A COMPARISON OF ACCIDENT CHARACTERISTICS
AND RATES FOR COMBINATION VEHICLES
WITH ONE OR TWO TRAILERS

by

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Accident involvement rates for tractors with single trailers (singles) are compared with rates for tractors with more than one trailer (doubles) using data from the Bureau of Motor Carrier Safety (BMCS) accident file and the Truck Inventory and Use (TIU) Survey exposure file. Major differences in the distributions of vehicle, driver, operating, and environmental factors for the two types of vehicles are noted, and a multivariate analysis is presented for those factors which are common in the accident and exposure data sets.

Overall, the involvement rate for doubles and singles is found to be nearly the same, although there are substantial differences in the type of accidents for each vehicle type. The multivariate analysis indicates that meaningful comparisons of these two vehicle types must account for variation in trailer type (van, tanker, flatbed) and area of operation (local or intercity), since these factors interact strongly with the single/double designation. Other factors, such as the time of day of travel, driver age and experience, and road class are likely to be important determinants of accident rate, but exposure data are not currently available in the form required to conduct the same kinds of analyses for these. The need for further exposure information is discussed.
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SUMMARY AND CONCLUSIONS

A review of recent literature regarding accident involvement and stability of combination vehicles indicates:

(1) Most studies based on accident statistics show little difference in the overall accident rate of singles and doubles.

(2) Studies on specific physical characteristics of combination vehicles indicate that many factors influence the stability of the vehicles, including the number of axles, trailer type (e.g., tanker versus van), length of trailer(s), number of articulation points, tractor wheelbase, location of the fifth wheel, mix of tire types, load distribution among trailers, gross vehicle weight (and height of the center of gravity), and liquid versus solid cargo. These differences suggest that there would be different distributions of accident types associated with such variation, but that this variation might be present within singles and doubles as well as between them.

(3) There is evidence in the literature that accident rates vary significantly by road class and by time of day, and this suggests that these factors should be considered in comparing accident frequencies of various types of trucks.

(4) Studies of driver factors are more subjective, often being based on interviews. They suggest, however, that driver experience is an important factor—more experienced drivers exhibiting a greater capability for handling emergency situations. Conversely, it has been reported that inexperienced drivers tend to overreact to emergencies.

The data presented in this report indicate that singles and doubles as classes vary substantially across many of the vehicle, environment, and driver factors, which the literature suggests are important to accident causation. In particular:
(1) Vehicle Factors:
   a. Most doubles operate with a single powered axle on the tractor; singles operate most often with two powered axles.
   b. Among doubles, 80 percent of the tractors are cabovers, versus 51 percent among singles.
   c. Doubles have a larger proportion of van trailers than singles, and a smaller proportion of tanker and platform trailers.

(2) Operational Factors
   a. Doubles have a larger share of mixed cargo (general freight) and a much smaller share of heavy cargo.
   b. Doubles have a larger share of trip lengths over 200 miles.

(3) Environmental Factors
   a. Doubles have more accidents (and presumably more miles traveled) at night than do singles.
   b. Doubles have more accidents (and presumably more miles) on divided roadways than do singles.

(4) Driver Factors
   a. Doubles have a smaller proportion of accidents (and presumably miles) with drivers with low experience.
   b. Doubles have a smaller proportion of accidents (and presumably miles) with drivers younger than 30 years of age.

(5) There are also various degrees of interaction among and within vehicle, operational, environmental, and driver factors, for example, trip length and cargo type, trailer type and product carried, road type and time of day, etc. Interactions of higher degree are more difficult to describe, but may also be important, requiring appropriate statistical techniques to identify and account for their effects.

Analysis Results

Ideally the multivariate analysis to understand accident causation should include information across all of the elements discussed above, both in an exposure data set and in an accident data set. Further, such
information should have compatible bases--i.e., the exposure and the accident data should pertain to the same populations, and should have the same detailed definitions. This would require, for example, a knowledge of miles traveled by road class for the vehicles being compared, as well as the number of accidents by road class. Consideration of higher order interactions would necessitate the many factors discussed all being in this form at the same time.

For a variety of reasons, the present accident and exposure data sets will not support such an extensive analysis which will include all the factors considered relevant. While the TIU represents the truck population of the country well with respect to many vehicle characteristics, it does not contain information about drivers, nor any detail about the time of day or road class for vehicle operations. Several important factors, however, are common to the TIU and BMCS data sets, and the analyses presented in this report are based on those. The BMCS data are believed to be relatively complete with respect to ICC-authorized carriers, and the TIU exposure data can be subset to provide a comparable population.

The initial analyses presented here concern those factors which are common to the exposure and accident data sets, namely vehicle configuration (singles versus doubles), trip length (local versus intercity, a partial surrogate for road class), and trailer type (van, tanker, flatbed, etc.).

Based on the 1977 Bureau of Motor Carrier Safety accident data and the comparable subset of the TIU, the overall accident rates of singles and doubles are essentially the same. The computed rate for singles is 123.4 involvements per $10^8$ miles traveled, and for doubles, 122.8.

The log-linear model was used to analyze the involvement rates of combination vehicles. Included in the analysis were the three factors: vehicle configuration, trip length, and trailer type. The log-linear model essentially examines the effects on involvement rates of the individual variables as well as all possible interactions of various degrees among the factors. In the case where there are no interactions among the variables at all, one could conclude that the overall rates presented above are "true" for singles and doubles in all circumstances.
In the present case, limited to only three variables, the finding of no interaction would permit the more limited conclusion that singles and doubles exhibit the involvement rate independent of trip length and trailer type. On the other hand, in the case where the model indicates that interactions are significant, only involvement rates computed by adjusting for these interactions are true, or meaningful.

Considering these three factors, the results from the log-linear model indicate that all pairwise interactions are significant. This means that it will be inappropriate to consider involvement rates of combination vehicles without accounting for all three of these factors. We recognize that singles and doubles operations are different across many factors, and the model indicates that differences by trip length and trailer type are important. While doubles and singles in the aggregate have essentially the same involvement rate, it is unlikely that this would be true for all circumstances.

Involvement rates for the combinations of factors analyzed are presented in Section 5 of this report. Subsets of particular interest are reviewed in this summary. For intercity operation with van trailers, the involvement rates for singles and doubles are again essentially the same--74.9 involvements per 10^8 miles traveled for singles, and 73.0 for doubles. For local operation with van trailers, the involvement rate for singles is 168.0 involvements per 10^8 miles traveled, as compared with 99.2 for doubles. For intercity operation with tanker trailers, the involvement rate for singles is 78.1 as compared with 111.8 for doubles. For intercity operation with flatbed trailers, the involvement rate for singles is 106.8, and for doubles, 264.1. Confidence intervals based on the random error observed in the mileage data indicate that these differences are significant. However, the confidence intervals computed do not include the effects of possible bias due to under-coverage of the files or missing data.

The relative influence of each factor on involvement rates was also determined for this three-factor analysis. In this application, all three factors are significant, but their order of importance (in explaining accident rate) is, first, trip length, then trailer type, and finally configuration (or single/double). This emphasizes the
importance of considering trip length (or perhaps road class) and trailer type in any comparison of involvement rates of singles and doubles.

Since the majority of the doubles miles are accounted for by intercity van operation, this subset is of particular interest. The involvement rates for the two configurations in this group are essentially the same. Yet further examination of the data reveals that the distribution of accident types between singles and doubles is quite different--41 percent of the doubles involvements being classified as "non-collision" types (e.g., rollover, ran-off-road, jackknife), versus only 27 percent for the singles. Even within the non-collision class of accidents, doubles have a higher proportion of rollovers and a lower proportion of jackknifes than do singles. One is faced with the question, "How can doubles have the same overall accident rate, but a smaller proportion of two-vehicle crashes?" While exposure and accident data sets with sufficient detail to allow the same sort of analysis with other variables do not exist, some explanations may be suggested. We infer from the accident data that doubles travel more at night and more often on divided highways--both factors tending to reduce the probability of multi-vehicle collisions (or increase the probability of single vehicle collisions). Doubles are presumed to have an older (more experienced) driver population--in the BMCS data drivers of doubles are, on the average, about five years older than drivers of singles. And we are told that experienced drivers have a lower accident probability. It is also possible, and perhaps likely, that vehicle factors (instability of the second trailer, varying and/or uneven load distributions, within and among the trailers, and multiple articulation points) contribute to the different distribution of accident types. More detail in the exposure data set would permit a more complete examination of this.

The log-linear modeling technique was also used to examine accident severity (rather than accident rate). An accident can either be a fatal, an injury-producing, or a property-damage-only event. The analysis was based on the 1977 BMCS files, with the independent variables again being trip length, trailer type, and single/double. The relative importance of the independent variables was in the order of
single/double first, then trip length, and trailer type last. In general, doubles exhibited lower fatality/injury rates per accident. For intercity operation of vans, the doubles exhibited a slightly lower fatality/injury rate per accident. For intercity flatbed trailers, doubles and singles had essentially the same rates. For intercity tankers, doubles showed a 25 percent lower injury/fatality rate per accident than singles. For local van operations, doubles showed about a 20 percent lower injury/fatality rate.

The finding that double tankers are involved in accidents 50 percent more often than single tankers is thus tempered by the fact that crashes involving the doubles are much less severe. This, in turn, suggests that accidents involving double tankers may be occurring at lower energy.

Comment

These findings should be regarded as preliminary due to the complex nature of the problem, and the lack of data on some factors that seem important, such as road class and driver experience. We believe that the information provided in this report is an accurate description and interpretation of the analyses carried out and data used. However, any errors or omissions in the source data that were not accounted for in the analysis could, of course, influence the results.

Overall, doubles and singles involvement in accidents is similar in involvement rate, but different in the kinds of accidents which ensue. With regard to the involvement rate, there are other factors—notably trip length and trailer type—which interact with truck configuration and are more important explanatory variables than is the configuration. A general conclusion at this point in the study is that this is a very complex subject because trucks operate in so many different ways, with most of these use factors having some potential for affecting the probability of an accident.

The findings to date have strongly suggested two further efforts. The first of these is to look more completely into the accident data sets in an attempt to identify factors or groups of factors that are frequently present in the various accident types associated with singles
and doubles. For example, what factors are present which associate with rollovers of doubles, or what factors associate with singles having more multi-vehicle crashes? The results of these further studies should suggest specific issues which might be further investigated by laboratory or field investigations.

The second effort is to continue acquisition of exposure information which can be combined with the accident data sets in the manner presented in this report. In particular, better information is needed concerning road class, time (of day, week, or month), and driver factors. Some additional detail on vehicle factors, such as weights which correspond directly with weights reported for accidents, and trailer lengths would also be desirable. While a new exposure survey, with the trip as the sampled unit, might be considered the ideal method, these data will not be available in the immediate future. In the meantime, the induced exposure technique offers some promise, and can be further explored.

In summary, van doubles operated in intercity service exhibit an accident involvement rate essentially the same as that of their single counterparts, and a slightly lower proportion of injury/fatality per accident involvement. The distributions of accident type for these two vehicles are, however, quite different. How much these findings may be the result of driver or environmental (time and space) factors as opposed to vehicle factors cannot be precisely assessed with the necessary detailed exposure data being unavailable at the time of writing this report. Because it appears likely that such factors as driver experience, road class, and time of travel could be important, the immediate subsequent tasks should be to perform induced exposure analyses using the currently available accident data sets. Such analysis should shed some light on the influence of these factors on particular accident types of interest involving singles and doubles.
1.0 INTRODUCTION

The University of Michigan's Highway Safety Research Institute is engaged in a study of truck accident causation, using accident records and exposure (i.e. miles traveled) information for various subsets of the commercial vehicle population. One characteristic of considerable interest is the number of trailers pulled by a prime mover. Although there are a modest number of triples operating in the U.S., the configurations most available for comparison in accident records are "singles" and "doubles"—i.e. tractors with one and two trailers attached, respectively. This report is concerned, then, with comparisons of the accident experience of these two vehicle classes.

Combination vehicle annual mileage increased about 75 percent in the eight-year period from 1970 to 1977, as compared with only a 40 percent increase in passenger car travel. An estimate of the change in vehicle miles traveled by doubles (as compared with singles) may be inferred from the BMCS accident records. In the 1971 and 1972 doubles in the BMCS file accounted for 3.5 percent of the total combination vehicle accidents reported; in 1976, 1977, and 1978 this proportion was 5.1 percent, 4.9 percent, and 4.9 percent respectively. Data for the intervening years are unavailable. Although the BMCS reporting criteria changed somewhat between 1972 and 1976, the inference is drawn that the proportion of doubles has currently stabilized after a period of increase. Table 1 shows the actual data from the BMCS records.

The increasing use of doubles can be attributed to several factors, the most notable of which are:

1) doubles satisfy larger volume requirement,

2) doubles are more maneuverable than singles (better off-tracking characteristics for cornering), and

3) doubles offer operational flexibility because trailers which make up the train can be loaded separately and simultaneously at various points at the origin, then assembled into a train for haul between cities, then disassembled for simultaneous delivery of individual units.

The relationship between the configuration of combination vehicles and safety has been, to date, unclear, and a subject of some
TABLE 1
Singles and Doubles in BMCS Accident Files for Various Years

<table>
<thead>
<tr>
<th>Year of Accident</th>
<th>Number of Singles</th>
<th>Number of Doubles</th>
<th>Percent Doubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1971</td>
<td>46,176</td>
<td>1,676</td>
<td>3.50%</td>
</tr>
<tr>
<td>1972</td>
<td>52,671</td>
<td>1,903</td>
<td>3.48%</td>
</tr>
<tr>
<td>1976*</td>
<td>20,871</td>
<td>1,113</td>
<td>5.1%</td>
</tr>
<tr>
<td>1977*</td>
<td>24,351</td>
<td>1,245</td>
<td>4.9%</td>
</tr>
<tr>
<td>1978*</td>
<td>28,228</td>
<td>1,463</td>
<td>4.9%</td>
</tr>
</tbody>
</table>

* Criteria for reporting accidents in 1976-1978 included accidents with injury or $2000 damage compared with $500 damage for the earlier period.

controversy. Some past studies which have attempted to clarify the issue have been based on special populations--from a single company or state--and it is difficult to extrapolate the findings to a national figure. Other studies have focused on a single design parameter--for example, a study of instability resulting from specific mechanical coupling arrangements.

It is clear from inspection of both accident and exposure data that driver and environmental factors vary with combination vehicle style, or configuration. In reviewing data at the national level, it will be important (to a causation study) to consider the effects of the vehicle configuration, driver factors, and environmental factors--including interactions of these with each other.

Studies comparing the relative safety of doubles and singles are relatively few in number, and generally have the kinds of limitations (lack of national representativeness and lack of control for interacting factors) referred to above. Some particular studies will be reviewed in the following section in more detail, but it is not uncommon, and probably not unreasonable, for these studies to have reached different
and sometimes conflicting conclusions regarding the relative safety of doubles and singles.

Data available now from three relatively recent national files make possible a more complete treatment of this topic. These sources are (1) the Fatal Accident Reporting System, developed by NHTSA, (2) the Truck Inventory and Use Survey, developed by the Census Bureau under sponsorship of the Department of Transportation, and (3) the Bureau of Motor Carrier Safety Accident files, long maintained by BMCS but more comprehensive in coverage in recent years.

The Fatal Accident Reporting System (FARS) is a compilation of special reports filed by the individual states for fatal traffic accidents occurring in their jurisdiction. The consistency of these data has improved since the first full year of operation (1975), and in the work reported here only the later years' data will be used. Trucks are identified in various weight categories, and combination vehicles are categorized as those with one trailer versus those with more than one trailer.

The Truck Inventory and Use Survey (TIU) was conducted during calendar year 1977 by survey of registered truck owners in the United States. The survey instrument sought to determine such detail as maximum operating weight, number of trailers pulled, type of trip, annual mileage, make, model, etc. These data have been placed in a working file with weighting factors which make possible national frequency estimates of the various characteristics.

The Bureau of Motor Carrier Safety (BMCS) computerized accident files were modified in the early 1970's, and have been rather stable in content since that time. The level of detail is comparable to that of the TIU—including such information as cargo type, number of trailers, type of trailer, carrier type (private versus authorized), etc. While the TIU is most comparable with FARS (the latter being a census and the former a sample of the national truck population), it also serves as an exposure estimator for BMCS by subsetting both files to a more comparable (i.e., authorized carrier) group.
Following this introduction the recent literature pertinent to a discussion of singles and doubles in accidents is reviewed in Section 2. Section 3 presents information on the usage (exposure) factors relating to the operation of singles and doubles. Any differences in these factors for singles and doubles are also identified.

In Section 4, the accident statistics derived from BMCS and FARS are presented, including some discussion of interacting factors. In Section 5 accident and exposure are analyzed jointly with a view to obtaining accident involvement rates that take into account the important interactions.

One general conclusion of the present work is that the characteristics, operation and uses of singles and doubles are so different, both among themselves and between the types, that any simple comparison of overall involvement rates is likely to provide an inadequate understanding of their relative safety. Indeed, with few exceptions, observed differences in single and double involvement rates seem to be explained by a combination of factors other than the vehicle configuration.
2.0 LITERATURE REVIEW

This review of the literature is limited to reports concerning comparisons of doubles and singles, particularly with regard to their stability characteristics and accident rates. Such studies can be divided into five main categories:

1. Statistical analysis of accident data, accident exposure, and accident rates
2. Handling and stability of all combination vehicles
3. Drivers' experience and knowledge in operating combination vehicles.
4. Comparison of the stability and other handling characteristics of singles and doubles
5. Effects of roadways and environment on accident rates

The recent literature is reviewed below in these categories. An overall summary is presented at the end of this section.

2.1 Accident Statistical Analysis Studies

Scott and O'Day (1971)[1] reported that during 1966-1970 the records on the Indiana Toll Road indicated that tractor-double-trailer combinations were involved in 14 accidents for a rate of 84 involvements per 100 million vehicle miles, and that the involvement rate for single tractor-trailers during the same period was 171.8. Since the number of involvements was low for doubles, the question of confidence intervals for these rates was pertinent. The authors calculated the 95 percent confidence interval on the expected number of doubles accidents (assuming they followed the Poisson distribution) to be 7.7 to 23.5, yielding a range of 46 to 142 involvements per 100 million vehicle miles. Based on this calculation, the authors concluded that on the Indiana Toll Road, doubles had a significantly lower involvement rate than singles.

[1] Numbers in brackets identify references listed at the end of the report.
R. Zeiszler (1973) [2] reported on 31,883 fatal and injury accidents occurring in California during the latter half of 1972. The number of fatal and injury accidents per million miles of travel for doubles and singles was no different (the rate for each was about 0.5 fatal and injury accidents per million miles of travel), and that the rate for other types of trucks and all other motor vehicles during the same period was actually higher (0.7 per million vehicle miles). These rates for the singles and the doubles were based on the estimated miles of travel derived from the mileage proportion established by the California Division of Highways from counts at various traffic sampling stations throughout the state. About 1.5 percent of vehicles on California's state-maintained roadways were doubles and 2.8 percent singles. To support the findings which were based on these estimated mileages, accident rates were obtained from two major trucking firms—Pacific Intermountain Express Company (PIE) for the first eight months of 1972, and Consolidated Freightways. The accident rates (including all accidents) of the former were 2.5 and 3.4 accidents per million miles for doubles and singles, respectively. The accident rates of the latter fleet were 2.6 and 3.7 for doubles and singles. It was the author's belief that these firms were in a position to keep accurate mileage statistics. Regarding the severity of accidents involving doubles and singles, no significant differences were detected in the number of persons killed and injured per accident. In analyzing the causes of accidents, it was reported that doubles were less often involved in "improper" passing than singles, doubles showed slightly higher incidence of defective brakes, and doubles were more often identified with an "unsafe lane change" hazard. Maneuverability of doubles, as measured by "off-tracking" and "minimum cornering radii," was reported to be considerably better than singles.

The Bureau of Motor Carrier Safety, Federal Highway Administration, (1977) [3] summarized the accident rates of doubles and singles from 1969 to 1976 using the mileage data from seven major carriers who operated both doubles and singles. The accidents per million vehicle miles traveled for "intercity" operations of doubles were consistently lower than for singles, with the exception of the year 1975 where doubles exhibited slightly higher accident rates. The number of
fatalities per mile (or per accident) for doubles versus singles varied slightly above and below 1.0, making any general conclusion from this statistic difficult.


(1) There was no difference between the number of accidents per mile of travel for doubles and singles

(2) Doubles had fewer accidents per cargo ton-mile than did singles

(3) Double accidents had a higher incidence of fatalities per mile of travel than singles (0.535 and 0.376 fatalities per mile of travel for doubles and singles, respectively), i.e., doubles had a 40 percent higher rate.

These results were based on 1974 accident data provided by the California Highway Patrol and estimated mileages derived from on-road vehicle counts for singles and doubles in California.

G. R. Vallette et al. (1981) [5] conducted a study to determine the effect of truck size and weight on the accident experience of singles and doubles using the accident and exposure data collected from 78 sites in six states. These authors concluded that, based on the data in California and Nevada, doubles had a higher mean accident rate (per mile traveled) than singles and that their difference was especially significant for vehicles operating in the empty mode. The authors also reported that there were no differences in the characteristics of drivers of singles and doubles. Evidently the doubles referred to in this report were restricted to a tractor plus twin 27-foot trailers. Of the studies on accident rate reviewed here, this is the only one reporting a higher mean rate (per mile traveled) for doubles.

Vallette et al. (1981) [5] also reported that the following truck and trailer types showed higher (than the average truck or tractor trailer) accident rates:

(1) tankers for all truck or tractor types
(2) dump trailers
(3) doubles platform
(4) vehicle carriers
(5) pole/log carriers
J. Glennon, in an unpublished study, has compared the accident rate in a matched pair analysis of singles and doubles operated by Consolidated Freightways. This particular analysis method provides the same operating environment for each vehicle type. The principal finding of this work was that the two types had nearly equal accident involvement rates, but that the accident types were different. The doubles exhibited a higher rollover rate. The most common unit to rollover was the second trailer. However, the doubles also exhibited, on the average, slightly less severe crashes (as measured by the injury ratio).

All of the studies mentioned above, with the exception of Vallette et al. (1981) [5], reported similar findings in that doubles appeared to exhibit either an equal or lower number of accidents per mile traveled. With the exception of Glennon (1980), they all share the following problems:

1. The estimated overall accident rates were highly aggregated.

2. Differences in the usage of the two vehicle configurations that may influence their relative safety were not thoroughly examined.

3. The exposure estimation procedures used in these studies were different, and the estimates were difficult to verify.

4. The bulk of these studies were based on data from the State of California, where the operation of doubles is the most extensive. While the conclusions may apply to operations within that state, it is difficult to justify extrapolation of such findings to the nation as a whole.

2.2 Studies of Combination Vehicle Stability

The most recent studies in this area are two by the same author, R. D. Ervin et al. (1979, 1978) [6,7]. These reports contain extensive bibliographies and reviews of previous work, both outside and inside the U. S. In the more recent of these (1979) [7], Ervin reports that yaw (swaying) instability in tractor-semitrailers traversing curves can lead to partial jackknifing and rollover. The study examined the effect of design and operating variables such as frame stiffness, suspension stiffness, tire mix, fifth wheel placement, and variation in semitrailer
loading. It was concluded that certain combinations of design options and operating practices can severely lower the yaw instability threshold of a tractor-semitrailer. Factors associated with reduced yaw stability were:

1. A two-axle tractor (as opposed to a tractor with tandem rear axles)
2. A short wheelbase tractor (e.g., 105" - 120")
3. A low front suspension rating (e.g., 9,000 lbs.)
4. A high rear suspension rating (e.g., 23,000 lbs.)
5. A mix of tire types in which the front tires have a relatively higher cornering stiffness than the rear tires (e.g., radials in the front and bias-ply lug tread tires in the rear).
6. The fifth wheel located in an aft position (e.g., directly over the rear-axle center)
7. A high center of gravity of the trailer payload (e.g., height of 85" to 95" above the ground)
8. A semitrailer with low roll stiffness in its suspension system.

In the earlier study (1978) [6], Ervin listed hazards shared by all combination vehicles:

1. Free clearance which existed in the vertical travel of the suspension leaf springs
2. Tire blowout on the steering axle of the tractor
3. Jackknifing of the tractor, which is a large uncontrolled rotation of the tractor, usually concluding with the tractor's cab striking the semi-trailer.
4. Loss of control during heavy braking

This study also indicated that oscillation, or "sloshing," of liquids in partially filled tankers with no internal baffles (field surveys results showed that tankers transporting fuel in Michigan frequently operated with partial loads) during dynamic maneuvers lowers the rollover threshold significantly. This was particularly true when the tanks were between 25 percent and 75 percent full.

Studies of combination vehicle stability indicate that these vehicles, whether single or double, share certain handling
characteristics. For instance, both singles and doubles may experience dynamic instability of the tractor unit when traversing a steady curve at a high level of lateral acceleration, as well as instability during heavy braking. One common vehicle design feature that reduces roll stability is the free clearances which exists in the vertical travel of the suspension leaf springs. Other features that can reduce yaw stability were the number of tractor axles (a single axle versus a tandem axle), length of tractor wheelbase, the suspension ratings of tractor axles, front and rear axles, mix of tire types, fifth wheel placement, center of gravity of trailer payload, roll stiffness in the suspension system, and load distribution. These factors can influence the stability of any combination vehicle and may confound efforts to compare the two. Conversely, if some of these factors are more prevalent in singles or doubles, they can provide a basis to hypothesize that these vehicles may exhibit the particular types of instability described in the references discussed in this section.

Regarding the dynamic characteristics which are peculiar to doubles and other combinations having more than one payload-carrying element, the first major work on the subject was by F. Jindra [11] in 1964. Jindra identified the basic oscillatory character of the response of the rear-most trailing elements to transient steering inputs and suggested that the response of the last trailer could be taken as an index of performance for such vehicles. Subsequent researchers, Nordstrom [13], Hales [23], Hazemoto [15], and Ervin [12] all emphasized the response of the last trailer as the key dynamic feature distinguishing the safety qualities of doubles versus singles. In general, the concern with the exaggerated or amplified response from the rear-most trailer of the double involves the occurrence of either an overshoot in the path of this trailer, thus causing it to cover a wider swath during rapid lane change maneuvers, or a premature rollover of the last trailer at a level of maneuvering severity which would be insufficient to produce rollover in a comparably-loaded tractor semitrailer.
Studies Regarding Driver Experience With Combination Vehicles

E. C. Mikulcik (1973) reported on the types of stability problems experienced by combination vehicles. This information was obtained through interviews with the officials of the Department of Highways of each province in Canada, users of vehicle trains, equipment manufacturers, and related transport associations.

Lateral instability problems could be encountered under steady state operation as well as during the application of brakes. Instability under the steady state conditions took the form of weaving or swaying of the entire vehicle train, with the last unit frequently oscillating to a greater extent than the others. Instabilities during braking included the oscillation described above, jackknifing (which is characterized by tire skid at one or more axles), large angular displacements at one or more articulation points, and loss of control by the driver. Drivers generally agreed that instability under steady state was rare, or was only encountered during the learning phase of driving combination vehicles, and that experience would eliminate these situations or correct them when they occurred. Therefore, the occurrence of steady-state instability was likely to be the result of mechanical problems with the vehicle and/or driver's inexperience or fatigue. There was a general agreement that double-trailer combinations had a lesser tendency for jackknifing than did single.

Experience, training, and physical condition of a driver were important to the stable operation of a combination vehicle. The driving of doubles and triples required a greater degree of alertness and concentration than the driving of singles. Also, there were differences in driving techniques. Inexperienced or untrained drivers often encountered swaying problems with vehicles that were inherently stable. Excessive steering inputs by a driver were cited as being a common error.

Swaying under the steady state driving condition was more likely at higher speed. Swaying, particularly of the last trailer was more likely on downgrade than on upgrade. Acceleration usually eliminates swaying, while braking might increase the magnitude of the motion. Vehicle alignment should be such that no wheels of any trailer would tend to
pull the trailer away from the in-line tracking position. It was also generally agreed that factors such as load distribution among trailers and within trailers, tire maintenance, and correct tire pressure, truck tractor wheelbase, kingpin position, trailer overhang, lubrication of fifth wheel, slack in hitches, length and slope of tow bar, brake sequencing, and axle widths, affected the stable operation of the vehicles.

R. W. Eck and S. A. Lechok (1980) [9], in their study of truck drivers' perceptions of trucks' runaway problems, found that inexperience in mountain driving was the second most frequently cited reason, the first being equipment failure. It was also noted that only about 70 percent of the drivers stated that their brakes were inspected once a week or more frequently.

L. J. Wilson and T. W. Horner (1979) [10] reported on surveys of 3,608 International Brotherhood of Teamsters (IBT) drivers and 299 Professional Drivers Council (PROD) drivers. They reported that factors affecting driving comfort were tire type (radial, non-radial), fifth wheel type, rear-suspension type, trailer configuration (singles or doubles), trailer type, shock type, and seat adjustment. Doubles were found to be less comfortable to drive than singles. Flatbed trailers were reported to be more comfortable to drive than tankers, which, in turn, were more comfortable than van trailers.

Vallette et al. (1981) [5] reported that large truck accident rates generally decreased with increasing driver age from 30 to 50, and then increased. Truck drivers under 20, then 20-29, and then over 59 had the highest accident rates. In general, it was found that drivers with more experience had lower accident rates.

In summary, interviews of drivers of singles and doubles yielded a general consensus that drivers' experience could help eliminate or correct swaying or swerving of the vehicles when it occurred, particularly under steady state operation. Driver factors such as experience, training and physical conditions were cited by drivers as important factors to the safe operation of combination vehicles. The drivers interviewed reported that there were differences in driving technique of singles and doubles, and that one of the common errors in
trying to cope with swaying vehicles was excessive steering input. Equipment failure was reported as a major contributor to runaway accidents involving combination vehicles. Swaying was reported to be more likely at high speed and on downgrades.

2.4 Studies of Comparative Stability of Singles and Doubles

In 1980, R. D. Ervin [24] reported the results of a simulation effort in which a variety of singles and double combinations were analyzed to distinguish their stability and control characteristics. The vehicles covered a range of high-gross-weight configurations intended for hauling gasoline in the State of Michigan. The minimum gross weight was 85,000 lbs. and the maximum gross weight was 150,000 lbs. The double trailer types were all of the so-called "B-Train" configuration in which the conventional dolly coupling between the first and second trailer is eliminated. The second trailer is coupled as a semitrailer by means of a fifth wheel connection to a cantilevered structure extending from the rear of the front trailer. This vehicle combination is common in Canada for the transportation of bulk commodities and is receiving serious attention for usage in the U.S. Results showed the following:

(1) B-train doubles having 65 feet overall length exhibited low speed offtracking characteristics which were comparable to those seen with tractor semitrailers having an overall length of 59 feet.

(2) Because of their longer length, the examined doubles exhibited levels of static rollover threshold which were approximately 10 percent higher than those seen with tractor semitrailers having the same values of gross weight.

(3) In response to a range of steering input frequencies, the tractor semitrailers exhibited no amplification of lateral acceleration such as tends to overturn the unit in rapid lane changes. By contrast, the B-train doubles were seen to amplify lateral acceleration at the last trailer unit by 30 to 60 percent over the value experienced at the tractor during rapid steering reversals.
Because the rear trailer in a B-Train combination is coupled to the leading unit by means of a roll-rigid connection, the net dynamic roll stability of such configurations was seen to be as high as that of tractor semitrailers having the same value of gross vehicle weight.

In 1978 [12], Ervin reported the results of a study on the stability of the conventional 11-axle double bottom tankers used in Michigan. This combination is a tractor, a semitrailer, a dolly, and a second trailer (pup trailer). Tests showed that the pup trailer had low rollover threshold caused by the dominant yawing motions arising as an interaction of the dolly and the pup trailer. This interactive mode could easily be observed by motorists behind it. The double-bottom tanker had a tendency to produce exaggerated motions of the pup trailer during accident avoidance maneuvers leading to the premature rollover of the pup trailer while the tractor and semitrailer were still standing. Seven out of thirteen accidents of the double-bottom tankers were of this type. The authors pointed out that although the problem of tire blowout on the steering axle of the tractor was observed to be common for all articulated vehicles, when it happened to the Michigan double-bottom tankers, the loss of control of the vehicle led to the same yawing response causing the premature rollover the the pup trailer. The doubles which had multiple pivot points yielded greater instability hazards due to the likelihood that the dolly or pup trailer could pivot rapidly under certain conditions of brake imbalance. The authors also reported that doubles were considerably more maneuverable than singles.

Five combination vehicles were examined by Ervin (1978) [12] to obtain values for the physical parameters that contribute to vehicle stability. The parameters included weight, center of gravity, wheel base, track width, geometric measurements, mass and inertial parameters, suspension parameters, and tire parameters. Investigation of the rollover threshold values of the Michigan double-bottom tanker, 6-axle short single tanker, 5-axle van semitrailer, 11-axle single tanker, and 5-axle single tanker revealed that the double-bottom tanker had the lowest estimated rollover threshold followed by the other four in the above-mentioned order. These rollover threshold results are shown in
Figure 1a. The low rollover threshold of the Michigan double-bottom tanker was attributable to its high center of gravity and the amplification of the lateral acceleration of the second trailer during lane-change maneuvers. The introduction of a rigid dolly hitch and the reduction of spring clearances would, however, double its rollover threshold, making the modified double comparable to the 11-axle single tanker and the 5-axle van semitrailer. A full-scale field test confirmed the analytical results. It also showed that double-bottom tankers were substantially more maneuverable than single-tankers.

Ervin (1978) [12] also reported that the delivery of fuel using short Michigan single-tankers (6-axle short single tanker) probably yielded a higher exposure of the traffic system to fire hazard than modified double-bottom tankers or large single-tankers, since a larger number of vehicles (and vehicle miles) would be required to distribute a fixed amount of fuel.

O. Nordstrom and L. Strandberg (1974) [13] published results based on their simulations and field tests on combination vehicles' dynamic stability. The criterion chosen for evaluating the dynamic stability was a double-lane change maneuver. Typical accidents caused by the dynamic behavior of combination vehicles included skidding accidents (including jackknifing or accidents involving the trailer swinging with excessive side slip angles), overturning accidents due to low overturning stability often in combination with acceleration or side slip angle amplification toward the rear, and accidents caused by excessive space demand due to the width of the vehicle in combination with moderate side slip angles. The evaluation results indicated that the stability of double bottoms (tractor plus semitrailer plus full trailer) were speed dependent and inferior in dynamic behavior to either of the single designs (truck plus full trailer or tractor plus semitrailer). Furthermore, comparison of double-lane change performance between double bottoms and truck plus full trailers indicated that double bottoms showed the largest risk factor in the middle part of the lane change maneuver where lateral acceleration is maximum. It was reported that the possibility that the vehicle movements became uncontrollable to the drivers increased with the number of articulations.
and degrees of freedom (tractor plus semitrailer has one articulation, truck plus full trailer and tractor plus semitrailer plus full trailer have two and three articulations, respectively). At high speed, although the rear unit appeared most critical, it offered the poorest sensory feedback to the drivers. For both singles and doubles, dynamic
stability was found to depend on load distribution and vehicle weight. For example, the overturning risk for a 24 meter truck plus full trailer combination was the smallest when the trailer had full load on the front axle and empty load on the rear axle, and greatest when the trailer was fully loaded. For a 24 meter double, the best combination was a fully loaded semitrailer and partly loaded second trailer, although this loading may produce higher single-axle loads than other distributions. Furthermore, outside off-tracking\(^1\) (under steady-state conditions) of combination vehicles increased with increasing number of articulations.

The high-speed offtracking issue was also treated for tractor semitrailers by Bernard and Vanderploeg \cite{26} by means of a simulation of both the steady and transient articulation motion of the semitrailer. It was noted that a certain value of speed exists for any articulated vehicle at which the total offtracking is zero. At speeds lower than this value, the trailer(s) track inboard of the tractor trajectory, and at higher speeds the trailer(s) track outboard of the path of the tractor. The reported calculations show that combinations having shorter trailing elements (such as conventional doubles in comparison to full-length tractor semitrailers) arrive at this "zero offtracking" response at lower speeds, thus establishing the conditions for a net outboard offtracking at a speed level which is closer to normal highway speeds.

In Bernard and Vanderploeg's analysis of transient offtracking during rapid lane change maneuvers, they reported small levels of offtracking with tractor semitrailers. In the previously-cited work of

\(^1\)"Off-tracking" refers to the tendency of trailing units to follow a different path than the power unit. Outside off-tracking indicates a larger radius of curvature for the trailer path than for the tractor. In a subsequent paper, Strandberg et al. \cite{25} point out that the measures taken to reduce low-speed offtracking adversely influence high-speed offtracking. Whereas the use of more articulation pivots is beneficial to reducing the offtracking which occurs at low speed, just the opposite occurs at high speed where more articulation pivots result in increased outwards offtracking. Additionally, the high-speed offtracking of doubles is dependent not only upon the number of articulation points but also upon the fore/aft location of the center of mass of each trailer unit and upon the cornering stiffness characteristics of tires.
Ervin et al. [12], substantial levels of overshoot in the response of the rear trailer of the Michigan doubles combination was seen in a similar rapid lane change type of maneuver.

R. L. Eshleman et al. (1973) [14] reported the results of a study involving an analytical and experimental investigation of the stability and handling of articulated vehicles. The initial test was of a tractor plus a 45-foot van semitrailer; the second test was of a tractor plus a 27-foot van semitrailer; and the third was a tractor plus two 27-foot van semitrailers. The findings included the following:

1. Stability limits were highly dependent on road-tire friction coefficient
2. Stability limits were sensitive to braking with decreased allowable maneuver velocity
3. Stability limits for evasive and lane-change maneuvers were similar
4. Based on articulated vehicles with 27 foot trailers performing lane changing and evasive maneuvers on a dry surface, the single was found to have lower lateral accelerations than the double.
5. Handling of tractor double-semi trailer vehicles was tedious on wet surfaces. Experiments showed that the control of the vehicle was lost at the dolly during severe braking resulting in jackknifing. In violent maneuvers with empty trailers it was found that large unallowable trailer swing occurred.

T. Hazemoto (1973) [15] summed up the findings of the simulation results on the lateral stability of the doubles as follows:

1. Based on various loading combinations of the double, the following results were obtained:

<table>
<thead>
<tr>
<th>First Trailer</th>
<th>Second Trailer</th>
<th>Peak Gain Ratio (PGR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty</td>
<td>Loaded</td>
<td>4.04</td>
</tr>
<tr>
<td>Empty</td>
<td>Empty</td>
<td>1.68</td>
</tr>
<tr>
<td>Loaded</td>
<td>Loaded</td>
<td>2.17</td>
</tr>
<tr>
<td>Loaded</td>
<td>Empty</td>
<td>Unpeaked</td>
</tr>
</tbody>
</table>

(High PGR values represent instability)
(2) Wheelbases of the tractor should be as long as permissible

(3) Cornering powers of the tires on the tractor wheels and on dolly should be as large as permissible.

(4) Dolly length and the overhang of the first trailer pintle hook should be as small as possible.

(5) An increase in the offset of fifth wheel position of the tractor is desirable.

Hazemoto's study included consideration of doubles comprised of 20, 24, and 40 foot trailer lengths. His results showed that the combinations having longer individual trailers exhibited higher levels of stability. The double comprised of 40 foot trailers produced less than half of the peak gain levels of its rear trailer than did the double having 24 foot trailers. Also, results showed the strong destabilizing influence of increased speed for doubles of various lengths.

Nelson and Fitch (1968) [16] and Department of Highway and Transport of Alberta (1970) [17] carried out an experimental study of combination-vehicle stability. On braking, it was reported that on dry and wet pavements a tractor-semitrailer (a single) required greater stopping distances than did doubles and triples. On swaying or weaving of the second and third trailers, it was reported that swaying could be controlled, and that triple trailer combinations were completely safe from danger of jackknifing or swerving when stopping quickly. Furthermore, it was reported that trucking companies should be able to reduce swaying of triples to a negligible amount by matching the trailers with their intended use, intense and rigid maintenance of equipment, and having mature and experienced drivers with special training in operating triples.

The studies reviewed identified numerous factors that influence the stability of combination vehicles. The following paragraphs attempt to summarize those factors most relevant to analyses of the accident experience of combination vehicles, particularly with respect to the number of trailers. Most studies agreed that lateral stability decreased as the number of units in the combination increased. However,
this generalization must be qualified by consideration of the wheelbase and number of axles. Tandem axles and longer wheelbase generally provide better lateral stability.

Loading is an important in-use factor that interacts with configuration to influence vehicle stability. In general, stability decreases with increasing load. This is, in part, related to the increase in the height of the center of gravity of the vehicle. For double-trailer combinations, the most stable load distribution is with the first trailer full and the second trailer partially filled or empty. The least stable load distribution is with the first trailer empty and the second full. Increased loads generally increase stopping distances.

2.5 Studies of Roadway and Environmental Effects on Combination Vehicle Accidents

Herd et al. (1980) [18] reported that on rural roads the overall traffic accident rate at night was higher than that during the day. The ratio of the night to day accident rates was greatest for rural expressway (1.98) and smallest for four-lane roads (1.47). Accident rates at dusk were higher than those at dawn. The rate for fatal accidents was also higher at night, and there was a slightly higher incidence of injury accidents.

2.6 Literature Review Summary

Studies of combination vehicle stability by simulation and/or field tests and experiments indicated that singles and doubles did share common stability characteristics. These characteristics include yaw (swaying) instability caused by free clearances which exists in the vertical travel of the suspension; loss of control due to tire blowout on the steering axle of the tractor; a large uncontrolled rotation of the tractor during heavy braking; off-tracking; etc. The extent of these problems for singles and doubles were likely to be different and to depend on many vehicle design features, the component units of the combination, connection of these units, etc. Interaction of these features were also likely to be significant. All these resulted in the
differences not only between singles and doubles but also within singles and doubles themselves.

Sometimes there appeared to be disagreement among the various findings cited. We have not attempted to resolve these. This summary is intended to reflect those findings that were generally supported in the literature reviewed.

It was a consensus that dynamic stability of combination vehicles generally decreased with increasing number of articulation points. Doubles, with multiple pivot points, were more likely to rollover than singles during high-level maneuvers due to the pivoting dolly and pup trailer elements. However, doubles were less likely to jackknife than singles because of their greater maneuverability. Rigidifying the dolly hitch and reducing the clearances of the leaf springs were reported to substantially reduce the rollover propensity of doubles.

It was also reported that there were differences in driving techniques of singles and doubles. Doubles tended to be more difficult to handle on wet surfaces although, in general, doubles (and triples) required less stopping distance for a given load than did singles on all surfaces.

Other factors that were believed to affect the combination vehicle stability included type of axles of tractor/trailer (a single-axle or a tandem axle), trailer type, length of trailer, length of tractor wheelbase, mix of tire types, fifth wheel location, load distribution, gross vehicle weight, single-axle weight, center of gravity of trailer payload, liquid cargo (in partially filled tanks), and front/rear suspension ratings.

Many studies reported the influence of driver age, driver experience, road type, and time of day. Young drivers (under 30) and those over 60 exhibited higher accident rates than other age groups. Excessive steering input (by inexperienced drivers) and equipment defects were frequently cited accident factors. Night-time accident rates (for all traffic) on rural expressways were twice as high as those during day-time; on other rural four-lane roads, nighttime accident rates were about 1.5 times the daytime rate.
3.0 ACCIDENT EXPOSURE OF COMBINATION VEHICLES

Single tractor-trailers and double tractor-trailers do not always operate in the same environment; neither do they necessarily have identical exposure to accident involvement. The differences in the exposure of the two make the comparison of their safety much more complex than merely comparing the total number of accidents per mile of travel. The Truck Inventory and Use (TIU) Survey is used to derive basic exposure information on the vehicle mile accumulated by singles and doubles, and on the differences in the use of these two vehicle types. Some induced exposure estimates are derived from the BMCS accident files for factors not included in the TIU Survey.

3.1 The Truck Inventory and Use Survey (TIU)

The Truck Inventory and Use (TIU) Survey was conducted by the Bureau of the Census as part of the 1977 Census of Transportation. Trucks were randomly selected for this survey from each state's motor vehicle registration files as of July 1, 1977. Unlicensed and government-owned vehicles, as well as ambulances, motor homes, buses, farm tractors, and open utility vehicles were excluded from the sample.

Survey questionnaires were completed by 82 percent of the selected owners. Details of cargo types, gross vehicle weights, trip length, etc. were reported on an aggregate (or "usual") basis—e.g., respondents were asked if this truck operated "most of the time" in long-range service. While this method of reporting is not directly comparable with the accident data, it is the best available at this time. Variable levels in most cases correspond well with those reported to BMCS, and advantage is taken of this in the present report. However, errors or omissions in the TIU file that are not accounted for in the analysis could influence the results.

The weighted estimate of the number of combination vehicles operating in the U. S. in 1977 include 802,882 vehicles for which the number of trailers was specified. Of these, 771,878 were single; 30,805 were doubles; 199 were triples. While doubles are used in most parts of the U. S., they are most plentiful and visible in the west. In California 36 percent of the total combination vehicle mileage is
accumulated by doubles. Arizona follows with 19 percent, then Nevada with 18 percent, and Utah with 11 percent. In Hawaii, doubles account for 10 percent of the combination vehicle mileage. Most New England states have no doubles registered. For states east of the Mississippi, Michigan accounts for the largest proportion of doubles miles at 3.7 percent.

Figure 1 shows this distribution in graphical form for the continental U. S. The preponderance of doubles in the west is obvious from inspection of the map. The nationwide average for doubles miles is 5.1 percent of total combination vehicle miles.

In the Truck Inventory and Use Survey respondents were asked to categorize their normal operation into one of four "trip length" categories--local, less than 200 miles, over 200 miles, and off-road operation. Weighted by the estimated annual mileage, doubles account for more of their mileage in long range (over 200 mile) operation than do singles, and a somewhat smaller proportion of the off-road operation. These distributions are shown graphically in Figure 2. In all trip length categories an average double puts on more miles than an average single. For example, in the over 200 mile group, doubles averaged 105,200 miles annually compared with 85,370 miles for singles.

In the Truck Inventory and Use Survey the principal product carried by the truck is reported in some detail. We have combined many of these products to permit a simpler comparison between the doubles and singles. Farm products includes crops, fruit, and live animals. Light products include processed foods, textiles, household goods, furniture, and paper products. Heavy products include mining products, logs and other forest products, chemical and petroleum products, primary and fabricated metal products, machinery, transportation equipment, scrap, and garbage. Mixed cargo (general freight) is a category in itself in the TIU survey, and will be used unchanged in this report.

The distribution of reported cargo type (in these categories) weighted by the estimated annual mileage, is shown in Figure 3 for doubles and singles. Cargo types for singles are distributed broadly, with light cargo accounting for a little more than one-third of the total. Doubles, however, have nearly half of their loads classified as
FIGURE 2
TIU: Mileage Distribution by Trip Length

FIGURE 3
TIU: Mileage Distribution by Cargo
mixed cargo. The doubles role in heavy products is relatively small compared with singles.

In the TIU survey, respondents were asked to report the maximum operating weight for that vehicle during the preceding twelve-month period. This was defined as the vehicle empty weight plus heaviest cargo weight carried in that period. This is not necessarily the gross vehicle weight capability of the combination, nor is it the same as the usual or typical weight of the vehicle on the highway. The Bureau of Motor Carrier Safety accident file reports the actual total weight and cargo weight at the time of the accident. The TIU estimate is clearly neither of these. Nevertheless, the TIU-reported weight permits a qualitative comparison of how doubles and singles are loaded. Figure 4, which is weighted by the estimated annual mileage, indicates that doubles are about half as likely as singles to have a maximum weight under 50,000 lbs., and nearly twice as likely to be over 80,000 lbs. Not shown is the fact that the average annual mileage (per vehicle) for doubles is greater than for singles for all levels of gross vehicle weight.

![Figure 4](image-url)

**Figure 4**
TIU: Mileage Distribution by GVW
TIU respondents were requested to report the type of trailer most frequently pulled by the tractor, and these may grouped into categories similar to those used in BMCS reporting. Weighted by the estimate of miles traveled, doubles have a larger share of van trailers (than do singles), and a smaller share of everything else. These distributions are shown in Figure 5.

A major difference between singles and doubles is in the number of drive axles on the tractor. Weighted by the estimate of annual mileage, the majority of singles mileage (72 percent) is accumulated by tandem-axle tractors, whereas doubles accumulate 82 percent of their miles with single drive-axle tractors. The single drive axle is most often associated with twin 27-foot trailers, whereas the tandem drive axle is more likely to be found on the Rocky Mountain double (one long, one short trailer) or with the turnpike double (two long trailers). The drive axle count distributions are shown in Figure 6.

Hazardous materials were defined in the TIU survey as those which required a placard indicating their presence on the truck. Respondents
were asked whether their vehicle had been used at any time during the past twelve months to carry hazardous materials. Additionally, they were asked to report the percent of the time hazardous materials were handled. Figure 7, which is also weighted by annual mileage, implies that an individual double is more likely to carry hazardous materials at some time during a year. Not shown is the fact that many doubles (91 percent) report carrying such materials less than 25 percent of the time, so that a given double on the road is somewhat less likely to have hazardous cargo than is a single (6 percent versus 7.9 percent).

There are several categories of cab style reported in the TIU survey, but the most common is the cabover configuration. About 50 percent of the singles miles are attributed to the cabover as compared with more than 80 percent for doubles. Short and medium conventional cabs are fairly common among singles, but rare for doubles. These distributions are shown in Figure 8.

The above univariate analyses illustrate that differences exist between singles and doubles in many aspects of vehicle type, operation, and usage. The following list summarizes these factors. Factors are listed in order by the magnitude of the difference.

1. **State of Operation**: Operation of doubles is very much a western-states phenomenon.

2. **Number of Powered Axles of the Tractor**: Most doubles are associated with one-powered axle tractors while most singles are associated with two-powered axle tractors.

3. **Cab Style**: Cabover configuration accounts for over 80 percent of doubles operation and 51 percent of singles operation.

4. **Cargo Type**: Doubles have a larger share of mixed cargo but a much smaller share of heavy cargo than singles.

5. **Trailer Type**: Doubles have a larger proportion of vans but a smaller proportion of platforms and tankers.

6. **Trip Length**: Doubles have a larger proportion of over-200-mile trips.
FIGURE 6
TIU: Mileage Distribution by Powered Axles

FIGURE 7
TIU: Mileage Distribution by Hazardous Materials
Up to this point we have looked at differences between single and double usage across several individual variables, finding that there are many differences. Interactions among these variables are also likely to be important in understanding the variations in usage between singles and doubles, and ultimately in understanding differences in accident characteristics.

The presence of interactions among explanatory variables, if not accounted for in the accident rate computation, can lead to a misleading result. Our ultimate goal is to evaluate the relative safety between singles and doubles through their accident rates. However, such accident rates must be derived from compatible bases, and they should be free from the effects of any "lurking" variables. In this regard, it is
meaningful to compare accident rates between singles and doubles if the distributions of all explanatory variables are similar and the interactions among explanatory variables are properly accounted for. If these conditions were not met, the resulting difference in the computed accident rates might be caused by either the inherent characteristics of singles and doubles, or simply the difference in exposure, or both. Two of the most readily apparent interactions are described here.

For a trip length less than 200 miles one way, the proportions of annual mileage and the number of doubles carrying farm products are two and a half times higher than that of singles; singles' proportions are slightly higher with other products. For one-way trip lengths over 200 miles, the proportion of annual mileage and the number of doubles carrying mixed cargo are three times as high as that of singles; the proportions of singles carrying light and heavy products are, however, higher than those of doubles. These proportions clearly indicate the interaction of trip length with products carried for doubles and singles. Furthermore, doubles have higher average annual mileage per vehicle than singles do, especially for light products and mixed cargo. Singles, however, have higher average annual miles per vehicle for heavy products with trips over 200 miles one way.

Singles and doubles show some differences in trailer type and product carried also. For instance, singles with platform trailers are used for heavy products 71 percent and farm products 22 percent of the time, while doubles with platform trailers are used for farm products 65 percent and heavy products 33 percent of the time. Doubles do not pull beverage, utility, crane, wrecker, transport, or mixer trailers as do singles. Doubles carrying heavy products are made up of dump trailers 40 percent of the time, and platform and tanks another 46 percent of the time, while singles carrying heavy products are made up of platform and tanks 57 percent of the time and dump trailers only 12 percent of the time. Singles carrying farm products are made up of platform trailers 44 percent and cattle trailers 17 percent of the time, while doubles carrying farm products are platform 57 percent of the time and are cattle only 7 percent of the time, etc.
These two interactions immediately suggest that the usage of singles and doubles depends at least on cargo type and trip length. Furthermore, the use with different trailer types of singles and doubles (van trailers, flatbed trailers, tankers, etc.) is also influenced by the cargo carried. The implication here is that the differences in the use exist not only between singles and doubles, but also within singles and within doubles. Interactions involving more than two variables rapidly escalate the degree of complexity. In Section 5, a multivariate analysis technique is used to address such interactions.

3.2 The Exposure Inferences From 1977 BMCS Accident Data

All interstate motor carriers who are subject to the Department of Transportation Act are required to report to the Bureau of Motor Carrier Safety (BMCS) accidents involving their vehicles that result in death, injury, or over $2,000 in property damage. Excluded are occurrences that involve only boarding and alighting from a stationary motor vehicle, loading and unloading of cargo, and private carriers engaged in farm-to-market agricultural transportation. The accident information is reported to BMCS by the carriers themselves on a standard form. The BMCS dataset is, therefore, the near-census on interstate carrier (ICC authorized) trucks involved in the accidents that produced the above-mentioned results. It also contains some accident reports involving private carriers, but is much less complete on private carriers than on the ICC authorized vehicles.

The BMCS file contains a large number of variables related to the accident, vehicle, and driver characteristics, and the accident environment for both single tractor-trailers and double tractor-trailers. A number of these variables are examined in Section 4 with a view to identifying the differences in the characteristics of accidents involving singles or doubles. While observed differences may be the result of different accident propensities of the two vehicle types, very large variations may sometimes be interpreted as differences in exposure. For example, examination of accidents by road type indicates that about 60 percent of doubles accident involvements occurred on 4-or-
more-lane divided roads, while only about 49 percent of singles accidents occurred on the same roads, as shown in Table 2.

**TABLE 2**

Proportion of Involvements by Road Class for Singles and Doubles
(Based on BMCS Accident Data)

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Singles</th>
<th>Doubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-lane</td>
<td>49%</td>
<td>60%</td>
</tr>
<tr>
<td>Other</td>
<td>51%</td>
<td>40%</td>
</tr>
</tbody>
</table>

Of course, the percentages shown here do not represent exposure directly, since the accident rate on the two different road classes may be different. If we knew the accident rate for singles and doubles by road class, we would not need to derive this induced exposure measure. But we need the accident rate to determine the exposure—a sort of bootstrap operation. We may begin with an external estimate of the general accident rate for roads of different quality, and assume that the accident rate on the 4-lane roads is half that of the "other" road class and that the rate difference is not dependent on truck (single/double) configuration. With that assumption we may estimate the proportion of miles for each vehicle type by road class, and these are shown in Table 3.

An alternate roadway classification in the BMCS data is "divided" versus "undivided." In this case 32 percent of the doubles accidents occurred on undivided roads (compared with 43 percent of the singles accidents). If the probability of an accident on a divided roadway is one-third that of the undivided roadway (and if this ratio does not vary with the number of trailers), we may compute that the proportion of double miles on divided roadways is 86.4 percent, that for singles 79.9 percent.
TABLE 3
Estimated Proportion of Miles Traveled by Road Class
for Singles and Doubles
(Based on BMCS Accident Data)

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Singles</th>
<th>Doubles</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-lane</td>
<td>66%</td>
<td>75%</td>
</tr>
<tr>
<td>Other</td>
<td>34%</td>
<td>25%</td>
</tr>
</tbody>
</table>

These data, of course, derive from the BMCS files, and are no doubt somewhat biased toward long haul operations. They may not represent the total truck population of the country, but probably do represent authorized carriers in interstate operation.

Similarly 56 percent of the doubles accidents (reported in BMCS) occurred at night (between 8:00 p.m. and 8:00 a.m.), while only 40 percent of the singles accidents occurred during the same period. To interpret this as an exposure difference, we should know the relative likelihood of an accident in the daytime and nighttime. The assumption of a higher nighttime rate suggests that doubles have a large proportion of their mileage at night. Herd et al (1980) reported that the relative likelihood of an accident at night was 1.5 to 2 times greater than in the daytime, and thus the adjusted mileage proportions from the BMCS data are 48 percent at night for doubles, and 31 percent for singles (using the 1.5 increase in accident probability). We interpret this as meaning that doubles travel essentially an equal amount in each 12-hour period of the day, but singles travel nearly 70 percent of their miles in daylight.

While this induced exposure method has more uncertainty than a direct measurement, it is useful because the primary exposure set (TIU) does not contain information on either road class or time of day. The adjustment method discussed here will continue to leave some doubts, but is expected to be helpful in further interpretation of the accident data. It is likely too, that both time of day and road class interact.
with each other and with vehicle type. Such interactions may be important to accident rate computation, but the method discussed here seems to have been stretched too far already. In the rate computations in Section 5, the exposure estimates derived from the accident data sets will not be used directly, but may be considered in explanation of findings.
4.0 ACCIDENT STATISTICS

The statistics presented here are the distributions of accident-involved vehicles involving singles and doubles across a number of vehicle, roadway, environment, and driver characteristics as well as by combinations of these variables in those situations where such interactions appear significant. The accident statistics presented in Section 4.1, are based on the 1977 BMCS file, which contains a relatively-complete record of accidents involving ICC-authorized carriers that produced at least an injury or damages exceeding 2000 dollars plus a smaller proportion of accidents involving private carriers. The accident statistics presented in Section 4.2 are based on the 1977 FARS file which is a census of fatality-producing accidents for the entire country.

The examination of accident data is important to this analysis for two reasons. First it is of interest to know the characteristics of accident-involved single and double trailer combination vehicles and any differences in their accident experience. In addition, the available accident data have more detailed information on many of the factors which distinguish different types of use such as road class, time of day, driver age, cargo, etc. than is currently available in the exposure data. Examination of the accident data from this point of view provides indirect evidence of possible exposure differences.

4.1 1977 BMCS Accident Statistics

The BMCS accident files for 1977 report 23,462 single combination vehicles and 1210 multi-unit vehicles. Again a small proportion (less than 1 percent) of the latter may be triples, but their presence will be neglected in the analyses presented here.

The BMCS data include, of course, many non-fatal crashes, and thus have a larger number of cases than FARS for the same time period. However, because of reporting practices, their coverage is incomplete—particularly for private carriers, and to a lesser extent for authorized carriers. Because of this, national estimates are more representative when limited to the authorized carrier subset (common and contract), and the estimated accident rates presented in Section 5 of this report will
be for that group. Tabulations in this section are based on all combination vehicles in the file.

The major contribution of the BMCS data to this study comes from its rich detail about the carrier, the vehicle, the accident, and the driver. Whereas FARS identifies combination vehicles only by make and model (and single or multi-unit), BMCS data yield a description of the cargo, the cargo and gross weights, number of axles on each unit, trailer body type, vehicle length and width, etc. A shortcoming of this data set is that it underreports agricultural carriers--some of whom are exempt from reporting. About 8 percent of the combination vehicles (and a smaller proportion of miles traveled) reported in the TIU are listed as carrying agricultural products, and many of these would not have their accidents reported to BMCS. Any other errors or omissions in the BMCS file not accounted for in the analysis could, of course, influence the results.

The percentage of all combination vehicles involved in accidents that are double tractor-trailers varies considerably from state to state (Figure 9). The three states with highest proportion of doubles involvements to total tractor-trailer involvements are California (28 percent), Nevada (26 percent), and Arizona (24 percent). In Michigan the percentage of doubles involvements is 6 percent.

Figure 1 displayed the proportion of combination vehicle mileage accounted for by doubles for the various states. Although this was based on the total mileage (anywhere) for trucks registered in the indicated state, it is a first approximation to the mileage distribution. Figure 9 displays the proportion of combination vehicle involvements that are doubles by the state in which the accident occurred. Although the two plots are not directly comparable (for computing accident rates for individual states), it is clear that both accidents and mileage for doubles are western phenomena.

The TIU data permitted trip length to be defined in four categories, namely local, less than 200 miles, over 200 miles, and off-road. In the BMCS report, only two levels are provided for trip length--local and intercity. Doubles account for only 7.2 percent of
FIGURE 9
BMCS-77: Percent of BMCS Accidents Involving Doubles
the BMCS-reported accidents in the local category, compared with 14.3 percent for the singles. These distributions are shown in Figure 10.

Road class is categorized in the BMCS reports in two ways. The first defines the number of lanes, ranging from one to more than four. The second reports whether the roadway was divided or undivided. Neither of these are directly consistent with the usual accident report coding by FHWA highway class. Overall doubles exhibit a somewhat higher proportion of their involvements on divided roads, as shown in Figure 11.

Among BMCS-reported accidents, doubles have a higher proportion of their accident involvements at night than do singles. This is true for both intercity and local operation, as shown in Figures 12 and 13. For intercity trips more than half of the doubles involvements occur at night.

The major types of trailers making up singles and doubles are categorized as vans, flatbeds, and tankers. A number of other types have been grouped in this report as "other." More than half (54.2 percent) of the doubles in accidents were pulling van trailers, compared with 42.9 percent of the singles. These distributions are shown in Figure 14.

Weight of cargo is reported for BMCS accidents. These distributions are shown in Figure 15 for doubles and singles. Overall, doubles are less often empty (15.5 percent versus 22.6 percent for singles); also doubles are more than three times as likely to have a load over 50,000 lbs.

The distributions of total vehicle length are found to be different for singles and doubles, as would be expected. About 82 percent of the singles involved in accidents are made up of 50-55 foot vehicles, while 84 percent of the doubles involved in accidents are made up of 56-69 foot vehicles. The proportion of accident-involved singles greater than 70 feet in length is negligibly small but the proportion of accident-involved doubles 70 feet or longer is 6 percent.

Singles and doubles are found to be different in the type of accidents in which they are involved. BMCS defines non-collision
FIGURE 10
BMCS-77: Percent of Accidents by Trip Length

FIGURE 11
BMCS-77: Percent of Accidents by Road Type in U.S.
FIGURE 12
BMCS-77: Intercity Trips in the U.S.,
Percent of Accidents by Time of Day

FIGURE 13
BMCS-77: Local Trips in the U.S.
Percent of Accidents by Time of Day
FIGURE 14
BMCS-77: Percent of Accidents in Trailer Type in U.S.

FIGURE 15
BMCS-77: Percent of Accidents by Cargo Weight
accidents to include ran-off-road, jackknife, rollover, separation of units, loss or shift of cargo, and pre-crash fire. These accident events are distinct from accidents in which a fixed (or parked) object is struck. Non-collision accidents are much more common with doubles than singles; overall they account for 40 percent of the doubles involvements and only 27 percent of singles involvements. Singles are more often involved with another moving vehicle than are doubles. This accident type distribution also varies with road class, and this will be discussed later in this section.

There are major differences in the driver population of singles and doubles. For example, the proportion of singles with drivers 30 years of age or younger in BMCS-reported accidents is 28.9 percent as compared with only 15.2 percent for doubles (both restricted to intercity operations). Another driver dimension of interest is experience, defined in the BMCS reports as the number of years that the driver has been employed by the same company. About 65 percent of drivers of accident-involved doubles have more than one year of experience whereas only 48 percent of the drivers of singles are in this category. The distributions are shown in Figure 16.

The univariate analyses of individual variables in the BMCS file described above indicates the differences in accident characteristics of singles and doubles. The factors reviewed are summarized below, with factors showing the greater differences listed first.

(1) **State in Which Accidents Occurred:** Accidents involving doubles are very much a western-states phenomenon.

(2) **Type of Accident:** Doubles appear to have a considerably higher proportion of non-collision accidents than do singles for all road classes.

(3) **Time of Day:** The proportion of nighttime accident-involvements is higher for doubles.

(4) **Cargo Weight:** The proportion of involvements with empty trailers is smaller for doubles, but that with cargo weights over 50,000 lbs. is three times larger for doubles.
(5) **Road Class**: The proportion of involvements on divided roads for doubles is higher.

(6) **Trailer Type**: The proportion of involvements with van trailers is higher for doubles. The proportion involving all other types of trailers is smaller for doubles.

(7) **Trip Length**: Doubles have a larger proportion of involvements on intercity trips than singles.

(8) **Driver Experience**: Doubles have a smaller proportion of involvements with drivers having one year or less of experience. However, doubles have twice as large a proportion of involvements with drivers having over eight years of experience.

The above-mentioned individual variables also interact with one another to produce differences for particular combinations of factors that are greater than a simple summation of the individual effects of each factor. While two-factor interactions can be identified without the aid of sophisticated statistical analyses, interactions involving
more than two factors are much more difficult to detect. Even with two-factor interactions, precise interpretation of all two-factor interactions (in cases where several variables are present in the data set) requires a multivariate analysis technique. In this section, only two-factor interactions that are easily detectable are described. A more complete analysis involving interactions is presented in Section 5.

Bigger and better roadways tend to increase the proportion of non-collision and hitting-fixed-object accidents involving doubles while the proportion of these collisions for singles varies little by road class. Figures 17-19 illustrate distributions of collision type by roadway type. On such roadways accidents involving doubles are more common after midnight and at dawn. On the other hand, accidents involving singles, regardless of roadways and accident types, tend to occur during the day.

Cargo weight is another interesting factor which tends to interact with other factors. For example, for both singles and doubles, the proportion of non-collision accidents appears to increase with increasing cargo weight, while the proportion of hitting-fixed-objects appears to decline with increasing cargo weight.

Empty doubles and empty singles exhibit some differences with regard to time of the accident. There appear to be more accidents involving empty or lightly-loaded doubles at dawn than at any other time. Empty singles exhibit a larger accident proportion in the afternoon than any other time. Loaded doubles (mostly with mixed cargo) appear to have more accidents after midnight and at dawn, while loaded singles (mostly with light, heavy, and mixed cargo) appear to have more accidents during the day, as is the case for doubles irrespective of load.

Doubles involved in accidents, whether they are pulling van, flatbed, or tanker trailers, are, on the average, about 10 feet longer in their "overall vehicle length" than their single counterparts. Within both subsets, singles and doubles, van, flatbed, and tanker trailers show similar distributions of accident type (non-collision, hitting another vehicle, hitting fixed objects). However, non-collision accidents represents only 25–30 percent of total accidents involving

54
FIGURE 17
BMCS-77: 2-3 Lanes Undivided Roads in the U.S.
Percent of Accidents by Accident Type

FIGURE 18
BMCS-77: 4 or More Lanes Undivided Roads in the U.S.,
Percent of Accidents by Accident Type

FIGURE 19
BMCS-77: 4 or More Lanes, Divided Roads in the U.S.
Percent of Accidents by Accident Type
singles, compared with 30-35 percent for doubles. Collision with another vehicle represents 60 percent of total involvement of singles, compared with 50-55 percent for doubles.

4.2 1977 FARS Accident Statistics

Another important source of data used in the present study is that contained in the NHTSA Fatal Accident Reporting System (FARS) files. While data are available for the entire period from 1975 to date (1980), most FARS analyses in this report are based on the 1977 file so as to be compatible with the 1977 TIU information.

In calendar year 1977 FARS reported 3725 combination vehicle involvements in about 3514 fatal accidents. Of the 3725 vehicles, 149 are listed as multi-unit (i.e., two or more trailers). Triples (combination vehicles with three trailers) are permissible in several western states, and they are not specifically identified in FARS. However, based on the proportion of triples reported in the Truck Inventory and Use Survey (less than 1 percent of the number of doubles) the effect of any contamination of doubles statistics with triples will be neglected.

The cases entered into the FARS file typically derive from a report filed with the state by a police agency. FARS analysts refer to other available data (vehicle registration and driver record), to complete the standard federal form detailing the accident, vehicle, and occupant factors for the case. Detailed vehicle configuration, such as the identification of doubles as compared with singles, would be determined from the information furnished by the reporting officer. Some states provide a specific entry for the number of trailers, but others may identify doubles only from the text of the report. This suggests that doubles might be underreported, and there seems to be no independent source of data to check this. Systematic errors or omissions in the FARS data that are not accounted for in the analysis could influence the results.

In addition to FARS providing a census of fatal accident involvements, the FARS data are important to the present study because of many of the detailed data elements available. Within the limits of
understanding coding peculiarities from state to state, FARS provides identification of road classes, time, region of the country, type of accident, environmental (weather) conditions, as well as further vehicle and driver detail.

The distribution of doubles involvement in fatal accidents (from FARS 1977) can be plotted in a manner similar to the exposure (Figure 1) and the BMCS (Figure 12) data. This is shown in Figure 20. Again the western region of the U. S. shows the highest proportion of fatal accidents involving doubles, and the state of Washington stands out as being different from the exposure distribution. The BMCS accident count for doubles was also relatively high in Washington.

Figure 21 shows the distribution of fatal accident involvement by road type—with essentially the same road classification as used in the BMCS presentation. Doubles appear to have had a slightly larger proportion of fatal involvements on divided roadways but a smaller proportion on undivided roadways.

Figure 22 shows the distributions of fatal involvements of singles and doubles by time-of-day. The day time (8:00am to 4:00 pm) accounts for 39 percent of singles' fatal involvements and 30 percent of doubles' fatal involvements. The night time and dawn (midnight to 8:00 am) accounts for 30 percent of singles' fatal involvements and 44 percent of the doubles'.

Figure 23 shows the distributions of fatal involvements of singles and doubles by accident type (i.e. non-collision accident, collision with another vehicle, collision with a fixed object, etc.). Of particular interest is the smaller proportion of fatal non-collision involvements for doubles compared with the considerably larger proportion of the same accident type for doubles in BMCS. This suggests that, while doubles have a higher probability of a handling-related crash, those crashes are likely to be less severe.

As with BMCS accidents, individual factors in FARS interact to produce differences in the characteristics of fatal accidents involving singles and doubles. Some interactions are more readily detectable
Figure 21
FARS-77: Percent of Fatal Accidents by Road Type in U.S.

Figure 22
FARS-77: Fatal Accidents by Time of Day
As in the BMCS data, the proportions of fatal accidents on divided roadways involving singles and doubles between midnight and 8:00 a.m. are larger than the proportions for any other 8-hour period. This is specially true for fatal accidents involving doubles. On undivided roadways, the distributions of fatal involvements appear relatively more uniform throughout the day, with the largest proportion occurring in the afternoon.

Seventy-seven percent of the doubles were involved in accidents in rural areas and 72 percent of the singles were involved in accidents on rural roadways. Doubles on rural roadways appear to have had a slightly larger proportion of fatal involvements on divided roadways. On urban roadways, doubles had a much larger proportion of fatal involvements on divided roadways than did singles.

For singles, the distributions of fatal involvements in the urban and the rural areas are such that their peaks occur in the afternoon.
(noon to 4:00 pm). For doubles, the distribution of fatal involvements in the rural area has the peak at dawn (4:00 to 8:00 am), and the distribution in the urban area has the peak between midnight and 4:00 am. It is noted that the number of fatal involvements of double tractor-trailers in urban accidents is quite small (only 34 cases).

To summarize the FARS data, on an individual-variable basis, fatal accidents involving doubles are very much a western-state phenomenon as has also been shown in the TIU Survey data and the BMCS accident data. Fatal accidents involving singles and doubles appear to differ by many other factors as well. These factors include time-of-day, road type, and accident type (i.e., non-collision, collision with another vehicle, and hitting fixed objects).

Doubles exhibit a much higher proportion of fatal involvements after midnight and at dawn than do singles. Doubles also show a larger proportion of fatal involvements on divided roadways than do singles. Doubles have a smaller proportion of fatal non-collision involvements than singles.

The two-factor interactions described above indicate that doubles have proportionally more fatal involvements on divided roadways than do singles in both rural and urban areas. On divided roadways, fatal accidents involving either singles or doubles appear to happen more after midnight and at dawn. On undivided roadways, the proportion of fatal involvements appears uniform throughout the 24-hour period. Furthermore, more of the fatal involvements of singles (in both rural and urban areas) happens in the afternoon than at any other time. Fatal involvements of doubles on rural roads appear to happen more frequently at dawn, and those on urban roads more frequently after midnight.

Although a number of variables in FARS have the same detailed definition as those in BMCS, the two files do differ in the population of combination vehicles. While BMCS has a relatively complete coverage on ICC-authorized vehicles with a partial coverage on private carriers, FARS is believed to contain a complete census of combination vehicle fatal accidents for the entire country.
Without the exposure data, interpretation of the accident characteristics from both FARS and BMCS should be made with caution. The differences exhibited by singles and doubles in both files, whether individual-factor effects or interactions, can reflect the inherent differences in accident nature of the two and/or the differences in their exposure.
5.0 MULTIVARIATE ANALYSES

The data from two national files -- BMCS and TIU make possible the estimation of accident involvement rates (i.e. number of vehicles involved in accidents per vehicle mile) for accidents that produced at least an injury or damages exceeding $2,000. This section focuses on the comparison of involvement rates for singles and doubles using a multivariate analysis technique. In addition to an analysis of involvement rates, multivariate analyses of accident type and accident severity are also presented in this section.

5.1 Accident Involvement Rates

The simplest accident involvement rate is the overall rate for singles and doubles, making no adjustment for the effects of any other factors. These overall rates do not reflect the differences in the use, or exposure, of singles and doubles. Such differences may be related to vehicle features, trailer types, operational characteristics, and the environment in which the vehicles are operated. The danger of such oversimplified statistics should not be overlooked. Statisticians have recognized the problems of such aggregated statistics as reflected by the well known Simpson's Paradox. A good discussion of this point is given in Bishop, Feinberg, and Holland (1975), which states:

"...thus the practice of examining all two-way marginal tables of a complex data base may be misleading if any of the variables are inter-related." [19]

There is, of course, a converse statement to this -- that is if the variables are not inter-related, one can aggregate at will without a danger of misleading outcome.

A potentially more useful analysis (for understanding the problem or developing countermeasures) is one that is capable of accounting for interactions among significant factors. The previous sections have identified numerous factors that may influence the accident experience of singles and doubles, and therefore, may confound efforts to compare the relative safety of the two configurations. As a preliminary attempt to address the multivariate nature of this problem, this section presents an analysis that incorporates trip length and trailer type as
well as vehicle configuration. Possible interactions of these variables are also included.

Because BMCS contains only a portion of accidents involving private carriers, it is difficult to identify a comparable exposure population for the private carriers. The alternative is to exclude such cases from the rates calculation. The BMCS accident involvement rates reported here are those for ICC-authorized carriers only.

The national overall accident involvement rates for singles and doubles based on the data from the 1977 BMCS and TIU files are as follows:

Singles: 123.4 BMCS-reported involvements per $10^8$ miles
Doubles: 122.8 BMCS-reported involvements per $10^8$ miles

These overall accident involvement rates, however, do not provide a full understanding of the accident experience of singles and doubles. The next step is to disaggregate the rates based on a multivariate analysis of accident involvements and exposure. This step is restricted by those variables that are available and readily comparable in both the accident and the exposure data. Using the BMCS and the TIU files, these variables are vehicle configuration, trip length and trailer type. Vehicle configuration is either a semi-tractor-trailer (a single) or a two-trailer combination (a double); trip length is either local or non-local (intercity); and trailer type is either van, flatbed, tanker, auto, dump, or other.

The disaggregate mileage estimates are shown in Tables 4 and 5. Table 4 shows the estimated average annual mileage per vehicle for each

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The absolute values of the accident involvement rates are not well determined. FHWA estimates of the number of combination vehicles and total vehicle miles are 50 percent higher than those derived from the TIU file. If the FHWA estimates were used, the computed involvement rates would be about 50 percent lower. However, when the BMCS accident counts are broken down by trailer type and trip length, approximately 30 percent of the accidents are omitted due to missing data on these variables. Adjustment for this missing data would increase the absolute value of the rates by about 30 percent. Neither of these adjustments was made since the absolute rates would still not be well defined, and since the focus of this analysis is only on the comparison between singles and doubles.
Table 5 shows the estimated annual total mileage for each cell, and the 95 percent confidence interval derived from the sampling error for each estimate.

<table>
<thead>
<tr>
<th>Trailer Type</th>
<th>Single</th>
<th></th>
<th>Double</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Local</td>
<td>Intercity</td>
<td>Local</td>
<td>Intercity</td>
</tr>
<tr>
<td>N</td>
<td>AAM</td>
<td>N</td>
<td>AAM</td>
<td>N</td>
</tr>
<tr>
<td>Van</td>
<td>689</td>
<td>19,833</td>
<td>1899</td>
<td>82,128</td>
</tr>
<tr>
<td>Flatbed</td>
<td>60</td>
<td>34,336</td>
<td>513</td>
<td>67,024</td>
</tr>
<tr>
<td>Tank</td>
<td>33</td>
<td>45,077</td>
<td>362</td>
<td>75,148</td>
</tr>
<tr>
<td>Auto</td>
<td>5</td>
<td>35,231</td>
<td>159</td>
<td>69,747</td>
</tr>
<tr>
<td>Dump</td>
<td>26</td>
<td>40,634</td>
<td>64</td>
<td>64,872</td>
</tr>
<tr>
<td>Other</td>
<td>10</td>
<td>22,307</td>
<td>50</td>
<td>43,685</td>
</tr>
<tr>
<td>Total</td>
<td>823</td>
<td>22,643</td>
<td>3047</td>
<td>76,709</td>
</tr>
</tbody>
</table>

The confidence intervals estimate the influence of random errors (the variability of the data) and of the sample design. Surveys are also subject to nonsampling errors. These arise from nonresponse, misinterpretation of survey questions, or improper coverage of the sampling frame (the list from which survey vehicles were selected). Estimates of the magnitude of nonsampling errors are subjective, but in this case they are likely to be larger than the sampling errors. Only the sampling error is included in the tabulated confidence intervals.
Disaggregated BMCS-reported accident involvements are shown in Table 6. Since the BMCS file is a census of accidents for authorized carriers, there are no sampling errors for these frequencies.

New analytical techniques which are appropriate for the analysis of heavy-truck accident experience are being developed as part of this project. Preliminary results, which follow, are promising. The method uses the log-linear model for Poisson rates (Haberman, 1978) [20]. In fitting the accident frequencies, adjustments are made for the exposure differences of the individual cells. The ECTA program developed by Goodman (1971) [21,22] was used for the model fitting. At this time, the goodness-of-fit can be evaluated, but coefficient estimates are not available.
Modelling of the effects of trip length, trailer type, and configuration and of their interactions on the accident involvements, adjusting for the exposure, indicates that the main effects of all three variables are significant; so are all pairwise interactions of these variables. The triple interaction has been found insignificant. The fact that these pairwise interactions are significant implies that all three variables are minimum requirements in order to explain the accident involvement rates of combination vehicles—just the single/double variable, and that the absence of any one of these variables will considerably restrict the explanatory power of the accident involvement rates, if not altogether producing misleading outcome. This, in turn, indicates that the table of accident involvement rates cross-classified by these factors should not be collapsed.

The disaggregated table of involvement rate identified by the log-linear model are shown in Table 7. Involvement rates are computed by dividing the involvements shown in Table 6 by the mileage figures from Table 5. Confidence intervals reflect the influence of the variability
of the mileage estimates on the computed rate. This computation includes no estimate of error for the numerator (involvements). Since the BMCS file is a census of accidents for authorized carriers, there is no sampling error. For this situation, the confidence interval (CI) for the rate is given by:

\[
(CI)_{rate} = \frac{(Rate) \cdot (CI)}{(Miles)} \text{ miles}
\]

This expression is equivalent to an assumption of equal coefficient of variation, or equal percentage error in the mean.

TABLE 7
Involvement Rates (per $10^8$ Vehicle Miles)
(ICC-Authorized Carriers Only)

| Trailer Type | Single | | | | | Double | | | |
|--------------|--------|--------|--------|--------|--------|--------|--------|--------|
|              | Local  | Intercity | Local  | Intercity | Rate  | Intercity | Rate  | Intercity |
|              | Rate   | CI      | Rate   | CI      | Rate  | CI      | Rate  | CI      |
| Van          | 168.0 ±12.2 | 74.9 ±2.0 | 68.4 ±16.2 | 73.0 ±7.0 |
| Flatbed      | 69.9 ±13.1 | 106.8 ±4.8 | -      | -      | 264.1 * |
| Tank         | 142.2 ±34.6 | 78.1 ±4.2 | -      | -      | 111.8 ±8.8 |
| Auto         | 241.6 ±55.3 | 73.6 ±3.7 | -      | -      | -      |
| Dump         | 46.1 ±8.1  | 33.1 ±3.6 | -      | -      | -      |
| Other        | 277.4 ±122.0 | 250.7 ±38.1 | -      | -      | -      |
| Total        | 151.0 ±10.5 | 81.2 ±1.7 | 98.1 ±20.5 | 83.3 ±7.8 |

*Sample size is insufficient to estimate the sampling error, so that the confidence interval should be presumed to be large.

Again, bias error is not included. About 30 percent of the BMCS cases are missing data on trailer type or trip length. The possible bias arising from these missing data is probably a greater source of
error than the sampling errors associated with the estimated mileage. Only the sampling errors are shown because these can be estimated from the data. Bias estimates are subjective, and are left to the reader.

A review of the involvement rates shown in Table 7 indicates the following:

1) There is little difference in the accident involvement rates between van-singles and van-doubles for intercity trips (long haul). The estimated rates are 74.9 and 73.0 involvements per 10 miles for van-singles and van-doubles respectively.

2) For local trips, van-doubles exhibited a much smaller accident rate than did van-singles (the rates are 168.0 and 68.4 accidents per 10 miles for van-singles and van-doubles respectively).

Van trailers dominate the operation of both singles and doubles. About 65 percent of singles' mileage and 92 percent of doubles' mileage are contributed by van trailers.

3) Flatbed-doubles exhibited higher accident involvement rates than did flatbed-singles, particularly for intercity trips, where the rate for flatbed-doubles is 2.5 times that of flatbed-singles (264.1 and 106.8 accidents per 10 miles respectively). However, the small sample size in the TiU file for this subset makes this finding uncertain.

Flatbed trailers make up 16 percent of total singles' mileage and 3 percent of doubles' mileage.

4) Double tankers in intercity travel exhibited about 1.5 times higher an accident involvement rate than did single tanker (111.8 and 78.1 accidents per 10 miles for double tankers and for single tankers respectively).

Tankers make up 12 percent of total singles' mileage and 4 percent of total doubles' mileage.

Figure 24 shows the accident involvement rates for combination vehicles operated by ICC-Authorized carriers for some classes of service.

The findings from this three-factor analysis are significant. They also help explain why some past studies on accidents of singles and doubles often produced different, and sometimes conflicting, findings. For example, Glennon reported no significant difference in the accident rates for singles and doubles. Glennon's study was based on the Consolidated Freightways' fleet in long-haul operations. His conclusion seems to be consistent with our finding in (1) above; Glennon used for
Accident Rates for ICC-authorized Combination Vehicles

Figure 24

Note: Accidents per 108 miles.
his study a population of combination vehicles which was essentially made up of long-haul van-singles and van-doubles. Glennon's study did not include other types of trailers or local deliveries.

BMCS (1977) [3] reported that for intercity operations, doubles exhibited a slightly smaller number of accidents per mile than did singles consistently during 1969-1976. Their finding was based on the exposure data supplied by seven major carriers who operated both singles and doubles. It is highly likely that van-combination vehicles may have dominated their studied vehicle population since their exposure data came from big trucking companies. If so, their findings are also consistent with our findings in (1) as well as Glennon's.

Most other studies reviewed in this report indicated no significant difference in the overall accident involvement rates for singles and doubles. Their data was essentially based on the operation in California of combination vehicles with various trailer types and for both local and intercity trips. Their findings on the overall accident involvement rates for singles and doubles, are quite consistent with our overall accident involvement rates for the situation when the data are aggregated over all trailer types and trip lengths. It is noted that the doubles' mileage for vehicles registered in California, according to TLU, represents about 36 percent of the overall doubles' mileage in the country.

Vallette et al. (1981) [5] is the only study reviewed in this report to have stated that doubles exhibited a higher accident involvement rate than did singles. Their study was based on the data collected from a number of selected sites in California and Nevada. Our analysis suggests that their findings, though not nationally representative, are possible depending on the mix of trailer types, the mix of short-haul/long-haul operation, and the percentage of vehicle carrying agricultural products in their sample. The BMCS file, unfortunately, does not have complete accident records on intrastate vehicles or on vehicles used for agricultural purposes, since private carriers engaged in farm-to-market agricultural transportation are not required to report accidents to BMCS.
Table 8 repeats the results presented in Table 7 in a format which facilitates the comparison of involvement rates for singles and doubles. Looking down the last column of Table 8, one sees pairs of rates for singles and doubles for each combination of levels of trip length and trailer type. The important thing to notice is that the difference in the rate between singles and doubles fluctuates as the levels of trip length and trailer type change. For example, intercity double vans have an involvement rate virtually the same as intercity single vans, whereas intercity flatbed doubles have more than twice the rate of intercity flatbed singles. This type of result requires the kind of models under development which incorporate interactions among the variables.

The reader should keep in mind that tractors operating intercity with van trailers account for more than 50 percent of the total combination vehicle mileage, and nearly 90 percent of the doubles mileage. Sample sizes, particularly in the exposure data, are small in some of the cells. Sample sizes are small for all of the doubles experience except for the van trailers. Sample sizes are also small for the local service categories for single trailers, except for van trailers in local service. Although the sampling errors are shown to be small, nonsampling errors may be responsible for some of the observed differences.

Table 9 repeats the results in a format which facilitates the comparison of the different trailer types. Again, the difference in involvement rates from one trailer type to another fluctuates as the levels of trip length and configuration (single, double) change, demonstrating the interactions among these variables. Table 10 presents similar results for the trip length variable.

The effect of trip length and trailer type on the accident involvement rates of combination vehicles has been found to be quite significant. Of particular interest is that, in this three-factor model, the presence of trip length and trailer type has overshadowed the degree of importance of the single/double variable in explaining the accident involvement rates of combination vehicles. Table 11 gives the contributing effect of each of these three variables based on a log-linear model fitting of the accident and the exposure data sets. The
<table>
<thead>
<tr>
<th>Trailer Type</th>
<th>Trip length</th>
<th>Configuration</th>
<th>Involvement Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van</td>
<td>Local</td>
<td>Single</td>
<td>168.0</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>Double</td>
<td>68.4</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Single</td>
<td>74.9</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Double</td>
<td>73.0</td>
</tr>
<tr>
<td>Flatbed</td>
<td>Local</td>
<td>Single</td>
<td>69.9</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>Double</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Single</td>
<td>106.8</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Double</td>
<td>264.1</td>
</tr>
<tr>
<td>Tank</td>
<td>Local</td>
<td>Single</td>
<td>142.2</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>Double</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Single</td>
<td>78.1</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Double</td>
<td>111.8</td>
</tr>
<tr>
<td>Auto</td>
<td>Local</td>
<td>Single</td>
<td>241.6</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>Double</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Single</td>
<td>73.6</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Double</td>
<td>--</td>
</tr>
<tr>
<td>Dump</td>
<td>Local</td>
<td>Single</td>
<td>46.1</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>Double</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Single</td>
<td>33.1</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Double</td>
<td>250.7</td>
</tr>
<tr>
<td>Other</td>
<td>Local</td>
<td>Single</td>
<td>277.4</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>Double</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Single</td>
<td>--</td>
</tr>
<tr>
<td></td>
<td>Over-the-Road</td>
<td>Double</td>
<td>--</td>
</tr>
</tbody>
</table>

Contribution of a variable to the fitting of the data is represented by the magnitude of the chi-square statistic ($G^2$) for that factor per
degree of freedom in the model. Table 11 implies that, although statistically significant, the effect of single/double configuration, having accounted for trip length and trailer type is overwhelmed by the effect of the other two factors. In other words, the three-factor analysis implies that the differences in accident involvement rates with different trip length operations and different trailer types are more pronounced than the differences between singles and doubles.
<table>
<thead>
<tr>
<th>Configuration</th>
<th>Trailer Type</th>
<th>Trip length</th>
<th>Involvement Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single</td>
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<td>Local</td>
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<td></td>
<td>Over-the-road</td>
<td>74.9</td>
</tr>
<tr>
<td></td>
<td>Flatbed</td>
<td>Local</td>
<td>69.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td>106.8</td>
</tr>
<tr>
<td></td>
<td>Tank</td>
<td>Local</td>
<td>142.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td>78.1</td>
</tr>
<tr>
<td></td>
<td>Auto</td>
<td>Local</td>
<td>241.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td>73.6</td>
</tr>
<tr>
<td></td>
<td>Dump</td>
<td>Local</td>
<td>46.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td>33.1</td>
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<td></td>
<td>Other</td>
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<td></td>
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<td>Over-the-road</td>
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</tr>
<tr>
<td>Double</td>
<td>Van</td>
<td>Local</td>
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<td></td>
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<td>Over-the-road</td>
<td>73.0</td>
</tr>
<tr>
<td></td>
<td>Flatbed</td>
<td>Local</td>
<td>264.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tank</td>
<td>Local</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td>111.8</td>
</tr>
<tr>
<td></td>
<td>Auto</td>
<td>Local</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dump</td>
<td>Local</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>Local</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Over-the-road</td>
<td></td>
</tr>
</tbody>
</table>

### 5.2 Accident Type

Section 5.1 indicates the relative safety (measured by the number of accident involvements per mile traveled) of singles and doubles by various combinations of trip length and trailer type. These accident
involvement rates per mile traveled do not differentiate the kind of accidents that are more likely to involve a certain type of combination vehicle and less likely for others. Further investigation of the accident types can lead to a better understanding of the inherent differences in accident characteristics between singles and doubles, as well as the factors (vehicle, environment, driver) associated with the accident occurrences. Furthermore, if there were indeed evidence of significant differences in the distribution of accident type between singles and doubles, there would be a good reason to believe that such differences could give rise to a difference in the severity of accidents involving singles and those involving doubles.

Figure 25 shows the distribution of accident type for various subsets of singles and doubles. The figure is based on the two-year BMCS (1977-1978) accident data set. These subsets are similar to those identified in Section 5.1 (i.e., authorized carriers, intercity van singles, intercity van doubles, etc.). Accident type is either non-collision, collision with another vehicle, or hitting fixed objects. Figure 25 immediately suggests that doubles have a considerably larger proportion of non-collision accidents and a smaller proportion of hitting-another-vehicle accidents for all subsets. This is even true for the intercity van singles and doubles which were identified in Section 5.1 as having similar accident involvement rates.
FIGURE 25
BMCS (77-78): Distribution of Type of Accident of Singles and Doubles
Non-collision accidents can be divided into ran-off-road, jackknife, overturn, separation of units, fire, cargo shift/spill, and others. Figure 26 shows the distribution of various types of non-collision accidents for the same subsets of singles and doubles as in Figure 25. Figure 26 indicates that singles tend to have more jackknifes than do doubles, and that van-doubles tend to have more rollovers than van-singles.

The difference in accident types between singles and doubles warrants further investigation, particularly with regard to the tractors pulling van trailers, since vans make up 92 percent of doubles' mileage and 65 percent of singles' mileage. Detailed analysis on accident types is not included in this report but should be among one of the next tasks to be undertaken. The analysis, if carried out, can identify factors or groups of factors that are frequently present in the accidents of singles and doubles. These findings can then be tested or further explored by laboratory and/or field observations.

The induced exposure estimates for singles and doubles (Section 3.2) suggest that doubles are more likely to be on the road at night. If non-collision accidents are more likely at night, this might partially explain the over-representation of doubles in this category. Direct exposure data in this form are not currently available, however, and this must remain speculation.

5.3 Accident Severity

The BMCS file permits the identification of whether an accident resulted in a fatality, an injury, or only property damage in excess of $2000. A severity variable was created from the 1977 BMCS data set to reflect these levels. Subsequently, each accident involving ICC-authorized carriers was assigned one of the above severity classifications so that the probability that an accident was either fatal, or injury-producing, or property-damage-only could be assessed for the various combinations of factors of interest. The log-linear model was also tried with these data using accident severity as the dependent variable. Independent variables and levels remained the same.
FIGURE 26
BMCS (77-78): Distribution of Non-collision Events of Singles and Doubles
(trip length, configuration, and trailer type). Again, all interactions were included.

The result of the model fitting indicates that accident severity is influenced by trip length, configuration, trailer type, the interaction between trip length and configuration, and the interaction between trip length and trailer type. The observed probability of an accident being a fatal, an injury-producing, or a property-damage-only is shown in Table 12 for various trailer types, trip lengths, and single/double. These percentages sum to one hundred for each combination of trip length, trailer type, and configuration. For example, single vans in local service have 3.13 percent fatal involvements, 73.51 percent injury, and 23.35 percent property damage only. Table 12 indicates that for intercity operations, doubles exhibited a slightly lower fatality and injury proportion for van trailers, but a considerably lower proportion for tanker trailers. Over-the-road flatbed trailers exhibited the same proportion of fatality and injury for singles and doubles. For local operations, doubles exhibited a considerably lower proportion of fatality and injury than do singles for van trailers.

Table 13 shows the contributing chi-squares ($\chi^2$) of each factor in fitting the data. This is a measure of the lack-of-fit if any one of these factors is not included. The relative magnitude of the chi-square per degree of freedom implies that, of the three factors, vehicle configuration (single/double) is the most important factor explaining the severity of the accidents, followed by trip length and trailer type. Of particular interest is the fact that doubles appear to have a smaller proportion of fatality/injury accidents than do singles for most combinations of trip length and trailer type.
### TABLE 12
Severity of Combination Vehicle Accidents (ICC-Authorized Carriers Only)

<table>
<thead>
<tr>
<th>Trip Length</th>
<th>Trailer Type</th>
<th>Percent of Each Severity Level</th>
<th>Single</th>
<th>Double</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Property</td>
<td>Fatal Inj</td>
<td>Damage</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local</td>
<td>Van</td>
<td>3.13</td>
<td>73.51</td>
<td>23.35</td>
</tr>
<tr>
<td></td>
<td>Flatbed</td>
<td>5.62*</td>
<td>67.42</td>
<td>26.97</td>
</tr>
<tr>
<td></td>
<td>Tank</td>
<td>5.26*</td>
<td>64.47</td>
<td>30.26</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>13.11*</td>
<td>54.10</td>
<td>32.79</td>
</tr>
<tr>
<td>Intercity</td>
<td>Van</td>
<td>7.52</td>
<td>60.35</td>
<td>32.13</td>
</tr>
<tr>
<td></td>
<td>Flatbed</td>
<td>8.50</td>
<td>58.68</td>
<td>32.82</td>
</tr>
<tr>
<td></td>
<td>Tank</td>
<td>8.72</td>
<td>58.36</td>
<td>32.92</td>
</tr>
<tr>
<td></td>
<td>Other</td>
<td>7.41</td>
<td>61.78</td>
<td>30.81</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>7.32</td>
<td>61.46</td>
<td>31.23</td>
</tr>
</tbody>
</table>

*Cell with frequency less than 10.

### TABLE 13
Contributing Effect of Trip Length, Trailer Type, and Single/Double to Accident Severity (ICC-Authorized Carriers Only)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Total Contributing Chi-Square Per Degree of Freedom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single/Double</td>
<td>1172.4</td>
</tr>
<tr>
<td>Trip Length</td>
<td>789.4</td>
</tr>
<tr>
<td>Trailer Type</td>
<td>497.0</td>
</tr>
</tbody>
</table>

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REFERENCES


