Commercial Vehicle Accident Factors

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The results of a 12-month study of commercial vehicle accidents in California are reported. Statistics on approximately 3000 accidents were studied. The objectives were to establish and evaluate appropriate procedures for developing the data base and associated statistical analysis techniques. Other objectives included deriving inferences about accident causation and evaluating the potential of possible countermeasures. The characteristics of the sample and the format and procedures used in data collection and reduction are summarized, and selected results are presented.

This paper describes the results of a 12-month study of commercial vehicle accidents in California, with the objectives of establishing and evaluating appropriate data base development procedures and statistical analysis techniques and of deriving inferences about accident causation and the potential of possible countermeasures.

An earlier study for the National Highway Traffic Safety Administration (NHTSA) performed by the University of Southern California (USC) involved a more limited effort directed toward similar objectives. The present study has extended and deepened the earlier work in a number of ways.

The data base of the previous study consisted of some 925 California traffic collision reports (form 555) together with an additional form developed by USC, the commercial vehicle accident report supplement (CVARS), that was completed by officers of two divisions of the California Highway Patrol (CHP) during the period May 15 to August 15, 1975. Vehicle exposure data consisted of counts of certain relatively specific truck characteristics and of less detailed supplementary truck traffic volumes observed at several weighing stations by the California Department of Transportation (Caltrans) during this time period.

The present study uses similar data, now derived from some 2097 additional reports, for a total of 3022 reports for a time period of approximately one year (May 15, 1975, to May 1, 1976). Moreover, the present study includes an in-depth appraisal of the quality of these data and points out numerous important problems in their development. These begin with the field reports and extend through the verification, coding, and keypunching of those reports. Evaluating and overcoming these problems have been major tasks in the present study.

TRUCK ACCIDENT DATA FILE

Characteristics of the Study Areas

The commercial vehicle accident reports analyzed in both studies derive from the period May 15, 1975, to May 1, 1976, and from two geographically separated highway patrol areas of the state of California: zone 2, now the Valley Division, in the Sacramento area; and zone 5, now the Southern Division, in the Los Angeles area.

The southern study area covers a major portion of the county of Los Angeles and small, contiguous sections of Ventura and Kern Counties. The northern area includes a cluster of 14 counties around the Sacramento-Lake Tahoe region of the state. Within these study areas, the CHP provided accident reports on all truck-related traffic collisions that occurred on all Interstate, U.S., and state roads and certain adjacent county roads.

Accident Reports

The CHP standard traffic collision report form (form 555) and the CVARS ("green sheet") of USC were the instruments for accident data acquisition in both the previous and present studies. In support of the studies, the forms were completed by a CHP officer for each accident in the geographical study areas during the period of interest that involved a commercial vehicle of a gross weight of 4545 kg (10 000 lb) or more. The forms were verified for internal consistency by another CHP officer and then sent to the USC project staff for processing. Copies of the two forms can be found in the project technical report (1).

The CVARS provides for the analysis of 45 accident variables in addition to those analyzed in form 555. These variables are (a) a set of characteristics for vehicle and equipment type, (b) a number of load or cargo descriptors, (c) equipment status, (d) vehicle weights (as estimated by CHP officers), (e) braking performance, and (f) causal factors. A total of 3022 accident reports with completed CVAR supplements were obtained, coded, edited, keypunched, and filed for analysis.

Ensuring the consistency and quality of the data sets used for analysis has been of concern to the project staff. All reports and supplements were audited for obvious errors and omissions. When required, forms and supplements with gross errors were returned to the CHP for revision. Normally, follow-up telephone calls to the reporting officer were initiated by the CHP for immediate correction of omissions, errors, or illogical inclusions. A CHP officer also carried out an intensive final verification of the accident reports. Removal of all detectable recording errors from the accident reports prepared them for the data-processing procedures.

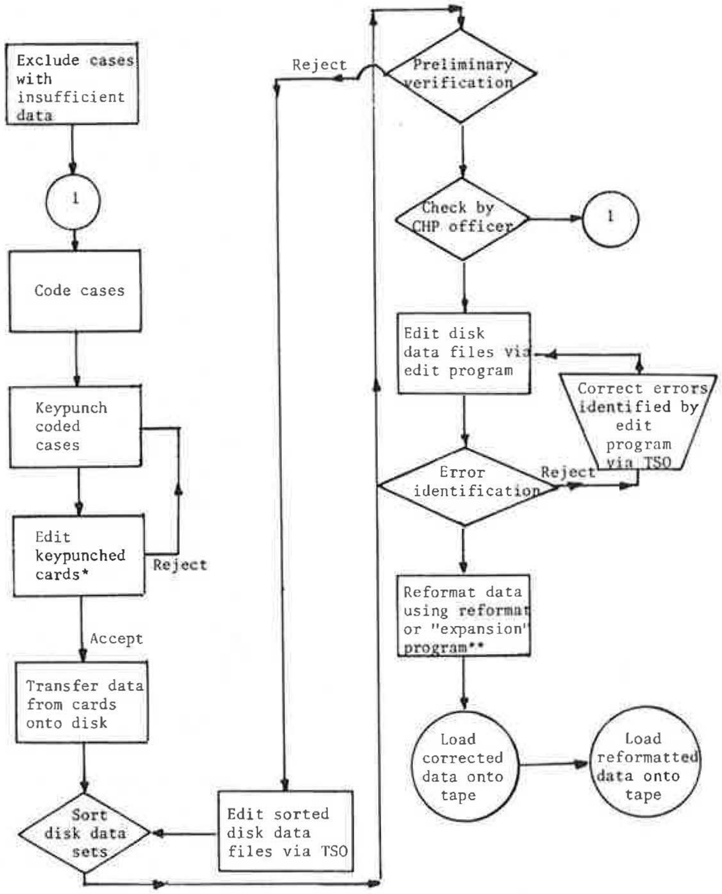
Data Processing

Figure 1 shows a flowchart of the overall process of establishing the computer file of accident reports. The two functions of principal interest are data editing and reformatting of the data files to facilitate the statistical analyses. These functions are described at length in the project technical report (1) and summarized in the summary report (2). Editing and data quality checks were run on the data to find and correct obvious effects of keypunch errors or bent, unsorted, or misplaced cards at various stages throughout the process.

ESTIMATION OF VEHICLE EXPOSURE

Two approaches are presented for the estimation of exposure for the various categories of commercial vehicles (defined by type, number of axles, and weight). The first approach is a direct process that makes use of existing assessment data on the vehicle population and em-

Figure 1. Data-processing flowchart.



*Keypunched cards are automatically verified by keypunch machine, i.e., cards are repunched and the two copies are compared when the machine is set to verification mode.

**Reformat or "expansion" program is a FORTRAN program which reformats the data so that all records have the same length as required by most standard statistical packages.

ploys many linear extrapolations to arrive at the final estimates. The second approach is that of "induced" estimation, which essentially makes use of accident data only. Here, vehicle exposure is defined as millions of vehicle kilometers traveled during the study period and in the two CHP zones of the study area.

Direct Estimates

Two sets of data established by Caltrans have been used in the direct-exposure estimation process: (a) annual average daily traffic (AADT) observations of commercial vehicle counts, categorized only by number of axles of the vehicle and obtained at many locations on state roads; and (b) truck weight study (TWS) observations of commercial vehicle counts and, for certain periods, weights. The TWS data, categorized by vehicle type and number of axles, and weight when available, are obtained at a number of weighing stations in the state.

A series of linear extrapolations have been performed to arrive at estimates of vehicle kilometers traveled for 46 categories of commercial vehicles. These vehicles are defined by type—single-unit bus or truck, tractor-semitrailer, truck plus full trailer, tractor-semitrailer-full trailer, number of axles ranging from two to seven or more—and by weight—4545-11 363, 11 364-27 272, and >27 272 kg (10 000-25 000, 25 001-60 000, and >60 000 lb). These extrapolations generally extend small, more specific samples (e.g., 8 h of observations involving all the above-mentioned vehicle characteristics) to larger samples of less specific observations (e.g., 24 h of observations of types and axle counts only) by disaggregating the larger sample into finer categories in the same proportions as these categories exist in the smaller sample.

The process is quite involved. In many instances, it may be assessed as reasonable but not rigorously justified. Furthermore, the basic AADT and TWS data are themselves not well justified in all important respects. Nevertheless, the procedure is believed to be the best possible for existing data, and its exposition provides a clear-cut framework for improvements developed from more comprehensive and higher-quality data.

The results are given in Table 1. The values appear to be fairly reasonable in relation to one another, but their absolute accuracy is questionable. The very small values, in particular, probably suffer from large percentage errors in view of the approximations that were used in their development.

Induced Estimates

The process of induced estimation is entirely different. It is based on a theoretical approach initiated by Thorpe (2) and extended by Haight (3). It assumes that the proportions of the various categories of vehicles to be found on the roads at any time are the same as the proportions of their involvements in accidents that are collisions (a) with a single noncommercial vehicle and (b) for which the commercial vehicle is not responsible. Thus, only data from accident reports are required for estimates of these proportions. Categorized estimates

Table 1. Direct estimates of vehicle exposure.

Truck Type	Number of Axles	Vehicle Kilometers of Travel (000 000s) by Vehicle Weight: 4545-11 363 kg	11 364-27 272 kg	>27 272 kg
Single unit	Bus	0	27.1	0
	Two	1287.7	26.6	0
	Three	182.4	653.2	0
	Four or more	0	0	0
Tractor-semitrailer	Three	88.7	144.3	0
	Four	11.3	80.9	0.5
	Five	151.6	250.8	231.6
	Six or more	0.5	0.6	0
Truck-full trailer	Three	24	0.8	0.3
	Four	15.6	23.7	0.16
	Five	10.8	31.3	85
	Six or more	0	1.6	2.7
Tractor-semitrailer-full trailer	Four	0	0.16	0
	Five	25.6	489	190.9
	Six	0	5.3	7.9
	Seven or more	0	0.16	0.3

Notes: 1 km = 0.62 mile; 1 kg = 2.2 lb.
Total vehicle kilometers of travel = 3918.

Table 2. Induced estimates of vehicle exposure.

Truck Type	Number of Axles	Vehicle Kilometers of Travel (000 000s) by Vehicle Weight: 4545-11 363 kg	11 364-27 272 kg	>27 272 kg
Single unit	Bus	0	27	0
	Two	660.5	67.7	11.3
	Three	186.3	96.7	11.3
	Four or more	0	0	0
Tractor-semitrailer	Three	96.7	84.8	0
	Four	90.3	107.4	17.1
	Five	186.3	553.2	400.9
	Six or more	0	5.8	0
Truck-full trailer	Three	11.3	0	0
	Four	22.6	17.1	5.8
	Five	79	73	146.7
	Six or more	0	5.8	5.8
Tractor-semitrailer-full trailer	Four	0	0	0
	Five	96.7	400.6	344.2
	Six	0	90.3	0
	Seven or more	0	17.1	0

Notes: 1 km = 0.62 mile; 1 kg = 2.2 lb.
Total vehicle kilometers of travel = 3918.

of vehicle kilometers of travel then derive from multiplying the derived proportions of the categories by some overall vehicle-kilometer estimate that has been obtained as the total of the direct-exposure estimate. More generally, it would derive from such sources as data on vehicle registration or gasoline consumption. Whatever its problems, the single overall estimate is clearly easier to establish than the many values for the various vehicle categories.

The procedure for developing induced-exposure estimates is relatively straightforward. It requires only a cross tabulation of accident involvement frequencies by vehicle category (type, number of axles, and weight) and counting only those accidents in which only one other vehicle, a noncommercial vehicle, is involved and the particular category of commercial vehicle is judged to be not responsible by the reporting CHP officer.

The results are given in Table 2. It is noted that they often differ considerably from, and are generally "smoother" than, the direct estimates in Table 1 even though total vehicle kilometers of travel over all categories is the same in both tables. It has not been possible so far to determine which set of estimates is to be preferred. From what has been said, it is clear that neither is entirely satisfactory, however, and their complementary natures give promise of future utility as mutual tests and, perhaps, as calibrators of one another.

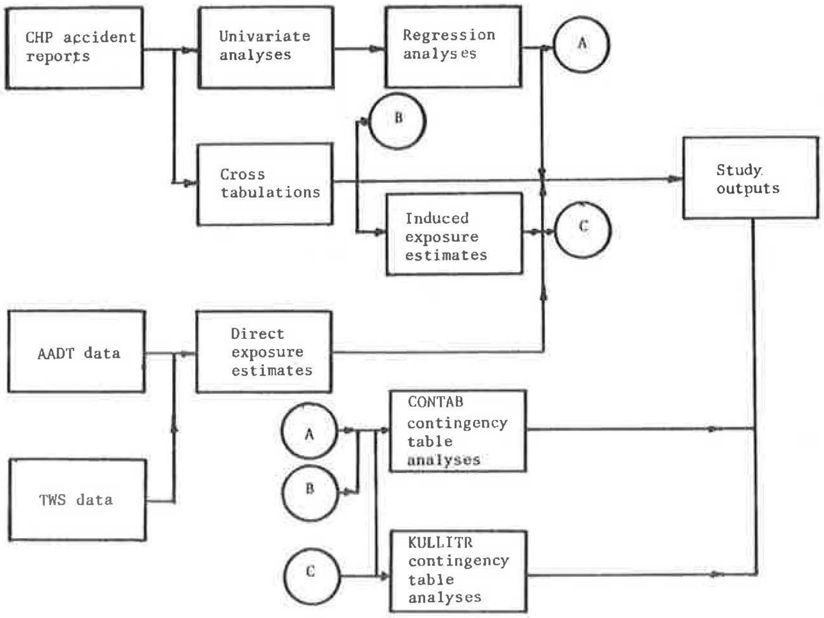
STATISTICAL ANALYSIS

Figure 2 shows the statistical analysis process that was used. The principal methodological and numerical results that have been obtained in the indicated steps of this process are summarized below.

Univariate Analyses

Univariate frequency tables, histograms, and associated statistics (mean, median, standard deviation) for the variables in the accident reports have been produced and are presented in detail in the project technical report (1). There are over 300 of these variables; they describe such factors as the circumstances of the accident (e.g., time and place of occurrence and physical features of the roadway), the vehicle characteristics (e.g., number of axles and location of brakes and controls), and the

Figure 2. Summary of statistical analysis process.



persons involved (e.g., age, status of driver's license, and severity of injury).

The results, which are discussed in the following section, describe the accident data base through simple summaries of the variables. Certain elementary indications about accident factors emerge easily from these descriptions. In addition, comparison of the values of certain summary ratios developed from the univariate results with the same ratios developed in a previous independent study (4) is a means of establishing some confidence in the validity of the present data base. The exhibited univariate frequencies also make possible a more efficient categorization of the levels of some variables (e.g., vehicle weight has been reduced to only three levels, in each of which there are approximately equal sample populations). Finally, the univariate results provide some initial indication of interesting dependent variables and of potentially significant independent variables by showing whether the variables have significant amounts of variation.

Selected Results of Univariate Analyses

Certain of the implications of the univariate analysis results are of immediate interest and worthy of note here. These implications are summarized briefly in four categories of results: accident factors, involved commercial vehicle factors, noncommercial vehicle factors, and human factors. Human factors are discussed with respect to occupants of commercial and noncommercial vehicles.

Accident Factors

Accident factors can be summarized as follows:

1. The frequencies of commercial vehicle accidents in the study area tend to peak seasonally in the late summer and early fall and daily in the early afternoon, apparently as a consequence of increased truck operations at these times. The latter result is somewhat surprising; previous studies—as well as intuition—would lead one to expect more accidents during rush hours, especially in a study area that includes the Los Angeles freeways.
2. The number of vehicles involved in an accident has a sharply maximum frequency at two: 68.4 percent of the accidents involved two vehicles; 20.3 percent were single-vehicle accidents.
3. In 2920 accidents, there were 66 fatalities. This rate (2.26 fatalities/100 accidents) compares closely with the findings of a 1969 Texas study (2.39 fatalities/100 accidents) (4).
4. In 2923 accidents, 967 injuries were reported. This rate (33.1 injuries/100 accidents) is comparable with the Texas study rate of 27.0 injuries/100 accidents.
5. Eighty-six percent of the accidents occurred on freeways or conventional two-way highways. Only small percentages occurred at intersections, ramps, etc.
6. The most frequently occurring collision factor (in 26 percent of all accidents) was "other speed", i.e., an unsafe speed other than one that exceeds the maximum allowable speed (the Texas study reports a value of 22 percent). "Unsafe lane change" was the second most prevalent factor at 16.5 percent. Vehicle equipment or cargo problems were noted as primary collision factors in 14.4 percent of the accidents (11.3 percent in the Texas study).
7. Weather and road conditions were normal in about 90 percent of the accidents. It is important to note, however, that the study period occurred during unusually dry conditions in California. Much more rain, and snow at higher altitudes, are normally expected. Thus, a bias undoubtedly exists in these data.
8. Among the principal accident events were sideswipe collisions and rear-end collisions, which occurred at frequencies of 32.6 and 28.4 percent, respectively.

Commercial Vehicle Factors

Commercial vehicle factors can be summarized as follows:

1. Approximately 3124 commercial vehicles were involved in the 2923 accidents analyzed; 77 of these vehicles were transporting hazardous materials.
2. Of the 3124 commercial vehicles, approximately 24.1 percent were two-axle trucks, buses, or tractors; 25.5 percent were three-axle tractor and two-axle semitrailer combinations (25.8 percent in the Texas study); 17.3 percent were two-axle tractor, one-axle semitrailer, two-axle full trailer combinations.
3. Speeds of commercial vehicles before accidents showed a peak frequency of occurrence at 80.6-88.7 km/h (50-55 mph), a mean of 54.6 km/h (33.9 mph), and a median of 63.8 km/h (39.6 mph).
4. In 53.4 percent of the 3124 reported involvements of commercial vehicles, the vehicle was proceeding straight before the accident. "Changing lanes" occurred in 9.6 percent of the cases, "slowing or stopping" in 6.7 percent.
5. Of the 3124 vehicles, 105 (3.4 percent) jackknifed before the collision and 121 (3.9 percent) after. Other such events occurred as follows:

	Percentage of Occurrence	
Event	Before Collision	After Collision
Separation of units	1.6	1.9
Cargo spill	2.5	8.0
Cargo shift	2.7	4.0

6. An automobile rear-ended and underrode a commercial vehicle 193 times (6.2 percent). A commercial vehicle struck with its front end and overrode an automobile 239 times (7.7 percent). This result is also roughly consistent with that of the Texas study, in which trucks struck automobiles about as often as automobiles struck trucks.
7. Of the 3124 commercial vehicles involved in the accidents, 1031 (33 percent) were on other than level roads when the accidents occurred. Of these, 15.8 percent were proceeding downhill and 12.6 percent uphill.
8. Although they were not necessarily primary causes of accidents, certain functional inadequacies were noted in some of the 3124 commercial vehicles:

Area of Inadequacy	Vehicles (%)
Braking in lane	27.0
Steering (only)	24.3
Braking and steering	15.8
No brake, loss of control	32.7
Wheel lockup	
Motor unit	9.0
Towed unit	6.2
Brake fade	0.7
Runaway on grade	1.0
Brake as cause of	
Skid	3.3
Leaving lane	3.3

9. Equipment violations were cited by the reporting officer in only about 200 cases (6 percent).

10. Total vehicle weight distribution was, briefly, 32 percent from 4545 to 9091 kg (10 000 to 20 000 lb) and 90.7 percent from 4545 to 34 091 kg (10 000 to 75 000 lb).

11. The driver was found to be at fault in 45.7 percent of the 3124 cases; vehicle equipment was at fault in 10.8 percent of the cases (11.3 percent in the Texas study).

12. Among causes of driver failure, the following distribution is established (expressed as percentages of total commercial vehicle drivers involved in reported accidents):

Cause of Failure	Drivers (%)
Fatigue	2.2
Excessive driving time	0.3
Drugs or alcohol	1.0

13. Vehicle dimensions were identified as significant factors in relatively small percentages of accidents (expressed here as percentages of total commercial vehicles involved):

Vehicle Dimension	Vehicles (%)
Height	0.8
Width	0.7
Length	3.1
Weight	0.6

14. Damage to the commercial vehicle was found by the reporting officer to be minor at most in 66.1 percent of the cases. The damage was considered to be total in 2.8 percent of the cases.

15. The univariate tables give frequencies of occurrence of numerous descriptive vehicle factors that need not be repeated here. One such factor, however, is worthy of note because of its present interest in studies of accident severity: Of 1031 trucks involved, 262 (25.4 percent) had "cab-over" configurations; 1139 (61.3 percent) of 1856 tractors had "cab-behind" configurations.

16. It is also of interest that 65.4 percent of the trucks, 64.3 percent of the semitrailers, 59.7 percent of the full trailers, 59.1 percent of the buses, and 65.1 percent of the school buses were carrying cargo or passengers when they were involved in accidents.

Noncommercial Vehicle Factors

Noncommercial vehicle factors can be summarized as follows:

1. Of noncommercial vehicles involved in accidents with commercial vehicles, 80.9 percent were automobiles and 10.1 percent were pickup and panel trucks [vehicles with a gross weight of less than 4545 kg (10 000 lb) were considered noncommercial for purposes of this study].
2. The mean speed of noncommercial vehicles before the accident was 65.8 km/h (40.8 mph); the median speed was 72 km/h (44.8 mph).
3. The noncommercial vehicle was proceeding straight in 44.2 percent of the cases, stopped in 14.6 percent of the cases, changing lanes in 9.2 percent of the cases, and slowing or stopping in 7.9 percent of the cases.
4. Damage to noncommercial vehicles was no more than minor in 33.5 percent of the cases and total in 7.9 percent.

Human Factors

Drivers and Passengers of Commercial Vehicles

Commercial vehicle driver and passenger factors can be summarized as follows:

1. In cases in which gender was reported, 96.1 percent of commercial drivers were male. The mean age of drivers was 36.5 years and the median 34.6 years. Mean years of driving experience was 9.2 and the median 5.9.
2. Alcohol, drugs, or physical impairment was reported in only a few cases.
3. No injury to the driver of a commercial vehicle occurred in 91.7 percent of the cases; fatal injuries occurred in 13 of 3014 cases (0.4 percent).
4. Of only 54 passengers of commercial vehicles who suffered injury in the total set of accidents, 5 had major injuries. There were no fatalities for this class of occupants.
5. In the judgment of the reporting officer, human operational shortcomings contributed to accidents with the following frequencies:

Type of Difficulty	Frequency (%)
Obscurement of vision	3.0
Inattention	34.7
Stop-and-go traffic	7.9
Entering and leaving ramp	3.6
Preceding collision	1.4
Unfamiliarity with road	1.8

Drivers and Passengers of Noncommercial Vehicles

Noncommercial vehicle driver and passenger factors can be summarized as follows:

1. Of the 2314 drivers involved, 70.8 percent were male. The mean age was 36.8 years and the median age 22.0 years.
2. Alcohol, drugs, or physical impairment was involved in about 7 percent of the cases; alcohol predominated.
3. The severity of injury to drivers of noncommercial vehicles was no worse than minor in 96.6 percent of the cases; there were 32 fatalities (1.4 percent).
4. The single most common violation of the California vehicle code was unsafe speed (26 percent).
5. As with the commercial vehicle drivers, human operational inadequacies, particularly inattention (32.3 percent), were found by the reporting officer to have contributed to a significant fraction of the accidents.
6. In the accidents reported, 222 passengers in noncommercial vehicles suffered injuries. Of these, 86.9 percent were at most minor and 10 (4.5 percent) were fatal.

Cross Tabulations

A selected set of cross tabulations has been developed to exhibit the joint frequencies of certain combinations of variables. The most striking implications of these cross tabulations are as follows:

1. The ratio of overturn to nonoverturn accidents in the reported commercial vehicle accidents on conventional two-way roads (0.096) and at intersections and ramps (0.103) is about twice as large as it is on freeways and expressways (0.048). Overturn accidents thus appear to be significantly less likely on the latter types of roadways.

2. No significant difference appears to exist between the ratios of the numbers of single-vehicle to multiple-vehicle accidents for the cases in which there are one or more commercial vehicle occupants. It has been conjectured that the likelihood of single-vehicle accidents could differ when there are several occupants, but the approximate equality of the two ratios tends to militate against this.

3. The relative likelihood, given that an accident occurs, of major injuries to occupants of cab-over commercial vehicles (0.018) appears to be significantly greater than for non-cab-over vehicle occupants (0.010). Interestingly, however, the chance of minor injuries may be slightly greater for the occupants of non-cab-over vehicles (0.087 versus 0.093).

4. As had been expected, accidents that involve an automobile underriding a commercial vehicle do tend to result in significantly more injuries to the occupants of the automobile than other kinds of accidents.

Cross tabulations have also been produced for inputs to the contingency table and induced-exposure analyses.

Study of Jackknifing Before Accident

A highly satisfactory model has been obtained for explaining or predicting the occurrence of vehicle jackknifing as the cause of accidents by incorporating all of the individual two-way interactions between jackknifing before accident (JKBA) and road surface (RS), lockup (LU), and number of drive axles (DA). But no higher-order interactions with jackknifing (e.g., JKBA, RS, and LU jointly) need be considered. Thus, in particular, sample information on such interactions need not be obtained. As the JKBA regression analysis shows, RS is the most important independent variable; the interaction between JKBA and RS explains the greatest variance of the three first-order interactions.

The model's predicted, or smoothed, values of the joint frequencies of all the possible combinations of the levels of the variables JKBA, RS, LU, and DA can be used to predict the odds of the occurrence of JKBA, compared with its nonoccurrence, for various possible conditions. The dominant results are that the odds of occurrence of JKBA are about 10 times greater on a wet road than on a dry one, whatever the condition of LU and DA:

Variable	Dry Surface	Wet Surface
Wheel lockup		
One drive axle	0.22	2.0
Two drive axles	0.06	0.56
No wheel lockup		
One drive axle	0.03	0.29
Two drive axles	0.009	0.08

A secondary note is that, as would be expected, the presence of two drive axles significantly decreases the odds of jackknifing. It is less to be expected, however, that the proportion of this decrease would remain the same for either road surface when lockup occurs: on a dry road, by a factor of 0.22/0.06 = 3.7 and, on a wet road, by a factor of 2.0/0.56 = 3.6. When lockup does not occur, the corresponding factors are 0.03/0.009 = 3.3, and 0.29/0.08 = 3.6, still about the same as before. The interesting conclusion, therefore, is that the presence of two drive axles reduces the odds of the occurrence of jackknifing before accident by about a factor of 3.5 under all conditions. The data provided can be used in further investigations along these lines.

It is finally worth noting generally that a complete analysis of odds enables the identification of the combinations of those levels of the independent variables that produce the lowest odds of a deleterious level of the dependent variable. To the extent that the levels of the independent variables are controllable, countermeasures to the occurrence of a deleterious level could then be defined by these combinations. For example, in the present case of JKBA, if two drive axles could be required for certain vehicles that would not otherwise employ them, the odds of the occurrence of JKBA would be decreased. Results of this character could often be expected to be found.

Contingency Table Analysis

Injury Severity

An earlier contingency table analysis by Hedlund of NHTSA used the CONTAB program. Hedlund's analysis was directed to the factors involved in the occurrence of a fatality and used a nationwide data base (5). An analogous study has been performed by using the present data base and the following closely related variables:

1. Dependent variable—occurrence or nonoccurrence of severe (more than minor) injury to an automobile occupant;
2. Independent variables—(a) road type (conventional two-way roadway or freeway or expressway), (b) truck type [semitrailer or full trailer (and thus generally a double-bottom)], and (c) weight 4545-11 363, 11 364-27 272, or >27 272 kg (10 000-25 000, 25 001-60 000, or >60 000 lb).

The analysis of interactions leads to primary results that are consistent with Hedlund's (if one takes into account the difference in the two studies imposed by the differences in the data bases). It is found that road type is by far the most important individual variable.

A highly satisfactory model includes the two second-order ("three-way") interactions among severity, road type, and weight and among severity, truck type, and weight (the third such interaction—among severity, road type, and truck type—is not required).

By using the predicted joint frequencies of the model, an analysis can now be conducted that compares the odds for the occurrence of high-severity injuries to an automobile occupant with those for the occurrence of only low-severity (at most) injuries. For example (1 kg = 2.2 lb),

	Odds Ratio (high-severity/low-severity injuries)	
Type of Vehicle	On Conventional Two-Way Roads	On Freeways and Expressways
Lightweight (< 11 363 kg) tractor-semitrailer	0.15	0.06
Heavyweight (> 27 272 kg) combination	0.20	0.14

Thus, the odds for the occurrence of a very severe injury to the occupant of an automobile involved in an accident with the two types of vehicles cited in the table are 2.5 times as great (with the lightly laden tractor-semitrailer) and 1.5 times as great (with the heavily laden full-trailer combination) on conventional roads as on freeways and expressways. Although they are not as significant as road type, extreme variations in combinations of vehicle type and weight can also be important factors in the severity of accidents.

Thus, road type is clearly the dominant factor in the odds on severe injuries—as Hedlund also notes (for fatalities only)—and conventional roads are more involved with such injuries than are freeways, evidently brakes accidents

to a significant extent. The dominance appears to be significantly more pronounced, however, for lighter vehicles (by a factor of 0.15/0.06 = 2.5) than for heavier vehicles (0.20/0.14 = 1.4).

Brake-Related Accidents

A highly significant class of commercial vehicle accidents is brake-related accidents. A contingency table analysis has been performed of the interaction between the dependent variable—the occurrence or nonoccurrence of a brake-related accident—and the independent variables—vehicle category (type, number of axles, and weight) and road direction (downhill or not downhill).

Road direction was established in the regression analysis as the most significant variable. Vehicle characteristics were considered to be particularly relevant to NHTSA evaluation of new brake systems and appropriate in the evaluation of the causes of high-cost brake-related accidents, which are considered later in this paper. The analysis therefore treated the variables as follows:

1. Dependent variable—occurrence or nonoccurrence of brake-related accident; and
2. Independent variables—(a) road direction (downhill or not downhill), (b) vehicle configuration (16 combinations of type and number of axles), and (c) vehicle weight (three levels).

Some representative odds analyses have been performed by using the predicted joint frequencies of the accepted model. It was found, for example, that the odds that a single-unit, two-axle truck will have a brake-related accident on a downhill road are twice as great as the corresponding odds on such an accident on a nondownhill road (0.16 versus 0.087). For a five-axle tractor-semitrailer the odds on the occurrence of a brake-related accident are 4.6 times as great on a downhill road as they are on a nondownhill road (0.14 versus 0.03).

High-Cost Brake-Related Accidents

The variables that appear to be significant in the explanation of the frequency of a given type of accident may change if the total economic cost of accidents is considered instead of only the frequency. Time has not permitted the development in this study of a satisfactory procedure for directly introducing costs. (The simplest procedure, that based on regressions, has not been carried out because of the poor fits of the regressions discussed above. A contingency table procedure is not immediately available.) Consequently, a surrogate procedure has been established and briefly tested. It assumes that high-cost accidents are largely those in which relatively severe injuries have occurred. Given this assumption, it is only necessary to first delete from the data base all accidents that are not in the severity range of interest and then conduct the analysis of interactions as before but only for the high-severity portion of the cases.

This surrogate procedure has been carried out in a CONTAB analysis of brake-related accidents in which vehicle category and road direction were the independent variables. The accidents considered were those in which the levels of severity were fatal, major injury, or minor visible injury. Low levels of severity—complaint of pain and no injury—were excluded. The analysis was done exactly as that described in the previous section.

The results on important interactions were the same: The model that incorporated only the three-way interaction of brake-related accident with direction with vehicle configuration was satisfactory (it explained 55 percent of the initial variation). Again, vehicle weight was not important.

The following results reflect the odds on a brake-related accident:

	Odds Ratio (occurrence/ nonoccurrence)	
Type of Vehicle	On Downhill Road	On Non-downhill Road
Light, single-unit, two-axle	0.14	0.08
Heavy, five-axle tractor-semitrailer	0.03	0.06

The odds ratios for accidents involving single-unit vehicles (0.14 and 0.08) do not appear to differ very significantly from those derived from the full data base for downhill and nondownhill roads, respectively (0.16 and 0.087). The implication is that, for this type of vehicle, the variables and interactions that are important in high-cost brake-related accidents are those that are important, and have essentially the same effects, in all brake-related accidents.

For the tractor-semitrailer vehicles, however, although the same significant variables and interactions apply to high-severity as to all brake-related accidents, their effects appear to be different in high-cost accidents than in all accidents. On a downhill road, the odds of a high-cost brake-related accident are only 20 percent (0.03 ÷ 0.14) of the corresponding odds for unrestricted brake-related accidents; on a nondownhill road, the odds of a high-cost accident are twice as great (0.06 ÷ 0.03) as they are for unrestricted brake-related accidents. It may be conjectured that these results indicate a relatively greater effort on downhill roads by the drivers of these larger vehicles to avoid conditions that can lead to more severe accidents. Then again, it may be merely the sparseness of the data that is causing the observed results. A deeper investigation must await a future study.

KULLITR Contingency Table Analyses

To treat the interaction of commercial vehicle exposure (in terms of millions of vehicle kilometers traveled) in the two CHP zones during the study period, the KULLITR contingency table analysis program was used. Two sets of estimates of vehicle kilometers of travel have been developed: direct and induced. The procedures and results of these estimates have already been discussed. The effects of their incorporation in the KULLITR interaction analyses are described here.

The dependent variable considered is occurrence of a commercial vehicle accident as a function of the independent variables of vehicle configuration (type and number of axles), weight, and exposure, exposure being in turn a function of vehicle configuration and weight. It is found that vehicle configuration and vehicle weight together are more important than exposure in the explanation of accident occurrence. However, exposure is also important, and its inclusion adds significantly to the explanation. This conclusion holds for both direct and induced estimates but is somewhat stronger for the latter.

The joint frequencies predicted by the model that resulted from the inclusion of both vehicle characteristics and vehicle exposure do not fit the observed data on accident frequency very well. Nevertheless, as the best frequencies available they have been used, together with the two sets of exposure estimates, to establish two corresponding sets of estimates of accident involvement rates for the vehicle categories considered.

Data given in Tables 3 and 4 illustrate accident involvement rates for the various truck categories (in accidents per million kilometers traveled) by using direct- and induced-exposure measures. Although the relative values of the rates for different vehicle categories appear to be reasonable in many cases, the absolute accuracy of their individual values cannot now be ascertained. Moreover, the direct and induced estimates generally differ greatly. Perhaps the highest-confidence results are the relatively high involvement rates that appear in both sets of estimates for tractor-semitrailer combinations. These rates range from about 0.9 to 6 involvements/1 000 000 km (1.5 to 9.7 involvements/ 1 000 000 miles) in the direct estimates and from about 0.66 to 6.9 with the indirect estimates. Single-unit vehicles, truck-full trailer combinations, and tractor-semitrailer-full trailer combinations tend to have relatively lower involvement rates. The values and the trends in them appear generally to be more consistent with the induced than with the direct estimates of exposure but, as discussed previously, this does not necessarily mean that the induced estimates are more "correct".

Table 3. Accident involvement rates for various truck categories determined by direct estimation of vehicle exposure.

		Accidents per Millions of Vehicle Kilometers by Vehicle Weight		
Truck Type	Number of Axles	4545-11 363 kg	11 364-27 272 kg	>27 272 kg
Single unit	Bus	ND	0.16	ND
	Two	0.27	1.98	ND
	Three	0.44	0.37	ND
	Four or more	ND	ND	ND
Tractor-semitrailer	Three	1.86	1.73	ND
	Four	5.14	1.05	172[a]
	Five	0.93	1.11	1.3
	Six or more	6	4.65	ND
Truck-full trailer	Three	ND	ND	ND
	Four	0.42	0.38	58.4
	Five	4.15	1.98	0.87
	Six or more	ND	1.55	0.99
Tractor-semitrailer-full trailer	Four	ND	ND	0
	Five	3.49	0.51	0.87
	Six	ND	4.46	3.35
	Seven or more	ND	28.3[a]	15.5[a]

Notes: 1 km = 0.62 mile; 1 kg = 2.2 lb.
ND = not determined, zero exposure estimate.

[a] Anomalous value caused by very small exposure estimate.

Table 4. Accident involvement rates for various truck categories determined by induced estimation of vehicle exposure.

		Accidents per Millions of Vehicle Kilometers by Vehicle Weight		
Truck Type	Number of Axles	4545-11 363 kg	11 364-27 272 kg	>27 272 kg
Single unit	Bus	ND	0.16[a]	ND
	Two	0.54	0.8	4.2
	Three	0.8	1.5	10.3
	Four or more	ND	ND	ND
Tractor-semitrailer	Three	1.9	2.85	ND
	Four	0.74	0.87	4.28
	Five	0.4	0.74	0.62
	Six or more	ND	0.68	ND
Truck-full trailer	Three	ND	ND	ND
	Four	0.3	0.5	1.6
	Five	0.54	0.74	0.56
	Six or more	ND	0.43	0.47
Tractor-semitrailer-full trailer	Four	ND	ND	ND
	Five	0.58	0.6	0.61
	Six	ND	0.32	ND
	Seven or more	ND	0.28	ND

Notes: 1 km = 0.62 mile; 1 kg = 2.2 lb.
ND = not determined, zero exposure estimate.

[a] Uses direct exposure estimate in place of undetermined indirect estimate.

CONCLUSIONS AND RECOMMENDATIONS

A capability for comprehensive statistical analysis of commercial vehicle accidents has been developed. Its strengths and weaknesses have been demonstrated for a range of cases of initial interest. Certain useful implications about accident causation have been established, and some (still very limited) means for enhancing the understanding of potential countermeasures have been presented.

The data base for this study—commercial vehicle accident reports—is capable of supporting an almost endless set of statistical analyses. A small, initial sampling of such analyses has been done. The required procedures and computer programs have been installed or developed and, although they are capable of further improvement, complete analysis methods have been demonstrated and certain initial implications for accident causation and mitigation have been derived.

Vehicle exposure has been found to be important in explaining accident occurrence although not as important as vehicle configuration and weight. Two independent procedures for estimating exposure provided the exposure values used in obtaining this result. More important, they have illuminated the general capabilities and shortcomings of the processes and the data involved. The results establish a foundation for the further development of techniques of estimating exposure.

Many areas for further study are now evident. The following areas are specifically recommended as the most important ones to be considered in future efforts:

1. The univariate tables should be reviewed jointly by the CHP and NHTSA, and relatively unimportant variables should be deleted. Other important variables that may have been neglected should be added to the redesigned forms.
2. Even with the present data base and retrieval procedures, it is possible to develop many more useful cross tabulations or joint frequency tables. Such tables provide immediately useful perceptions of interactions among variables, even without measures of statistical significance. More of these tables should be compiled for their inherent value and as guidance in more rigorous statistical analyses of interactions among variables of interest.
3. A powerful capability for contingency table analysis is now available for use. A larger data base is required to make its application possible at the necessary levels of detail in studies of accident factors that can be affected by meaningful countermeasures (e.g., specific vehicle equipment and driver characteristics). These further analyses should be conducted in conjunction with the building of a larger data base, which has already been recommended.
4. An improved procedure for direct estimation of vehicle exposure is vitally needed. It is believed that the procedure developed in this study makes the best possible use of the AADT and TWS data that were readily available. Other available special data should be incorporated as well as new data from new procedures of data development, some of which are already receiving attention elsewhere (e.g., special traffic sampling at selected locations). The present procedure has deliberately been built on a framework that can help to structure the integration of these new procedures and data

into the estimation process.

5. A process of contingency table analysis that incorporates vehicle exposure is desirable to allow more detailed investigation of the impact of exposure on important interactions among accident variables and thus on accident causation.

6. A process of contingency table analysis that incorporates the economic costs of accidents more directly than it was possible to do in this study should also be developed.

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Analysis of Bicycle Delays at Intersections and Crossings by Computer Simulation

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Computer simulation models were developed to analyze the delay to bicycles and motor vehicles at crossings and intersections where the two types of vehicles interact. The objective was to generate some understanding of the level of delay to each type of vehicle under various methods of traffic control and combinations of traffic conditions. Observational experiments on bicycle traffic behavior and interactions between bicycles and motor vehicles were carried out in the field, and the models were structured based on these data. The basic elements and assumptions of the simulation models are presented, and the behavior of bicyclists observed in traffic in the field is reported. Results of the simulation of traffic delays to bicycles and motor vehicles under various traffic conditions and controls are discussed in relation to traffic control strategies.

In areas where there is relatively heavy use of bicycles as a mode of transportation, it is often difficult to develop traffic control plans that will satisfy both bicyclists and motorists. The problem lies in trading off the time and safety of the bicyclist for the convenience, fuel economy, and time of the motorist.

In the city of Davis, California, a situation in which a bicycle path crossed a one-way street generated heated debate and was not resolved for a period of more than two years. In the end, motorists were controlled by a stop sign and bicyclists were not controlled. The use of bicycles has been promoted in Davis by provision of safe and convenient bicycle facilities because the bicycle is more energy and transportation efficient than the motor vehicle. On the other hand, it is undesirable to stop motor vehicles unnecessarily because they consume fuel and emit more pollutants when stopped. Guidelines and standards would be useful in similar future situations.

In 1974, a survey was mailed to 45 individuals whose work was connected with bicycle traffic. The objective of the questionnaire was to determine what considerations were given to bicycles in traffic control. Twenty-five responses were received. The respondents were unable to report any specific warrants in use that gave consideration to bicycle traffic. Two of the respondents commented that bicycles should be treated as pedestrians, and one alluded to the concept that a bicycle is a vehicle and should be treated as a motor vehicle when warrants for traffic control devices are established. Neither approach is satisfactory, however, because of differences in the traffic behavior of motor vehicles, bicycles, and pedestrians.

A more satisfactory basis needs to be established to resolve issues of traffic control at intersections and crossings where motor vehicles and bicycles interact. Although it is desirable to construct bicycle facilities