved at least one truck was categorized as a truck accident. The same accident was not counted as an accident involving another type of vehicle, even though the other vehicle (in case of a multiple-car accident) might have been a passenger car, a bus, or any type of vehicle other than a

Table 3. Summary of VMT of trucks, other vehicles, and passenger cars, 1963-1977.

	Truck VMT (000 000s)			VMT of All Other Vehicles (000 000s)		
Year	Highway Statistics	American Trucking Associations	Census of Transportation	All Motorized Vehicles Except Trucks	Passenger Cars	Total in Michigan
1963	4 995	4987		31 460	29 204	36 452.2
1964	5 325	5280		33 314	30 583	38 617.6
1965	5 663	5601		35 225	32 362	40 857.4
1966	5 560	5512		38 403	33 420	43 940.1
1967	5 978	5905	6161	39 111	34 191	45 053.6
1968	6 591	6494		41 504	35 950	48 047.4
1969	6 963	7101		43 872	37 889	50 904.9
1970	7 301	7205		45 894	39 094	53 148.1
1971	7 726	7655		47 848	41 012	55 539.7
1972	8 948	8893	8975	48 896	43 435	57 817.1
1973	9 119	9179		49 328	44 321	58 478.4
1974	9 225	NA		46 522	43 066	55 748.4
1975	9 616	NA		46 644	44 584	56 260.5
1976	10 644	NA		50 993	46 000	61 638.0
1977	11 335	NA	NP	53 518	48 744	64 853.0

Notes: NA = not available.
NP = not published as of the writing of this report.

Table 4. Accidents rates for trucks and all other vehicles.

	Trucks				All Other Vehicles			
Year	Fatal ($\times 10^{-8}$)	PI ($\times 10^{-6}$)	PD ($\times 10^{-6}$)	Total ($\times 10^{-6}$)	Fatal ($\times 10^{-8}$)	PI ($\times 10^{-6}$)	PD ($\times 10^{-6}$)	Total ($\times 10^{-6}$)
1970	4.97	1.31	3.14	4.51	3.27	2.01	4.07	6.12
1971	4.58	1.45	3.87	5.36	3.21	1.86	3.80	5.70
1972	4.36	1.70	4.45	6.19	3.29	2.01	4.18	6.22
1973	4.61	1.77	4.71	6.52	3.09	1.91	3.97	5.91
1974	3.74	1.61	4.70	6.35	2.81	1.73	3.96	5.72
1975	3.77	1.66	4.69	6.38	2.67	1.76	4.04	5.83
1976	4.07	1.80	5.15	6.99	2.54	1.72	3.96	5.71
1977	4.34	1.93	5.49	7.47	2.33	1.64	3.76	5.42
Avg	4.305	1.65	4.25	6.22	2.90	1.83	3.97	5.83

Table 5. Comparison of accidents between trucks and all other vehicles (accidents per VMT).

	Mean Rate					
Accident Type	Trucks	Other Vehicles	t_{calc}	t_{crit}	df	Conclusion
Total	6.2212	5.8287	1.1604	1.761	14	Accept null hypothesis (no difference)
Fatal	4.3050	2.9012	7.0623	1.761	14	Reject null hypothesis (trucks higher)
PI	1.6537	1.8300	-2.0594	1.761	14	Reject null hypothesis (trucks lower)
PD	4.5250	3.9675	2.1128	1.761	14	Reject null hypothesis (trucks higher)

truck. This approach may be criticized as being too restrictive on trucks, particularly when one considers the fact that most truck accidents involve a single truck, whereas most other-vehicle accidents involve more than one vehicle (e.g., two passenger cars as the most common case). The resolution of this issue was beyond the scope of this study.

The accident rates derived by dividing the number of accidents by the corresponding VMT are presented in Table 4, along with the overall average. For the analysis period 1970-1977, an average of 4.305 fatal accidents occurred for every 100 million vehicle miles of truck travel. Similarly, for every 100 million vehicle miles of travel by all other vehicles, an average of 2.90 fatal accidents was recorded.

Results of the statistical analysis by using data from Table 4 are shown in Table 5. As explained earlier, the acceptance of the null hypothesis is indicative of no difference, and the rejection of the same implies the existence of a significant difference. It is evident from Table 5 that, for fatal and PD accidents, trucks had a statistically higher rate. For injury accidents, trucks were lower; for all accidents considered together, there was no significant difference.

The overall implication of Table 5 can be summarized as follows: When all accidents involving trucks and all other vehicles are considered, there does not appear to be any significant difference in the accident rates between these two vehicular categories. For fatal accidents, truck rates are definitely higher (note that the t_{calc} of 7.062 is considerably higher than the t_{crit} of 1.761). For the other two accident categories, the accident experiences are reasonably close, although the statistical tests place trucks lower in one case and higher in the other. The relatively small difference between t_{calc} and t_{crit} values in these two cases provides support for such a conclusion.

RESULTS: STAGE 2

In stage 2, the truck data collected and analyzed in the earlier stage were further classified into three categories: (a) pickups, panels, and vans (PPVs); (b) straight trucks; and (c) truck tractors. The classification was accomplished in a manner that would permit the use of the available accident and exposure data. The second-stage analysis was conducted for 1972-1977, since accident data classified by the three different truck categories were not available prior to 1972.

Estimation of VMT Data by Truck Categories

The procedure applied for estimating VMT generated by the three truck categories is essentially similar to the one used in the stage 1 analysis. Truck vehicle registration data were obtained from MDOT and used in conjunction with the annual average travel mileage rate for each vehicular category as obtained from Highway Statistics (2) based on nationwide data. The data thus generated were checked for reasonableness with other independent data sources,

Table 6. Accident rates of three truck categories.

	Pickups, Panels, and Vans				Straight Trucks				Truck Tractors			
Year	Fatal ($\times 10^{-8}$)	PI ($\times 10^{-6}$)	PD ($\times 10^{-6}$)	Total ($\times 10^{-6}$)	Fatal ($\times 10^{-8}$)	PI ($\times 10^{-6}$)	PD ($\times 10^{-6}$)	Total ($\times 10^{-6}$)	Fatal ($\times 10^{-8}$)	PI ($\times 10^{-6}$)	PD ($\times 10^{-6}$)	Total ($\times 10^{-6}$)
1972	3.95	1.75	4.29	6.08	15.1	6.32	17.4	23.8	6.74	1.39	4.02	5.48
1973	3.49	1.72	4.35	6.11	18.1	7.19	19.8	27.1	7.43	1.42	4.14	5.63
1974	3.26	1.66	4.69	6.38	14.5	7.83	23.5	31.5	5.10	1.00	3.12	4.17
1975	3.62	1.69	4.76	6.49	18.3	9.24	26.4	35.8	3.97	0.98	2.96	3.98
1976	3.90	1.91	5.38	7.33	16.9	8.56	25.8	34.5	4.96	1.21	3.49	4.76
1977	4.17	2.10	5.81	7.98	17.7	9.12	27.8	37.2	5.72	1.22	3.69	4.98
Avg	3.73	1.8050	4.88	6.728	16.766	8.04	23.45	31.65	5.65	1.20	3.57	4.83

Table 7. Number of trucks by type involved in accidents in Michigan, 1972-1977.

	Type of Accident				
Year	Fatal	PI	PD	Total	VMT (000 000s)
Pickups, Panels, and Vans					
1972	223	9 726	23 878	33 827	5245
1973	208	10 186	25 469	35 863	5524
1974	186	9 568	26 789	36 543	5390
1975	216	10 305	28 678	39 199	5685
1976	274	13 457	37 525	51 256	6513
1977	316	15 984	43 712	60 012	7013
Straight Trucks					
1972	97	3 986	10 955	15 038	594.6
1973	115	4 473	12 402	16 990	589.5
1974	82	4 506	13 418	18 006	537.6
1975	100	5 158	14 607	19 865	521.9
1976	102	5 178	15 486	20 748	559.9
1977	105	5 458	16 511	22 074	553.8
Truck Tractors					
1972	101	2 051	5 939	8 091	1393
1973	122	2 305	6 677	9 104	1521
1974	94	1 875	5 773	7 742	1744
1975	66	1 665	4 976	6 707	1583
1976	86	2 124	6 026	8 236	1613
1977	110	2 358	7 046	9 514	1784

primarily the census data and other information available locally.

Accident Data Collection by Truck Categories

For this part of the analysis, accident data were available on the number of trucks (by each of the three categories) involved in any one of the four types of accident. Similar information on number of accidents was not directly available but was estimated.

It was assumed that the average number of truck types involved in a given accident category and in a given year did not vary. This average figure was computed for each accident type for each of the analysis years from data collected in stage 1. The number of accidents for each truck category was obtained by dividing the corresponding number of trucks involved in accidents by the average figures obtained. The accident rates derived by dividing the number of accidents (by truck categories and accident types) by the corresponding VMT are given in Table 6. Table 7 provides the data on the number of trucks (by type) and the corresponding VMTs that were used in developing the rates used in Table 6.

Statistical Comparison of Accident Data

The data generated in Table 6 were the basis for a statistical comparison. Essentially, two sets of comparisons were made. In the first set, the rates for each truck category and accident type were compared with the corresponding rates for all other vehicles. In the second set, accident rates were compared for different truck categories. The results of these comparisons are presented below.

Comparison with Accident Rates for All Other Vehicles

The statistical procedure used in the second-stage analysis is similar to the one used in the first stage. Results of comparing accident rates for PPVs, straight trucks, and truck tractors (Table 6) with similar rates for all other vehicles (Table 4) are presented in Table 8. Although the entries in this table are self-explanatory, some general observations are in order. Except for PI accidents for PPVs, in all other accident categories, both PPVs and straight trucks have a statistically higher accident rate than all other vehicles. On the other hand, truck tractors have a higher accident rate only in fatal accidents. In the other three accident categories, the rates of truck tractor accidents are statistically lower than those of all other vehicles.

Comparison Among Truck Categories

Table 9 provides the results of the statistical analysis of accident rates for the three truck categories compared with one another. The table indicates that compared with PPVs, straight trucks had a consistently higher rate in all categories and that, compared with PPVs, truck tractors had a higher rate in fatal accidents and lower rates in the other three accident categories. The table also indicates that, in all accident categories, straight trucks had higher accident rates than did truck tractors.

CONCLUSIONS

The objective of this study was to investigate the role of trucks in highway accidents compared with all other motorized vehicles, based on an analysis of data from the state of Michigan. The analysis was conducted in two stages. In stage 1, a comparison was made of accidents between all trucks and all other vehicles. In stage 2, truck accident data were divided into three truck categories and a comparison was made between those data and data for all other vehicles. In addition, accident data were compared among the three truck categories. The conclusions of the study follow.

Stage 1 Analysis

1. In the case of fatal and PD accidents, trucks had a higher accident rate than did all other vehicles.
2. For PI accidents, trucks had a lower accident rate than did all other vehicles.
3. When all accidents were considered together, it appeared that there was no significant difference in the accident rates of these two vehicle categories.

These conclusions are schematically represented below (X = higher accident rate for trucks than for all other vehicles; * = lower accident rate for trucks than for all

Table 8. Comparison of accidents between trucks (PPVs, straight trucks, and truck tractors) and all other vehicles (accidents per VMT).

Accident Type	Mean Rate: Trucks	Mean Rate: All Other Vehicles	t_{calc}	t_{crit}	df	Conclusion
PPVs Versus All Other Vehicles						
Fatal	3.7317	2.7883	4.735 7	1.812	10	Reject null hypothesis (PPVs higher)
PI	1.8050	1.7950	0.112 49	1.812	10	Accept null hypothesis (no difference)
PD	4.8800	3.9783	3.594 9	1.812	10	Reject null hypothesis (PPVs higher)
Total	6.7283	5.8017	2.812 1	1.812	10	Reject null hypothesis (PPVs higher)
Straight Trucks Versus All Other Vehicles						
Fatal	16.767	2.7883	20.790	1.812	10	Reject null hypothesis (straight trucks higher)
PI	8.0267	1.7950	13.016	1.812	10	Reject null hypothesis (straight trucks higher)
PD	23.450	3.9783	11.695	1.812	10	Reject null hypothesis (straight trucks higher)
Total	31.650	5.8017	12.015	1.812	10	Reject null hypothesis (straight trucks higher)
Truck Tractors Versus All Other Vehicles						
Fatal	5.6533	2.7883	5.353 7	1.812	10	Reject null hypothesis (truck tractors higher)
PI	1.2033	1.7950	-6.261 3	1.812		Reject null hypothesis (truck tractors lower)
PD	3.5700	3.9783	-2.028 5	1.812	10	Reject null hypothesis (truck tractors lower)
Total	4.8333	5.8017	-3.291 7	1.812	10	Reject null hypothesis (truck tractors lower)

Table 9. Comparison of accidents among PPVs, straight trucks, and truck tractors (accidents per VMT).

Accident Type	Mean Rate: First Category	Mean Rate: Second Category	t_{calc}	t_{crit}	df	Conclusion
PPVs Versus Straight Trucks						
Fatal	3.7317	16.767	-19.435	1.812	10	Reject null hypothesis (straight trucks higher)
PI	1.8050	8.0267	-12.951	1.812	10	Reject null hypothesis (straight trucks higher)
PD	4.8800	23.450	-11.041	1.812	10	Reject null hypothesis (straight trucks higher)
Total	6.7283	31.650	-11.479	1.812	10	Reject null hypothesis (straight trucks higher)
PPVs Versus Truck Tractors						
Fatal	3.7317	5.6533	-3.6051	1.812	10	Reject null hypothesis (truck tractors higher)
PI	1.8050	1.2033	5.8634	1.812	10	Reject null hypothesis (PPVs higher)
PD	4.8800	3.5700	4.2010	1.812	10	Reject null hypothesis (PPVs higher)
Total	6.7283	4.8333	4.5704	1.812	10	Reject null hypothesis (PPVs higher)
Straight Trucks Versus Truck Tractors						
Fatal	16.767	5.6533	13.316	1.812	10	Reject null hypothesis (straight trucks higher)
PI	8.2067	1.2033	14.172	1.812	10	Reject null hypothesis (straight trucks higher)
PD	23.450	3.5700	11.867	1.812	10	Reject null hypothesis (straight trucks higher)
Total	31.650	4.8333	12.381	1.812	10	Reject null hypothesis (straight trucks higher)

other vehicles; NS = no significant difference):

Truck Category	Accident Type: Fatal	PI	PD	Total
All trucks	X	*	X	NS
PPVs	X	NS	X	X
Straight trucks	X	X	X	X
Truck tractors	X	*	*	*

Stage 2 Analysis

1. PPVs appeared to have a higher accident rate than did all other vehicles in fatal, PD, and total-accident categories. In PI accidents, the rate for PPVs was lower.

2. For straight trucks (stakes, dumps, etc.) the accident rates in all accident types were higher than those for all other vehicles.

3. Only in fatal accidents did truck tractors have a rate higher than that of all other vehicles.

4. A comparison of the accident rates among the three truck categories revealed that (a) straight trucks had a higher rate in all accident categories than did PPVs and truck tractors; (b) PPVs had a higher accident rate in PI, PD, and total accidents than did truck tractors; and (c) truck tractors appeared to have a higher accident rate than did PPVs in the fatal-accident category.

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The opinions and viewpoints expressed in this report are entirely ours. They do not in any way reflect the plans, policies, or programs of any particular agency mentioned above.

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Truck Drivers' Perceptions of Mountain Driving Problems

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A questionnaire was used to determine truck drivers' perceptions of mountain driving problems and truck escape ramps. A postage-paid self-mailer form was used in a variety of situations. Some questionnaires were mailed to drivers, some were distributed at truck terminals in West Virginia, and others were distributed at truck stops along Interstate highways. Difficulties encountered in obtaining a reasonable response rate are described. The questionnaire, which was completed by 180 drivers, sought information on driver age and experience and on the nature of trucking operations. Other questions dealt with mountain driving problems such as gear selection, signing, brake inspection, and use of brake-check areas. The final section of the form examined driver attitudes toward truck escape ramps. It was found difficult to obtain information from truck drivers by using standard survey techniques; a personal-contact approach was necessary. Questionnaire results indicated that load carried and weather conditions were important factors in gear selection on downgrades. Speed-limit signs on problem downgrades had little effect on gear selection by drivers. Drivers strongly supported the use of brake-check areas at summits of grades; however, a significant number indicated that they do not inspect their brakes regularly. Equipment failure and inexperience in mountain driving were the most frequently cited reasons for runaway-truck accidents. More than 90 percent of the drivers said that they would use an escape ramp if they were out of control on a downgrade. Some drivers fear that ramps will cause either personal injury or property damage or both.

Highways in mountainous terrain pose a number of special problems for motor vehicle operators, problems that may be critical for large commercial vehicles. Among the most serious of these is the possibility of brake failure on long, steep downgrades. In such situations, trucks often accelerate uncontrollably down the steep grades, endangering not only the lives of truck drivers but also the occupants of other vehicles on the highway and residences and business enterprises adjacent to or at the foot of these downgrades. Due to the high speeds involved, a large percentage of runaway-vehicle accidents result in fatalities.

Various types of runaway-vehicle accident countermeasures have been developed by highway agencies; these vary from improved signing to truck escape facilities and alternate routing schemes for trucks of specified sizes. Until recently, little formal study had taken place with regard to warrants for runaway-vehicle accident countermeasures. Since the mid-1970s, however, there has been increased interest in the runaway-vehicle problem, specifically in the area of truck escape facilities (1-4).

The West Virginia Department of Highways (WVDH), in cooperation with the Federal Highway Administration (FHWA), U.S. Department of Transportation, sponsored a research project at West Virginia University that dealt with truck escape ramps. The overall objective of this research was to develop warrants for the use and location of truck escape ramps. To meet this general objective, a number of detailed objectives were developed. These included

1. Use of a mail questionnaire to determine experiences and practices of state highway agencies in relation to truck escape ramps,
2. Use of a second questionnaire to determine truck drivers' perceptions of the runaway-vehicle problem,
3. Collection of accident data for locations where there were frequent accidents involving runaway vehicles,
4. Performance of statistical analyses of the accident data to determine significant factors in runaway-vehicle accidents, and
5. Development of warrants for the use of truck escape ramps based on the collected data.

The purpose of this paper is to discuss the second objective, i.e., the truck driver survey.

The literature review and the questionnaire to state highway agencies indicated that there is a growing amount of engineering data on truck escape ramps. However, since escape facilities are installed for use by runaway vehicles, any criteria for determining their need and location should also include input from vehicle drivers. Wyckoff (5) recently completed a project in which he examined the views of several thousand professional truck drivers. The survey included driver training, background, attitudes, health and equipment problems, and safety. However, neither mountain driving nor escape ramps were mentioned explicitly. In our study, a questionnaire was used to determine truck drivers' perceptions of mountain driving, the runaway-vehicle problem, and possible accident countermeasures.

QUESTIONNAIRE PREPARATION AND DISTRIBUTION

The purpose of the truck driver survey was to determine through questionnaires and personal interviews truck drivers' experiences and needs in mountain driving, particularly in regard to runaway vehicles. Development of the questionnaire was a two-stage process. First, a pilot study was done by giving the questionnaire to a small sample of drivers from trucking firms in north-central West Virginia and, based on analysis of this pilot study, modifications were made to the original questionnaire. Second, a sample of drivers was asked to complete the questionnaire; the drivers were contacted at trucking firms in Charleston, West Virginia; at truck stops on the Interstate system; and through a West Virginia Motor Truck Association (WVMTA) mailing.

Preparation

From our literature review, we had already identified a number of variables as important in the runaway-vehicle accident problem, e.g., truck brakes, driver condition and experience, and roadway signing. The pilot version of the truck driver questionnaire asked drivers about their perceptions of these problems. To ensure input from different perspectives, discussions were held with representatives of the FHWA, the National Transportation Safety Board, the California Highway Patrol, and a consulting firm that was investigating runaway-vehicle accident countermeasures. Since most truck drivers were on rigid schedules and a long questionnaire would have meant that fewer drivers would have completed the form, a decision was made to limit the questionnaire to one page.

The truck driver has been found to be an important factor in runaway-vehicle accidents; therefore, the preliminary questions were designed to obtain information about the driver's experience and background: age, number of years as a professional driver, distance driven each year, and size and type of vehicle usually driven. Since vehicle maintenance has been found to vary with the type of trucking operation, drivers were asked to indicate (a) whether they were owner-operators or drivers for a common carrier (note that it is possible to be in both these categories); (b) whether travel was over a regular route or trips varied from week to week, which was intended to provide a rough indication of driver familiarity with routes; and (c) whether they had ever experienced being out of control on a long downgrade, which was to separate drivers who had been involved with runaway vehicles from those who had not experienced problems on long downgrades to see whether their responses differed.

The main part of the questionnaire asked drivers about important factors in selecting gears for long, steep downgrades and about improved signing to enable a better choice of gear selection. Another question dealt with brake-check areas at summits of steep grades. Several questions dealt with truck driver use of escape ramps and suggested locations for the ramps. All these questions could be answered either yes or no.

The final questions on the form required drivers to make comments on the reason for runaway trucks in mountainous areas and on what specific grades in West Virginia escape ramps might be beneficial. This last question was included to provide the WVDH with an indication of downgrades that truck drivers felt were especially severe, information that might not have come to their attention through the usual channels, e.g., the accident-records system.

Trucking firms in north-central West Virginia were contacted about distributing questionnaires to their drivers. We wanted the questionnaires to go to over-the-road drivers rather than to city drivers, who handle single-unit trucks or small semitrailer units that make pickups and deliveries in urban areas. Over-the-road drivers handle large semitrailer units in intercity service where most long, steep downgrades on open highways are encountered. Although city drivers often face difficulties with short, steep downgrades in built-up areas, this problem was outside the scope of the research.

We originally intended to distribute the questionnaire personally to each driver at the terminals and be available to answer any questions that might arise and to engage in informal discussion with drivers. However, given the nature of trucking operations, over-the-road drivers arrive at and depart from terminals at any hour of the day or night. In addition, since most drivers are on a tight schedule, there is not always sufficient time to complete the questionnaire at the beginning or end of a run. The decision was made to leave copies of the questionnaire with the dispatcher or terminal manager, who was to distribute them to the drivers. We were to collect completed forms later. This method proved unsatisfactory. Although the response rate was good, an inordinate amount of time was consumed in arranging pickup of the completed forms.

For this reason and because of the possible reluctance of drivers to submit completed forms to their supervisors, a postage-paid self-mailer was used for the final form of the questionnaire. Its length was limited to one legal-sized [216 x 256-mm (8.5 x 14-in)]sheet of paper. The form was folded to letter size, and a business-reply-mail label was printed on it.

Of the 38 pilot questionnaires distributed, 18 were returned. No serious deficiencies were revealed in the design of the questionnaire; the drivers seemed to respond in the manner we had intended. Several minor changes were incorporated into the final version of the form. (Copies of the final version of the truck driver questionnaire may be obtained from the Department of Civil Engineering, West Virginia University, Morgantown, WV 26506.)

Distribution

Initially, the questionnaire was distributed at truck terminals in the area of Charleston, West Virginia. Since Interstates 64, 77, and 79 pass through or terminate in Charleston and since several large chemical plants exist in the region, there are many large truck terminals out of which over-the-road drivers operate. To maximize the information obtained and recognize limitations on time, we decided to contact drivers personally at the large terminals, where there was a steady flow of drivers. At small terminals, which had fewer over-the-road drivers, the questionnaires were left with the terminal managers and dispatchers, who distributed the forms.

We had informal discussions with approximately 15 drivers at two terminals in the Charleston area. Eight smaller terminals in the Charleston area were visited, and questionnaires were left with terminal managers or dispatchers, since no drivers were immediately available. A total of 155 questionnaires was distributed in the Charleston area, of which 19 were returned. This response rate—only 12 percent—prompted us to use other means to obtain a larger response rate.

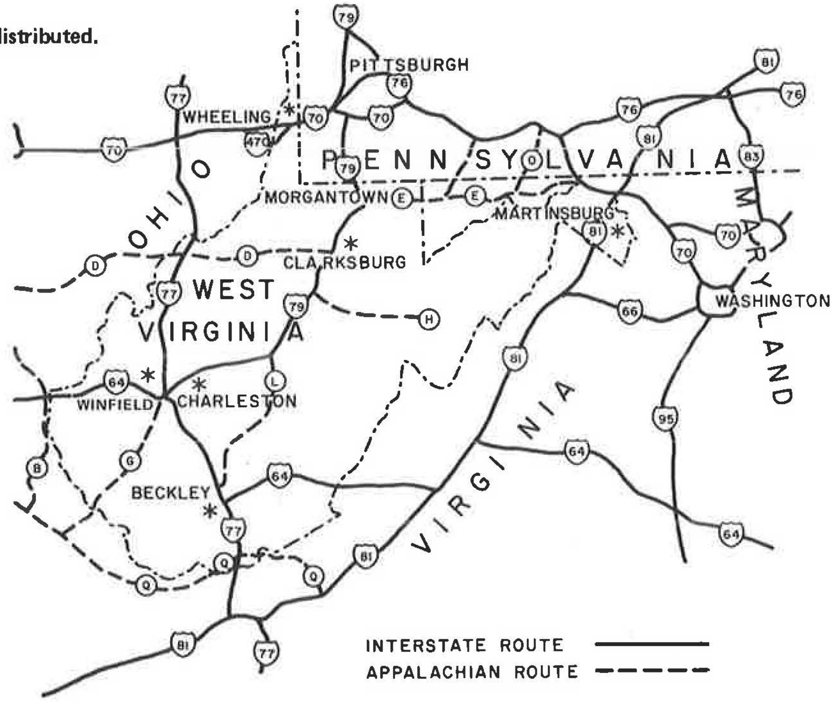
We decided to distribute questionnaires at two large truck stops on I-70 near Wheeling, West Virginia, on a weekday afternoon. We stood near the entrance to the restaurant area of the truck stop in order to contact the greatest number of drivers. As they approached, we attempted to talk informally with them. Although most drivers indicated that they did not have time to talk, approximately 10 percent were quite willing. A great deal of insight was gained from these conversations. During a 5-h period, a total of 60 questionnaires was distributed at the two truck stops.

Only six questionnaires were returned from the Wheeling area; this is a response rate of 10 percent, which was disappointing because we had spoken to all 60 drivers, most of whom expressed interest in the runaway-truck problem. However, the poor response rate is probably attributable to the nature of trucking operations. As was noted earlier, truck drivers usually adhere to a rigid schedule. During break or rest periods they are busy completing log books or making safety checks of their vehicles. Drivers interested in our questionnaire probably set it aside to complete later. If so, the questionnaire could easily have been lost or misplaced in the cab of the truck.

Due to the poor response rate by using the preceding method, we decided to take the questionnaire to the drivers while they were still in their rigs and to use two female assistants to distribute the questionnaires. It was thought that involvement of female interviewers would cause the truck drivers to be more receptive to questioning. One of the women was a senior in civil engineering; the other was a graduate student in environmental economics. The civil-engineering student had completed a course in highway engineering and thus was knowledgeable about highway design. Both students were mechanically inclined and familiar with motor vehicle components and terminology and had performed maintenance on their own automobiles. They also had had first-hand experience with the hazards and techniques of mountain driving.

Personality was another factor that went into the selection of the student assistants. Both women liked

Figure 1. Location of contacts with truck drivers. Asterisks indicate places where questionnaires were distributed.



meeting people and were friendly and outgoing. They were somewhat assertive; this was important because perseverance was needed in encouraging the drivers to talk. Because of these attributes, the women were able to develop rapport with and engage in discussions with drivers that led to insight about mountain driving problems not obtainable from the questionnaires. The drivers questioned seemed less defensive and more willing to talk about their driving habits and experiences than they had been with the male interviewers.

The women interviewers approached the drivers while they were seated in or working on their vehicles in the truck-stop parking lot. Many drivers filled out the questionnaire on the spot. Other drivers were willing to answer questions orally while they worked on their vehicles. In these cases, the interviewers filled in the questionnaires for them. Since the forms were completed in the drivers' presence, the interviewers were able to discuss some of the items in more detail and to clarify ambiguities about particular questions. The success of this approach, other than the use of women interviewers, was attributed to the fact that drivers tended to feel more comfortable and relaxed around their own vehicles than if approached at some other location at the truck stop. Because of the longer dialogue between truck driver and interviewer, this method resulted in distribution of fewer questionnaires. However, a much greater response rate meant that more completed questionnaires were received for that same amount of time. By using this method, the mail return of questionnaires was negligible, since virtually all interested drivers returned the completed forms to the interviewers before departing.

With the interviewer approach described above, questionnaires were distributed at four locations in West Virginia: Wheeling, Martinsburg, Winfield, and Beckley. These sites were selected because major truck stops on Interstate highways existed at each location and because a good geographic coverage of West Virginia was obtained. Locations of the four sites (and of the truck terminals where questionnaires had been distributed) are shown in Figure 1. Due to the nature of trucking operations in West Virginia, major truck stops are generally not found away from Interstate routes. Study efforts were confined to major truck stops with large traffic volumes to maximize contacts with drivers within the time constraints involved.

A total of 207 questionnaires was given out at the four locations by the women interviewers. Of these, 106 were returned; this is a response rate of 51 percent. The response rate by using the personal-contact approach with female assistants was approximately five times greater than that using male interviewers. However, the total number of completed questionnaires still remained relatively small, primarily due to the amount of time devoted to talking to each driver.

In an attempt to get a larger sample size, we contacted WVMTA. The association agreed to include a copy of the truck driver questionnaire in one of its monthly mailings to members. Each mailing reaches approximately 500 trucking firms (most firms are in West Virginia; there are members from other states as well). Although the mailings themselves go to management personnel, the note attached to the questionnaire asked that they be forwarded to drivers and that the drivers be encouraged to complete and return the forms.

Of the 500 questionnaires mailed by WVMTA, only 31 (6 percent) were returned. The poor response rate reconfirmed the problems encountered in using mail-type questionnaires when dealing with truck drivers. It was apparent that the personal-contact approach was a more satisfactory method of obtaining information from this particular population.

QUESTIONNAIRE RESULTS

From all sources, 162 questionnaires were returned. In addition, 18 pilot questionnaires were received from terminals in Clarksburg, West Virginia. Since a few questions on the final form differed from those on the pilot questionnaire, it was not possible to combine the two sets of results completely. However, in the discussion that follows, those questions that were the same on both forms will be discussed on the basis of 180 responses. All other questions will be discussed on the basis of 162 respondents. Driver characteristics will be discussed first, followed by the questions related to mountain driving and truck escape ramps.

Table 1. Variation in truck driver characteristics according to sampling location.

Source	Number of Responses	Mean Age (years)	Mean Professional Experience (years)	Mean Distance Driven Annually (miles)	Type of Trucking Operation (number of responses) Regular Route	Variable Route	Mean Percentage of Time on Mountain Roads
Terminal							
Charleston	19	40.6	17.6	93 300	2	17	57.7
Clarksburg	18	43.7	17.9	53 900	8	10	ND
Truck stop							
Wheeling	48	36.1	12.2	119 059	2	39	40.6
Martinsburg	19	36.0	12.0	100 560	2	17	42.2
Winfield	31	35.7	10.9	104 840	2	25	46.3
Beckley	14	40.6	14.5	100 710	2	12	47.2
WVMTA	31	39.7	16.6	77 214	3	28	57.5
Total	180				21	148	
Avg		38.2	14.0	97 465			48.3

Notes: 1 mile = 1.6 km.
ND = no data.

Driver Characteristics

Drivers responding to the questionnaire varied in age from 21 to 60 years, with a mean of 38.2 years. Experience as a professional driver ranged from 2 months to 41 years, with a mean of 14.0 years. There was a large variation in the distance driven per year. Annual travel ranged from 16 090 to 482 700 km/year (10 000-300 000 miles/year) with a mean of 156 821 km/year (97 456 miles/year). Of the drivers responding, almost 61 percent drove for a common carrier. Approximately 33 percent were owner-operators. About 15 drivers indicated that they were owner-operators but had working agreements with a common carrier. Only 7.5 percent of the drivers were employed by private carriers.

Slightly more than 12 percent of the drivers traveled a regular route, and 85 percent traveled routes that varied from day to day or from week to week. The remaining drivers either did not respond to this question or indicated a mixture of regular route and variable routes. Percentage of time on mountain roads ranged from 5 percent to 100 percent. Mean time on mountain roads was 48.3 percent. It was interesting to note the variation in the amount of time on mountain roads. Drivers contacted at truck terminals and through the WVMTA mailing indicated a mean time on mountain roads of 55.4 percent. Drivers at Interstate truck stops averaged only 43.2 percent of the time on mountain roads. This result is probably due to the fact that drivers who typically operate on Interstate routes would be expected to do less mountain driving than those operating primarily within West Virginia.

As might be expected due to differences in location, nature of driver contact, and types of trucking operation, there were differences in driver characteristics among the various sites. These differences are shown in Table 1 and are discussed below.

It is interesting to note that the drivers at Wheeling, Martinsburg, and Winfield were, on the average, several years younger than those at the other locations. All three sites were located on Interstate facilities, whereas the three other sources through which drivers were contacted were at terminals or by mail.

Although the data are not shown in Table 1, drivers contacted through the Charleston and Clarksburg terminals were different from those at the other locations in that they drove only for common carriers. Locations on the Interstate such as Wheeling, Martinsburg, and Winfield had roughly equal amounts of owner-operators and drivers for common carriers. This was to be expected, since at these locations the questionnaires were distributed at truck stops that served all classes of motor vehicles. It is important to keep this difference in mind in the following discussion.

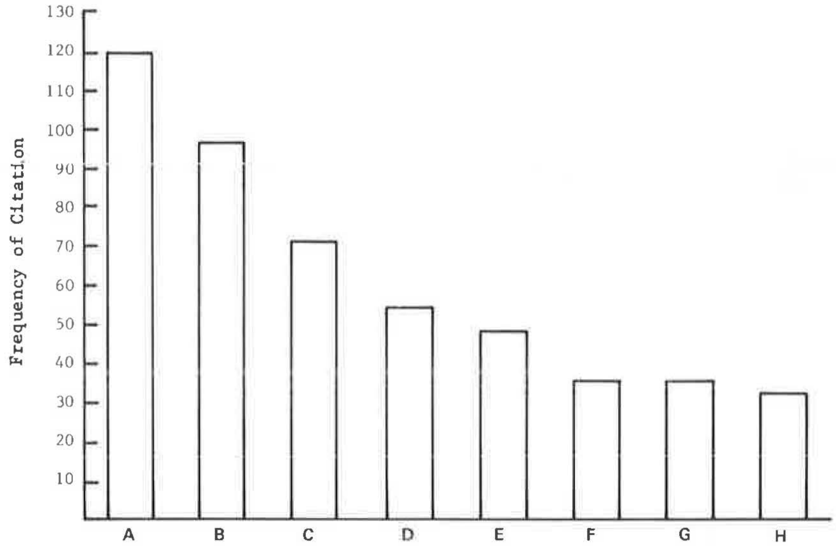
There were also differences between locations in the amount of time spent in mountain driving. Drivers contacted at Charleston terminals and through WVMTA did more mountain driving than did drivers contacted at Interstate truck stops. Although data were not available from the pilot questionnaire, it was known from experience that much of the driving done by truckers at Clarksburg terminals is on mountain roads. Drivers on I-70 near Wheeling had the lowest percentage of time on mountain roads. This might be expected intuitively, since many drivers came from both the East and Midwest, where little mountain driving would be encountered.

Of the 180 drivers, 44 (24.0 percent) had experienced being out of control on a long downgrade; they were probably overrepresented in this sample. The reason for this is that they would have been more likely to return the questionnaire than drivers who had not lost control of vehicles on long downgrades. For example, while interviewing drivers in the Charleston area, we talked with a driver who had only recently returned to work after being seriously injured in an accident involving an out-of-control vehicle. The driver indicated that he wished there had been an escape ramp on the grade where he lost control. He strongly encouraged the other drivers present to complete the questionnaire and drop it in a mailbox.

Characteristics of drivers who had lost control on downgrades were compared with those who had not. The average age of drivers who had experienced being out of control was 38.8 years. This is very close to the overall mean age of 38.2. Those who had experienced being out of control had been driving professionally for a greater number of years—15.7 versus 13.7 years for those who had not experienced loss of control. In mountain driving, those who had experienced loss of control averaged 51.0 percent of their time on mountain roads. Those who had not experienced loss of control spent an average of only 45.0 percent of their time on mountain roads. Note that these results do not include Clarksburg data since the question about percentage of mountain driving did not appear on the pilot questionnaire.

In terms of distance driven per year, those who had experienced loss of control of a truck on a downgrade averaged 157 787 km/year (98 121 miles/ year) versus 157 455 km/year (97 859 miles/year) for the other group. Thus, both groups travel approximately the same amount annually. However, by combining these data with the results on percentage of time spent in mountain driving, it can be concluded that those drivers who have experienced being out of control on a downgrade have had greater exposure in terms of vehicle-kilometers of mountain driving. However, it is difficult to draw conclusions based on these data alone. For example, we do not know whether the runaway-vehicle incident occurred early or late in the driver's career, since driver experience seems to be an important factor in safety on mountain roads. Nor do we know from these data whether the percentage of time spent in mountain driving has remained constant over the driver's career.

Figure 2. Frequency of citation of factors that influence gear selection on downgrades (156 drivers).



Note: A = weight being carried; B = weather conditions; C = road familiarity; D = experience with downgrade; E = vehicle brake condition; F = posted speed limit; G = gear used to climb grade; H = desired downhill speed.

Mountain Driving

Figure 2 indicates the relative importance of factors that influence truck drivers' choice of gear for descending a grade as indicated by the responding drivers (from all sites except Clarksburg). The weight of the load being carried was the most frequently cited factor; it was mentioned by 76 percent. The next most frequently cited factor was the weather. Two interrelated factors—road familiarity and experience with downgrade—were the next two most frequently cited factors. It is significant to note that, for this sample of drivers, the posted speed limit had minor influence on the gear selected for a downgrade; only 22 percent of the drivers indicated this factor.

Drivers were asked whether improved signing before a grade would enable them to make a better choice of gear selection. If drivers responded positively, they were asked what information should be indicated on the sign. Overall, 146 of the 177 responding drivers (82 percent) felt that improved signing would help them. Those drivers who responded affirmatively indicated that information on length and steepness of grade and on sharp horizontal curvature would be helpful. Several drivers recommended that a diagram of the hill be shown.

It is interesting to note that one driver who responded negatively to the question commented, "You cannot believe what you read on signs in most states." It is to be hoped that this is not the feeling of other drivers who answered "no" to this question. However, the results of the gear-selection question indicated that other drivers may feel the same way. If this is so, it will be necessary for state highway agencies to redevelop credibility with truck drivers. One driver emphatically suggested that signs not give recommended downhill speeds.

Another question was how often tractor and trailer brakes were inspected. Apparently the format for answering this question was confusing to some drivers since they gave only one answer on the form instead of the desired two. The following data were obtained from 160 drivers who responded to the brake-inspection question:

	Number of Responses	
Inspection Policy	Tractor Brakes	Trailer Brakes
Every trip	86	54
Once a week	28	20
Once a month	17	15
Once a year	1	2
Other	28	25
Total	160	116

Slightly more than half the drivers indicated that tractor brakes were inspected every trip. This proportion appears to be low in view of the fact that truck brakes have been found to be defective in a large number of cases. It is somewhat surprising that 11 percent of the drivers inspected their tractor brakes only once a month.

A variety of responses was made for the "other" category. One driver replied, "Can't be done often enough." From this it might be assumed that the driver checked his brakes more than once on each trip. Several drivers indicated that brakes were checked daily. Some drivers stated their brake-inspection frequency in terms of distance: Inspection ranged from once every 8045 km (5000 miles) to once every 32 180 km (20 000 miles). Two drivers stated that they did not know how often brakes were inspected.

Truck drivers were asked whether brake-check areas should be provided at the summit of problem grades; 76 percent of the respondents indicated that such facilities should be provided. However, there was not nearly so much support for making these brake-check areas mandatory: Only 80 out of 176 drivers (45 percent) agreed with mandatory checking.

The final question dealing with mountain driving was whether maps of the downgrade posted at brake-check areas would be helpful; 83 percent of the drivers responded affirmatively. These results are consistent with those discussed previously; i.e., the more familiar a driver is with a grade and the more information that is made available, the better the decision on gear selection is.

Truck Escape Ramps

Drivers were asked whether they would use an escape ramp if their vehicle was out of control on a steep hill. Most drivers (91.0 percent) indicated that they would. Those drivers responding negatively were asked to state their reasons for not wanting to use a ramp. Some typical responses are quoted: (a) "because I've never seen one I thought was safe to use and because it might damage my truck"; (b) "running into a sandpile is just like hitting a brick wall and escape ramps are always at the tops of mountains"; (c) "the state should control the cost of pulling out rigs, as local towing services have made a racket out of the price"; (d) "when you are three-fourths of the way up the ramp, the truck starts going back down the ramp"; and (e) "if jake brakes [engine brakes] were mandatory, we could do away with escape ramps."

These responses are of interest to the highway engineer for several reasons. Statements (a), (b), and (d) indicate that some drivers feel that escape ramps cause property damage and injury. It appears that greater emphasis should be placed on the public-information aspects of truck escape ramps.

Statements (c) and (e) appear to require legislative action, and the highway engineer would have limited input. The problem concerning rates charged by tow-truck operators may require investigations by state public service commissions. Similarly, the recommendation concerning mandatory engine brakes would be within the jurisdiction of the National Highway Traffic Safety Administration rather than state highway agencies or FHWA.

The location of a ramp may be the deciding factor in whether a truck driver will use it. Even if a driver is out of control near the top of a downgrade, there will be a tendency to ride out the grade rather than use an escape ramp near the summit. For example, one driver said that he would use a ramp but only if he felt that he would be unable to ride the grade out. Another said that the ramp would be used only as a last resort. This means that the driver would attempt to negotiate horizontal alignment until more favorable vertical alignment was reached. Although truck drivers are reluctant to state reasons for making such decisions, it appears to be due to a feeling that escape ramps may damage the truck or the load and that, when trapped by an escape ramp, the driver incurs extra cost and delay while a tow truck is summoned to remove the truck.

Drivers were asked to indicate where escape ramps should be located: halfway down the grade, at the bottom of the grade, between halfway and the bottom, or another location. Responses to this question are shown below; the responses do not sum to 180 since several drivers did not reply or gave other locations.

	Number of Responses by Location		
Source	Halfway Down Grade	Bottom of Grade	Between Halfway and Bottom
Terminal			
Charleston	6	1	9
Clarksburg	3	2	12
Truck stop			
Wheeling	17	6	17
Martinsburg	7	2	9
Winfield	10	2	12
Beckley	7	0	6
WVMTA mailing	10	4	20
Total	60	17	85

A ramp location between halfway down the grade and the bottom was preferred by most drivers. This is in agreement with the statements made in the preceding paragraph, but it is not as strong an expression of support as might be expected. Ten percent of the drivers surveyed preferred a ramp at the bottom of the grade. This question elicited a large number of comments from respondents, who apparently realized that the categories listed on the form were too general to be of much value in actual escape-ramp location.

There are numerous situations in which topography or land use precludes installing escape ramps on the right-hand side of two-lane two-way roads. Australia has constructed ramps on the side of the road opposite the direction being traveled; however, Wyoming is the only one of the United States where this has been done. Since the left-hand side of the road is a potential (although not necessarily desirable) location for a ramp, it was of interest to obtain data on drivers' attitudes to such a location. A majority (91 out of 170, or 54.0 percent) indicated that they would use escape ramps on the left-hand side of the road. However, it should be noted that most of the drivers who answered "yes" said that they would do so only if they could see sufficiently far ahead to be sure that there was no oncoming traffic. Drivers who stated that they would not use a ramp on the left-hand side noted reasons such as possible head-on collisions, the high risk involved, and the fact that they would not use any escape ramp.

Another question was whether signs for existing escape ramps were adequate; 71 percent of drivers felt that they were. Several drivers included recommendations for improved signing: the need for more signs, more-descriptive signs, and larger signs; the location of signs within the reach of headlights; the use of lighted signs and ramps; and the location of signs further in advance of the ramp to allow greater reaction time. One driver noted that signs should be posted to keep vehicles from parking at ramps and to keep vehicles with four-wheel drive out of arrester beds.

Drivers were asked to list their reasons for runaway-truck accidents in mountainous terrain. A variety was stated; a frequency plot is shown in Figure 3. Each driver's wording of the response differed, but an attempt was made to group the reasons into the categories shown.

According to those truck drivers responding, equipment failure was the most frequent reason for runaway-truck accidents. It is difficult to evaluate equipment failure as a causal factor without additional information. The literature indicates that truck brake systems frequently contain defects that could lead to system failure when subjected to the extreme demands of mountain driving. It is also possible that, due to error or inadvertence, truck drivers may make demands on brake systems that exceed braking-system capabilities. For example, a driver who descends a steep grade in a high gear will make more brake applications than another who descends the same grade in a lower gear.

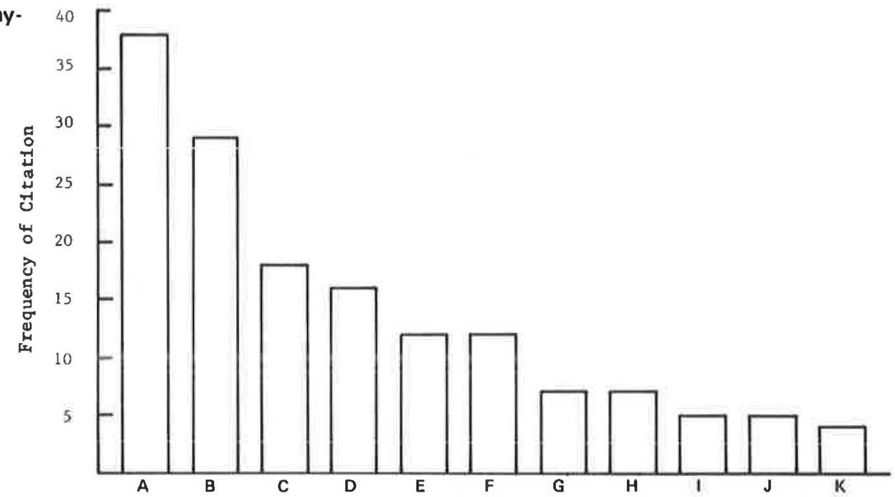
Inexperience in mountain driving was the second most frequently cited reason. This has important implications in terms of driver training: There may be a need for driver-training programs that place greater emphasis on the special demands of mountain driving. This is especially true for new drivers who will be driving mainly on off-Interstate highways, i.e., on state and local highways. The third most important reason was driver error—mistakes made by drivers due to illness, fatigue, or other reasons or due to simple carelessness. The highway engineer probably has little influence in this area. Strict enforcement of regulations regarding hours behind the wheel and use of thorough driver-training programs might improve the situation somewhat, especially if drivers are made aware of the unique demands of mountain driving.

Several other reasons were also cited by drivers; however, these did not appear as frequently as those previously discussed. These included too-rapid descent, too-slow descent, inadequate signs, poor truck inspection, poor roads, lack of engine brakes, and overloaded vehicles. Highway engineers should note that, although inadequate signs and poor roads were cited as reasons for runaway-vehicle accidents, they were not regarded as important causes. In general, drivers tended to feel that vehicle condition and driver behavior were the primary reasons for such accidents.

CONCLUSIONS AND RECOMMENDATIONS

This paper has described development of a questionnaire designed to obtain insight into truck drivers' perceptions about mountain driving and truck escape ramps. One of the important findings is that it is difficult to obtain information from truck drivers by using standard survey techniques. Drivers are naturally defensive when questioned

Figure 3. Frequency plot of reasons for runaway-truck accidents given by truck drivers.



Note: A = equipment failure; B = inexperience in mountain driving; C = driver error; D = unfamiliarity with road; E = too-slow descent; F = too-rapid descent; G = poor truck inspection; H = inadequate signs; I = poor roads; J = lack of engine brake; K = overloaded vehicle.

about their driving and, due to their time schedules, do not have much time to complete written questionnaires. We recommend that researchers planning to study truck drivers use a personal-contact approach rather than a mail or telephone survey. However, even by using this approach, resistance and apathy from the truck driver should be expected.

The load being carried and the weather conditions were the most important factors in gear selection on a downgrade; road familiarity was also an important factor. Although the highway engineer has no control over weather conditions and little control over vehicle loading (other than to ensure that it is within legal limits), the engineer can assist drivers with road familiarity. This can be accomplished through adequate signing and marking that allow truck drivers to select an appropriate gear for descent.

One sign that apparently had little influence on the drivers sampled in this study was the downgrade speed-limit sign. Responses to the questionnaire seemed to indicate that drivers will select a safe speed if furnished with sufficient information about the characteristics of the downgrade. It was concluded that location of signs indicating a reduced speed limit on problem grades has little effect on gear selection.

There is a need for additional driver training and awareness about inspection of truck brakes. Although a majority of drivers inspected their vehicle brakes regularly, a significant number did not. This is very important, since not only have faulty brakes been implicated in many truck accidents (6-8), but evidence indicates that brake-system defects are one of the most frequent types of violations noted in vehicle inspections (9). Truck drivers seemed to feel that, wherever possible, brake-check areas should be provided at the summit of problem downgrades.

There were many misconceptions among truck drivers concerning what takes place when a vehicle uses an escape ramp. Some drivers feared that ramps would cause either personal injury or property damage or both. It is recommended that techniques be developed for informing drivers about the operation of truck escape ramps. State highway agencies should consider developing pamphlets or brochures that could be distributed to truck drivers at weigh stations, rest areas, truck stops, or truck terminals. Other media could be used, such as short filmstrips or slide-tape presentations to be shown at driver-training sessions.

Truck drivers felt that escape ramps should be located between halfway down the grade and the bottom of the grade. Ramps located farther upgrade than this may not be used, since drivers would bypass the escape facility in an effort to ride out the grade. Escape ramps on the left-hand side of two-lane roads would be used by drivers only in situations where sufficient sight distance existed to check for oncoming traffic.

Drivers felt that equipment failure and inexperience in mountain driving were important factors in runaway-vehicle accidents. Although the influence of highway engineers is limited in these areas, they can play an important role by seeing that signing on problem downgrades provides adequate information to drivers. This is especially important on routes that serve as major interregional corridors for freight and passenger movement, since one might expect to find a larger percentage of drivers unfamiliar with mountain driving on these roads. As a minimum, length and steepness of grade (in percent) should be indicated. Where tortuous horizontal alignment exists, signs should so indicate. Where rest areas or brake-check areas are located at the summit of grades, engineers should give serious consideration to signs giving a pictorial representation of the plan and profile of the grade.

In conclusion, it should be emphasized that engineers need to be very careful about drawing conclusions based on driver opinion or perception. Although these viewpoints should be considered in formulating solutions to problems such as ramp location or signing, the solutions should be based on actual data. Thus, additional studies may be warranted in some of the areas outlined above.

ACKNOWLEDGMENT

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We wish to thank the many trucking firms who cooperated in this study by distributing questionnaires and by permitting their drivers to be interviewed at terminals. We also express appreciation to WVMTA for assisting in the questionnaire distribution. Thanks are due the truck drivers who took the time to complete the questionnaire.

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Development of a Master File of Essential Highway-Safety Planning and Evaluation Data

CLINTON H. SIMPSON, JR., AND MICHAEL P. HAGGERTY

The National Highway Traffic Safety Administration requires that each state file an annual highway-safety work program as a prerequisite for obtaining federal Section 402 safety funds. However, the work program serves as more than a mechanism for obtaining funds; it induces planning, programming, and budgeting of highway-safety projects. The commonwealth of Virginia has endorsed the work program concept and is continually striving to improve its highway-safety planning process. The most recent improvement was the incorporation of the concept of problem identification and management by objectives into the state's highway-safety work program. Local highway-safety commissions and state traffic-safety agencies were asked to complete their annual work program submissions by using this concept, the intent being to enhance the quality of their planned highway-safety activities. The research reported here was an attempt to further implement the concept by offering refinements. Under these refinements, the local commissions and state agencies are not asked to generate much of the problem identification data; the necessary information is provided to them. These data should aid the local commissions and state agencies in identifying problem areas. This approach was well received when first used in preparing Virginia's FY 1977 annual highway-safety work program. However, the methods of compiling and disseminating information proved laborious and time-consuming. Therefore, methods for automating various parts of the information-retrieval, assimilation, and dissemination stages were developed.

With the advent of the annual highway-safety work program (AHSWP) in 1969, the National Highway Traffic Safety Administration (NHTSA) plotted a new course for the administration of the state highway-safety program. Before then, NHTSA (or its predecessor, the National Highway Safety Bureau) had required that its personnel review each highway-safety project for which federal funds were requested. Afterward, federal funding was integrated into state planning. That is, each state was required to develop a comprehensive plan for highway-safety management and, to obtain federal funds, each was asked to document its safety-program needs. This annual state submission became known as the annual highway-safety work program.

The new approach was aimed at the overall goal of identifying problem areas in the highway-safety program structure. This approach also had several secondary goals. First, by introducing statewide planning, the AHSWP attempted to produce a systematic, continuous review of safety programs. Second, by linking planning and budgeting, the AHSWP forced the states to review their current and future needs so that federal funds would be used efficiently. Finally, the AHSWP's emphasis on planning was designed to mesh with an evaluation process to ensure effective program implementation, review, and continuation.

Yet from its inception the AHSWP has created some problems. In Virginia, the program was initiated in precisely the manner described by NHTSA (1). Each state traffic-safety agency and local highway-safety commission was asked to complete a subelement plan in which each organizational unit concerned was to list safety programs it wished to implement and the associated costs. No emphasis was placed on problem identification. Consequently, the programs listed under the subelement plan were sometimes chosen quite arbitrarily.

In 1976, the Virginia Highway and Transportation Research Council (VHTRC) proposed revisions to the AHSWP in Virginia (2). After a review of the existing system for completing the AHSWP, it was concluded that the system was inadequate, and a resurrection of the goals outlined by NHTSA when the AHSWP was created was recommended. Specifically, an AHSWP was outlined in which the identification of highway-safety problem areas was emphasized.

On the adoption of the VHTRC recommendation, state agencies and local commissions were given problem-identification statements for each program area to aid in focusing attention on problem areas. The agencies and commissions were asked to use these problem-identification statements in completing their subelement plans. However, in the initial year of implementing the revised plan, a number of commissions and agencies failed to complete the work program in the prescribed format. As a result, some subelement plans were again prepared in a less-than-creditable manner.

The VHTRC recommendation pointed out that, for the AHSWP to work, those formulating the tangible safety programs (i.e., the local commissions and state traffic-safety agencies) must be provided the data necessary for identifying problem areas and that, once these problem areas had been identified, the agency or commission could create a plan to give them the needed attention and request funds on a priority basis. These requests could then be compiled in the state's AHSWP and submitted to the appropriate federal agencies. Thus, the AHSWP would accurately represent Virginia's funding and programming needs. Furthermore, when the block grant was received, the submissions from the commissions and agencies could be used as a basis for systematically and fairly distributing the funds.

STATEMENT OF THE PROBLEM

The approach introduced by VHTRC in 1976 focuses on submission of the subelement plan by the commissions and agencies. The information on a particular program area to be presented to the commissions and agencies must be gathered routinely from the various state agencies directly involved. For instance, the information presented to the local commissions concerning the driver-education programs in their localities is obtained from the Driver Education Services of the State Department of Education. Because most of the needed data are not computerized, the information must be obtained manually. As one can imagine, this task is formidable. The data must be manually gathered from each state agency in whatever format they are available, be rearranged in the format required for the problem-identification statement, and be compiled in information packets to be sent to each commission and state agency.

To provide a solution to this problem, a study was undertaken to investigate automation of the compilation and dissemination stages for the problem-identification data needed in the commonwealth's AHSWP and, if deemed appropriate, to prescribe a viable method for accomplishing such automation.

An overview of the processes used in collecting the information needed in the problem-identification statements and supplying it to the local commissions showed that different costs, efforts, and skills were associated with the different standard areas in the AHSWP. These processes are described in the following discussion.

Retrieval of Information

Depending on what standard area and what state agency or agencies were involved, the methods of retrieving information varied. Three general methods were used. One of these was used to gather the information processed by computer and available on either computer printouts or computer tapes. The Division of Motor Vehicles (DMV) and the state police were the only two agencies that supplied computerized information.

A second method of retrieval involved traveling to those state agencies that had stored in their files information related to their particular highway-safety program areas. The standard areas involved were driver education and emergency medical services. The information to be retrieved was determined by prescreening the data bank and then visiting an agency to extract the raw data from the files and record them on prepared forms. This task took several days. This noncomputerized information is manually updated and filed periodically.

The last method employed various activities fashioned to fit the situation. Some information, such as that for pupil transportation, is available on request from the agencies involved. Other information, such as that for debris, hazard control, and cleanup, is not under the auspices of any particular agency and therefore is difficult to obtain. This last type of information is also referred to as noncomputerized information.

Assimilation of Information

Once the information has been retrieved, it is compiled, processed, and recorded in rough-draft form. For this process, which is the most time-consuming activity in the entire system, two general methods are used. One is used for computerized information, available in the form of printouts or computer tapes. The data on printouts must be manually processed; however, for the data on computer tapes, a computer program can be written for automatic processing into the format desired. During the past year, a program was written that automatically processed about 90 percent of the accident data received from the Department of State Police. The information from DMV was processed manually from computer printouts.

The second method of assimilating information is the manual processing of noncomputerized information available from agencies or bureaus that do not store or process the information on computers. The data are available in a wide array of written formats, ranging from an agency's complete annual report to sheets of raw data. This information is manually translated into the desired format.

Dissemination of Information

The final process in supplying information to the local highway-safety commissions is printing or typing it into final form and reproducing it. If this process is done manually, the information is typed in final form for reproduction on a copying machine. If the process is automated, the information can be manually typed into a data file and then automatically typed in the final format with as many copies as required.

AUTOMATED APPROACH TO PREPARING AHSWP

Although complete automation of the Virginia AHSWP is not possible at this time, the initial stages of automation should be developed. Even in the absence of computerized information, it would seem that a format program could be developed to type out a data page of the information packet. The data could be retrieved as usual but then keypunched into the format program. Thus, a completed work-program information package could be obtained without the cumbersome dissemination stage.

The development of a format program would (a) allow data to be keypunched and stored in the computer as they are retrieved throughout the year (thereby avoiding the bottleneck that develops during the final stages of preparing the program) and (b) permit information to be stored by year (thereby creating a useful data base and enabling a comparison of the work programs for successive years).

Although a completely automated AHSWP is impossible at present, completely automated standard areas would be possible where computerized information is available. These areas will be noted in the ensuing discussion.

General Information

The first data sheet in the work program's information package contains general data ranging from population figures to crash statistics. The diverse sources of data for this sheet make it useful in illustrating the gamut of processes that can be performed in advance of complete automation.

Noncomputerized information for this data page includes the following:

1. Population: These data come from a brochure prepared by the University of Virginia's Tayloe Murphy Institute. The data change annually and therefore would require annual keypunch additions to the format program. It is unlikely that computerized information on these statistics will become available in the near future.
2. Number of licensed drivers and registered vehicles: DMV provides computer printouts containing this

information. At present, this information would have to be keypunched annually; however, it has been recommended that the source tapes be furnished to VHTRC. Once this computerized information has been received by the council, these two sources could be completely automated. Progress could be made in this area in the near future.

3. Road miles: This information is gathered from Mileage Tables, a publication of the Virginia Department of Highways and Transportation (VDHT). The road mileage for some localities could change annually and therefore require additional keypunching by VHTRC. In other instances the data will be unchanged and the previous year's data could be recalled and used for current needs so as to make further keypunching unnecessary.

Computerized information is only available for crash data. These data are illustrative of an area in which complete automation would be possible. At present, VHTRC receives crash data in computerized form. A program has been written to extract the data required for the work program. In the absence of complete automation, this printout would be the source for keypunching changes to the format program. Pervasive changes would be required annually. However, complete automation could be achieved if a program were written to interface with the present program for extracting the data from the tape and the format program. This complete automation should be accomplished in the near future by VHTRC.

Motorcycle Safety

Noncomputerized information in this area is only available for training data. These data have been difficult to obtain because of the absence of a state agency that focuses directly on motorcycle education programs. The data that are made available, however, come from driver education files, which makes complete automation in the future extremely improbable. However, as will be seen in various other standard areas, this information changes only slightly, thus making format programming quite significant. If no new information is obtained, the previous year's information, which has been stored in the computer's memory, could be recalled and printed on the appropriate line for current needs. No manual process would be involved.

Assuming no changes in the training data section and the complete automation of the crash data section, these data could be furnished without manual effort.

Computerized information, again, was only available for motorcycle crash data. This section parallels the crash data section on the general information sheet. At present, the computerized information is converted into a printout from which the appropriate data are collected. These data could be keypunched into the format program. However, this section should be completely automated in the near future.

Driver Education

The data source for this standard area must be drastically changed before complete automation can occur. The data are from the driver education files, from which they are manually compiled into the AHSWP format. The information thus gathered would have to be keypunched into the format program. Extensive keypunching would be required annually.

Codes and Laws

This locally gathered information, although not computerized, rarely changes. Once keypunched into the program, the data would not need much updating from year to year. Since computer recall would suffice, manual labor would be eliminated.

Traffic Courts

These data are now received from DMV in computer-printout form. The printouts list convictions by court jurisdiction and by violation number. The various violation numbers, which correspond to the general types of violations involved, must be compiled and added to the work sheets. The data must then be transferred from the work sheets to forms that reflect the work-program format. In essence, there is a deficiency in each of the general stages: retrieval, assimilation, and dissemination. Systematic improvement in each stage could be readily achieved, however.

First, by using the format program, the data could be keypunched directly from the work sheets into the program, which would significantly improve the dissemination stage.

Second, if VHTRC could obtain the source tapes rather than computer printouts, the standard area could be completely automated. This automation would be a two-step process. A program would have to be written to extract the data required for the work program. Note that this would require a subprogram to compile and add those violation numbers that correspond to the types of violations involved. Once this program has been written, it could be interfaced with the format program. In summary, the computer could extract the appropriate data from the source tape, assimilate the data to correspond to the prescribed violation types, and print out a completed form. Thus, complete automation for the standard area would be achieved.

Alcohol in Relation to Highway Safety

In this area, the noncomputerized information consists of breath-test data, the automation of which will remain a burdensome process. The data are now sent to VHTRC by Consolidated Laboratories in the form of brochures and will not be computerized in the near future. Thus, the data would have to be keypunched into the format program at VHTRC. Annual changes would be extensive.

Under the category of computerized information, the only data are those on crashes. Crash data for this section differ from those described for other areas in that the data are presented as percentages, not straight figures. This difference would require a program to be written to perform the mathematical computations once the information was extracted from the crash tapes but before it was fed into the format program.

If this stage could not be computerized, the process would be considerably lengthened. These crash data also differ in that they are derived from a separate printout prepared for the Virginia Alcohol Safety Action Program (VASAP). Presumably this printout would still be generated even if the general AHSWP crash-data printout were discontinued when complete automation of those data was achieved. If so, the manual computations would not be more expensive or burdensome than under the present system. However, if the VASAP printout were discontinued, the absence of a computer program for performing mathematical computations would require a separate printout of these data so that the computations could be manually performed. This extra step would be a waste of time. Therefore, a program should be written to extract the appropriate data from the source tape and to perform the necessary calculations; this program should then be interfaced with the format program.

Identification and Surveillance of Accident Locations; Highway Design, Construction, and Maintenance; Traffic Engineering Services

The data for these three standard areas all follow the same pattern. For all counties except Henrico and Arlington, the data are treated similarly, since they are under the control of VDHT. Moreover, the data rarely change. For all cities, plus the counties of Henrico and Arlington, the data are unique to each location, but here again the data rarely change. The changes that do appear are made by each local commission. The likely continuity in these areas would mean that they would benefit particularly from the format program.

Traffic Records; Debris, Hazard Control, and Cleanup

Like that for the previous three standard areas, the information for these two rarely changes, making them particularly amenable to format programming. However, these areas are not controlled by any one state agency. Thus, any changes made could come from a number of state agencies as well as from various county and city commissions. The likelihood that these areas will be completely automated is very slight.

Emergency Medical Services

This standard area does not lend itself to extensive automation. The data source is noncomputerized information, the data change extensively each year, and the source data will not be computerized in the near future. The changes would require annual keypunching.

Pedestrian Safety

As was the case for crash data from other areas, this standard area would immediately benefit from increased automation. The data source is computerized information, and no calculations would be necessary. Thus, complete automation could be achieved by interfacing a retrieval program with a format program.

Police Traffic Services

Only noncomputerized information is available in this area. Program data and system-operations information cannot be gathered from one state agency; instead, it must be updated by the local commissions. This indicates that it is unlikely that computerized information will be forthcoming. This standard area would benefit from the format program, however, because annual changes would be minimal.

Traffic-summons data are not now computerized. The data, received in computer-printout form, would have to be keypunched annually. However, if the source tapes for the data could be obtained from DMV, complete automation of this standard area could be achieved.

Pupil Transportation Safety

School-bus operations are considered noncomputerized information. These data are received in brochure form from Pupil Transportation Services. The extensive changes in these noncomputerized data would have to be keypunched annually. Complete automation of this area in the near future is unlikely.

As with other types of crash data, those from this area would be easily automated.

Accident Investigation and Reporting

Data for this standard area undergo extensive annual changes. For this reason, complete automation should be attempted. At present, the data are in the form of computer printouts. If the source tapes can be obtained, complete automation would be possible in the near future.

SUMMARY

The prior discussion has revealed that the information for various standard areas or portions thereof could at present benefit from automation. The areas are as follows:

1. Areas in which computerized information is currently available and that should be completely automated in the near future:
   a. General information—crash data
   b. Motorcycle safety—crash data
   c. Alcohol in relation to highway safety—crash data (assimilation stage would require computerization)
   d. Pedestrian safety
   e. Pupil transportation safety—crash data
2. Areas in which computerized information is not available but in which complete automation might be achieved in the near future:
   a. General information—licensed drivers and registered vehicles
   b. Traffic courts
   c. Police traffic services—traffic summons data
3. Areas that are substantially the same each year and thus would particularly benefit from partial automation:
   a. Motorcycle safety—training data
   b. Codes and laws
   c. Identification and surveillance of accident locations
   d. Highway design, construction, and maintenance
   e. Traffic engineering services
   f. Traffic records
   g. Debris, hazard control, and cleanup
   h. Police traffic services—program data and systems operation
4. Problem areas that will not be completely automated in the near future and that would require extensive annual changes:
   a. General information—population and road miles
   b. Driver education
   c. Alcohol in relation to highway safety—breath-test data
   d. Emergency medical services
   e. Pupil transportation safety—school-bus operations

CONCLUSIONS

The time and manpower needs for handling the problem-identification data in the compilation and dissemination stages of the work-program information packet are immense. Therefore, it is essential that an ongoing program be initiated to achieve complete automation of these stages and, if possible, the remaining planning components of the highway-safety plan. This program would ensure optimum use of personnel in preparing the work program and would foster the level of validity and the reliability of and accessibility to data necessary for sound program management.

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Traffic Accidents: Day Versus Night

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A comparison of accidents during daylight and darkness was made for both rural and urban roads. Accident rates on all types of rural roads were higher during darkness than during daylight. Critical accident rates during darkness for various types of roads were calculated. In urban areas, a larger percentage of accidents occurred on wet pavements during darkness than during daylight, but there were no significant differences for rural roads. No significant difference was found between average speeds during conditions of daylight and darkness. On rural roads, imposition of the 24.6-m/s (55-mph) speed limit resulted in a reduction in accident rates for both daylight and darkness. However, there were changes in the percentages of wet-pavement accidents on rural roads: For the entire rural system, there was a decrease during daylight and an increase during darkness.

Several sorting factors were employed in deriving traffic-accident statistics in Kentucky. Roadway geometrics (1) and factors related to the energy crisis (2) were investigated. However, statistics related to day and night and dawn and dusk had not been determined. Average and critical accident rates were calculated for various types of highways, but basic rates for daylight and darkness had not been determined. Accident records have now been searched and sorted to obtain those statistical indices. Others have reported significant differences in accidents during daylight and darkness (3,4).

Accident experience since the 24.6-m/s (55-mph) speed limit was imposed was analyzed to determine the effect of increased speed on many highways during the hours of darkness. The speed limit in Kentucky was set at 24.6 m/s on March 1, 1974. This speed limit applied to all vehicles for both daylight and darkness driving conditions and on all types of roads. Before that, the speed limit on Interstate and four-lane divided toll systems had been 31.3 m/s (70 mph) during both daylight and darkness. The speed limit on most other rural roads in Kentucky was 26.8 m/s (60 mph) during the day and 22.4 m/s (50 mph) at night. A dramatic decrease in the number of traffic accidents, injuries, fatalities, and accident rates followed the so-called energy crisis of late 1973 (2). The biggest reductions coincided with speed reductions and the speed-limit change in March 1974. A major conclusion from those statistics was that vehicle speed was highly relatable to accident involvement. However, that study did not deal with the effects of an increase in posted speed on many roads during the hours of darkness.

PROCEDURE

Accident and volume data were obtained for both rural and urban roads. The data for rural areas were those reported by the Kentucky state police, and those from urban areas were obtained from the city of Louisville. Data for 1973 and 1975 were used for the rural system, and data for 1973 and 1974 were used for the urban roads (1975 urban accident data were not available). The data from 1973 and 1975 were used when comparing conditions before and after the 24.6-m/s speed limit. However, only 1975 data for the rural system and 1974 data for the urban system were used in most comparisons, because those data better reflected the current road environment.

The rural highway system was sorted into (a) two- and three-lane roads, (b) expressways (Interstate and toll-road parkway), and (c) four-lane (undivided and divided, no access control) roads. Accidents in the urban area were not classified by type of road.

To accurately determine periods of daylight and darkness, the hours of sunrise and sunset were obtained from the Nautical Almanac Office (5). After the two different time zones within the state and daylight saving time had been accounted for, the hours of daylight and darkness were defined for each month (6,7). Dawn was defined as the hour before sunrise (rounded to the nearest hour); dusk was defined as the hour after sunset. Accidents were obtained on an hourly basis and then summarized by those times.

Total vehicle kilometers of travel on the rural system had been obtained earlier (2). By using several representative 24-h counts, the hourly volume distribution was determined, and accident rates were calculated for each period. Rates during darkness were calculated for each type of rural road. Total vehicle kilometers traveled in the urban area were not known, and only the percentage of accidents and traffic volume in the respective periods could be compared.

RESULTS

Rural Accidents

Accident Rates

According to 1975 state police statistics, 22 percent of all rural accidents and 32 percent of expressway accidents occurred during darkness, as shown below:

Road Type	Percentage of Accidents			
	Daylight	Darkness	Dawn	Dusk
Two-lane	71.6	21.1	1.9	5.3
Four-lane	72.8	18.2	3.6	5.4
Expressway	60.2	31.9	3.9	4.0
All	70.8	21.9	2.1	5.2

The higher percentage was probably due to the higher volume of traffic on these routes during darkness. The highest accident rate, according to the same source, was on two-lane roads during darkness, although the rate at dusk was also high. The rates during darkness were the highest on each type of road (100 million vehicle miles = 160 million vehicle kilometers):

Road Type	Accident Rate (accidents per 100 million vehicle miles)				
	Daylight	Darkness	Dawn	Dusk	Combined
Two-lane	238	412	175	317	263
Four-lane	102	150	140	135	111
Expressway	55	109	95	68	67
All	192	309	156	256	211

The overall rate during darkness on the rural system was 1.6 times greater than the rate during daylight. As expected, expressways had the lowest rates; the rate at dusk was surprisingly high compared with that at dawn.

Critical Accident Rates During Darkness

By using the average rates for periods of darkness as determined previously, critical rates can be calculated for any given section length, annual average daily traffic, and probability level (8). Resulting critical-rate curves may be used to determine whether an accident problem exists during darkness and whether safety improvements may be warranted. Critical rates were calculated for each type of rural road by using

$$A_c = A_a + K\sqrt{A_a/M} + 1/2M \qquad (1)$$

where

A_c = critical accident rate,
A_a = average accident rate,
K = constant related to level of statistical significance selected (for p = 0.95, K = 1.645; for p = 0.995, K = 2.576), and
M = annual 160 million vehicle kilometers (100 million vehicle miles).

A probability level of 0.95 was selected, and calculations were based on data for one year. The resulting critical-rate curves are presented in Figures 1-3. Critical rates were determined for section lengths ranging from 1.6 km (1 mile) to 32.2 km (20 miles). A different set of graphs could be developed for two or more years of accident data. Increasing the number of years of data would result in lower critical rates.

To determine whether the nighttime accident rate of a section is critical, the section length, average annual daily traffic (AADT), and the accident rate during the period of darkness must be known. The critical rate is determined by using the AADT and section length. If the accident rate is above the critical rate, the location should be investigated.

Wet or Dry Conditions

The percentage of accidents during the four light conditions for wet or dry pavement according to 1975 state police statistics is given below:

Light Condition	Wet Pavement (%)	Snow or Ice (%)	Wet/Dry Ratio	Ratio of Wet/Dry Time Daily
Daylight	19.3	3.3	0.25	0.19
Dawn	25.7	15.0	0.43	0.22
Dusk	19.8	3.8	0.26	0.20
Darkness	18.7	5.1	0.24	0.21

There were no significant differences in the percentages of accidents on wet pavements. Slightly less than 19 percent of the accidents were on wet pavements during darkness; this was comparable to slightly more than 19 percent during daylight. The ratio of wet- to dry-pavement accidents showed that the only significant difference occurred at dawn, when the ratio was significantly higher. The hours of precipitation had to be considered before valid comparisons could be made. Rainfall data were obtained from the Weather Bureau. By using this information, we calculated the ratio of wet to dry time for each part of the 24-h period. No significant differences were found.

Severity

The percentage of injury and fatal accidents during darkness and daylight according to 1975 state police reports is given below:

Road Type	Injury Accidents (%)		Fatal Accidents (%)	
	Daylight	Darkness	Daylight	Darkness
Two-lane	31.7	37.7	1.6	3.7
Four-lane	31.7	33.8	1.1	3.9
Expressway	34.9	36.6	2.1	3.5
All	31.9	37.5	1.6	3.7

Figure 1. Critical accident rates during periods of darkness for rural two-lane roads.

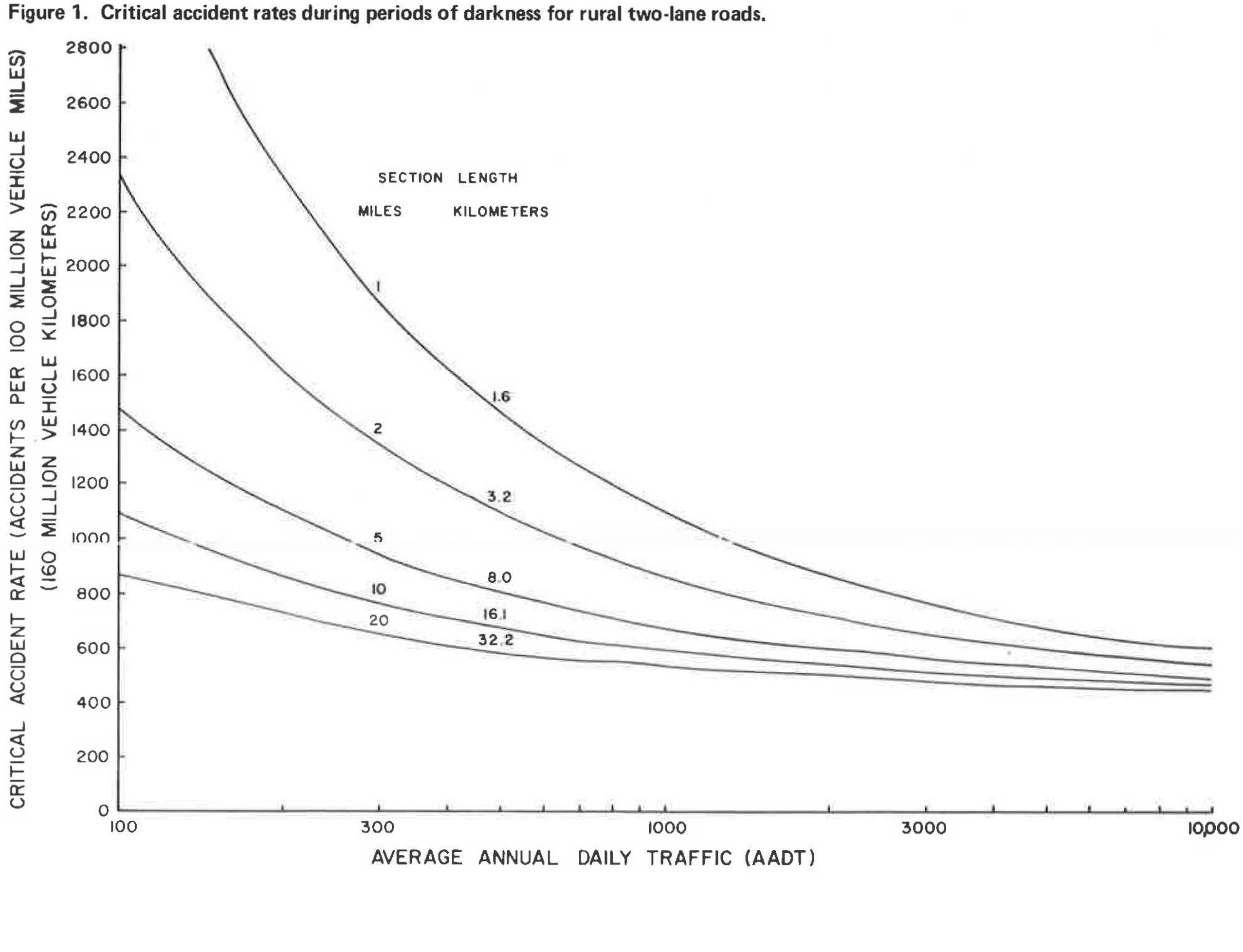


Figure 2. Critical accident rates during periods of darkness for rural four-lane roads (no access control).

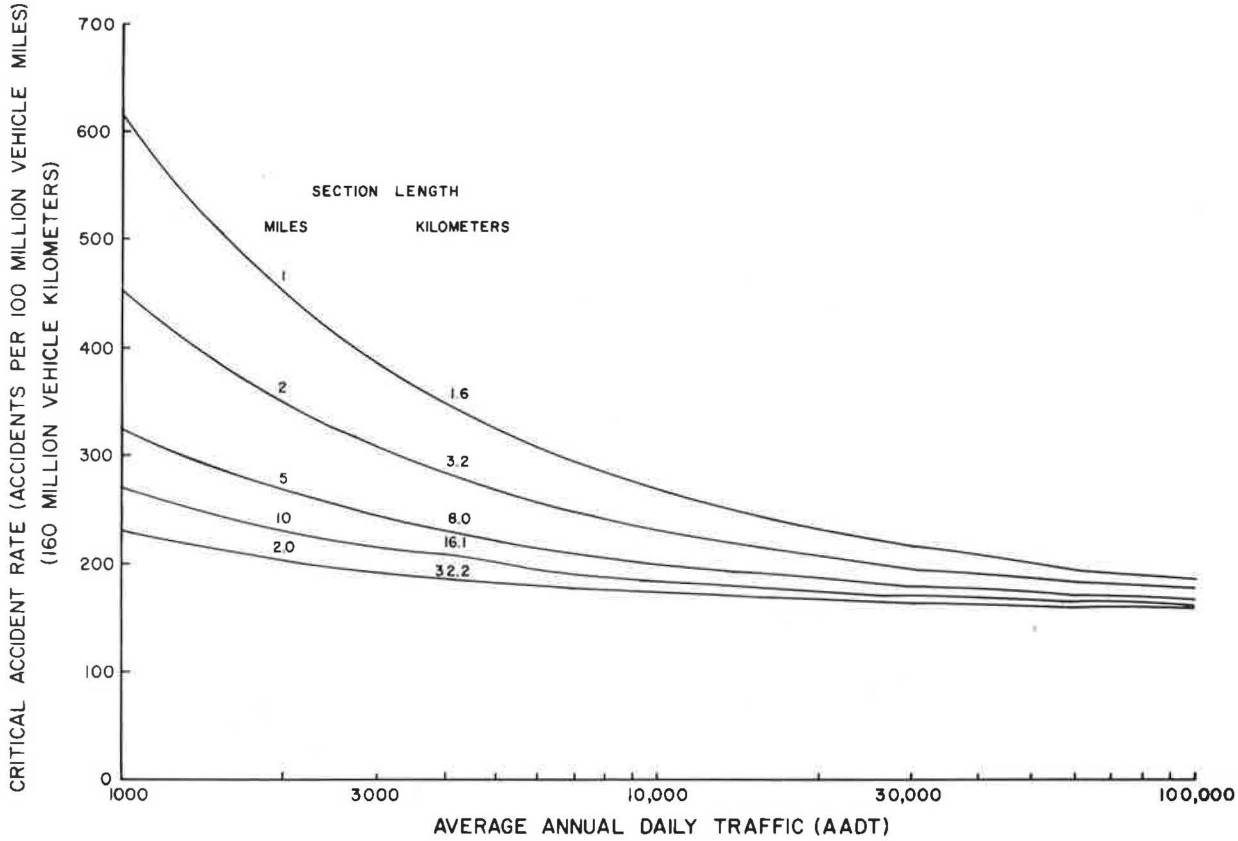
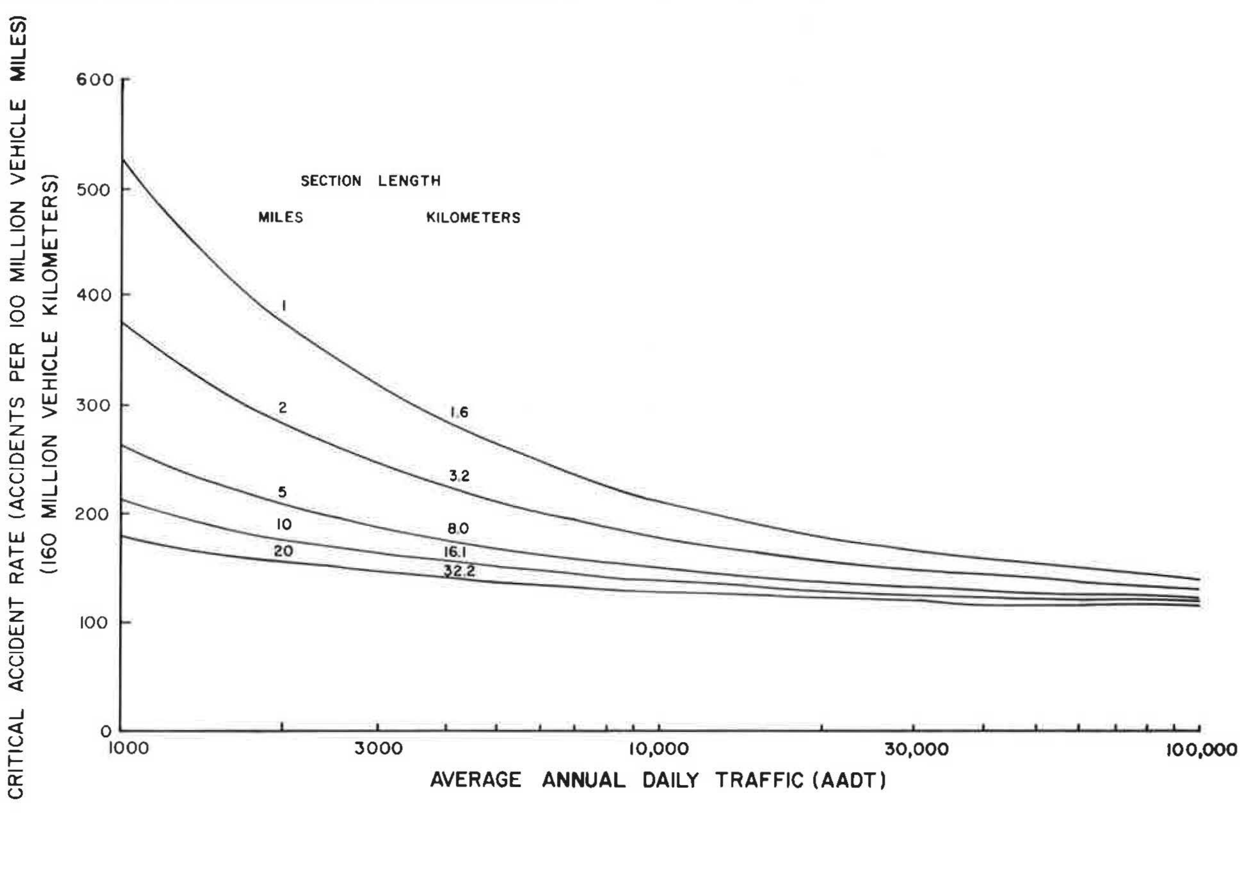


Figure 3. Critical accident rates during periods of darkness for rural expressways.



Accidents were more severe during darkness on all roads. Fatal accidents were 2.3 times more likely to occur during darkness than during daylight. Only slightly more injury accidents occurred during darkness than during daylight.

Effect of Speed

No significant differences were observed between average day and night speeds (Table 1). However, speed was not measured during the early morning hours. Table 1 shows that average speeds after the speed-limit change were reduced on all roads. Average speeds on Interstates decreased from 29.9 m/s (66.9 mph) to 26.3 m/s (58.9 mph).

Percentage of accidents during darkness before and after the change in speed limit and percentage of change are as follows:

Road Type	Before (1973) (%)	After (1975) (%)	Change (%)
Two-lane	20.0	21.2	+6.0
Four-lane	23.2	18.2	-21.6
Expressway	28.5	31.9	+11.9
All	21.0	21.9	+4.3

As expected, the percentage of accidents during darkness increased slightly on two-lane roads in 1975. Contrary to what was expected, the percentage of accidents on expressways increased significantly.

The percentages of wet-pavement accidents before and after the speed-limit change are compared in Table 2, where significant changes may be seen. For all highways, there was a decrease in the percentage of wet-pavement accidents during daylight but an increase during darkness. This increase was directly attributable to the increase in accidents on two-lane roads and corresponded to an increase in the speed limit during darkness (from 22.4 m/s to 24.6 m/s). This finding was significant and represents a true increase in the percentage of accidents because both the before and after periods experienced equal times of rainfall.

Accident rates before and after the speed-limit change are given in Table 3. The changes in the accident rate were similar for both daylight and darkness. As shown below, the ratio of daylight to darkness accident rates before and after the speed-limit change also showed no change for the total system. The larger ratio after the speed-limit change for four-lane highways reflects the larger decrease in accident rate during darkness than during daylight. On expressways, the accident rate during daylight decreased more than that during darkness.

Road Type	Before (1973)	After (1975)
Two-lane	0.58	0.58
Four-lane	0.50	0.68
Expressway	0.59	0.51
All	0.62	0.62

Accident Summary by Hour of Day

An accident summary by hour of day from 1975 state police statistics for the entire rural system is presented in Table 4. It shows higher accident rates and greater severity during darkness (particularly during early morning hours). The highest hourly accident rate was between 1:00 and 2:00

Table 1. Average speeds on rural roads during daylight and darkness.

	Average Speed (mph)								
	Daylight			Darkness			Both Light Conditions		
Road Type	Car	Truck	All	Car	Truck	All	Car	Truck	All
Interstate roads									
Before 55-mph speed limit	69.6	62.8	67.0	68.8	63.0	66.7	69.6	62.8	66.9
After 55-mph speed limit	59.0	58.5	58.9	59.3	58.3	59.0	59.2	58.4	58.9
Two-lane roads									
After 55-mph speed limit	53.3	51.8	53.1	53.4	53.2	53.4	53.4	52.3	53.2

Note: 1 mph = 0.45 m/s.

Table 2. Percentage of wet-pavement accidents on rural roads before and after the speed-limit change.

	Before (1973) (%)		After (1975) (%)		Change (%)	
Road Type	Daylight	Darkness	Daylight	Darkness	Daylight	Darkness
Two-lane	23.0	16.4	19.6	19.0	-14.8	+15.9
Four-lane	26.0	21.6	21.9	20.3	-15.8	-6.0
Expressway	29.0	17.6	14.7	15.1	-49.3	-14.2
All	23.7	16.7	19.3	18.7	-18.6	+12.0

Table 3. Accident rates on rural roads during daylight and darkness before and after the speed-limit change.

	Accidents per 100 Million Vehicle Miles					
	Before (1973)		After (1975)		Change (%)	
Road Type	Daylight	Darkness	Daylight	Darkness	Daylight	Darkness
Two-lane	250	433	238	412	-4.7	-5.0
Four-lane	129	259	102	150	-21.2	-42.0
Expressway	86	144	55	109	-35.7	-24.8
All	207	333	192	309	-7.4	-7.2

Note: 100 million vehicle miles = 160 million vehicle kilometers.

Table 4. Accident summary by hour of day (all rural roads).

Hour	Number of Accidents	Accidents per 100 Million Vehicle Miles	Injury and Fatal Accidents (%)
1[a]	610	448	44.8
2	485	509	47.0
3	309	320	41.1
4	282	387	44.3
5	240	264	42.5
6	316	164	35.8
7	682	153	32.3
8	973	125	31.2
9	1148	168	30.3
10	1182	144	28.3
11	1276	153	29.8
12	1594	187	29.5
13	1627	198	31.6
14	1681	197	34.1
15	2104	236	34.1
16	2293	225	32.8
17	2441	222	32.7
18	1990	194	35.1
19	1725	248	36.1
20	1403	263	38.4
21	1108	274	37.7
22	992	304	42.5
23	857	313	42.6
24	425	218	43.6

Note: 100 million vehicle miles = 160 million vehicle kilometers.
[a]Midnight to 1:00 a.m.

Table 5. Accidents during various light and pavement-surface conditions on urban roads.

Light Condition	Accidents on Wet Pavement (%)	Accidents on Snow or Ice (%)	Ratio of Wet- to Dry-Pavement Accidents	Ratio of Wet- to Dry-Time Pavement Conditions
Daylight	19.5	1.7	0.25	0.19
Dawn	32.1	10.0	0.55	0.22
Dusk	22.8	1.5	0.30	0.20
Darkness	26.7	4.6	0.39	0.21

a.m. The hours between 9:00 p.m. and 4:00 a.m. generally had the highest accident rates. These same hours also had the highest percentage of injury and fatal accidents.

Urban Accidents

Accidents and Traffic Volume

Since the total vehicle kilometers traveled in the Louisville urban area were not known, accident rates for urban roads could not be calculated. A number of 24-h traffic volume counts were obtained for 1974, and the percentage of accidents and the volume during the various light conditions are shown below:

Light Condition	Percentage of Accidents	Percentage of Volume
Daylight	71.8	72
Darkness	22.2	20
Dawn	1.4	4
Dusk	4.6	4

For both daylight and darkness, the percentages of accidents and of volume were very similar. There were distinct differences in accidents at dawn and at dusk. The percentage of accidents at dawn was abnormally low compared with that at other times of the day.

Wet or Dry Conditions

The data in Table 5 show that there is a greater proportion of accidents during darkness than during daylight on wet pavements. The slightly higher ratio of wet- to dry-time pavement conditions during darkness does not account for the difference in the rates of wet- and dry-pavement accidents. As was seen for rural accidents, a higher ratio of wet- to dry-pavement accidents occurred at dawn.

In an effort to alleviate the problem of rainy-nighttime accidents, a recent safety program in urban areas in Kentucky involved the installation of raised pavement markers. Their effect on wet-nighttime accidents has not yet been determined.

Severity

The severity of accidents was found to increase during the hours of darkness:

Light Condition	Injury Accidents (%)	Fatal Accidents (%)
Daylight	9.7	0.14
Dawn	9.4	0.67
Dusk	11.6	0.22
Darkness	14.4	0.53

The percentage of injury accidents showed an increase, but the largest increase was in the percentage of fatal accidents, which was almost four times that during daytime. Accidents at dawn and dusk were more severe than daytime accidents but less severe than accidents during nighttime.

Effect of Energy Crisis

The effects of the energy crises on accidents (primarily the effect of the 24.6-m/s speed limit) are summarized in Table 6. The reduction in the speed limit, of course, involved primarily roads in rural areas and should have had a smaller effect in urban areas because the speed limits there were already under 24.6 m/s. Considering all accidents, there were no significant changes in the percentage of injury and fatal accidents. The data showed that the energy crisis had a greater overall effect on accidents at night than on those during the day.

SUMMARY AND CONCLUSIONS

On rural roads the accident rate at night was higher than that during the day. The ratio of the night and day accident rates was greatest for rural expressways (1.98) and least for four-lane roads (1.47). Generally, accident rates at dusk were higher than those at dawn, which may be due to the higher traffic volumes associated with dusk. About 22 percent of all rural accidents occurred during darkness. Rural expressways had the highest percentage of accidents during darkness (31.9 percent).

Critical rates of accidents during darkness for various types of rural roads were calculated. Graphs presenting the critical rate as a function of volume and section length were prepared for each type of rural road. The critical-rate curves may be used to determine whether an accident problem during darkness exists.

In the Louisville urban area, wet-pavement accidents were more of a problem during darkness than during daylight, but there was no significant difference between the percentages during darkness and daylight on rural roads. At dawn, both urban and rural roads had a higher incidence of wet-pavement accidents than dry-pavement accidents. Both urban and rural accidents were more severe at night. The rate of fatal accidents was higher at night, and there was a slightly higher incidence of injury accidents.

No significant differences were observed between average speeds during daylight and darkness.

Table 6. Effect of energy crises on accidents during daylight and darkness for urban roads.

Item	Before Energy Crisis (1973)			After Energy Crisis (1974)			Change (%)		
	Daylight	Darkness	Total[a]	Daylight	Darkness	Total[a]	Daylight	Darkness	All
Number of accidents	14 525	4575	20 512	14 582	4514	20 314	+0.4	-1.3	-1.0
Percentage on wet pavement	19.6	31.1	22.0	19.5	26.7	21.5	-0.5	-14.1	-2.3
Percentage of injury and fatal accidents	9.8	15.6	11.3	9.8	14.9	11.1	0	-4.5	-1.8

[a]Totals do not include accidents that occurred at dawn and at dusk, not shown in this table.

On rural roads, the 24.6-m/s speed limit resulted in changes in the accident rates that were similar for both daylight and darkness. However, there were significant changes in the percentage of wet-pavement accidents after the speed-limit change. Throughout the rural system, there was a decrease in the percentage of wet-pavement accidents during daylight but an increase during darkness. This nighttime increase resulted from the increase in the percentage of accidents on the two-lane roads. On these roads, the nighttime speed limit had been raised from 22.4 m/s to 24.6 m/s. Considering all accidents in the urban areas, there were no significant changes in accident occurrence after the 24.6-m/s speed-limit change; however, there was a greater overall decrease of accidents during darkness than during daylight.

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