mance of officers assigned to traffic duties. In addition, the widespread availability of low-cost hardware brings the costs of microcomputer technology within reach of all but the smallest communities.

Such a purchase is even more sensible with the growing availability of software such as the MTRS. Coupled with modern management techniques, the information produced by the MTRS can enhance the efficiency and productivity of police agencies, provide support for justifying programs, and help to reduce the incidence of motor vehicle accidents and traffic violations.

In spite of the success of the first generation of MTRS, work remains to be done to make it an even better product. Areas that need to be investigated include improvement of the transportability of the software, removal of all software restrictions on accident case complexity, enhancement of system response times, and expansion of system capabilities to incorporate traffic engineering and statistical functions.

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Systematic Procedure for Incorporating Exposure Factors in Truck Accident Analysis

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The development and testing of a methodology for assessing the involvement rate of trucks in highway accidents are described. Existing procedures for incorporating exposure factors in truck accident analysis have been reviewed and their merits and demerits are discussed. Three alternative approaches for analyzing truck accidents are discussed, and approach 3 is identified as the most logical one based on its ability to incorporate exposure factors for arriving at appropriate measures. In the suggested methodology, a set of three vehicle-accident categories are identified: truck-only accident (TOA), passenger-car-only accident (POA), and combined accident (CA). A procedure for developing rates (accidents per vehicle mile of travel) for each category is defined that incorporates appropriate exposure factors. To check the validity of the proposed approach, Michigan accident data for a 10-year period (1970-1979) have been used as a case study. Standard statistical techniques (ANOVA and t-test) were applied. A comparison of accident data among TOAs, CAs, and POAs indicated that there is a significant difference in fatal, personal-injury, and property-damage accident rates when the three vehicle categories are considered together. When a comparison is made between TOAs and POAs, TOA rates are significantly higher for fatal and property-damage accidents. In addition, the CA category, which comprises a significant number of trucks, has generally a higher accident rate compared with others. Overall, trucks appear to have experienced a higher accident rate.

Passenger cars and trucks are the prime users of highway facilities. For example, during the year 1977, a total of 65 000 million vehicle miles of travel (VMT) was generated by all motorized vehicles in the state of Michigan, approximately 11 335 by trucks and 49 000 by passenger cars (1). Thus, approximately 93 percent of all travel in the state is attributable to trucks and passenger cars alone, and the remaining 7 percent of the travel is generated by other vehicles, including buses, motorcycles, and other commercial vehicles. Furthermore, the fact that the relative proportion of travel for these vehicle categories has remained unchanged during the past 10 years indicates that the year 1977 is typical in this respect.

The relative involvement rate of trucks and passenger cars in the incidence of highway accidents has been a topic of research interest for a number of years. In Michigan in the year 1977, a total of 636 259 vehicles were involved in all highway accidents--91 000 trucks and 505 000 passenger cars. This indicates that more than 95 percent of all vehicles involved in accidents were either trucks or passenger cars (1). A review of the national accident data base for the year 1977 shows that the same proportion generally holds true when all accidents on the nation's highways are considered (2). Table 1 gives the data compiled for the nation and for Michigan. Furthermore, when one considers fatal accidents alone, similar trends generally hold true when nationwide data are compared with Michigan data. As Table 1 indicates, approximately 18 percent of all vehicles involved in fatal accidents in Michigan in 1977 were trucks and 62 percent passenger cars. Corresponding figures compiled on a nationwide basis are 22 and 67 percent, respectively.

PROBLEM STATEMENT

The intent of the above discussion was to present some basic accident and exposure data and to demonstrate that the state of Michigan is typical of most states in the nation relative to highway accidents and that in terms of both travel and accidents the role of trucks is significant. However, little research reported in the literature addresses the question of whether trucks are carrying a heavy or light share of highway accidents. The purpose of this paper is to develop and test a methodology for assessing the relative involvement of trucks in highway accidents.

As a part of this methodology, one must establish at the outset an appropriate measure that can be used to compare accident experience by different vehicle categories over an extended time period. The development of such a measure appears to be a simplistic task; however, certain conceptual and operational problems must be resolved when the objective is to separate accident data into two or more vehicle categories (i.e., trucks, passenger cars, etc.). The problem arises from an apparent lack of agreement among traffic experts as to what constitutes exposure to accident, particularly when a comparison of accident data by different vehicle categories is involved. Although limited research in the area of exposure estimation has been reported in the literature, there is little agreement among researchers on how to incorporate exposure factors in accident analysis (3-5).

The problem addressed in this study is the question of exposure factors in analyzing accident data for the purpose of assessing the involvement rate of trucks in the incidence of overall highway accidents. This paper is presented in two separate sections. First, the development of a methodology for considering exposure factors in truck accident analysis is presented. Next, the application of this proposed method is demonstrated by using the Michigan data base. The data sources for this study are publications of the Michigan Department of State Police (1) and the U.S. Department of Transportation (DOT) (2), earlier work reported by Khasnabis and Atabak (6,7), and other work (8-10).

TRADITIONAL APPROACH

The measure used in most accident studies can be described as follows:

Accident rate = number of accidents/VMT (1)

Note that the denominator of Equation 1 is designed to discount the effect of varying amounts of travel generated in different facilities and has commonly been referred to as "exposure." Implicit in the designation of VMT as exposure is the premise that the more the amount of travel generated on a given facility, the greater the amount of risk or exposure to accidents to which the vehicles on the facility are subjected; therefore, the rate must reflect the effect of varying amounts of travel.

The above rate is quite appropriate in comparing accident data for different types of facilities or different locations. However, certain problems in logic would appear if one were to use the same measure in comparing accident data for different vehicle categories. By extrapolating the above definition, the rate for trucks can be defined as

Truck accident rate = number of accidents in which trucks were involved ÷ VMT generated by trucks (2)

The use of the above measure implies that, on a given facility or a network containing a number of facilities, exposure to accidents for a given type of vehicle (trucks in this case) is caused by travel generated only by that type of vehicle. However, if one departs from the original concept of exposure and redefines exposure as opportunity for interaction between different types of vehicles, the use of an alternative measure for exposure might appear appropriate.

It can be argued that exposure to accident for a particular vehicle type i is created not only by travel generated by type i itself but also by travel generated in part by all other types of vehicles present in the traffic stream. For example, referring back to the 1977 truck accident data base in Michigan, a total of 84 640 truck accidents was recorded in the state, where a truck accident is defined as one that involves at least one truck. Note that these truck accidents involved approximately 90 000 trucks and 63 000 nontrucks, mostly passenger cars. An argument could be made that truck accidents are, at least in part, the result of conflicts between trucks and nontrucks (as exemplified by the involvement of 63 000 nontrucks). Thus, the measure used should reflect the exposure effect of these nontrucks or, alternatively, the rate should have in the numerator those accidents that involved only trucks.

Another difficulty associated with the traditional approach is related to the use of the term "truck accident." A truck accident is generally referred to as one that involves at least one truck. By the same token, an accident that involves at least one passenger car is a passenger-car accident. The question remains as to how to treat an accident between a truck and a passenger car. These questions are addressed below.

METHODOLOGY

In this research, three possible approaches for incorporating exposure factors in truck accident analysis were originally developed.

Approach 1

Approach 1 requires the categorization of the accident data into truck accidents (accidents involving at least one truck) and passenger-car accidents (accidents involving at least one passenger car). Next, the percentage of passenger cars in truck accidents is computed, and the VMT attributable to passenger cars is included in the denominator along with the VMT for trucks. A similar procedure is followed for including truck VMT in the compilation of the passenger-car accident rate. This rate can then be written as

Truck accident rate = number of accidents involving at least one truck ÷ (VMT by truck + contribution of VMT by passenger cars) (3)

It was also postulated that the contribution of VMT by passenger cars could be estimated as a fraction of all passenger-car VMT, prorated for the number of passenger cars involved in truck accidents and the number of all passenger cars involved in all accidents. For example, in the year 1977, 505 000 passenger cars were involved in all accidents, and 59 000 of these were involved in truck accidents (11.7 percent). Thus, method 1 calls for including 11.7 percent of passenger-car VMT in the denominator of truck accident rate.

Note that the purpose of including the contribution of VMT by passenger cars in Equation 3 is to add a surcharge to the exposure, attributable to the increased opportunity of interaction resulting from the presence of other vehicles in the traffic stream. It should also be noted that, in computing the accident rate for passenger cars, a similar contribution by trucks in the VMT attributable to the truck-car accidents needs to be added.

This method was not adopted, however, because of one inherent deficiency. The comparison of the accident rates for the two vehicle categories by this method does not ensure the use of two mutually exclusive data bases. The rates for both trucks and passenger cars included accident data from the other vehicle category, which resulted in some overlap in the sample space. Specifically, an accident between a truck and a passenger car would be accounted for in both categories by this method.

Table 1. Comparison of vehicle involvement in highway accidents in U.S. and Michigan in 1977.

	All Accidents		Fatal Accidents	
Vehicle Category	U.S.	Michigan	U.S.	Michigan
All vehicles	29 900 000	636 259	63 700	3037
Trucks				
Number	4 700 000	91 000	14 100	532
Percent	15.7	14.3	22.1	17.5
Passenger cars				
Number	23 900 000	505 000	42 900	1874
Percent	79.9	79.4	67.3	61.7
Trucks and passenger cars combined (%)	95.6	93.7	89.4	79.2

Approach 2

Approach 2 required the development of a rate based on a numerator containing the number of vehicles involved in accidents rather than number of accidents. This approach would represent a significant departure from the traditional approach used in most accident analysis, where the number of accidents (as opposed to the number of vehicles) has been used in the numerator. Thus, according to this approach,

$$\text{Truck involvement rate} = \text{number of trucks involved in accidents} \div \text{total truck VMT} \quad (4)$$

Note that Equation 4 would automatically ensure the use of mutually exclusive data bases and there would be no overlap of sample space in the two rates to be compared. However, the method totally disregards the concept of the opportunity for interaction (between different vehicles) by separating trucks and passenger cars in the two distinct categories. The 1977 data base for Michigan shows that, of a total of 374 751 highway accidents, 84 640 accidents involved at least one truck (termed "truck accident"). These truck accidents involved approximately 90 000 trucks and 60 000 passenger cars, whereas the remaining 290 111 nontruck accidents involved 505 000 passenger cars and only 40 000 other vehicles (the majority of which are trucks).

It was felt that the use of vehicles in the numerator (as opposed to accidents) would inflate the rate for passenger cars due to the simple fact that most multivehicle truck accidents involve passenger cars as the other vehicle whereas most multivehicle passenger-car accidents involve another passenger car. Thus, because it was believed that the use of vehicles would have a tendency to overly exaggerate the adverse role of passenger cars in highway accidents in comparison with trucks, this approach was not pursued.

Approach 3

Approach 3 is an outgrowth of approach 1 and is an attempt to develop an analysis procedure by using mutually exclusive data bases with the provision that no overlapping sample space is considered. It was believed that the only way to avoid the use of a nonmutually exclusive data base would be to compare three sets of accident rates, even though the objective is to compare accident involvement by two types of vehicles. The following three rates were developed:

$$\text{Truck-only accident (TOA) rate} = \text{number of accidents involving trucks only} \div (F_t \times \text{truck VMT}) \quad (5)$$

$$\text{Passenger-car-only accident (POA) rate} = \text{number of accidents involving passenger cars only} \div (F_c \times \text{passenger car VMT}) \quad (6)$$

$$\text{Combined accident (CA) Rate} = \text{number of accidents involving all other vehicles} \div \text{VMT attributable to all other vehicles} \quad (7)$$

where F_t is the ratio of the number of trucks involved in all truck accidents to the number of all vehicles involved in all truck accidents, and F_c is the ratio of the number of passenger cars involved in all nontruck accidents to the number of all vehicles involved in all nontruck accidents.

In Equation 5, the numerator is the number of accidents in which all of the vehicles involved were trucks as opposed to the definition used in Equation 3, where any accident involving at least one truck is to be included. Thus, an accident involving a truck and a passenger car, or a truck and a motorcycle, is to be excluded from the numerator according to the new definition of TOA. The numerator would include single-truck or multiple-truck accidents (i.e., truck-fixed object and truck-truck). The same procedure would be used in deriving the rate for passenger cars given in Equation 6.

The advantage of using this numerator is that, because accidents involving a given type of vehicle are analyzed, the question of opportunity for interaction with other types of vehicles (and associated difficulties with exposure estimation) does not arise. Each of the three categories to be compared would thus represent mutually exclusive data bases with no overlap in the sample space.

It should also be noted that the denominators in Equations 5 and 6 represent the fraction of VMT (of the given type of vehicle) that is attributable to the fraction of the accident being considered in the numerator. The factors F_t and F_c in these two equations are designed for the purpose of transforming the denominator at the same base as the numerator. The factors F_t and F_c were derived as the ratio of vehicles of a given kind involved in a particular type of accident and all vehicles involved in the given accidents. Thus,

$$F_t = \text{number of trucks involved in all truck accidents} \div \text{all vehicles involved in all truck accidents} \quad (8)$$

$$F_c = \text{number of passenger cars involved in all nontruck accidents} \div \text{all vehicles involved in all nontruck accidents} \quad (9)$$

Both the numerator and the denominator of the last rate (Equation 7) are the complements of the accidents and exposures, respectively, considered together in Equations 5 and 6. Thus, all accidents and exposure data not considered in the previous two equations are contained in the last equation, which thus essentially represents a catch-all category. This category is specifically developed to preclude the use of overlapping sample space and to overcome the difficulties of estimating exposure associated with opportunities for interaction with other types of vehicles.

Figure 1 shows a flowchart depicting the process discussed above (approach 3), the method used in this study. Note that the process starts with consideration of all accidents and exposure data, sequentially progressing toward the goal of developing accident rates that constitute mutually exclusive data bases. Also note that the proposed approach lends itself to application through the use of data bases commonly available in most states.

CASE STUDY RESULTS

Approach 3 was used with the Michigan data base with two specific objectives in mind:

1. To demonstrate the applicability of the methodology and
2. To determine whether there is any significant difference in the accident experiences of the three vehicle classes (i.e., trucks only, passenger cars only, and all other vehicles) as reflected by the 10-year data base (1970-1979).

Availability of the necessary accident and exposure data and our familiarity with such a data base are the two primary reasons for selecting Michigan data for this study.

Standard statistical techniques were used to test the significance of difference between the mean rates. The null hypothesis tested was that there is no significant difference between the rates. The acceptance of this hypothesis would indicate the ab-

Figure 1. Flowchart of proposed methodology (approach 3).

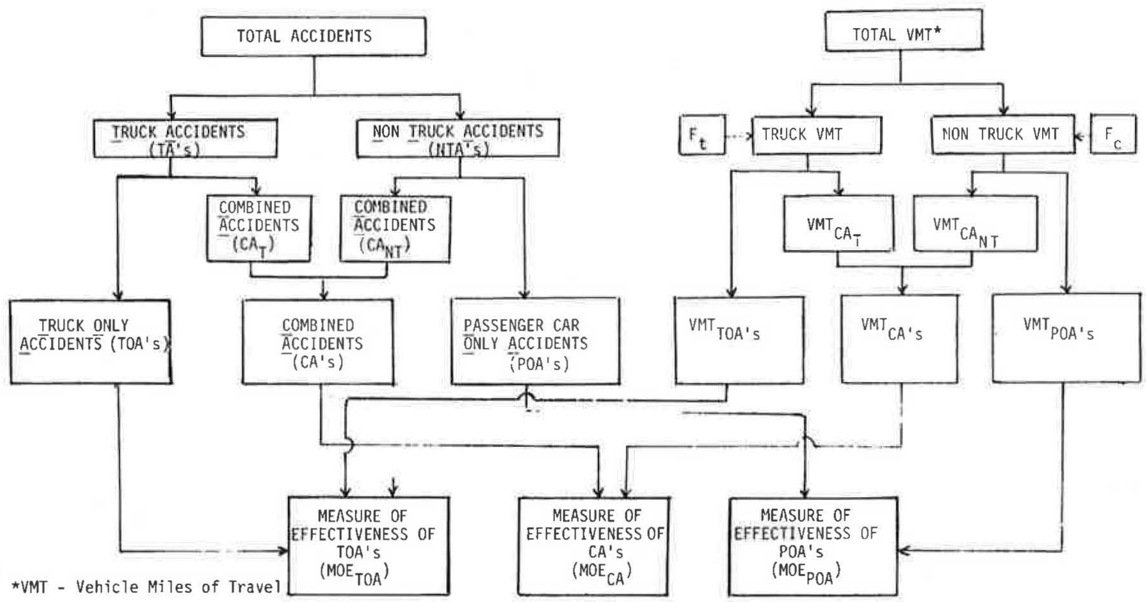

Table 2. Number of accidents involving trucks and all other vehicles and corresponding VMT data: 1970-1979.

	Type of Accident				VMT (000 000s)	
Year	Fatal	PI	PD	Total	Truck	Nontruck
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	
1978	546	24 828	67 268	92 642	12 132	
1979	511	25 174	65 487	91 172	13 301	
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
1978	1156	89 440	205 954	296 551		51 475
1979	991	85 320	188 970	275 281		48 308

Note: PI = personal injury and PD = property damage.

Table 3. Summary of accident data for 1977 developed by using proposed methodology (approach 3).

Category	Fatal	PI	PD	Total
Total accidents	1438	111 880	261 286	374 604
Truck accidents (TA - 84 640)				
TOA	254	13 119	36 988	50 361
CA_T	169	9 987	24 122	34 278
Nontruck accidents (NTA - 289 965)				
POA	870	81 811	185 961	268 642
CA_{NT}	145	6 963	14 215	21 323
Total CA = $(CA_T + CA_{NT})$	314	16 950	38 337	55 601
Accident rate[a]				
TOA	0.0436	1.95	5.48	7.4736
POA	0.0201	1.65	3.75	5.4201
CA	0.0402	1.98	4.51	6.5302

Note: CA_T = CA associated with trucks (truck accidents - truck-only accidents) and CA_{NT} = CA associated with nontruck vehicles (nontruck accidents - passenger-car-only accidents).

[a]VMTs for TOA, POA, and CA were calculated as 6748, 49 580, and 8525, respectively, by using the procedure described in the text. The F_t and F_c values for the year 1977 were estimated as 0.5953 and 0.9264, respectively. Accident rate for each category was obtained by dividing the number of accidents by the corresponding VMT.

sence of any significant difference, and the rejection would indicate otherwise.

Table 2 gives the basic Michigan accident data in four severity categories--fatal, personal injury (PI), property damage (PD), and total--for the two basic vehicle categories (trucks and nontrucks) along with the VMT information. Table 3 gives the development of the data for the three categories (trucks only, passenger cars only, and combined) for one given year (1977) by using the procedure described above. Similar tables for each of the 10 years were developed as a part of this study but are not given here for the sake of brevity. Table 4 summarizes all of the annual accident rates (expressed in number of accidents per million VMT) by the same four severity groups for each of the three vehicle classes. These rates were then subjected to standardized statistical testing procedures to determine the presence or absence of any significant difference. Two types of tests were conducted and these are briefly described below.

Test 1: Difference Between Mean Accident Rates for the Three Vehicle Categories Considered Together

In test 1, the null hypothesis tested was as follows:

$$(\mu_{TOA})_i = (\mu_{POA})_i = (\mu_{CA})_i \quad (10)$$

where

$(\mu_{TOA})_i$ = mean accident rate for TOA for severity type i,
$(\mu_{POA})_i$ = mean accident rate for POA for severity type i, and
$(\mu_{CA})_i$ = mean accident rate for CA for severity type i.

Table 4. Accident rates by severity and type of vehicle.

	Accident Rate (accidents/million VMT)											
	TOA				CA				POA			
Year	F	PI	PD	Total	F	PI	PD	Total	F	PI	PD	Total
1970	0.0493	1.33	3.13	4.5093	0.0391	1.89	3.37	5.2991	0.0284	2.08	4.02	6.1284
1971	0.0481	1.46	3.87	5.3781	0.0454	1.91	3.59	5.5454	0.0261	1.84	3.83	5.6961
1972	0.0450	1.70	4.43	6.1750	0.0425	2.09	4.06	6.1925	0.0274	2.02	4.18	6.2274
1973	0.0473	1.79	4.68	6.5173	0.0435	2.13	4.04	6.2136	0.0255	1.89	3.99	5.9055
1974	0.0323	1.62	4.69	6.3423	0.0371	1.89	4.07	5.9971	0.0224	1.70	3.99	5.7124
1975	0.0372	1.66	4.68	6.3772	0.0401	1.88	4.24	6.1601	0.0208	1.74	4.07	5.8308
1976	0.0420	1.81	5.13	6.9820	0.0350	1.90	4.46	6.3950	0.0216	1.72	3.97	5.7116
1977	0.0436	1.95	5.48	7.4736	0.0201	1.65	3.75	5.4201	0.0402	1.98	4.51	6.5302
1978	0.0457	1.96	5.62	7.6257	0.0402	1.95	4.80	6.7902	0.0213	1.74	3.99	5.7513
1979	0.0402	1.81	5.00	6.8502	0.0317	1.89	4.43	6.3517	0.0199	1.77	3.91	5.6999
Total	0.4307	17.09	46.71	64.2307	0.3747	19.18	40.81	60.3648	0.2536	18.48	40.46	59.1936
Mean	0.0431	1.71	4.67	6.4231	0.0375	1.92	4.08	6.0365	0.0254	1.85	4.05	5.9194

Table 5. ANOVA results comparing accident rates for all three vehicle categories.

Type of Accident	Source of Variation	Sum of Squares	df	Mean Square	Calculated F-Ratio[a]	Conclusion
Fatal	Total	0.003 53	29			Reject null hypothesis
	Between	0.001 65	2	0.000 826	11.88	(significant difference)
	Within	0.001 88	27	0.000 069 5		
PI	Total	0.89	29			Reject null hypothesis
	Between	0.27	2	0.14	5.92	(significant difference)
	Within	0.62	27	0.02		
PD	Total	9.41	29			Reject null hypothesis
	Between	2.70	2	1.35	5.44	(significant difference)
	Within	6.70	27	0.25		
Total	Total	11.88	29			Accept null hypothesis
	Between	1.87	2	0.94	2.52	(no difference in accident
	Within	10.01	27	0.37		rates)

[a] Critical F-value for 29 df @ $\alpha = 0.05 = 3.35$: If $F_{cal} \geq F_{crit}$, reject null hypothesis; if $F_{cal} < F_{crit}$, accept null hypothesis.

The results of the analysis of variance (ANOVA), based on the data from Table 4, are given in Table 5. Note that at the 5 percent level of significance the F_{calc} value for fatal, PI, and PD accidents exceeded the F_{crit} value of 3.35 at (2,27) df, which indicates that the null hypothesis is to be rejected. Simply stated, there is a significant difference in the accident rates studied. In addition, the data in Table 5 indicate that, when all accidents are studied together (i.e., the "total" category), there is no significant difference between the rates of these three vehicle groups.

Test 2: Difference Between Mean Accident Rates for Vehicle Categories Compared by Pairs

Because test 1 indicated the presence of a significant difference, the purpose of test 2 was to establish more clearly which pairs of the vehicle categories were significantly different in terms of accident experience. Essentially, three sets of null hypotheses were tested:

$$(\mu_{TOA})_i = (\mu_{POA})_i \qquad (11)$$

$$(\mu_{TOA})_i = (\mu_{CA})_i \qquad (12)$$

$$(\mu_{POA})_i = (\mu_{CA})_i \qquad (13)$$

The t-test of means was used for this purpose. At a 5 percent level of significance and 18 df, the t_{crit} value was established at 2.101 from standard statistical tables. If the t_{calc} value exceeded the t_{crit} value, the null hypothesis was to be rejected, which would indicate the existence of a significant difference between the two sets of means. On the other hand, the acceptance of the null hypothesis (when t_{calc} is less than t_{crit}) would suggest the absence of any significant difference.

The data in Table 6, which compares TOA and POA, indicate that in cases of fatal and PD accidents TOA rates are significantly higher, whereas in the other two cases (PI and total) no major difference is observed. The data in Table 7 indicate that TOA rates are significantly lower than CA rates for PI accidents and that in all three remaining categories no major difference is observed between TOA and CA. Table 8 compares POA and CA and the data indicate that CA rates are significantly higher for fatal and PI accidents but that there is no perceptible difference in the other two categories.

CONCLUSIONS

This study was conducted as part of an unsponsored research project at the Department of Civil Engineering, Wayne State University, in 1981-1982. The objective of the study was to develop a procedure for evaluating the relative role of trucks in highway accidents and to demonstrate the feasibility of the approach by applying it to an actual case study.

Three separate approaches have been presented in this paper, and special emphasis has been given to how to incorporate exposure factors in truck accident analysis. Approach 3, which calls for categorization of accident data in three vehicle groups (TOA, POA, and CA), was selected as the most logical approach, the one that appropriately assigns exposure factors to each vehicle group. The case study, conducted by using the Michigan accident data base for the 10-year period 1970-1979, led to the following conclusions:

1. When all three vehicle categories are considered together, a significant difference in the fatal, PI, and PD accident rates is observed.
2. In the case of fatal and PD accidents, TOA rates are significantly higher than POA rates. This finding appears intuitively logical because all TOAs include primarily rollovers, jackknife situations, and similar severe single-truck accidents, and truck-truck accidents are likely to be rare.
3. In case of PI accidents, the rate for TOA is significantly lower than that for CA.
4. The CA vehicle category has a significantly higher accident rate than POA for fatal and PI accidents. The reader should note that a majority of the CAs are likely to be car-truck accidents and that motorcycles, buses, and other nontruck vehicles would contribute an insignificant fraction of the CAs.
5. Overall, trucks involved in accidents appear to have a significantly higher fatality rate, as exhibited in the comparison of TOA versus POA and POA versus CA. (Note that the CA vehicle category comprises a significant number of trucks.)
6. The proposed approach uses the concept of opportunity for interaction in determining exposure measures and results in the use of mutually exclusive data bases in truck accident analysis. Furthermore, the procedure lends itself to application through the use of commonly available data bases, as demonstrated by the Michigan case study.
7. Although the proposed methodology is feasible and can be applied to any data base, conclusions 1-5 are valid only for Michigan data.

Table 6. Student's t-test results of comparison of accident rates between TOA and POA vehicle categories.

Accident Type	Mean Rate TOA	Mean Rate POA	t_{cal}[a]	Conclusion
Fatal	0.0428	0.0231	9.34	Reject null hypothesis (TOAs higher)
PI	1.71	1.82	-1.36	Accept null hypothesis (no difference)
PD	4.67	3.97	2.94	Reject null hypothesis (TOAs higher)
Total	6.4275	5.8121	2.01	Accept null hypothesis (no difference)

[a] t_{crit} for 18 df @ $\alpha = 0.05 = 2.101$: If $t_{cal} \geqslant t_{crit}$, reject null hypothesis; if $t_{cal} \leqslant t_{crit}$, accept null hypothesis.

Table 7. Student's t-test results of comparison of accident rates between TOA and CA vehicle categories.

Accident Type	Mean Rate TOA	Mean Rate CA	t_{cal}[a]	Conclusion
Fatal	0.0425	0.0390	1.59	Accept null hypothesis (no difference)
PI	1.71	1.94	-3.32	Reject null hypothesis (TOAs lower)
PD	4.67	4.14	2.00	Accept null hypothesis (no difference)
Total	6.4275	6.1170	0.95	Accept null hypothesis (no difference)

[a] See Table 6.

Table 8. Student's t-test results of comparison of accident rates between POA and CA vehicle categories.

Accident Type	Mean Rate POA	Mean Rate CA	t_{cal}[a]	Conclusion
Fatal	0.0231	0.0390	-9.04	Reject null hypothesis (POAs lower)
PI	1.82	1.94	-2.40	Reject null hypothesis (POAs lower)
PD	3.97	4.14	-1.18	Accept null hypothesis (no difference)
Total	5.8121	6.1170	-2.00	Accept null hypothesis (no difference)

[a] See Table 6.

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Discussion

Benjamin V. Chatfield

The authors have selected a timely subject on which enlightenment is badly needed. Measures of exposure are complex and not well understood by most of us who are involved in the analysis of accident data. Sources of reliable information on exposure are hard to find. If the state of the art is to improve, papers of this sort must be given more attention. They should not languish on the shelf because potential users of the proposals they contain are uncertain about their merits. If the proposals are good, they should be used; if not, their deficiencies should be clearly identified to expedite development of better proposals.

Measures of exposure are commonly used as the denominator in computing accident rates. These rates are used most often as indexes or as probabilities. (It has been noted by others that all probabilities are rates but not all rates are probabilities.) As indexes, rates may be relatively insensitive to approximations and other assumptions made in quantifying the numerator and denominator as long as the methods used are consistent. On the other hand, when rates are interpreted as probabilities for the purpose of analysis, the results may be very sensitive to minor differences in the way approximations and assumptions are made. In such cases, it is necessary to consider what the limitations of validity may be.

In their paper, Khasnabis and Reddy clearly intend that the rates they define be interpreted as probabilities. The comments that follow are meant to refer only to rates in the probability context.

After pointing out problems with current practice, the authors set up three clearly defined approaches to the resolution of these problems. Although they deal with trucks and passenger cars, the methods they propose could apply as well to any two categories of road vehicle (large car-small car, truck-motorcycle, etc.). Currently decreasing passenger-car sizes and increasing truck sizes make the relative roles of different vehicle categories a matter of major concern.

In dealing with rates as probabilities, exposure may be thought of, for example, as the number of attempts to travel a vehicle mile without becoming involved in an accident (E). Some of these attempts will fail (F) and some will succeed (S). From the basic axioms of probability theory, $E = F + S$ or, stated another way, $(F/E) + (S/E) = 1$. If the accident involvement rate (F/E) is to be regarded as a probability, the sum of successful attempts and failures must be equal to the total number of attempts.

Two aspects of the approaches described by the authors warrant particular consideration. The first deals with the treatment of failures in the numerator of rates. The second relates to the measure of exposure in the denominator.

First, an attempt has failed in the example above when there is an involvement in an accident. Using accidents in place of involvements in the numerator in computing a rate violates the axioms of probability theory if there are multivehicle accidents. In such a case, the rate understates the probability that an attempt will fail. This understatement is inconsistent with the requirement that the sum of the probabilities of success and failure be equal to one. It would be useful to determine under what circumstances, if any, this inconsistency alone may invalidate conclusions based on the authors' approaches 1 and 3.

Second, the measures of exposure in approaches 1 and 3 may not be valid. In approach 3, vehicle miles of exposure are divided into three distinct parts that are used in computing rates. The denominator used in computing each rate includes vehicle miles of travel by passenger cars or trucks or both. If these denominators are regarded as the number of attempts to travel a vehicle mile without an accident involvement, it is difficult to understand why none of the failures in the first two groups involves both trucks and passenger cars and why all failures in the third group occur in multivehicle accidents in which two or more types of vehicles are involved. Why is a unit of truck exposure in the third group less likely to result in a single-vehicle accident than a similar unit of exposure in another group? There may be interpretations of these exposure measures for which the rates are valid as defined, but these interpretations are not readily evident and should be explained.

In their paper, Khasnabis and Reddy appear to have made an implicit assumption that passenger cars and trucks are both traveling in the same environment. Under these circumstances, approach 2 may be promising. Instead of dividing accidents into categories such as truck only, passenger car only, etc., it might be productive to ask questions such as the following:

1. Is an attempt to drive a truck a given distance more likely to result in a single-vehicle accident than an attempt to drive a passenger car the same distance?
2. Is an attempt to drive a truck a given distance more likely to result in a collision in which the second vehicle is a passenger car than an attempt to drive a passenger car the same distance?

One of the biggest problems in comparing the relative safety of various types of vehicles is the lack of adequate exposure data. Part of the reason for this lack of data is the current confusion about what data are needed and how they are to be used. Development of easily applied criteria for distinguishing between valid and invalid exposure measures would be a major advance in the state of the art of accident analysis. New approaches such as those suggested by the authors should be analyzed more rigorously to resolve technical matters and to ensure that when good approaches are developed they are recognized.

Authors' Closure

We greatly appreciate Chatfield's thoughtful and constructive comments on our paper. We fully agree with him that measures of exposure are not well understood and that reliable exposure data are difficult to find. The basic purpose of the paper was to address the above two issues. Specifically, the objectives of the paper were twofold:

1. To demonstrate the complexity involved in measuring exposure in situations in which a comparison of the accident involvement rates of different types of vehicles is desired and
2. To identify and evaluate different procedures that can be used in such comparisons.

In more specific terms, the procedures presented were directed toward comparing historical accident experiences of trucks and passenger cars. However, as Chatfield points out in his discussion, the methods proposed could also be applicable to any two vehicle categories (e.g., large cars versus small cars and trucks versus motorcycles).

Chatfield raises the question that in cases of multivehicle accidents the rate that uses accidents in the numerator may understate the probability that an attempt to travel a vehicle mile without an accident will fail. In such cases, the sum of the probabilities of successes and failures indeed may not be equal to unity. We agree with the comment and would suggest that the definitions of success and failure may have to be modified so that the basic axioms of probability are satisfied. As the discussant points out, there is a need for more research in this area before the question can be satisfactorily resolved.

Our choice of approach 3 was based on the need to create mutually exclusive data bases so that the overlapping of sample spaces could be avoided during the comparison of accident data. To this end, approach 3 has more merit than approach 1. (It may be recalled that approach 3 is an outgrowth of approach 1.) Specifically, an accident between a truck and a passenger car would be accounted for in both accident categories--namely, truck rate and passenger-car rate--in approach 1. On the other hand, these combined accidents are accounted for in the third category in approach 3.

Regarding Chatfield's comment on why "all failures in the third group occur in multivehicle accidents," the third vehicle category itself is the multivehicle category that includes accidents involving trucks and passenger cars and is therefore the logical category in which these combined accidents could be considered. As Equations 5 and 6 in the main body of the text show, accidents involving trucks only and passenger cars only are captured in the first two rates. Furthermore, in each of the three rates in approach 3, the VMTs used in the denominators represent our best estimate of the exposure attributable to the accidents included in the corresponding numerator. Further insights into and better understanding of the exposure phenomenon through future research could lead to better estimates in this regard.

Chatfield suggests that approach 2 may be more promising when one considers the assumption that passenger cars and trucks are both traveling in the same environment. We fully agree with the comment and believe that further research is indeed necessary before a complete evaluation of approach 2 can be made. Our decision to discard approach 2 was made primarily on intuitive grounds. Specifically, it was believed that the use of vehicles (involvement rate) in the numerator would tend to overexaggerate the adverse role of passenger cars in highway accidents simply because of the vast majority of passenger cars in the distribution of the entire vehicle population. One could also argue that, because passenger vehicles represent the vast majority, the corresponding accident rate should be inflated accordingly. Again, approach 2 requires further investigation before one can justify the rationale of computing the rates for the purpose of comparison.

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The Promise of New Technology: Implications for Traffic Record Systems

WILLIAM W. STENZEL

Despite the technological revolution that is occurring with the availability of easy-to-use, low-cost, small computers, the development of automated traffic record systems for small police agencies will be a difficult task. The history of data-processing use by law-enforcement agencies over the past 15 years is reviewed, and it is concluded that the record is less than remarkable. Police data-processing projects usually take longer than predicted, cost more than estimated, and produce less than expected. Unrealistic expectations, infatuation with equipment, and the absence of quality software are identified as key factors contributing to these failures. A dramatically changing data-processing marketplace will produce future problems for small agencies that plan to automate traffic record systems. In an analogy between books and their contents and computers and software, it is noted that, just as the major production cost of every book today is the cost of authorship, the major cost of automation has become the development of quality computer programs and not the machines they are designed to run on. Faced with a marketplace that will be cluttered with dozens of data-processing vendors who may not offer adequate service after a sale, the acquisition of appropriate software and support will continue to be difficult for small agencies getting into data processing for the first time.

The electronic revolution is upon us. From digital watches to video recorders, cordless telephones, programmed microwave ovens, and diagnostic readouts in the dashboards of cars, a new and sometimes overwhelming, sometimes frightening technology is with us at every turn. Like it or not, it is a technology on which we are quickly becoming dependent. For example, without microprocessors, the U.S. telephone system as we know it today could not operate.

Perhaps the most exciting and remarkable innovation of this age is the development of general-purpose programmable microprocessors or microcomputers. I am using the word computer in the way that many people have always thought of computers--that is, large, oversized pieces of equipment. In reality, the basic characteristics of room-sized mainframes can not be constructed into briefcase-sized personal computers. Those characteristics include a central processing unit (CPU), data input-output devices, and some form of off-line data-storage capability. The Timex Sinclair Z100, which sells for about $100, is generally identical to the CDC Cyber 205. Both have the ability to follow a sequence of instructions supplied by the user as long as the instructions are formulated according to a precise set of rules. The only limitation to what can be accomplished by these instructions (code) is the imagination and programming skills of the user. (My purpose at this point is to stress the functional similarities of large and small computers. Functional similarity, of course, is not synonymous with performance similarity. The Cyber 205 is capable of billions of arithmetic operations per second; the capability of the Sinclair is much less.)

Despite their current performance limitations, small computers are rapidly becoming as common as hand-held calculators because of their low cost and small size. For the first time, a computer is a practical reality for almost everyone. If the past few years have taught us anything, it is that nothing is more uncertain than long-range forecasts of new technology. Despite the difficulty of tracking future trends, a few cautious predictions can be made. New technology over the next few years will succeed in cramming more and more circuitry into smaller and smaller volumes for remarkably little increase in cost. One tangible fallout of this trend will be the increased capability and use of hand-held computers that are no larger than the calculators people now carry in their vest pockets or purses. In fact, it is becoming increasingly evident that the only true limits to further size reductions may be human characteristics (e.g., finger size).

Equally important will be the accessibility of virtually unlimited off-line storage capacities at extremely low cost. In fact, it is possible that