Causal Analysis of Accident Involvements for the Nation's Large Trucks and Combination Vehicles

T. CHIRA-CHAVALA and DONALD E. CLEVELAND

ABSTRACT

The chance of accident involvements of the Interstate Commerce Commission-authorized, large, single-unit trucks and tractor-trailers was investigated using the 1977 Bureau of Motor Carrier Safety accident and the Highway Cost Allocation Study exposure data. The model used was discrete-multivariate and capable of simultaneously analyzing both the accidents and the exposure. The variables that were found to be important predictors of accident involvements include trailer style, vehicle configuration, number of axles of power unit, trip length, road class, road surface condition, loading status, day/night, driver experience, and driver age. Particularly high accident involvement rates, of 200 involvements per 10^8 mi or higher, were shown by all van singles in local service, 3-axle-tractor singles in local service, 2-axle straight trucks in local service, and flatbed doubles in over-the-road service. Low accident involvement rates of less than 50 involvements per 10^8 were shown by all 3-axle straight trucks and 2-axle straight trucks in over-the-road service. Van singles and tanker singles in over-the-road service showed moderate involvement rates (less than 100 involvements per 10^8 mi), while 2-axle-tractor van doubles and 2-axle-tractor tanker doubles showed higher rates (120 to 200 involvements per 10^8 mi).

This paper contains the results of an investigation of the association between the chance of accident involvements and several influencing factors for the nation's large single-unit trucks and tractor-trailers. The methodology developed for this study is aimed at obtaining stable estimates of the probabilities of accident involvements. The findings are useful as input for policy planning (including usage regulations for certain types of trucks and their route assignments, driver education, and training programs). They also provide input for vehicle tests and simulations, accident countermeasures, as well as identifying gaps in data collection efforts concerned with truck accidents and usage.

STATEMENT OF THE PROBLEM AND LITERATURE REVIEW

The current Federal Surface Transportation Act, passed by Congress in December of 1982, lifted the restriction that long barred the operation of large tractor-trailers in many states. However, the highway safety of these trucks is not fully understood. There is also no consensus on the estimates of the various accident characteristics of these trucks.

As with most other traffic accident problems, direct theoretical work has not led to sufficient understanding of how accidents involving these trucks occur. Data collected from actual past accident experience and truck usage, when properly analyzed, can provide insight into this complex phenomenon.

Several past major accident analyses of these trucks (1-3) have produced vastly different findings on their safety records. Vallette, McGee, Sanders, and Einger (1) reported that "doubles" (tractors pulling two trailers) had much higher accident involvement rates than both single-unit trucks and "singles" (tractors pulling one trailer). Their study was based on data collected from selected locations in California and Nevada. T-tests and analysis of variance were used to analyze the data.

Glennon (2) conducted a study of accident involvements of singles and doubles for a commercial carrier's fleet and reported that there was no statistically significant difference in the accident rates between singles and doubles. His study was a matched-pair analysis controlling for factors such as origin-destination pairs, routes, and trip length.

The Bureau of Motor Carrier Safety (BMCS) reported the accident rates for singles and doubles for each year from 1969 to 1976 (3). The overall number of accidents per million truck miles for doubles was found to be consistently lower than for singles, with the exception of 1975 when doubles showed a slightly higher rate.

The sources of incompatibility in the findings of past accident-analysis studies included (a) most studies only examined a special population of trucks (i.e., from certain companies, states, or regions of the country). Often, the selection of the samples was not necessarily random; thus, it is difficult to use or extrapolate their findings at the national level; and (b) methods of analyzing accident rates, t-tests, and/or analysis of variance in which one or two variables were investigated at a time, have shortcomings. One of these is the implicit assumption that these tests were carried out for "homogeneous" populations. That is, there were no other significant "confounding" factors at play. Such an assumption, when not met, gives rise to "Simpson's Paradox" (4) and, therefore, model misspecification and possible incorrect findings.

This study is based on the two currently available national data sets: the BMCS file for the accident involvements, and the Highway Cost Allocation Study (HCAS) file for truck mileage and uses. The model estimation technique for accident involvements is discrete-multivariate and capable of simultaneously adjusting for the difference in truck usage and mileage (the exposure). It also allows a large number of independent variables to be simultaneously examined.

THE DATA

BMCS

The BMCS file contains information on accidents involving interstate motor carriers that are subject to the Department of Transportation Act of 1966 (49 United States Code 1655). These carriers are required to report to the BMCS any accidents involving their vehicles that result in death, injury, or property damage over $2,000. Excluded are occurrences that involve any boarding and alighting from a stationary vehicle, loading and unloading of cargo, and farm-to-market agricultural transportation. The accident information is reported to the BMCS by the carriers themselves on standard forms.

There are altogether 74 variables and over 30,000 accidents reported each year. The variables provide information on the place and time of accidents, events leading to accidents, accident consequences, driver and occupation, vehicle description, road conditions, and some environmental conditions.

HCAS

The HCAS file is a modification of the Truck Inventory and Use Survey (TIU) (5). It provides information on vehicle factors and some operational characteristics of the nation's truck population, other than those owned by federal, state, and local government agencies. There are altogether 96 variables recorded. The original TIU file is based on a stratified random sample of trucks in the country. Truck operators were asked to furnish information on their vehicles on a standard questionnaire.

METHODOLOGY

Large single-unit trucks (straight trucks) are defined in this paper as those over 10,000 lb. Tractor-trailers (combination vehicles), whether singles or doubles, can operate with a variety of trailers, the most common of which are vans, flatbeds, and tankers. In this study, the population of large single-unit trucks and combination vehicles are limited to the ICC-authorized carriers, which were not carrying farm products. The scope of the analysis is for a 12-month period in 1977.

The lack of information on road class, environment, and drivers in the HCAS file has led to dividing the model estimation into two parts: "casual" and "deductive" models. In a causal model, the association between the probabilities of accident involvements and the independent variables, which are available in both files, is quantified. Deductive modeling assesses the influence of those independent variables that are missing from the exposure data file: road class, day-night, road surface condition, region of the country, loading status, driver age, driver experience, and so forth.

Causal Model

An accident-involvement model expresses the chance of involvements in terms of the effects of the significant independent variables, adjusted for the truck miles of travel (or exposure). The formulation of the accident-involvement model follows in Figure 1 for a simple case of two independent variables. For a larger number of the independent variables, the same derivation applies.

Boxes (i) and (ii) represent the contingency tables for the accident involvements and the truck mileage, and A and B represent the two independent variables whose effects on the accident involvements are under investigation. They have I and J levels, respectively, the variable m_{ij} is the number of accident involvements indexed by the levels of A and of B, and Z_{ij} is the exposure, also indexed by the levels of A and B. The model for accident-involvement can be expressed as:

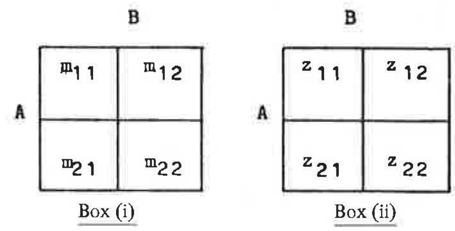

FIGURE 1 Formulation of the accident-involvement model for two independent variables.

$$P\{\text{an involvement adjusted for mileage}\} = f\{A,B\} \quad (1)$$

or

$$\text{Log } \{m_{ij}/z_{ij}\} = w + w_i^A + w_j^B + w_{ij}^{AB} \quad (2)$$

$$\text{Such that } \sum_i w_i^A = \sum_j w_j^B = \sum_i w_{ij}^{AB} = \sum_j w_{ij}^{AB} = 0$$

where

w = the grand mean,
w_i^A = the main effect of A,
w_j^B = the main effect of B, and
w_j^{AB} = the interaction between A and B.

Because the left-hand side of Equation 2 is expressed as the number of accident involvements per truck mile (or an accident involvement rate), this model is referred to as an accident-rate model. Whereas accident involvements (m_{ij}) are multinomial frequency data, truck miles of travel (Z_{ij}) are not. This has led to the following model-estimation technique.

Estimation of the model as represented by Equation 2 involves first fitting a log-linear model (6) to the accident data of box (i) and then adjusting this fitted model by the exposure of box (ii). This adjustment is necessary because of the differences in truck usage and mileage. The estimation procedure involves the following steps:

1. A log-linear model is fitted to the accident data of box (i). This model configuration can be expressed as:

$$\text{Log } \{m_{ij}\} = u + u_i^A + u_j^B + u_{ij}^{AB} \quad (3)$$

2. The model configuration so obtained is then applied to the exposure data of box (ii). This serves two purposes: (a) to determine the magnitude of the corresponding model terms for the exposure, and (b) to obtain the "smoothed" estimates of cell exposure. This is desirable because the observed cell exposure in a large contingency table can vary from a small to a large value, including zero. Usually, such zero cells are small cells and not structured zeros (i.e.,

cannot happen). They are zero because of the sample design. The result of this step can be expressed as:

$$\text{Log}\ \{z_{ij}\} = v + v_i^A + v_j^B + v_{ij}^{AB} \quad (4)$$

3. The estimated accident-involvement model as represented by Equation 3 is adjusted by the exposure. The resultant accident-involvement rate model can be expressed as:

$$\text{Log}\ \{m_{ij}/z_{ij}\} = w + w_i^A + w_j^B + a_{ij}^{AB} \quad (5)$$

where

$w = u - v$,
$w_i^A = u_i^A - v_i^A$,
$w_j^B = u_j^B - v_j^B$, and
$w_{ij}^{AB} = u_{ij}^{AB} - v_{ij}^{AB}$.

The goodness-of-fit measure for the accident involvements (Equation 3) is asymptotically distributed as chi-square with appropriate degrees of freedom as follows:

$$G^2 = -2\ \Sigma\ (\text{observed})\ \text{Log expected/observed} \quad (6)$$

Because of the sampling factors of the surveyed mileage and the fact that the mileage data do not have a multinomial distribution, the G^2 for the exposure is not a meaningful goodness-of-fit measure. In fact, the sampling factors will inflate the G^2 value for the exposure (7). The role of the exposure in the model estimation is then limited to adjusting the accident involvements of the trucks. The exposure does not affect the goodness-of-fit or the selection of the "best" accident-rate model.

In the event there are a number of model configurations that fit the accident involvements reasonably well, the following criteria are used to select the best accident-rate model:

1. Fewer high-order terms or higher degrees of freedom;
2. Estimated accident rates are close to observe rates; and
3. A reasonable goodness-of-fit for the accident involvements.

Deductive Modeling

This involves estimating a contingency table for the exposure to include the variable(s) whose effect on the chance of accident involvements (in the presence of all the significant independent variables from the causal modeling) is being investigated. The assumption for estimating this contingency table is that the variable(s) in question is (are) not significant. The estimated exposure so obtained is then assessed to see if it is realistically reasonable. If it is not, the variable(s) in question can be said to be significant. Furthermore, by examining this estimated exposure on a cell-by-cell basis, the manner in which this particular variable(s) affects (affect) the accident-involvement rates can be identified in greater detail. Deductive analysis can be used to examine one variable or a group of variables whose interactions with one another may be known a priori or suspected.

The deductive analysis involves the following steps:

1. A contingency table of accident involvements is obtained from the BMCS file. The table is cross-classified by all the significant variables from the casual modeling plus the variable(s) that is (are) being investigated.
2. A similar contingency table for exposure is obtained by estimating the exposure for all cells so that the variable(s) under investigation will be nonsignificant. (This table is cross-classified by the same variables as in step 1.)
3. The accident data and the estimated exposure obtained in step 2 are used to estimate the accident-rate model using the procedure described in the section entitled "Causal Model." If the variable(s) under investigation was (were) indeed nonsignificant, all the estimated model terms (w-terms of Equation 5) that involve that variable should be small or zero. If these model terms are not small, steps 2 and 3 are repeated until they are.
4. The reasonableness of the "best" estimated exposure table is assessed on a cell-by-cell basis and overall. If this estimated exposure is considered unrealistic, the variable(s) in question is (are) significant. Examining the estimated exposure on a cell-by-cell basis will help identify the pattern of the effect of such a variable or variables.

RESULTS OF MODEL ESTIMATION

Causal Model

The independent variables initially included in the causal analysis were those that were available in both the BMCS and the HCAS files. They are:

1. Vehicle configuration--single, double, or straight truck;
2. Trailer body style: van, flatbed, or tanker;
3. Number of axles of power unit: 2- or 3-axle;
4. Model year--pre-1974 (older) or post-1974 (newer);
5. Trip length--over-the-road or local service;
6. Number of axles of the trailer(s);
7. Vehicle length;
8. Gross vehicle weight (GVW);
9. Registered weight of vehicle;
10. Cargo type; and
11. Region of the country (or state) in which accident occurred.

The information on the first six variables is reasonably complete and the levels of these variables are compatible in both the BMCS and the HCAS files. However, the distributions of number of trailer axles for flatbeds and tankers resulted in a large number of empty cells for multi-dimensional contingency tables. This variable was therefore not included in causal modeling. Also excluded from causal modeling was vehicle length because it was recorded differently in the two files; the BMCS file recorded total length while the HCAS file recorded the length of cargo compartments.

The GVW in the BMCS file reflects the actual gross weights of the trucks at times of accidents. This variable in the HCAS file indicates the maximum weights that the trucks had operated in the past twelve months of the survey period. Because of this discrepancy, GVW was excluded from causal modeling. The registered weight variable also had recording inconsistency: some registered vehicle weights from the HCAS file reflect empty weights while some others reflect the allowable GVWs. It was therefore excluded from causal modeling. The weight variable, however, remained a candidate for deductive modeling.

Cargo type is another variable in which considerable recording incompatibility, caused by vastly different definitions of cargo types, exists in the two files. Considerable effort was made here to correct these mismatched cargo types in the two files. Unfortunately, the results were not satisfactory. It was noted that cargo type was highly correlated with vehicle configuration and trailer body style. Its exclusion from causal modeling was, therefore, not critical in the presence of the other two variables.

Regions of the country where the accidents occurred would be a good surrogate for factors that are usually not recorded or measured in both the accident and the exposure files. They are factors such as traffic density, traffic mix, operating speeds, general terrain, road or highway standard, traffic enforcement, and other ambient environmental characteristics that may affect the chance of accidents. Although the BMCS file contains both state of accident and state of registration data, the HCAS file only contains the latter. It is common for vehicles registered in, say, an eastern state to be operated in western states, and vice versa. Delaware, for example, accounted for a high percentage of total registrations in the country, yet it showed only a small proportion of in-state accidents. Because of the potentially important contribution of the regions of the country where accidents occurred toward explaining the chance of accident involvements, many attempts were made to create this variable for the HCAS file using the information on region of registration. The results of these attempts, however, were not satisfactory (8). It was thus excluded from causal modeling although it remained a candidate for deductive modeling.

At this stage of the analysis, there were five independent variables left for causal-model estimations: vehicle configuration, trailer style, number of axles of power unit, model year, and trip length. Because straight trucks do not usually have different trailer styles, a contingency table of accident involvements or exposure cross-classified by these five variables resulted in too many empty cells, many of which were "structured" zero. This suggested that separate modeling for the following two subsets were appropriate. They are: (a) combination vehicles and (b) straight trucks.

Combination-Vehicle Subset

The combination-vehicle subset was by far the larger of the two subsets. Table 1 gives the contingencies for the BMCS accident involvements for the ICC-authorized combination vehicles (excluding farm products). Table 2 gives contingencies for the HCAS annual truck miles of travel.

The "best" accident-rate model for the combination-vehicle subset, based on the estimation technique of the section entitled "Causal Model," was found to include the following terms:

[1345], [123], [124], [125], [234], [235], and [245] (7)

where

V1 = trailer style,
V2 = vehicle configuration,
V3 = number of axles of power unit,
V4 = model year,
V5 = trip length, and
[1345] = an interaction among V1, V3, V4, and V5, and so on.

TABLE 1 Accident Involvements of ICC-Authorized Carriers Excluding Those Carrying Farm Products

Trip Length	Model Year	No. of Axles (tractor)	Single/ Double	Van	Flatbed	Tanker
Over the road	Old	2	S	866	107	64
			D	270	—[a]	32
		3	S	3,135	2,027	861
			D	43	21	8
	New	2	S	607	53	35
			D	387	13	18
		3	S	5,022	1,334	931
			D	87	12	4
Local	Old	2	S	859	17	8
			D	18	—[a]	3
		3	S	523	66	97
			D	7	3	—[a]
	New	2	S	458	9	4
			D	13	—[a]	—[a]
		3	S	295	27	93
			D	—[a]	—[a]	—[a]

SOURCE: 1977 BMCS.

[a]Zero accident involvements and/or miles.

TABLE 2 Annual Mileage (in 10^6 Miles) of ICC-Authorized Carriers Excluding Farm Products

Trip Length	Model Year	No. of Axles (tractor)	Single/ Double	Van	Flatbed	Tanker
Over the road	Old	2	S	1,323.34	161.42	78.84
			D	230.96	—[a]	17.46
		3	S	2,967.58	1,183.42	874.25
			D	84.16	4.98	18.36
	New	2	S	826.06	122.71	97.34
			D	248.06	5.06	10.59
		3	S	5,188.33	1,196.81	897.33
			D	90.14	10.54	9.31
Local	Old	2	S	522.18	35.26	6.74
			D	27.33	—[a]	3.91
		3	S	258.19	77.15	69.97
			D	10.92	5.31	—[a]
	New	2	S	228.89	8.41	8.58
			D	7.04	—[a]	—[a]
		3	S	51.29	24.88	35.80
			D	—[a]	—[a]	—[a]

[a]Zero accident involvements and/or miles.

Because this model is a hierarchical model, it also contains, in addition to the preceding seven terms, all the lower interaction terms as well as the main effects of all five variables.

The G^2 value for the accident involvements was 17.40 for 9 degrees of freedom (p-value = .043), indicating a reasonable fit for the accident involvements. The estimated overall mean accident rate for all combination trucks, based on the model configuration of Equation 7, was 120.4 accident involvements per 10^8 vehicle mi.

Observed and Estimated Accident Rates

The observed and the estimated accident-involvement rates are given in Table 3. The rates indicate that the estimated accident-rate model fit the data quite well. There were seven cells in which the observed and the expected accident rates differed by more than 15 percent. These were mostly cells with a relatively small number of accident involvements.

TABLE 3 Observed and Estimated Involvement Rates, per 10^8 Miles, for Combination Vehicles

Configuration	Trip Length	No. of Axles (tractor)	Model Year	Observed Van	Observed Flat	Observed Tanker	Estimated Van	Estimated Flat	Estimated Tanker
Single	OR	2	New	73.48	43.19	35.96	72.64	46.10	37.81
			Old	65.44	66.29	81.18	65.96	63.95	78.72
		3	New	96.79	111.46	103.75	96.93	111.21	103.41
			Old	105.64	171.28	98.48	105.44	171.66	98.68
	Local	2	New	200.10	107.02	46.62	199.74	98.52[a]	42.02[b]
			Old	164.50	48.21	118.69	165.02	50.67	92.85
		3	New	575.16	108.52	259.78	580.55	108.33	257.67
			Old	202.56	85.55	138.63	201.49	84.83	143.36
Double	OR	2	New	156.01	256.92	169.97	159.20	242.02[a]	122.22
			Old	116.90	–[c]	183.28	114.24	–[c]	203.73
		3	New	96.52	113.85	42.96	89.52	132.99[a]	68.29[b]
			Old	51.09	421.69	43.57	57.95	342.52	39.29[a]
	Local	2	New	184.66	–[c]	–[c]	192.74[a]	–[c]	–[c]
			Old	65.86	–[c]	76.73	69.71	–[c]	116.36[b]
		3	New	–[c]	–[c]	–[c]	–[c]	–[c]	–[c]
			Old	64.10	56.50	–[c]	63.13[a]	69.51[b]	–[c]

Note: OR = over-the-road service.

[a] Fewer than 15 accident involvements.
[b] Fewer than 5 accident involvements.
[c] Zero accidents and/or miles.

The truck types that showed extremely high accident involvement rates were:

1. Newer, 3-axle-tractor van singles in local service (580 involvements per 10^8 mi);
2. Older, 3-axle-tractor flatbed doubles in over-the-road service (342 involvements per 10^8 mi); and
3. Newer, 3-axle-tractor tanker singles in local service (258 involvements per 10^8 mi).

Those with high accident involvement rates (approximately 160 to 200 involvements per 10^8 mi) were:

1. All van singles in local service;
2. Newer, 2-axle-tractor van doubles in local service;
3. Newer, 2-axle-tractor van doubles in over-the-road service;
4. Older, 2-axle-tractor doubles in over-the-road service; and
5. Older, 3-axle-tractor flatbed singles in over-the-road service.

Overall Influence of Independent Variables

Trailer Body Style

Among all the doubles in over-the-road service, flatbeds showed a much higher accident rate than did tankers or vans. Among 3-axle-tractor singles in over-the-road service, flatbeds showed a higher rate than did vans or tankers. For 2-axle-tractor singles, the rates were similar for vans, flatbeds, and tankers. For singles in local service, vans were found to have much higher accident rates than did tankers or flatbeds.

Vehicle Configuration

The influence of vehicle configuration (single or double) in over-the-road service is as follows:

1. Two-axle-tractor van doubles (the majority of van doubles) showed approximately a 30 percent higher accident rate than 3-axle-tractor van singles (the majority of van singles).
2. Two-axle-tractor tanker doubles (the majority of tanker doubles) showed a higher accident rate (1.2 to 2) than did 3-axle-tractor tanker singles (the majority of tanker singles).
3. Flatbed doubles showed a higher accident rate than did flatbed singles.

Number of Axles of Power Unit

The overall influence of this variable was different for the single and the double populations. For doubles in over-the-road service, 3-axle tractors always showed much lower rates (in general, approximately 50 percent lower) than did 2-axle tractors. For singles, 3-axle tractors showed higher rates than did 2-axle tractors under similar conditions.

Model Year

The overall influence of model year (pre-1974 or old, and post-1974, or new) was found to be smaller than the other four independent variables. For singles engaged in local service, newer models showed higher accident rates than did older models. For singles in over-the-road service, the influence of model year was usually small. For doubles, the pattern was less clear.

Trip Length

The overall influence of this variable was prominent for van and tanker singles. Local service showed considerably higher accident rates than did over-the-road service (up to 5 times for van singles and up to 2.5 times for tanker singles). Its influence on flatbed singles was less pronounced. The influence of trip length on doubles was difficult to assess due to lack of data for doubles engaged in local service.

Straight-Truck Subset

Table 4 gives contingencies for the BMCS-reported accident involvements for the ICC straight trucks.

TABLE 4 Accident Involvements and Exposure for Straight Trucks

Trip Length	Model Year	No. of Accidents Involved		No. of Miles (10^6)	
		2 Axle	3 Axle	2 Axle	3 Axle
Over the road	Old	99	40	189.35	249.17
	New	128	33	259.48	193.84
Local	Old	694	44	413.36	98.43
	New	373	27	181.60	90.69

Note: Data exclude farm products.

The table is a cross-classification of three variables. They are as follows:

1. V1--number of axles (2-axle or 3-axle),
2. V2--model year (pre-1974 or post-1974), and
3. V3--trip length (over-the-road or local service).

Table 4 also gives a similar contingency table for the exposure (miles of travel) that was obtained from the HCAS file.

The accident-rate model for straight trucks was estimated using the procedure described in the section entitled "Causal Model." The best-fitted model was found to contain the following model configuration:

[13] and [23] (8)

The G^2 value for the accident involvements was 3.04 for 2 degrees of freedom, indicating a reasonable fit for the accident involvements. The observed and the estimated involvement rates are given in Table 5. The table indicates that 2-axle straight trucks in local service had high accident rates (approximately 180 to 200 involvements per 10^8 mi). On the other hand, 3-axle straight trucks were found to have low accident rates, particularly those in over-the-road service (approximately 17 involvements per 10^8 mi). Two-axle straight trucks in over-the-road service and 3-axle straight trucks in local service also showed low to moderate rates (approximately 40-50 involvements per 10^8 mi). The estimate of the overall mean involvement rate for straight trucks was 48.6 involvements per 10^8 mi.

TABLE 5 Observed and Estimated Involvement Rates for Straight Trucks per 10^8 Miles

Trip Length	Model Year	Observed		Estimated	
		2 Axle	3 Axle	2 Axle	3 Axle
Over the road	Old	52.3	16.1	47.7	15.6
	New	49.3	17.0	53.3	17.4
Local	Old	167.9	44.7	204.7	37.1
	New	205.4	29.8	181.1	37.8

Overall Influence of Independent Variables

Number of Axles

The influence of this variable was prominent. In over-the-road service, 2-axle trucks showed approximately 3 times as high an accident rate as did 3-axle trucks. In local service, 2-axle trucks showed accident rates up to 6.5 times that for 3-axle trucks.

Trip Length

The influence of this variable was also important. For 2-axle trucks, over-the-road service showed a 3-4 times lower accident rate than did local service. For 3-axle trucks, the rate for over-the-road service was approximately one-half of those for local service.

Model Year

The influence of model year was negligible in over-the-road service, and was only moderate for 2-axle straight trucks in local service. This small influence of model year was similar to the combination-vehicle subset.

Straight Trucks Versus Combination Vehicles

Table 6 gives a comparison of the accident involvement rates for straight trucks and for singles and doubles. The table indicates the following:

1. In over-the-road service, straight trucks had the lowest overall involvement records. Their rates were considerably lower than those for most singles or doubles.
2. In local service, 3-axle straight trucks showed the lowest accident rate (38 involvements per 10^8 mi) of all truck types. On the other hand, van singles showed the highest accident rates in local service among all truck types.
3. Two-axle straight trucks showed a much higher accident rate than did 3-axle straight trucks. In general, the accident rates for straight trucks in over-the-road service were much smaller than those in local service. The difference was especially pronounced for 2-axle straight trucks where local service showed up to four times higher rates than did over-the-road service. A similar effect of trip-length was also observed for van singles and tanker singles.

Deductive Analysis

Combination-Vehicle Subset

The independent variables that were not considered in the causal model, due to the lack of the exposure data, were investigated by means of a deductive technique. The following list describes such variables:

1. Road class (undivided rural, divided rural, urban roads);
2. Day-night;
3. Loading status (empty or loaded);
4. Road surface condition (dry or wet-snowy);

TABLE 6 Comparison of Involvement Rates Among Truck Types

Trip Length	Model Year	No. of Axles	Straight Truck	Singles			Doubles		
				Van	Flat	Tanker	Van	Flat	Tanker
OR	New	2	53	73	46	39	159	242[a]	122
		3	17	97	111	103	90	133[a]	68[b]
	Old	2	48	66	64	79	114	–[c]	204
		3	16	105	172	99	58	343	39[a]
Local	New	2	181	200	99[a]	42[b]	193[a]	–[c]	–[c]
		3	38	580	108	258	–[c]	–[c]	–[c]
	Old	2	205	165	51	93[a]	70	–[c]	166[b]
		3	37	201	85	143	63[a]	70[b]	–[c]

Note: OR = over-the-road; the number of accident involvements is per 10^8 mi.

[a] Fewer than 15 accident involvements.
[b] Fewer than 5 accident involvements.
[c] Zero accidents and/or miles.

5. Driver age (18-30, 31-45, or 45+); and
6. Driver experience (less than 1 year, 1 year, 2-4 years, or more than 4 years).

These six variables are typically those for which the exposure is difficult to measure or obtain. To date, there is not a national exposure data set that contains such detailed information. The deductive analysis introduced here, therefore, also serves another purpose in that it demonstrates whether there is a strong need to add these variables in future data collection efforts for truck exposure.

In the deductive analysis, the effects of the five independent variables that had been found to be significant in the causal model were assumed to still hold true. This assumption was essential in order to assess whether the variable(s) under investigation would still be significant after having accounted for those five significant variables. If this variable was not significant, then the lack of the exposure information would not be as crucial to the understanding of accident involvements.

The deductive analyses of the preceding six variables were carried out based on the procedure described in the section entitled "Deductive Modeling." Only the summary results for the following groups of variables are reported here:

1. Road Class, Day-Night, and Road Surface Condition--There was a significant interaction effect on accident rates involving road class, road surface condition, and day-night. This interaction was important to the extent that the effect of day-night would not have been evident without the presence of the other two variables in the same analysis. In general, it was found that urban roads showed high accident rates for all trucks, especially during the day when the density of general road traffic was the highest. Doubles, more so than singles, often showed higher accident rates on undivided rural roads than on divided rural roads. Wet-snowy pavements raised the accident rates of all trucks on all roads. The road surface condition was found to accentuate the effect of day-night such that wet-snowy roads at night often had a particularly serious effect on singles and especially on doubles. Nighttime tended to affect doubles more than singles on divided rural roads. Daytime accident rates on urban roads and undivided rural roads were often high.
2. Driver Age and Driving Experience--The effect of driver experience and driver age was such that driver experience was found to be important in all (three) age groups considered. Driver experience appeared more critical for doubles than for singles, especially for 2-axle-tractor flatbed and tanker doubles. Drivers of doubles with 1 year or less of experience showed considerably higher accident rates than did drivers with over 4 years of experience. The influence of age was that younger ($\leq$30) and older drivers (45+), in general, showed higher accident rates than did 31 to 45-year-old drivers. Young drivers of tanker doubles showed higher accident rates than other drivers of the same vehicles.
3. Loading Status of Vehicle--The effect of loading status was also found to be important. In over-the-road service, most tanker singles and doubles showed lower accident rates when empty than when loaded. This was also true for flatbed singles and doubles.

Straight-Truck Subset

Deductive analyses were carried out to assess the influence of loading status and the interaction among road class, road surface condition, and day-night on accident rates of straight trucks (8). The results of these deductive analyses were as follows:

1. Most straight trucks had higher accident rates when loaded than when empty. This finding was similar to those for combination vehicles.
2. Wet-snowy conditions raised the accident rates of straight trucks on all roads, particularly the rates for 3-axle straight trucks. Wet-snowy conditions combined with night driving especially raised the accident rates of all straight trucks on all roads.
3. The effect of road class was that urban roads showed higher accident rates than did undivided rural roads, which, in turn, often showed higher rates than did divided rural roads under almost all environmental conditions. On urban roads, the accident rates at night were lower than those for daytime.

SUMMARY OF FINDINGS

The causal modeling indicated that the factors influencing the accident rates of large trucks and combination vehicles included vehicle configuration, trailer body style, trip-length, number of axles of power unit, and to a lesser extent, model year.

In over-the-road service, flatbed doubles had the highest accident rate followed by 2-axle-tractor tanker doubles, 2-axle-tractor van doubles, and 3-axle-tractor flatbed singles. In the other extreme, those with low accident involvements per mile were 3-axle straight trucks. Those with moderate involvements per mile included 2-axle straight trucks in over-the-road service, 3-axle-tractor tanker doubles in over-the-road service, and most 2-axle-tractor singles.

The deductive modeling revealed that road class, road surface condition, day-night, loading status, driver experience, and driver age were all significant predictors of accident rates. Of these, the most important variables were road surface condition, road class, loading status, and driver experience.

Wet-snowy pavements raised the accident rates of all trucks on all roads. The wet-snowy condition at night was especially hazardous. Urban roads were found to have higher accident rates than did rural roads for all trucks. Doubles usually showed a higher accident rate on undivided rural roads than on divided rural roads. The effect of loading status appeared to be more important for tankers and flatbeds than for vans. Tankers and flatbeds (singles or doubles) as well as straight trucks showed higher accident rates when loaded than when empty. Doubles, in particular, were found to be adversely affected more by less-than-favorable driving conditions than singles. These were conditions such as wet-snowy, undivided roads or nighttime driving.

The effect of driver experience appeared to be more prominent than driver age. Experience was found to be important for all three age groups considered. Drivers with less than 1 year of driving experience showed higher accident rates than did drivers with 2-4 years or over 4 years of driving experience. Driver experience appeared more critical for doubles than for singles, especially for 2-axle-tractor tanker and flatbed doubles. The following paragraphs summarize the findings on accident involvements and usage for straight trucks, singles, and doubles.

Straight Trucks

Straight trucks are not used as much as combination vehicles in interstate commerce. Their total annual mileage was less than 15 percent of that for van singles. Unlike combination vehicles, which are predominantly engaged in over-the-road service, straight trucks operated about equally in over-the-road and in local service. Both 2-axle and 3-axle straight trucks are used in over-the-road and in local service.

Straight trucks showed the lowest overall accident involvement rate among all truck types considered. In over-the-road service, their estimated involvement rates were one-sixth to two-thirds of those for most singles and van doubles. However, in local service, the involvement rate for 2-axle straight trucks was as high as those for most singles in local service. Factors that raised the involvement rate of straight trucks include the set-snowy condition, urban environments, undivided rural roads, and being loaded.

Analysis of accident type (8) indicated that approximately one-third of the accident involvements of straight trucks on rural roads were single-truck accidents; it was about one-fifth on urban roads.

Van Singles

Van singles are used far more extensively than any other truck type in interstate commerce and in the over-the-road operation. Approximately 80 percent of their annual mileage in over-the-road service was made by 3-axle-tractor van singles. Their mileage in local service was only 10 percent of that for over-the-road service.

The accident rate for 3-axle-tractor van singles in over-the-road service was similar to that for 3-axle-tractor tanker singles (approximately 100 involvements per 10^8 mi). Their accident rate was, on the average, approximately 30 percent lower than that for 2-axle-tractor van doubles. In local service, van singles showed a high accident rate (over 200 involvements per 10^8 mi).

Factors that raised the involvement rate of van singles include the wet-snowy condition, the wet-snowy condition at night, urban environments, and lack of driving experience. Van singles showed a higher involvement rate on wet-snowy divided rural roads than on wet-snowy undivided rural roads. On dry pavements during the day, their rate on undivided rural roads was higher than that on divided rural roads.

Flatbed Singles

Flatbed singles are used primarily in over-the-road service. The proportion of their annual mileage that was in local service was only 5 percent. Their annual over-the-road mileage was 25 percent of that for van singles. Most flatbed singles were operated by 3-axle tractors.

The involvement rate for 3-axle flatbed singles was higher than those for van singles and tanker singles (up to 170 involvements per 10^8 mi). The elements that raised their accident rate were the wet-snowy condition, urban environments, loaded flatbeds, and lack of driving experience.

Tanker Singles

Tanker singles are used primarily in over-the-road service. The proportion of their total annual mileage that was in local service was less than 5 percent. Their annual mileage in over-the-road was approximately 20 percent of that for van singles. Over 90 percent of tanker singles were operated by 3-axle tractors.

The accident rate for tanker singles in over-the-road service was similar to that for van singles (approximately 100 involvements per 10^8 mi). Their rate in local service was higher (150 to 250 involvements per 10^8 mi). Factors that raised the involvement rate of tanker singles include the wet-snowy condition, urban environments, loaded tankers, and lack of driving experience. Undivided rural roads showed a higher rate than did divided rural roads.

Analysis of accident types (8) revealed that for all empty singles on dry-pavement rural roads and on ramps, 20 to 40 percent of their total accident involvements were single-truck accidents. This proportion was higher, approximately 50 to 65 percent, for wet-snowy pavements. For loaded singles, the proportion of the total accident involvements that was single-truck accidents was approximately 50 to 65 percent on undivided rural roads and on ramps, and 30 to 50 percent on divided rural roads. Given similar roads and environmental conditions, loaded singles showed higher probabilities of single-truck accidents than did empty singles.

Doubles

(a) Van Doubles--Van doubles are used primarily in over-the-road service, which accounted for 95 percent of their total annual mileage. Approximately 80 percent of van doubles are operated by 2-axle tractors. The accident rate of 2-axle-tractor van doubles was approximately 115 to 160 involvements per 10^8 mi. Factors that raised the accident rate of van doubles include the wet-snowy condition, urban environments, undividued rural roads (during the day), and lack of driving experience.

(b) Flatbed Doubles--There were relatively few flatbed doubles in operation; their annual mileage was only 2 percent of that for van doubles and approximately 40 percent of that for tanker doubles. Their involvement rate was found to be the highest among all truck types that engaged in over-the-road service (up to 340 involvements per 10^8 mi).

Factors that raised their involvement rate include the set-snowy condition, the wet-snowy condition at night, urban environments, undivided rural roads (during the day), loaded doubles, lack of driving experience, and young and old drivers (less than 30 and over 45 years old).

(c) Tanker Doubles--Tanker doubles were used almost exclusively in over-the-road service. Two-axle-tractor tanker doubles showed an accident rate as high as 200 involvements per 10^8 mi. Their accident rate was higher than that for van doubles but lower than that for flatbed doubles. Factors that raised the involvement rates of tanker doubles include the wet-snowy condition, the wet-snowy condition at night, urban environments, undivided roads at night, loaded doubles, lack of driving experience, and young driver (less than 30 years old).

Analysis of accident type (8) indicated that for all doubles engaged in over-the-road service, approximately 40 to 50 percent of their total accident involvements on dry pavements was single-truck accidents. This proportion was higher, 70 percent, on wet-snowy pavements.

CONCLUSIONS

The findings in this paper were based on a discrete-multivariate analysis. The model used to analyze accident involvement rates was capable of quantifying both the independent (or main) effects and the interaction effects among all significant independent variables. Such a model, therefore, yielded estimates that were stable because the effects due to confounding variables were minimized.

The analyses conducted in this research indicate that, having adjusted for trailer style, trip length, model year, and number of axles of power units, most doubles and singles showed higher accident involvement rates than straight trucks.

In local operation and in the urban environments, van and tanker singles, as well as 2-axle straight trucks, indicated problems. The safety of singles on undivided rural roads and of 2-axle-tractor doubles should be further researched to find out why their accident rates were high. Countermeasures to reduce accident rates of all loaded combination vehicles, especially loaded tankers and flatbeds, should be investigated. Schemes aimed at increasing driver experience in operating combination vehicles, particularly doubles, are encouraged.

There is a strong need to improve the quality of the truck exposure data file so that information on variables such as road class, driver factors, region of the country where accident occurs, truck weight, load status, and loading practices can be made available. The future truck exposure data base should aim at obtaining a higher level of recording or measuring accuracy than that shown by the original TIU data base. Coverage in reporting truck accidents also needs improving and further research so that undercoverage biases, if they exist, may be reasonably identified. These shortcomings in the data bases can influence the findings of truck safety studies. All of the preceding information is vital to a better understanding of the accident experience of large trucks and combination vehicles.

ACKNOWLEDGMENTS

The authors wish to acknowledge Lidia P. Kostyniuk for her research encouragement and James O'Day for his insightful comments on the data sets used.

REFERENCES

1. G.R. Vallette, H.W. McGee, J.H. Sanders, and D.J. Einger. The Effect of Truck Size and Weight on Accident Experience and Traffic Operation, Vol. III, Final Report. Biotechnology, Inc., 1982.
2. J.C. Glennon. Trial Record: In the Supreme Court of the United States, Appendix. Report 70-1320. On Appeal from the United States Court of Appeals for the Eighth Circuit, Oct. Term, 1979.
3. A Safety Comparison of Doubles Versus Tractor-Semitrailer Operation. Technical Report, Bureau of Motor Carriers Safety, FHWA, U.S. Department of Transportation, Nov. 1977.
4. C. Wagner. Simpson's Paradox in Real Life. The American Statisticians, Vol. 36, No. 1, Feb. 1982, pp. 46-49.
5. Estimation of 1977 Truck Populations. Transportation and Socio-Economic Studies Division, FHWA, U.S. Department of Transportation, May 1982.
6. Y.M.M. Bishop, S.E. Fienberg, and P.W. Holland. Discrete Multivariate Analysis: Theory and Practice. Massachusetts Institute of Technology Press, Cambridge, 1975.
7. E.T. Jolayemi. A C_p Method to Select a Log-Linear Model. Ph.D. dissertation. School of Public Health, University of Michigan, Ann Arbor, 1982.
8. T. Chira-Chavala. Study of Accident Experience of Large Trucks and Combination Vehicles. Ph.D. dissertation. Department of Civil Engineering, University of Michigan, Ann Arbor, 1984.

Publication of this paper sponsored by Committee on Motor Vehicle Technology.