field. For such a large investment to be worthwhile, the results must be usable by more than just a handful of people. Most important, however, is that it must be possible to represent the knowledge by a set of rules.

To conclude, then, the system described here is theoretically feasible. Whether it can be reasonably designed and implemented is a question that must still be answered. It is hoped that the methodology presented here will be helpful in answering that question.

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# Safety Implications of Truck Configuration

OLIVER CARSTEN

**The relative safety of single and double tractor-trailer combinations is examined in the light of recent findings on the performance characteristics of the two classes of vehicle. In particular, the accident data are searched for evidence of a safety deficit for the doubles resulting from the phenomenon of rearward amplification. Although there is no conclusive evidence of an overall difference in fatal and injury accident involvement rates between singles and doubles, this is tempered by the finding of a generally safer operating environment for the doubles. There are strong indications that the doubles have a rollover problem in property-damage accidents. The overall conclusion is that the handling characteristics of large trucks are reflected in their accident experience.**

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In the last 15 years a considerable body of literature has appeared on the dynamic performance of truck combinations. One major focus of this literature has been the phenomenon of rearward amplification for combinations with one or more trailers (*1–3*). Rearward amplification is defined as the tendency in multitrailer combinations traveling at highway speeds for motions of the tractor to be exaggerated further in each successive trailer. The phenomenon is particularly severe in emergency maneuvers, when the motion of the tractor may be both abrupt and of large amplitude. But it may also occur in negotiating tight curves, such as those encountered on exit ramps, or even in regular highway driving if travel speed is sufficient. The major effect of the rearward amplification is to cause the second (or third) trailer to have a lower rollover threshold than the first trailer or, in turn, the tractor.

The advances in knowledge of the handling characteristics of combination vehicles have not been fully reflected in studies using accident data. In particular, there has been little success in exploring the issue of whether the theoretical dynamic handling problems for twin trailer trucks are reflected in the national safety experience of combination trucks. A number of recent studies comparing the accident experience of singles and doubles exist, and most, if not all, of these have been evaluated in the recent Double Trailer Truck Monitoring Study by the Transportation Research Board (*4*). However, some of these prior studies had serious deficiencies (*5*), whereas others depended on data that did not have complete coverage or did not clearly distinguish singles from doubles (*6*). With the availability of new data from the University of Michigan Transportation Research Institute (UMTRI), it is possible to examine issues of vehicle configuration using an accurate, national accident database. UMTRI has for several years been conducting a large-truck research program, focused primarily on vehicle issues. This program is using survey research to enhance the data on large-truck involvements in fatal accidents and to collect exposure data on the use of large trucks. The aim of this program is to address the area of vehicle safety, while controlling for environment (e.g., road class) and for use (e.g., carrier type). Although the exposure data collection is not yet complete, several years of accident data have been compiled and will be used here, along with other sources, to assess the safety experience of singles and doubles.

## DATA SOURCES AND DATA VALIDATION

The first step in the analysis here was an attempt to corroborate and reconcile the accident databases. The recently developed UMTRI file of Trucks Involved in Fatal Accidents (TIFA) has been used as a yardstick here. The TIFA database provides detailed descriptions of all medium and heavy trucks (greater than 10,000 lb gross vehicle weight rating) that were involved in a fatal accident in the continental United States, excluding Alaska. The file combines the coverage of the Fatal Accident Reporting System (FARS) with the descriptive detail of the Bureau of Motor Carrier Safety (BMCS) accident reports. The detailed vehicle and carrier descriptions are obtained either by matching a FARS case with the corresponding BMCS report or by conducting one or more telephone interviews. Extensive editing and consistency checking is performed on all information obtained by interview. For example, vehicle identification numbers are decoded to confirm that the make and model information and the power unit description conform to published model specifications. Overall, the TIFA files have a very low missing-data rate for the variables that document the truck configuration. In the 1980–1982 file, the vehicle combination type is unknown for only 1 percent of the cases. Given this low rate of missing data combined with the complete coverage of fatal involvements and the extensive checking performed for accuracy, there is every reason to believe that the TIFA data provide an accurate description of the relevant vehicles and accidents.

In performing the analysis on singles or doubles, only those sources or reporting levels that could be reconciled to match TIFA have been regarded as appropriate for use in calculating numbers of accidents. In addition, the various data sources have been examined for internal consistency and reasonableness. Sources or reporting levels that did not meet these requirements have been used for descriptive information where this was unlikely to be affected by bias from underreporting. The sources used in this assessment were the BMCS accident reports and data on large-truck involvements from the National Accident Sampling System (NASS).

Tables 1 and 2 show the comparison between NASS and

TABLE 1 TRACTOR-TRAILER ACCIDENT INVOLVEMENTS BY NUMBER OF TRAILERS: COMPARISON OF NASS AND TIFA

| Data Source | Number of Trailers | |
|---|---|---|
| | Single | Double |
| NASS 1981-84[a] | | |
| Property damage only | 465,521 | 5,996 |
| Injury (excl. fatal) . . . | 210,486 | 10,898 |
| Fatal . . . . . . . . . . . . | 12,806 | 673 |
| TIFA[b] . . . . . . . . . . . . | 13,103 | 627 |

[a]The cases in NASS where the vehicle had a trailer but the number of trailers was unknown were distributed proportionately to the cases with a known number of trailers within each accident severity level.

[b]The numbers in the TIFA file for 1981 through 1983 were inflated to four-year estimates.

TABLE 2 ICC-AUTHORIZED TRACTOR-TRAILER ACCIDENT INVOLVEMENTS BY NUMBER OF TRAILERS: COMPARISON OF BMCS AND TIFA

| Data Source | Number of Trailers | |
|---|---|---|
| | Single | Double |
| BMCS 1980–83 | | |
| Property damage only | 39,673 | 1,968 |
| Injury (excl. fatal) . . . | 41,071 | 1,786 |
| Fatal . . . . . . . . . . . | 5,106 | 241 |
| TIFA 1980–83 . . . . . . | 6,475 | 296 |

BMCS on the one hand and TIFA on the other. They also show the number of involvements reported at different accident severities. Because of the small number of cases of large-truck involvement in any single year of NASS, a 4-year file of all the tractor-trailer involvements was created. The counts obtained are shown in Table 1 and the good correspondence on the fatal accidents between NASS and TIFA should be noted. This shows that, in spite of small sample size, the NASS estimates for tractor-trailer involvements at the fatal level, and by inference at the injury level, are reasonable.

If the TIFA numbers for fatal involvements are combined with the NASS estimates of injury and property-damage involvement, one can calculate a ratio of property-damage to injury to fatal involvements for each class of vehicle. This works out to 36:16:1 for the singles and 10:17:1 for the doubles. If these numbers are to be believed, then for every fatal involvement of a single-trailer truck there are 16 injury involvements and 36 property-damage involvements. For each double-trailer truck fatal involvement, there are 17 injury involvements and 10 property-damage involvements. The very large difference between the two classes of vehicle in the ratio of property-damage to fatal involvements does not appear credible. This difference is apparently an artifact of the data and can be attributed to doubles units not being identified in NASS property-damage accidents. There is difficulty in identifying any kind of large truck in an accident for the NASS database because the vehicle has frequently left the area before the investigation begins. It appears reasonable that this problem would be more acute in the less severe accidents and that doubles, which are more likely to be on a long haul, would have a greater tendency than singles to have left the area. Therefore, the NASS estimates of property-damage accident involvement will be excluded as unreliable.

In Table 2 BMCS counts of involvements for tractors with trailers are shown by accident severity and number of trailers. They can be compared with numbers obtained from the TIFA database. Accidents in Alaska and Hawaii were excluded from the BMCS data because they are not covered by TIFA. In addition, a recode was performed on the BMCS combination type field in the UMTRI file. Examination of the BMCS cases incorporated into the TIFA file indicated that all but a handful of the vehicles reported as tractors with full trailers and tractors with other trailers are in fact tractors with semitrailers. Similarly, almost all of the tractors reported as pulling a semitrailer and some trailer other than a full trailer were in fact pulling a semitrailer and a full trailer. Therefore the appropriate recode was performed and Table 2 reflects the result. Because of known underreporting of accidents to BMCS by nonauthorized carriers, the counts have been restricted to the carriers authorized by the Interstate Commerce Commission (ICC). The TIFA numbers have been similarly restricted.

Comparing the BMCS counts of fatal accident involvements with the numbers from TIFA, it is clear that even for fatal accidents there is a certain amount of underreporting. However, it is almost identical for singles and doubles: for the former it is 21.1 percent and for the latter 18.6 percent. Thus any estimates of injury accident involvement rates derived from BMCS are not likely to suffer from differential reporting. There does, however, appear to be very substantial underreporting of property-damage accidents to BMCS. Even given the reporting threshold of $2,000 of damage, the roughly equal numbers of injury and property-damage accidents do not appear credible. To validate the rejection of the BMCS property-damage counts, a comparison was made with Texas and Michigan state accident files. BMCS defines an injury accident as one that requires medical treatment away from the scene, but both state files use the police KABCO coding for severity in which a C-injury is defined as "possible injury." These injuries are unlikely to require treatment and, for the purpose of making the comparison, the C-level injury involvements in the state data were grouped with the property-damage-only involvements. In 1984 Texas reported 4.5 times as many noninjury (property and C-injury) tractor combination involvements as injury involvements (A- and B-injury); Michigan reported 6.6 times as many noninjury involvements as injury involvements. The BMCS property-damage threshold of $2,000 clearly has an impact in the ratio of noninjury to injury accidents, but hardly appears capable of reducing the ratio to 1:1.

If the counts of BMCS-reported property-damage accidents are to be disregarded, this does not mean that all the information on them provided by the file has no value. The descriptive information would only be questionable if one could hypothesize a bias effect from missing data, that is, a situation in which the unreported cases might change one's conclusions about, for example, the proportion of rollover accidents by number of trailers or the amount of property damage from rollover accidents as compared with nonrollover accidents. In many situations the effect of such bias is unlikely to be great and the data

TABLE 3 TRACTOR-TRAILER FATAL ACCIDENT INVOLVEMENT RATES BY DATA SOURCE AND NUMBER OF TRAILERS

| Data Source for Involvement Counts | Number of Involvements | | Total VMT in Millions[a] | | Involvement Rate per 100 million VMT | |
|---|---|---|---|---|---|---|
| | Single | Double | Single | Double | Single | Double |
| TIFA 1982 | | | | | | |
| All ....... | 3,139 | 131 | 45,817 | 1,968 | 6.9 | 6.7 |
| ICC only ... | 1,611 | 66 | 16,490 | 854 | 9.8 | 7.7 |
| TIFA 1980-82 | | | | | | |
| All ....... | 9,914 | 448 | 137,451 | 5,903 | 7.2 | 7.6 |
| ICC only ... | 4,808 | 221 | 49,470 | 2,563 | 9.7 | 8.6 |

[a]From 1982 Truck Inventory and Use Survey. The mileages for 1980-82 are three times the 1982 mileages.

from the BMCS property-damage accidents can be used for the description of accidents and their consequences.

## THE OVERALL SAFETY EXPERIENCE OF SINGLES AND DOUBLES

With data from TIFA, NASS, and BMCS an overall comparison can be made between the safety experience of tractor and semitrailer combinations and of tractor and twin trailer combinations. Such a comparison will not, given existing use data, be able to take into account the operating environment in which the two classes of vehicles are used, but it will enable the observation of any differences in safety that are of sufficient magnitude to affect the overall picture.

In Table 3 counts of tractor-trailer fatal accident involvements from TIFA are combined with exposure estimates from the 1982 Truck Inventory and Use Survey (TIUS) to provide fatal accident involvement rates. With 1982 TIFA alone, the doubles units appear to have a slightly lower rate of fatal accident involvements, both overall and for the vehicles operated by the ICC-authorized carriers. However, if instead accident data from 3 years are used because of the relatively small number of doubles units involved in fatal accidents in a single year (130 in 1982), the doubles have a slightly higher rate overall, but a somewhat lower rate for the ICC-authorized carriers. A reasonable conclusion would be one of no difference in fatal accident involvement rate between the singles and doubles.

Table 4 provides rates of involvement in accidents that resulted in at least one injury. The two sources of the involvement counts here are the 1981–1984 combined NASS file and the 1982 BMCS file limited to ICC-authorized carriers only. Because the definition of an injury accident varies between the two data sources (BMCS requires reporting of an injury accident involvement only if there is medical treatment away from the scene, whereas NASS uses the observation of the police officer), no comparisons should be made between the BMCS and NASS counts. According to both sources, the doubles have a slightly lower rate, but the difference is small enough and the data quality is uncertain enough to lead to a conclusion of no difference in injury accident involvement rates. Thus the overall assessment is one of no difference in either fatal or injury accident involvement rates between singles and doubles. However, these numbers do not take into account the operating environment in which the vehicles are used. If one class of vehicle was used more often in a safer operating environment, the overall accident involvement rates, which are roughly similar, would conceal a real difference in safety.

Table 5 shows fatal accident involvement rates by operating environment for all combination trucks. The involvement counts are from TIFA, and the exposure figures are the esti-

TABLE 4 TRACTOR-TRAILER INJURY (including Fatal) ACCIDENT INVOLVEMENT RATES BY DATA SOURCE AND NUMBER OF TRAILERS

| Data Source for Involvement Counts | Number of Involvements | | Total VMT in Millions[a] | | Involvement Rate per 100 million VMT | |
|---|---|---|---|---|---|---|
| | Single | Double | Single | Double | Single | Double |
| NASS 1981-84 (All) .. | 225,769 | 9,094 | 183,268 | 7,870 | 123.2 | 115.5 |
| BMCS 1982 (ICC only) | 11,881 | 527 | 16,490 | 854 | 72.0 | 61.7 |

[a]From 1982 Truck Inventory and Use Survey. The mileages for 1980-84 are five times the 1982 mileages.

TABLE 5 COMBINATION-TRUCK FATAL ACCIDENT INVOLVEMENT RATE BY ROAD TYPE: TIFA, 1980–1982

| Road Type | Number of Involvements[a] | Total VMT in Millions[b] | Involvement Rate per 100 million VMT |
|---|---|---|---|
| Urban interstate . . . | 917 | 25,551 | 3.6 |
| Urban non-interstate | 1,979 | 27,164 | 7.3 |
| Rural interstate . . . . | 1,750 | 60,554 | 2.9 |
| Rural non-interstate | 5,678 | 66,078 | 8.6 |
| Unknown . . . . . . . . | 276 | — | — |
| All . . . . . . . . . . . . . | 10,600 | 179,347 | 5.9 |

[a]From TIFA.

[b]From Federal Highway Administration *Highway Statistics*, 1980 and 1982.

mates calculated by FHWA. Substantial differences in safety are revealed between operating environments, with the rural Interstates having the lowest fatal accident involvement rate. The involvement rate on rural Interstates is one-third that on rural non-Interstates. The rate on all Interstates is less than half that on all non-Interstates. If doubles log a greater share of their mileage on the relatively safe Interstates than did singles, one might conclude that the finding of no difference in overall accident involvement rates was unfavorable to the doubles. In the absence of true exposure data comparing the use of singles and doubles by operating environment, this cannot be tested directly. It is possible, however, to infer differences in use from the accident data. This procedure is by no means perfect, because it ignores the interactions of other factors beyond those being directly observed. But, if it does not permit an estimate of the *size* of differences in exposure, it does at least permit an estimate of the *direction* of differences.

Table 6 shows the proportions of fatal accident involvements by road class for singles and doubles. (All the data presented in Tables 6 through 15 are from two censuses of accident involvements and are therefore not subject to sampling variance. However, in order to establish that the dimensions shown in each of these tables were not independent of each other, the chi-square test was run for each table. For every table the chi-square was significant at the .05 level or less.) Here a classification into divided and undivided, which is not available in the FHWA exposure estimates, is used. This classification is more appealing from a safety viewpoint and is the only one common to both the TIFA fatal data and the BMCS accident data. According to Table 6, 48 percent of doubles fatal involvements occur on divided roads as opposed to 41 percent for singles. Table 7 shows the same comparison using all BMCS-reported involvements by ICC-authorized carriers. Here a remarkable 70 percent of the doubles involvements are on divided roads as compared with 52 percent of the singles involvements.

The distributions of involvements by road class point out the need for more detailed exposure data. But pending better data, it is still possible to test some hypotheses by using current data. One possible explanation for the very large concentration in Table 7 of doubles involvements on divided highways might be that rearward amplification is more of a problem on high-speed roads. However, if the ICC doubles involvements reported to BMCS are broken out by accident severity, the divided roads account for 60.5 percent of the fatal involvements, 72.5 percent of the injury involvements, and 68.8 percent of the property damage involvements. Rearward amplification, which may be a major causal factor in a few fatal accidents and perhaps in some injury accidents, cannot be expected to account for all of the observed distribution of accidents by road class. This distribution appears to be rather a reflection of use.

TABLE 6 TRACTOR-TRAILER FATAL ACCIDENT INVOLVEMENTS BY ROAD CLASS AND NUMBER OF TRAILERS: TIFA, 1980–1982

| Road Class | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| Divided | 4,057 | 40.9 | 215 | 48.0 |
| Undivided | 5,783 | 58.3 | 231 | 51.6 |
| Unknown | 74 | 0.7 | 2 | 0.4 |
| Total . . . | 9,914 | 100.0 | 448 | 100.0 |

TABLE 7 ALL ICC-AUTHORIZED TRACTOR-TRAILER ACCIDENT INVOLVEMENTS BY ROAD CLASS AND NUMBER OF TRAILERS: BMCS, 1984

| Road Class | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| Divided | 13,029 | 51.6 | 959 | 70.0 |
| Undivided | 10,383 | 41.2 | 364 | 26.6 |
| Unknown | 1,819 | 7.2 | 47 | 3.4 |
| Total | 25,231 | 100.0 | 1,370 | 100.0 |

From Table 5, it has been shown that travel on Interstates and presumably on divided highways is safer than on other kinds of roads. Because there is no evidence that the divided highways are any less safe for doubles than for singles, the differing split of accidents by road class between singles and doubles can only be explained by exposure. The data clearly imply that doubles log a greater share of their travel on divided roads than do singles. Hence one would expect doubles to have a lower overall accident involvement rate than singles. The fact that the rate is roughly equal to that of the singles is cause for concern. In mitigation, it should be noted that, according to Table 3, the doubles units operated by ICC carriers do have lower accident involvement rates than their singles counterparts. Hence, the expectation from the road class information of lower rates for doubles does appear to be met.

## ACCIDENT TYPE

Although the analysis of accident involvement rates of single-trailer and double-trailer vehicles cannot be carried any further pending the availability of more detailed exposure data, the accident data alone can be examined for indications of areas in which the safety performance of current doubles is deficient when compared with that of singles. The focus here, as indicated in the introduction, will be on handling-related factors.

Tables 8 and 9 show the proportions of single- and multi-vehicle accident involvements for the two classes of vehicle. Here the hypothesis is that if the current doubles fleet has greater handling problems than the singles fleet, the doubles should be overrepresented in the single-vehicle accidents. This indeed appears to be the case. For both fatal accidents (Table 8) and overall accidents in ICC-authorized vehicles (Table 9), the data show an excess of doubles involvement in single-vehicle accidents.

In the next two tables the distribution of the first harmful event and the most harmful event for fatal involvements is examined. In Table 10 (first harmful event) doubles are underrepresented in collisions with motor vehicles in transport, which follows from their overrepresentation in single-vehicle accidents. There is an excess of collisions with pedestrians and bicyclists, which may hint at some urban-related problems for doubles. As regards handling issues, the doubles are overrepresented in collisions with fixed objects, which might result from loss of control, but there are proportionately fewer first-event rollovers for doubles than for singles. (A first-event rollover is the primary event in the accident, whereas a subsequent-event rollover occurs after some other primary event.) The picture is not very different in Table 11, which gives the distribution of the most harmful event. Once again doubles demonstrate an excess of fatal collisions with pedestrians and bicyclists and an excess of collisions with fixed objects. Now, however, doubles slightly exceed singles in the proportion of overturns. This suggests that doubles have a tendency to roll over once an

TABLE 8 TRACTOR-TRAILER INVOLVEMENTS BY NUMBER OF VEHICLES INVOLVED AND NUMBER OF TRAILERS: TIFA, 1980–1982

| Number of Vehicles Involved | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| One vehicle | 2,159 | 21.8 | 119 | 26.6 |
| More than one vehicle | 7,753 | 78.2 | 329 | 73.4 |
| Unknown | 2 | 0.0 | 0 | 0.0 |
| Total | 9,914 | 100.0 | 448 | 100.0 |

TABLE 9 ALL ICC-AUTHORIZED TRACTOR-TRAILER ACCIDENT INVOLVEMENTS BY NUMBER OF VEHICLES INVOLVED AND NUMBER OF TRAILERS: BMCS, 1984

| Number of Vehicles Involved | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| One vehicle ........ | 12,203 | 48.4 | 786 | 57.4 |
| More than one vehicle | 13,028 | 51.6 | 584 | 42.6 |
| Total ............ | 25,231 | 100.0 | 1,370 | 100.0 |

TABLE 10 TRACTOR-TRAILER INVOLVEMENTS BY FIRST HARMFUL EVENT AND NUMBER OF TRAILERS: TIFA, 1980–1982

| First Harmful Event | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| Collision with: | | | | |
| motor veh. in transport | 7,245 | 73.1 | 301 | 67.2 |
| pedestrian ......... | 682 | 6.9 | 44 | 9.8 |
| pedalcycle ......... | 92 | 0.9 | 9 | 2.0 |
| parked motor veh. .... | 131 | 1.3 | 9 | 2.0 |
| other non-fixed object . | 254 | 2.6 | 14 | 3.1 |
| fixed object ......... | 845 | 8.5 | 43 | 9.6 |
| Overturn ........... | 603 | 6.1 | 25 | 5.6 |
| Other non-collision ..... | 62 | 0.6 | 3 | 0.7 |
| Total ............... | 9,914 | 100.0 | 448 | 100.0 |

TABLE 11 TRACTOR-TRAILER INVOLVEMENTS BY MOST HARMFUL EVENT AND NUMBER OF TRAILERS: TIFA, 1980–1982

| Most Harmful Event | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| Collision with: | | | | |
| motor veh. in transport | 6,775 | 68.3 | 295 | 65.8 |
| pedestrian ......... | 722 | 7.3 | 47 | 10.5 |
| pedalcycle ......... | 90 | 0.9 | 9 | 2.0 |
| parked motor veh. .... | 79 | 0.8 | 3 | 0.7 |
| other non-fixed object . | 180 | 1.8 | 10 | 2.2 |
| fixed object ......... | 423 | 4.3 | 24 | 5.4 |
| Overturn ........... | 964 | 9.7 | 46 | 10.3 |
| Other non-collision ..... | 287 | 2.9 | 14 | 3.1 |
| Unknown ........... | 394 | 4.0 | 0 | 0.0 |
| Total ............... | 9,914 | 100.0 | 448 | 100.0 |

TABLE 12 TRACTOR-TRAILER INVOLVEMENTS BY ROLLOVER AND NUMBER OF TRAILERS: TIFA, 1980–1982

| Rollover | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| None | 8,251 | 83.2 | 357 | 79.7 |
| First event | 618 | 6.2 | 23 | 5.1 |
| Subsequent event | 1,045 | 10.5 | 68 | 15.2 |
| Total | 9,914 | 100.0 | 448 | 100.0 |

accident has begun and that these rollovers are associated with fatal injury.

This conclusion is reinforced by the distribution of rollovers for fatal involvements (Table 12). Doubles have a somewhat lower probability of a first-event rollover but a considerably higher probability of a subsequent-event rollover. In Table 13 another handling-related factor, jackknifing (which, as coded in FARS, includes trailer swings) is examined. Here doubles have an excessive number of first-event jackknifes but a slightly lower probability of a subsequent-event jackknife. Thus, from fatal accidents, at least, there is clear substantiation of handling-related problems for doubles.

In Tables 14 and 15 data are presented to examine whether the indication of handling problems for doubles in the fatal data is borne out by information on all involvements reported by ICC-authorized carriers. Table 14 shows the distribution of noncollision accidents for the involvements reported to BMCS in 1984. Doubles have a smaller proportion of involvements in collision accidents. They are overrepresented in every major type of noncollision accident, particularly overturns. The probability of a rollover for a double is two-and-a-half times greater than the probability for a single. Table 15 makes the same comparison for property-damage-only accidents reported to BMCS by the ICC-authorized carriers. Here less than half the doubles involvements are in collision accidents, compared with almost three-fourths of the singles involvements. For these accidents, doubles have a probability of rollover that is more than four times greater than that for singles.

In the BMCS injury-level (not including fatal) involvements reported by the ICC-authorized carriers, doubles have about a 25 percent higher probability of rollover. Because there is evidence (Table 11) that doubles rollovers are correlated with injury, one might expect doubles accidents to result in somewhat more serious injuries than singles accidents. An examination of the NASS data, shown in Table 16, tends to confirm this. Here the distribution of the maximum on the Abbreviated Injury Scale (AIS) for any injury incurred in the accident is shown. Injuries of unknown severity (AIS-7) have been added to the AIS-2 group. (Of the singles involvements 13.5 percent had MAIS-7; of the doubles involvements, none. Adding the 13.5 percent to the MAIS-1 proportion for the singles would have resulted in concluding, purely on the basis of reallocating the MAIS-7 involvements, that there was a difference in the distribution of MAIS-1 and MAIS-2 involvements between the singles and the doubles and that this difference was unfavorable to doubles. It was believed that it was more conservative here to allocate the MAIS-7 involvements to the MAIS-2 category, because it is improbable that any of the AIS-7 injuries are really AIS-3 or greater.) According to Table 16 doubles are involved in a lower proportion of MAIS-2 accidents but a higher proportion of MAIS-3 accidents. Thus the most severe injury incurred is likely to be more severe in an injury accident involving a double-trailer combination than in an injury accident involving a single-trailer combination. Whether this difference is entirely attributable to handling-related accidents or whether it is a by-product of road class cannot be concluded

TABLE 13 TRACTOR-TRAILER INVOLVEMENTS BY JACKKNIFE AND NUMBER OF TRAILERS: TIFA, 1980–1982

| Jackknife | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| None | 8,966 | 90.4 | 384 | 85.7 |
| First event | 719 | 7.3 | 56 | 12.5 |
| Subsequent event | 229 | 2.3 | 8 | 1.8 |
| Total | 9,914 | 100.0 | 448 | 100.0 |

TABLE 14 ALL ICC-AUTHORIZED TRACTOR-TRAILER ACCIDENT INVOLVEMENTS BY NONCOLLISION TYPE AND NUMBER OF TRAILERS: BMCS, 1984

| Non-Collision Type | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| Ran off road ...... | 1,616 | 6.4 | 117 | 8.5 |
| Jackknife ........ | 1,749 | 6.9 | 138 | 10.1 |
| Overturn ......... | 1,942 | 7.7 | 262 | 19.1 |
| Separation of units . | 130 | 0.5 | 16 | 1.2 |
| Fire ............ | 172 | 0.7 | 5 | 0.4 |
| Cargo loss or spillage | 132 | 0.5 | 2 | 0.1 |
| Cargo shift ....... | 97 | 0.4 | 2 | 0.1 |
| Other non-collision . . | 47 | 0.2 | 1 | 0.1 |
| Collision ......... | 19,346 | 76.7 | 827 | 60.4 |
| Total ........... | 25,231 | 100.0 | 1,370 | 100.0 |

TABLE 15 ICC-AUTHORIZED TRACTOR-TRAILER PROPERTY-DAMAGE ACCIDENT INVOLVEMENTS BY NONCOLLISION TYPE AND NUMBER OF TRAILERS: BMCS, 1984

| Non-Collision Type | Number of Trailers | | | |
|---|---|---|---|---|
| | Single | | Double | |
| | N | % | N | % |
| Ran off road ...... | 724 | 6.1 | 45 | 6.7 |
| Jackknife ........ | 1,177 | 9.9 | 79 | 11.8 |
| Overturn ......... | 813 | 6.8 | 191 | 28.5 |
| Separation of units . | 111 | 0.9 | 14 | 2.1 |
| Fire ............ | 159 | 1.3 | 3 | 0.4 |
| Cargo loss or spillage | 102 | 0.9 | 1 | 0.1 |
| Cargo shift ....... | 62 | 0.5 | 2 | 0.3 |
| Other non-collision . . | 31 | 0.3 | 1 | 0.1 |
| Collision ......... | 8,700 | 73.2 | 334 | 49.9 |
| Total ........... | 11,879 | 100.0 | 670 | 100.0 |

TABLE 16 MAXIMUM AIS (MAIS) FOR INJURY-LEVEL TRACTOR-TRAILER INVOLVEMENTS BY NUMBER OF TRAILERS: NASS, 1981–1984

| MAIS | Number of Trailers | | | | | |
|---|---|---|---|---|---|---|
| | Single | | | Double | | |
| | N | Weighted N | % | N | Weighted N | % |
| MAIS-1 | 543 | 105,565 | 64.7 | 15 | 5,248 | 62.1 |
| MAIS-2 | 226 | 45,921 | 28.2 | 5 | 1,579 | 18.7 |
| MAIS-3 | 65 | 9,628 | 5.9 | 5 | 1,566 | 18.5 |
| MAIS-4 | 10 | 1,401 | 0.9 | 1 | 55 | 0.6 |
| MAIS-5 | 6 | 614 | 0.4 | 0 | 0 | 0.0 |
| Total . . | 850 | 163,129 | 100.0 | 26 | 8,446 | 100.0 |

from the NASS data. Unfortunately, there are insufficient cases to examine any accident factors.

Thus, although doubles have approximately the same overall accident involvement rate as singles, there are clear indications in the accident data that in certain areas of performance, conventional double-trailer vehicles do not perform as well as singles. Rollovers, in particular, are more common for these vehicles than for the tractor-semitrailer combinations. There is some evidence that these rollovers are related to injury and they tend to be costly. According to the 1984 BMCS data, the ICC-authorized carriers reported cargo spillage for 31 percent of their rollover involvements, but only for 4 percent of their nonrollover involvements. The same group of carriers reported a mean property damage of $12,846 for doubles involvements in which the primary event was other than a rollover and $15,540 for involvements in which the primary event was a rollover.

## CONCLUSIONS

Research on the physical handling of doubles combinations has indicated the potential for safety problems in the normal use of these vehicles. The findings from actual highway experience do not show a higher fatal or injury accident involvement rate for doubles. Nevertheless, this must be tempered by evidence that doubles are used more in safer operating environments. It must also be tempered by indications in the accident data of handling-related problems for doubles, and particularly by a finding of large overinvolvement in rollovers at the property damage level as compared with singles.

The comparison of singles and doubles demonstrates the influence of vehicle characteristics on accident experience. One might presume that drivers are able to compensate for differences in vehicle handling. The fact that the objective performance measures for doubles are reflected in the accident data indicates that drivers are unable to compensate fully. It seems likely, therefore, that improving the handling of double-trailer combinations will provide significant safety benefits.

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