Comparison of Accident Rates for Two Truck Configurations

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Industry-supplied data allowed a structured statistical comparison of the safety performance of tractor-semitrailers (singles) and doubles by comparing their accident experience on the same routes for 3 years. This paired structure essentially controls for roadway, environment and traffic conditions. Separate comparisons of vehicle safety performance were conducted for access- and non-access-controlled highways, local streets, and parking lots. In general, doubles experienced lower accident rates than singles in 1983 and 1985, but higher accident rates in 1984, which was a year of greatly expanding doubles operation. Doubles' accident rates are significantly lower than singles' accident rates for all types of operating environments over the entire period from 1983 to 1985. For the types of carriers represented in the data and for the conditions characterized by the routes in the sample, the consistent evidence is that doubles had better safety performance than singles except for the transition year 1984. The generalization derived from the study is that doubles are generally as safe or safer than singles, even when specifically controlling for roadway, traffic, and environmental conditions. This study was conducted on routes that are approved for doubles' operation. It is, therefore, not appropriate to extrapolate these findings to any specific route.

Motor carriage was a major area of governmental policy and legislative activity during the 1980s. The decade began with the partial economic deregulation of interstate carriage in 1980. Barriers to entry into the business and in selected markets were significantly lessened; pricing was also liberalized. The Surface Transportation Assistance Act (STAA) of 1982 revised highway user fees and initiated steps to standardize interstate size, weight, and vehicle configuration restrictions. One of the many changes brought about by this significant legislation was the more uniform legalization of the use of double combination tractor-trailers on Interstates and designated state and local roads. This expanded role for doubles overlapped with the passage of additional safety-related legislation in 1984 and 1986. The latter, the Commercial Motor Vehicle Safety Act of 1986, initiated a process that will likely culminate in more consistent examinations and procedures for licensing commercial drivers. The 1986 legislation also proposed strict penalties for drug and alcohol use during operation of a commercial motor vehicle.

Throughout all this legislative activity, the safety performance of the trucking industry has been a continuing point of debate and discussion. This is a legitimate concern when major changes occur in industry economic structure (as a result, for example, of economic deregulation), user fees, or operating regulations. Safety concerns are heightened by the continuing pressure to allow greater use of still larger trucks that must share the road with smaller automobiles. As truck and automobile mileage continues to grow year by year, these different types of vehicles are even more likely to confront each other on a roadway infrastructure that has had nearly fixed capacity for the past decade. The challenges posed by the confluence of these forces should be clear to all who seek to manage safety effectively.

The safety performance of doubles has been of particular interest because of their greatly expanded use following passage of the 1982 STAA. National less-than-truckload (LTL) carriers in particular (but not exclusively) have used doubles to increase their productivity and provide better customer service. Although the act was passed many years ago, battles continue to be fought concerning the access of doubles to state (and some Interstate) highways. The principal argument used to restrict access is the safety performance of the vehicle configuration.

There is a clear need to objectively assess the safety performance of doubles in a broad range of operating conditions. There have been numerous such studies, but they have often led to conflicting findings. This paper attempts to respond to the need for this safety assessment by reviewing the most recent literature assessing doubles' safety performance and presenting findings from new studies undertaken for this specific purpose.

OBJECTIVES

There is a need to better understand the safety performance of double combination tractor-trailers, particularly in comparison with the most likely alternative, a single combination (tractor-semitrailer). The authors seek to contribute to this understanding in two ways:

1. By briefly reviewing the literature concerning doubles' safety performance. This review focuses on the literature that has appeared since TRB Special Report 211 (*1*), which contains an excellent summary of safety studies up to that time. Particular attention is paid to data sources and methodology, because these are likely to have a strong influence on the interpretation of each study's findings.
2. By describing the results of studies conducted during the last few years at Northwestern University that were directed at obtaining a better understanding of doubles' safety performance. These studies have differed from those generally

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reported in that they use industry-supplied data sets, which provide much greater detail concerning both accidents and exposure.

The safety and operations data used in the Northwestern studies were from carriers with well-established safety programs and close monitoring of on-road driver performance. The analyses are not intended to typify the safety performance of all doubles operations. Rather, they are intended to respond to the following research questions:

1. If a carrier has a well-established safety program and generally makes a good-faith effort to adhere to federal safety regulations, are doubles inherently less safe than singles?
2. Does the safety performance change for different roadway types?

Given the acrimony and mysticism concerning doubles' and singles' safety performance, the authors believe that an answer to these questions would be a significant contribution.

STRUCTURE OF PAPER

The literature review describes three of the major doubles safety studies that have been conducted since 1986 as well as an overview of other relevant research. Next the structure of the empirical analysis is described, including data sources. The empirical analyses are presented, and the paper concludes with a summary and recommendations for future research.

LITERATURE REVIEW

Any review of doubles' safety performance must consider the findings of the major TRB doubles study completed in 1986 (*1*). Although the TRB study went well beyond safety to include issues such as pavement damage and user fees, it contained a comprehensive review of the existing safety literature, which included comparisons of doubles' and singles' handling characteristics as well as accident experience. The TRB report concluded that doubles were more likely to encroach on adjacent lanes in high-speed turns, to roll over (particularly the rear trailer), and to generally provide poorer sensory feedback to the driver. Doubles are more maneuverable in low-speed turns, however, so they are likely to perform better at intersections. After a summary of more than 15 studies concerning doubles' safety performance, the report concludes the following: the three most reliable comparisons of accident rates show that doubles have 2 percent lower, 6 percent higher, and 12 percent higher rates than singles, respectively. A comparison of the three most reliable fatal accident rate studies show that doubles have 7 percent lower, 5 percent higher, and 20 percent higher fatality rates than singles.

The review by the TRB study committee determined that there had been no definitive study of doubles' safety performance at that time. Special Report (SR) 211 concludes that doubles' accident rates are equal to or slightly higher than those of singles per vehicle mile and generally lower than those of singles per ton-mile.

Since publication of SR 211, there have been three research studies that focused on safety comparisons of doubles versus singles. Studies by the University of Michigan Transportation Research Institute (UMTRI) (*2*), the Insurance Institute for Highway Safety (*3*), and the University of Saskatchewan (*5*) differ greatly in data sources and method and are reviewed in the following three subsections.

UMTRI Study

Carsten describes a study to assess doubles' safety performance conducted by UMTRI in 1986 (*2*). A number of comparisons of singles' and doubles' safety performance were conducted using data from a variety of sources, including the National Accident Sampling System (NASS), accidents reported to U.S. Department of Transportation Office of Motor Carriers (formerly the Bureau of Motor Carrier Safety), Trucks Involved in Fatal Accidents (TIFA) and exposure data from the Truck Inventory and Use Survey (TIUS) compiled by UMTRI. The paper includes a discussion of operating difficulties with doubles (including rearward amplification) that may contribute to accident risk.

Carsten showed that there is no conclusive evidence of an overall difference in fatal or injury involvement rates for singles compared with doubles. This conclusion is tempered by the generally safer operating environment that characterizes doubles operations. Carsten further concludes that differences in truck handling characteristics are reflected in the differing accident experience of the two truck configurations.

Insurance Institute for Highway Safety Study

In a recent study by the Insurance Institute for Highway Safety (IIHS), Stein and Jones used a novel case-control methodology to compare accident involvements of doubles and singles (*3*). Accident data were obtained from 676 truck-involved crashes that occurred along Interstate 5 or Interstate 90 in the state of Washington from June 1985 through July 1986. Accidents were included in the data base if the truck weight exceeded 10,000 lb and the crash resulted in personal injury or property damage exceeding $1,500. The location, day of week, and time of day of the accidents provided the information needed to select a control sample for comparison with the accident cases. For each large truck involved in a crash, three trucks were selected for inspection from the traffic stream at the same time and place as the crash, but 1 week later. A comparison of relative involvement in accidents compared with relative involvement (occurrence) in the control sample was used to calculate overinvolvement ratios. The control sample can thus be thought of as a pseudo exposure measure. An advantage of the methodology is that it allows for direct comparison of a large number of attributes of accident involvements with a similar set of nonaccident involvements. This disaggregate structure facilitates comparisons of a range of potential contributing factors such as vehicle configuration (principally), driver age, hours driving, cargo weight, and fleet size.

Stein and Jones found that doubles were consistently overinvolved in accidents by a factor of 2 or 3. The overinvolvement of doubles was found regardless of driver age, hours of driving, cargo weight, or type of fleet. The authors conclude that increasing use of doubles will produce more large truck crashes, despite their increased load-carrying capacity. The authors correctly point out that their findings cannot be directly converted to an accident rate per vehicle mile, but it is clear that the IIHS finding of 2- or 3-times greater accident risk for doubles compared with singles is a much larger difference in safety performance than has been identified in any previous study. The authors further state that previous studies using conventional accident and exposure data to estimate accident risk are unable to control for possible differences in operating conditions between the two vehicle configurations.

Although the study is creative in its use of methodology, the novelty of the approach and the apparent inconsistency (in scale at least) with previous research findings argue for a closer examination of the case-control technique as used in this application. The principal area for additional discussion is the method used to obtain the control sample and any generalization that can be derived from a study using this technique.

The seminal research in the application of this technique to road safety was a study by Haddon investigating 50 fatal pedestrian accidents in Manhattan (*4*). Haddon carefully describes the technique used to collect the control sample and, in particular, discusses the characteristics of individuals who refused to participate as controls. Although the study used three slightly different techniques to obtain the control data (they varied somewhat by neighborhood and time of day), they shared the common objective of limiting investigator bias by stopping pedestrians at the accident scene immediately after the accident. By simply taking the first four pedestrians at the site (with some very limited restrictions), Haddon directly acknowledges an effort to restrict investigator bias. Haddon also qualitatively describes the characteristics of the 12 pedestrians that refused, at some stage, to participate and argues that 12 out of 200 individuals are unlikely to alter the study findings. Further, the refusals were widely distributed across study sites (38 of 49 sites had no refusals), strengthening arguments against bias.

The large-truck study by Stein and Jones is much less clear concerning experiences during collection of the control sample and any potential effects regarding bias. Rather than collect the control data on the first set of trucks passing a site, at the same time of day and day of the week but 1 week later, Stein and Jones staggered their control data collection to one-half hour before and after the time of the crash as well as at the time of the crash. Despite the most well-intentioned investigator, this staggering in time could allow for investigator bias to manifest itself.

Stein and Jones do discuss difficulties in obtaining control data at some sites because of high roadway volume, lack of space, and other safety considerations. Unfortunately, there is no discussion of the frequency with which these events occurred and what effect, if any, they might have on the findings. Although the authors state that 85 percent of the accidents were matched with control data, it is unclear how strictly the matching criteria were followed and whether stricter criteria should not have been used. In keeping with the concern that the study be representative, all trucks passing each site for the hour bracketing the accident time could have been counted. Although only three trucks would have been stopped for further investigation, a more thorough understanding of configuration flow rates would have resulted. The additional counts would have provided an even more accurate description of the exposure to risk at the sites for the two configurations.

The final, but in many respects the most important, point is the ability to generalize the findings to other Interstates in Washington or elsewhere in the United States. In the seminal research, Haddon cautions several times against the extrapolation of findings to a broader population. First he cautions that site bias may affect the presence of potential contributing factors (in this case blood alcohol concentration) in accident victims and the control group (*4*, p. 671). He specifically argues that the sites chosen through the method may not be typical of all Manhattan. He later goes on to caution concerning extrapolation to other cities (*4*, p. 675). He does present qualitative arguments using supporting data but goes on to say that similar research is needed in other cities before more generalizable conclusions may be drawn.

In contrast, the truck safety research seems to imply findings generalizable not only to the rest of Washington but to the remainder of the United States as well. There is virtually no discussion of the attributes of the two Washington Interstates and their generalizability to other Interstate segments in the state or across the United States. Because sites involving heavy trucks were selected, they may represent a selection bias (i.e., sites with an unusually high risk of truck crashes). The possible selection bias raises questions about whether the IIHS results could be replicated at randomly selected sites or at a broader sample of national sites.

University of Saskatchewan Study

In a recent paper from an OECD conference concerning heavy trucks (*5*), Sparks and Bielka described a comparison of doubles' and singles' accident rates in Saskatchewan. The study was conducted at two levels: a provincewide analysis of accident rates using data from police accident reports, average daily traffic (ADT) counts, and vehicle classification counts; and a comparison of accident rates using data from two large fleets.

In the regional analysis the authors paid particular attention to the implication of measurement errors on the final estimated accident rates. They found that uncertainties in the estimation of the percentage of trucks and the percentage of doubles within the truck fleet have the greatest influence on the estimated accident rates. The general conclusion of both the regional and fleet-specific analyses was that there was no apparent difference in accident rates.

This is a thoughtful and carefully conducted study that is important for two reasons.

1. It clearly demonstrates the uncertainty in using regional data to conduct these types of comparative safety studies, one of the few studies to address this topic.
2. It introduces the feasibility of using carrier-specific data to improve the understanding of doubles' safety performance.

Summary

The conclusion in two of three studies is that doubles' rates are indistinguishable from rates of singles. None of the reported studies, however, has been able to control for differences in how and where doubles operate. The research reported in this paper attempts to respond to the need for this type of carefully controlled study.

STRUCTURE OF THE ANALYSIS

Overview

Much of the uncertainty regarding comparative studies of the safety performance of doubles and singles results from two interrelated issues: first, exposure data are not generally available to conduct accurate comparisons of accident rates and, second, the accident comparisons do not control for the effect of other variables such as weather and road design on safety performance.

To overcome these difficulties, the following approach is adopted. Accident data and measured dispatch (exposure) data are obtained for randomly selected origin-destination terminal pairs used for national LTL carriage. The only condition for inclusion in the sample is that the route actually contain both singles' and doubles' operations over precisely the same highway segments. This approach allows the use of very accurate exposure data for both types of trucks. Further, by using routes that contain operations of both vehicle types, it is possible to control for differences in road design, traffic level, and, generally, weather conditions.

There are additional advantages of conducting the comparison with carrier-supplied data such as these. The statistical test more directly compares the vehicle configurations that are the actual options along a route. If an individual carrier is restricted from using doubles, the single combination vehicle is the most likely alternative. Within a firm, that alternative vehicle will be subject to the same level of maintenance and the driver to the same level of management as the double combination that they replaced. The paired structure thus avoids inaccuracies that may occur in conducting cross-sectional studies that obtain doubles data from carriers in the LTL industry but include singles data from private and truckload carriers. The argument is not that these other types of carriage are less safe than LTL. Rather, it is that restrictions on doubles' travel should be based on an assessment of the safety performance of the vehicle configuration itself, without confounding effects such as level of vehicle maintenance and driver management.

Analysis Method

In order to conduct a statistical comparison of doubles' and singles' safety performance controlling for roadway design, traffic, and environmental conditions, it is necessary to test hypotheses concerning the mean difference in the accident rates of doubles and singles. The unit of observation is therefore the accident rate difference for each terminal pair in the data. The test statistic is the paired-T-test (*6*), given as

$$T = \frac{\overline{D} - d_0}{S_d/(n)^{1/2}} \tag{1}$$

where

$\overline{D}$ = mean of the differences between the paired observations,
d_0 = difference to be tested for,
S_d = standard deviation of the differences, and
n = number of observations.

The degrees of freedom for the test equals $n - 1$.

The random variable D is calculated as the difference between the accident rates of doubles and singles on a terminal pair and $\overline{D}$ is the mean for these route-level differences:

$$D_i = \text{ARD}_i - \text{ARS}_i \tag{2}$$

$$\overline{D} = \left(\sum_{i=1}^{n} D_i\right) \Big/ n \tag{3}$$

where

ARD_i = accident rate per million truck miles for doubles on terminal pair i,
ARS_i = accident rate per million truck miles for singles on terminal pair i, and
n = number of terminal pairs.

The value for d_0 for these comparisons is zero. The other variables are as commonly defined.

It is important to emphasize that the statistical tests are conducted using the mean (and standard deviation) of the difference in accident rates for each vehicle configuration on all the routes. This mean is then tested against the distribution of mean differences that would occur under the null hypothesis. By the central limit theorem, no matter what the distribution of the random variable is, the sampling distribution of its mean is normally distributed and can thus be characterized by the standard normal distribution (for sufficiently large samples). It is therefore unnecessary to test for a specifically normal distribution in the data; the statistical theory is sufficient to support the validity of the method.

In addition to comparisons of the accident rates of the two configurations on each type of route, accident rates are compared for parking lots (both at terminals and at stops) used while en route. Because the etiology of accidents is likely to be different in these different environments, separate comparison of the rates is useful.

This methodology allows a direct comparison between the truck configurations. The means for each configuration are also reported in order to provide the reader with a frame of reference, even though the vehicle-specific means are not used in the test statistic (the differences in route-level means are used instead). Findings for each year are also reported, as are findings for the data as a whole. Some variation is expected from year to year because of exogenous factors. Further, as described earlier, passage of the 1982 STAA allowed more uniform use of doubles. It took the industry 2 to 3 years to respond, but the effect was greatly expanded doubles operations during 1984 and 1985. The accident data may reflect this "learning curve" as drivers familiar with singles more frequently drive doubles.

Data Description

Accident data include all accidents reported during the processing of internal company claims, those meeting U.S. Department of Transportation reportability thresholds as well as minor property damage accidents. In addition to obtaining the vehicle configuration involved in the accident, the location (access-controlled and non-access-controlled highway, local street, or parking lot) and origin-destination terminals are determined from accident reports.

For each of the randomly selected terminal pairs, exposure data included the total mileage for each vehicle configuration between each terminal pair for each year. In addition, precise vehicle routings were obtained from carriers and verified using highway maps. The routing information was used to calculate the proportion of each route's mileage that occurred on the three roadway types. Applying these proportions to the annual mileage provided an estimate of the annual truck mileage for each type of highway on each route. Combining these data with location-specific accident data allowed the computation of an accident rate for each type of highway along each route. Figure 1 shows the geographic distribution of the terminal pairs used in the study. The routes are fairly distributed among western, midwestern, and eastern states. It should be remembered that these routes resulted from a random sample of terminal pairs with both doubles' and singles' operations.

Initial screening of the randomly selected routes revealed the presence of some routes with an extremely low number of dispatches and thus vehicle miles. A complete comparison of configuration safety performance was conducted for this full data set as well as for a data set containing only higher-volume O-D pairs for the following reason. If an accident happened to occur on a low-volume route, the rate (per million vehicle miles) would be greatly and artificially inflated. These greatly inflated rates would be treated in the statistical analysis with the same weight as a very heavily traveled route with high exposure (e.g., 6,000 dispatches or more) because the analysis is conducted at the route level. In order to ensure that all O-D pairs had some minimum exposure magnitudes, it was decided to include in the analysis only O-D pairs with at least 100 dispatches per year for each vehicle configuration. Although the restriction alters somewhat the randomness of the sample, the concept of comparing roughly comparable O-D volumes seemed a reasonable one.

Table 1 is a summary of descriptive statistics for the sample used in this research. The data set includes nearly 900 accidents (376 involving singles and 507, doubles) and over 300 million vehicle-mi of operation (127 million by singles and 209 million by doubles). Included for the reader's information is the total number of accidents, total truck miles, and resulting accident rate (total accidents divided by total miles). This indicates that the accident rates are in the range previously reported in the literature (*2,5*).

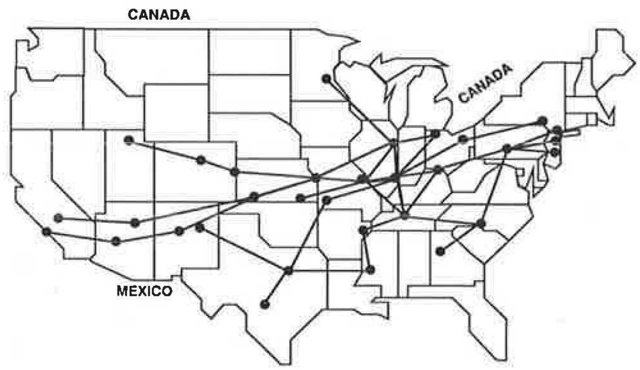

FIGURE 1 Geographic distribution of roadway segments.

TABLE 1 DESCRIPTIVE STATISTICS FOR TRUCK SAFETY AND OPERATIONS

ITEM	1983	1984	1985	TOTAL
Number of O-D Pairs	111	130	114	355
Average O-D Distance (Miles)	282	262	265	269
Number of Singles Trip (Million)	0.18	0.20	0.10	0.48
Singles Mileage (Million Veh-Miles)	50.0	51.0	26.6	127.6
Number of Singles Accidents	160	127	89	376
Singles Accident Rate*	3.20	2.49	3.34	2.95
Number of Doubles Trips (Million)	0.14	0.29	0.35	0.78
Doubles Mileage (Million Veh-Miles)	39.5	76.8	92.8	209.1
Number of Doubles Accidents	107	162	238	507
Doubles Accident Rate*	2.71	2.11	2.56	2.42

* Accident Rate = Accidents/Million Vehicle-Miles.

Clearly apparent in the data regarding both number of trips and number of vehicle miles per year is a strong shift toward doubles and away from singles during 1984 and 1985. Although singles' trips and mileage increased slightly from 1983 to 1984, doubles' trips and mileage increased by nearly a factor of 2. These data suggest that the increase in freight traffic accompanying the economic expansion during 1984 was taken up almost entirely by expanded doubles' use. Doubles' trips and miles continued to expand during 1985, whereas singles' operations on the terminal pairs were greatly reduced. These changes in the pattern of exposure to risk are reflected by changes in the annual number of doubles' and singles' accidents.

The data in Table 1 are intended to be purely descriptive. In particular, the accident rates that appear in rows 6 (for singles) and 10 (for doubles) are simply numbers obtained by dividing yearly accidents by yearly vehicle miles. Although this is informative, it is subject to the criticism that doubles may be operating on different roads and under different conditions than singles. It is only by conducting detailed route-level comparisons that differences in roadway and environmental conditions can be controlled and valid hypothesis tests concerning accident rate differences can be conducted.

FINDINGS

Overview

Tables 2 through 5 summarize the safety performance of the two vehicle configurations in each of the four operating environments. In computing the accident rate differences for doubles and singles, only the accidents occurring in each operating environment (access-controlled highways, non-access-controlled highways, local streets, and parking lots) are included. The "difference" is defined as the mean of the differences in accident rates between doubles and singles for each route. It must be remembered that statistical tests are conducted only using the data under the column titled "Difference," with variables as defined in Equations 1–3. The yearly mean accident rates for each vehicle type are included, along with their standard deviations, for informational purposes. A parallel set of tables was constructed using the entire data set; there were some differences in values for the full data set, but the interpretations derived from the tables are identical, so the tables are not replicated here.

The general expectation, given the data in Table 1, is that 1983 would reflect conditions as experienced before the 1982 STAA, owing to time lags to purchase and operate new equipment and the bare beginning of the economic recovery. The accident rate for doubles could be expected to increase in 1984 because of the rapid expansion of doubles operations and the requisite use of drivers in a vehicle to which they were unaccustomed. The rate was expected to drop somewhat in 1985 because the drivers were getting more familiar with doubles. Although these may be plausible hypotheses, it must be remembered that the firms participating in the study are conducting a variety of training programs to acquaint drivers with doubles operation. Given their generally high level of driving experience, drivers should have accomplished the transition to doubles relatively smoothly.

Safety Performance

Travel on Access-controlled Highways

With high geometric design standards and full access control, these highways should be more suitable to large-truck doubles operation than other types of roadways. If this assumption is true, the difference in accident rates for travel on access-controlled highways between doubles and singles should be much less than for travel on other roadways.

According to the statistics in Table 2, doubles experienced a lower accident rate per million miles than singles in 1985. Singles had a lower rate than doubles in 1984, but doubles had a lower rate again in 1985. Each of these yearly differences is statistically significant. The trend of safety performance by doubles followed by safer performance by singles may be explainable as part of a "learning curve" for doubles operation. This does not explain the increase in accident rates for

TABLE 2 ACCIDENT RATE DIFFERENCES FOR DOUBLE AND SINGLE COMBINATIONS ON ACCESS-CONTROLLED HIGHWAYS*

Year	Interstate Highways			No of Pairs	Paired-T Statistic
	Double	Single	Difference		
1983	2.79 (0.91)**	3.20 (0.94)	-0.41 (1.35)	110	-3.17
1984	4.59 (2.36)	4.26 (1.68)	0.33 (1.48)	127	2.50
1985	3.03 (0.83)	3.97 (1.84)	-0.95 (2.05)	112	-4.88
1983-5	3.52 (0.94)	3.83 (0.90)	-0.31 (0.95)	349	-6.09

* Accident Rate = Accidents / Million Vehicle-Miles.

**The term in parentheses is the standard deviation, S_d in Equation 1.

TABLE 3 ACCIDENT RATE DIFFERENCES FOR DOUBLE AND SINGLE COMBINATIONS ON NON-ACCESS-CONTROLLED HIGHWAYS*

Year	State Highways			No of Pairs	Paired-T Statistic
	Double	Single	Difference		
1983	15.21 (8.89)**	34.55 (18.16)	-19.34 (20.42)	41	-5.99
1984	22.48 (17.80)	8.43 (5.30)	14.05 (18.71)	47	5.09
1985	18.16 (9.26)	45.29 (23.52)	-27.13 (20.87)	41	-8.22
1983-5	18.80 (7.61)	28.45 (9.66)	-9.65 (11.54)	129	-9.46

* Accident Rate = Accidents / Million Vehicle-Miles.

**The term in parentheses is the standard deviation, S_d in Equation 1.

TABLE 4 ACCIDENT RATE DIFFERENCES FOR DOUBLE AND SINGLE COMBINATIONS ON LOCAL STREETS*

Year	Local Streets			No of Pairs	Paired-T Statistic
	Double	Single	Difference		
1983	9.19 (5.44)**	32.41 (12.58)	-23.23 (13.89)	108	-17.30
1984	13.49 (10.73)	9.39 (5.34)	4.10 (12.07)	126	3.80
1985	6.68 (3.20)	6.36 (2.96)	0.32 (4.45)	110	0.75
1983-5	9.96 (4.39)	15.65 (4.54)	-5.69 (6.38)	344	-16.52

* Accident Rate = Accidents / Million Vehicle-Miles.

**The term in parentheses is the standard deviation, S_d in Equation 1.

singles during the same time period. Because the pattern is so similar, one wonders if some common but exogenous factors such as weather conditions during a year or changes in automobile travel are affecting the results. When data for all 3 years are combined, doubles have an accident rate that is approximately 10 percent lower than that of singles (again the difference is statistically significant).

These statistics show that doubles experienced generally safer operations except for the transition to expanded use in 1984. This result runs counter to an assumption that doubles have a higher operating risk on access-controlled highways than singles.

Travel on Non-Access-controlled Highways

Non-access-controlled highways are designed to lower geometric standards than Interstate highways. Although speed limits are generally lower, one might expect the accident rates for both singles and doubles to be higher than on Interstate highways. The lower geometric design standards are generally perceived to increase the difficulty of operating doubles, hence the hypothesis that doubles have a higher accident rate than singles on state highways.

The accident rates shown in Table 3 are derived directly from the accidents and exposure on non-access-controlled highways alone. Doubles had a lower accident rate than singles by 19.34 accidents per million miles in 1983. Singles were lower by 14.05 in 1984, but doubles were lower by 27.13 in 1985. Again, all findings are statistically significant. The up-and-down pattern of accident rates seems to again indicate a learning curve for doubles' highway travel on non-access-controlled facilities.

On the basis of a statistical comparison between mean accident rates, large trucks traveling on non-access-controlled highways have consistently higher accident rates than those on access-controlled highways. These findings are consistent

TABLE 5 ACCIDENT RATE DIFFERENCES FOR DOUBLE AND SINGLE COMBINATIONS IN PARKING LOTS*

Year	Double	Single	Difference	No of Pairs	Paired-T Statistic
1983	0.30 (0.22)**	1.29 (0.87)	- 0.99 (0.90)	111	-11.54
1984	0.28 (0.07)	0.45 (0.30)	-0.17 (0.32)	130	- 6.03
1985	0.14 (0.07)	0.40 (0.21)	-0.26 (0.22)	114	-12.56
1983-5	0.24 (0.09)	0.70 (0.30)	-0.46 (0.31)	355	-27.92

* Accident Rate = Accidents / Million Vehicle-Miles.

**The term in parentheses is the standard deviation, S_d in Equation 1.

with the general position that Interstates are much safer than state highways for large-truck operation. The yearly pattern in accident rate differences was very similar to the pattern for Interstates: doubles had significantly lower rates in 1983, 1985, and all 3 years combined, whereas singles had lower rates than doubles in the transition year 1984.

Travel on Local Streets

Local streets have lower geometric design standards than Interstates and state highways and a generally higher level of conflicting traffic. However, both trucks and automobiles operate more slowly on local streets, and this allows drivers a longer time to react to unexpected events. As stated in SR 211, doubles' superior low-speed turning performance may result in this configuration's having a lower accident rate than singles on this type of road.

Table 4 shows the accident rates for travel on local streets for both doubles and singles. Doubles experienced 23.23 fewer accidents per million local street truck miles in 1983. The difference was 4.10 in favor of singles and was an insignificant 0.32 in 1985. Again, the trends in the doubles' accident rate differences are consistent with a driver learning process.

According to the mean accident rates over the 3-year study period, travel on local streets seems to have a higher risk than travel on Interstate highways, but a lower risk than travel on non-access-controlled highways. The doubles had a lower mean accident rate than singles in 1983 but a higher mean accident rate in 1984 and 1985. Over the entire 3-year period, doubles experienced a significantly lower accident rate than singles.

In Parking Lots

Accident occurrence in parking lots is not normally included in safety assessments of doubles. Perhaps it is because these accidents are generally of low severity and may represent minimal risk to the motoring public. However, such accidents are a source of cost to motor carriers and a source of delay and inconvenience to shippers. For these reasons, a comparison of doubles' and singles' accident risk in this environment is included here.

The most difficult decision in comparing parking lot accidents is to decide on an appropriate exposure measure. The exposure measure should be able to describe the number of opportunities for an accident in a parking lot for each trip. It was assumed that longer truck trips would result in a greater number of parking lot arrivals and departures. For this reason, truck miles was chosen instead of vehicle trips as the exposure measure for involvement in parking lot accidents. Table 5 shows the accident rates occurring in parking lots for doubles and singles. The parking lot accident rates decrease year by year for both doubles and singles, but singles experienced consistently higher parking lot accident rates than doubles for each study year. The difference is significantly different from zero for each year's comparison. This result contradicts the authors' intuitive assumption that doubles are more difficult to operate in parking lots than singles and result in higher parking lot accident rates than singles.

CONCLUSIONS AND RECOMMENDATIONS

The comparisons of doubles' and singles' safety performance have found significant differences in the accident rates of the two configurations. In general, doubles experienced lower accident rates than singles in 1983 and 1985, but higher accident rates than singles in 1984, which was the transition year for expanding doubles operation following the 1982 STAA. Doubles' accident rates are significantly lower than singles' accident rates for all types of operating environments over the whole period from 1983 to 1985. For the types of carriers represented in these data and for the conditions characterized by the routes in this sample, the consistent evidence is that doubles had better safety performance than singles except during the transition year 1984.

By separately analyzing safety performance on access-controlled highways, non-access-controlled highways, and local streets (also in parking lots), it was possible to compare the relative safety performance of each configuration in each operational environment. Truck accident rates on access-controlled highways were 5 to 7 times those on non-access-controlled roads. The safety performance on local streets was, somewhat surprisingly, in between the rates for Interstates and state highways. It should be remembered, however, that the paired comparison conducted in this research allowed more efficient detection of significant differences. Some may argue, therefore, that the approximate 9 percent difference between doubles' and singles' accident rates on access-controlled facilities may be statistically significant but practically irrelevant. It is not the authors' position to make judgments about how large a safety difference is required to be for it to be important. It is sufficient to say that the doubles rates are consistently less than those of singles.

There appears to be strong evidence of a learning curve that occurred during expansion of doubles operations in 1984. This evidence is particularly strong on state and local roads where doubles rates increased from 1983 to 1984 and then dropped in 1985 to nearly 1983 levels. No such consistent trend was observed for singles in these two operating environments.

The generalization derived from the study is that the double configuration itself is generally as safe or safer than the single configuration, even when roadway, traffic, and environmental conditions are specifically controlled for. One must remember, however, that these doubles operations occurred on routes that, de facto, were approved for doubles operation. It is therefore not appropriate to extrapolate these findings to any specific route. The authors believe that these findings, along with those of Sparks and Bielka and Carsten, generally support the widespread use of doubles unless specific data on their safety performance indicate conditions that differentially affect them.

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DISCUSSION

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To assess the safety of double trailer trucks, Jovanis et al. used carrier-supplied data sets containing both crash and exposure data. The crash data included all crashes reported during the processing of internal company claims; the exposure data consisted of route-specific mileage by vehicle configuration. Although the authors acknowledge that all participating carriers had "well-established safety programs" and made "a good faith effort to adhere to federal safety regulations," they nevertheless conclude that their study findings can be generalized, not to specific routes or to specific carriers, but to the trucking industry as a whole. However, such carriers do not represent the whole of the trucking industry, and the findings of this study cannot be generalized beyond the safety-conscious study participants.

The authors compared crash rates of paired groups of doubles and singles operating between the same origin and destination terminals. These "terminal pairs" consisted of at least 100 dispatches/year of each of the two truck configurations. Crash rates were calculated separately for Interstate highways, state highways, local streets, and parking lots. The rates were calculated separately for 1983 through 1985 and for all 3 years combined.

Unlike other studies of crash rates of trucks of various configurations, the authors controlled for roadway of exposure by selecting origin and destination terminal pairs and maintaining this pairing in the data analysis. Beyond this one important factor, however, no attempt was made to eliminate or even to recognize other potential sources of bias. Important mechanisms for bias include, for example, the possibility that driver safety records and tractor maintenance records routinely influence the configuration choice. Had the companies in the study typically assigned doubles to the drivers who have better safety records and more experience, the results of this study would reflect the success of such assignment policies rather than the performance of doubles. Controlling for the age of drivers, the time and the day when the crash occurred, and the type and weight of the cargo carried could have provided some assurance that the results were not confounded with a crude selection bias.

It was not necessary for the authors to discard data for the less-traveled routes; with the appropriate statistical technique, all data could have been retained and included in a weighted analysis. The crash rate comparison specified by Equations 1–3 accords equal weight to rates based on small and large traffic volumes and results in unnecessarily unreliable estimates. Moreover, it is puzzling that in Tables 2–4 most of the differences between the doubles' and singles' crash rates are statistically significant on the basis of the paired-T-tests, yet the standard error estimates typically exceed the difference estimates, a situation that normally indicates the absence of statistical significance. The lack of consistency in the direction of the difference is also puzzling. It is not easy to understand how it is possible for doubles to be significantly superior to singles with regard to safety in 1983 and 1985, and significantly inferior to them in the intervening year, 1984.

In contrast, in their study, Stein and Jones (*1*), rather than determining crash rates by configuration, studied risk factors for crash involvement using the case-control method. Contrary to the criticism by Jovanis et al. of the "novelty of the approach," modern case-control studies have been used in medicine, public health, and sociology since the 1920s.

In the Schlesselman (*2*) design, the unit of analysis is the individual rather than the group, making it possible to study many factors relating to the crash. Each crash-involved truck and truck driver (case) was matched to and compared with three trucks and truck drivers who were not crash involved (control). By matching on roadway, time of day, and day of the week, the cases and controls were comparable with respect to these attributes and the hazards associated with them. Control trucks were selected by Washington State Patrol commercial vehicle enforcement officers according to a specific and rigorous research protocol. Controls were selected one week after each crash. The first control truck was stopped for inspection 30 min before the time of the crash, the second was stopped at the time of the crash, and the third was stopped 30 min after the crash. The officers were instructed to select the first truck going through the crash site at the sampling time. Although the officers could not be blinded to the case or control status of the truck entering the study sample, they were not aware that one objective of the study was to determine the association between configuration and crash risk. Thus, there is no reason to believe that the study objective would have influenced the selection of control trucks.

Both case and control trucks were subjected to a rigorous vehicle inspection. Case and control drivers were interviewed regarding their age, experience, and hours of service. After adjusting for truck and driver characteristics, Stein and Jones found that double trailer trucks were consistently over-involved in crashes by a factor of 2 to 3. The strength of the finding lies in the fact that the study compared different truck configurations operating in the same environment, analyzed the confounding effects of other truck and driver characteristics, relied on data collected by state patrol officers rather than motor carriers, and sampled from the population of trucks traveling on the Interstate system rather than the limited population of trucks operated by a nonrepresentative segment of the trucking industry.

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AUTHORS' CLOSURE

We appreciate the time and effort contributed by Hertz and Zador in their formal comments concerning this research. In addition to a recapitulation of the IIHS study method and findings, their comments focus on three major areas: the design of the experiment and structure of the analysis, the treatment of data and reporting of findings, and the generalizability of the study findings and their implications for policy. We are happy to share our response in each of these areas.

IIHS STUDY

There has never been, nor is there ever likely to be, a definitive study of doubles' safety performance. Our research was not developed in response to specific IIHS findings, so a point-by-point comparison serves no purpose. Although we stand by our comments in the text of our paper, one point needs to be reemphasized: It is not the novelty of the case-control method per se that is at issue; it is the soundness of its execution and the interpretation of the findings. The discussants and the authors of the IIHS study imply that their findings are an accurate assessment of doubles' accident risk across the United States in broad highway operation. We simply disagree with that generalization for all the reasons stated in the text.

We understand the value of the disaggregate analyses conducted with the case-control methodology. Jovanis and Chang have adapted another method from biostatistics, survival theory, to construct a disaggregate model of accident occurrence (*1,2*). We fully support the concept of disaggregate analyses; it is the interpretation given to the IIHS data that we find unacceptable.

TREATMENT OF DATA AND REPORTING OF FINDINGS

The discussants suggest that weights be applied to the accident rate data as an alternative to eliminating low-volume O-D pairs. Beyond this general recommendation, the discussants offer no specifics on how the weights are to be determined. Vehicle miles of doubles and singles differ greatly at individual O-D pairs. If one wishes to retain the paired structure, the difficult decision is how to assign a weight to the accident rate difference when it is composed of vehicle configurations with two different levels of exposure. Rather than develop an ad hoc rule or forego the increase in statistical power associated with the paired structure, we chose the approach of parallel analyses—one with all data and one with higher-volume O-D pairs only.

The discussants are correct in their identification of an inconsistency concerning the standard errors that appeared in Tables 2–5 of the earlier version of the paper. The numbers in parentheses in Table 2–5 are now correctly labeled as the sample standard deviation of the random variable in question. The standard error is obtained by dividing this value by $(n)^{1/2}$. The variables are now correctly labeled and defined in the text; there is no change in the analysis or interpretation of the data.

The discussants indicate that the change in the direction of statistical significance from year to year is "puzzling" and shows a "lack of consistency." We speculated that the reversal in statistical significance in 1984 was due to a driver learning curve and other exogenous phenomena (an increase in automobile VMT). There are many other hypotheses for the reversal in statistical significance, but none can be tested with our data. There is a very clear and consistent pattern for each of the 3 years and for each operating environment; it is this consistency that is the strength of the analyses.

DESIGN OF EXPERIMENT AND STRUCTURE OF ANALYSIS

The discussants argue that the research controls for only type of roadway and does not seek to eliminate or recognize other sources of "bias." Clarification is needed on both points.

The paired structure of the analysis does much more than control for the type of highway exposure. By studying the O-D pairs throughout each year for 3 years, the research implicitly controls for the volume of automobile traffic on each route. As singles and doubles are dispatched throughout the day, they experience generally the same level of automobile traffic. Increases in automobile traffic increase the risk of multiple-vehicle accidents; therefore the paired structure more explicitly controls for traffic level than would a cross-sectional design that compared configurations on similar but not identical routes. Similar arguments can be made for weather conditions.

The discussants argue that time of day is not controlled for, but this is only an issue if doubles are dispatched at consistently different times than singles (and thus exposed to a different level of risk). Carriers do not dispatch vehicles with this differential policy applied to vehicle configurations. They generally dispatch many trips for both vehicle configurations late at night and early in the morning. An independent analysis of accidents occurring on a broader set of O-D pairs reveals no difference in the time of day of accident occurrence for doubles and singles.

Driver experience may be a differential factor for doubles and singles but not for the reasons posed by the discussants. Drivers are not assigned to a vehicle by the firm but by an elaborate process using a bidding system that combines the time at which a driver becomes available for a load and his seniority. It is not possible to examine this hypothesis for the O-D pairs in the study, but for a broader set of routes, the experience of randomly selected drivers is displayed in Table 6. The distribution of driver experience is statistically independent of configuration at the .05 significance level. Although this is not as direct as considering the study O-D pairs alone, the finding, along with knowledge of how drivers are assigned to trucks, gives confidence that driver experience is essentially controlled for in the experiment. Furthermore, the discussants fail to recognize that a firm will manage its drivers in a consistent way, independent of which configuration they drive on a particular day. By conducting the paired comparison for doubles and singles operated by the same firm, even more general driver attributes than experience are controlled for. Differences in safety performance are thus more directly associated with the vehicle configuration, not confounding effects.

Other comments made by the discussants concerning driver and vehicle records presuppose what is at issue. Companies do not routinely "assign" their safest drivers to doubles (even if they could) because they do not believe that doubles are inherently less safe. Although it would have been advantageous to explicitly control for cargo weight and driver age, we believed it more important to control for highway type, traffic level, and weather conditions, because we believe that these are more important contributing factors to accidents than are cargo weight and driver age.

GENERALIZABILITY

The discussants argue quite strongly that the study findings are not generalizable to the industry as a whole. This is a complex issue, which is perhaps best discussed in the context of the original research question; that is, if a carrier has a well-established safety program and generally makes a good-faith effort to comply with federal safety regulations, are doubles inherently less safe than singles? Further, does safety performance change for different roadway types? The direct short answers to these questions based upon this research are that doubles are not inherently less safe than singles and that this finding applies across all highway types included in the study. We believe that this is an important finding that is a research contribution.

Do the data in this study characterize practices throughout the LTL industry? We don't think anyone knows, or can hope to know, the answer to this question, given the questionable accuracy of publicly available accident and operations data for firms (*3*). Any discussion of generalizability that is argued on the basis of characterizing motor carriers' concerns for safety management is thus more likely to be based upon belief or supposition rather than scientific evidence. The alternative is to consider the findings in the context of the extant literature on doubles' and singles' safety performance.

Given the documented evidence regarding differences in configuration handling characteristics (*4*) and related accident outcomes (*5*), it is clear that configuration plays a role in accident causality. The findings here suggest that the differences in causal mechanisms do not result in differences in broad accident risk (i.e., accidents per million miles). The weight of recent evidence from this study, the study by Sparks and Bielka and the study by Carsten suggest, as a composite, that doubles are at least as safe as singles. Safety regulation should thus focus on broad oversight of driver hours, training,

TABLE 6 RANDOM SAMPLE OF DRIVER EXPERIENCE FOR TWO VEHICLE CONFIGURATIONS

	Level of Experience					
	<1	1-3	3-5	5-10	>10	TOTAL
Drivers of Singles	78	49	57	326	407	917
Drivers of Doubles	87	38	36	291	359	811
Total	165	87	93	617	766	1728

substance abuse, and vehicle operation (for all configurations), not on regulations that restrict doubles in particular.

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The findings and conclusions are strictly those of the authors, who assume all responsibility for them.

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