PROBLEMS OF COMBINATION TRUCKS ON WET PAVEMENTS: AN ACCIDENT ANALYSIS

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AN ACCIDENT ANALYSIS

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ABSTRACT

Based on 1979 through 1981 Bureau of Motor Carriers Safety (BMCS) accident data, a study concerning wet-pavement truck accidents was carried out for over-the-road Interstate Commerce Commission (ICC-authorized) trucks. The analysis was limited to truck accident involvements on 4-or-more-lane highways in Texas. Discrete-multivariate methods were used for the analysis.

The analysis indicates that empty trucks show up to 3 times higher propensity for single-truck accident involvements (run-off-road, jackknife, overturn, and separation of units) on wet pavements than do loaded trucks.

The ratios of wet-pavement to dry-pavement accident involvements were found to be influenced by empty/loaded, truck type, and accident type, but not by day/night. The ratio of single-truck accident involvements on wet pavements to those on dry pavements was found to be much higher for empty trucks than for loaded trucks, after adjusting for truck type. Heavy-Truck involvements in multi-vehicle collisions were used as a comparison group.

These findings appear to strongly support the prediction by W.B. Horne and the laboratory study conducted by D. L. Ivey, that truck tires can hydroplane at highway speeds when the trucks are empty or lightly loaded.

PROBLEMS OF EMPTY COMBINATION TRUCKS ON WET PAVEMENTS: AN ACCIDENT ANALYSIS

I. OBJECTIVE

The purpose of this paper is to identify possible causes of combination-truck accidents that result from loss of control. In particular, an in-depth analysis of past accident experience of empty combination trucks in wet conditions will be carried out. The data source for this investigation is the Bureau of Motor Carriers Safety (BMCS) file for the Interstate Commerce Commission (ICC-authorized) carriers.

II. INTRODUCTION

Combination truck accidents that result from loss of control are complex phenomena. They are usually the result of failures in the system comprising vehicle, roadway, driver, visibility, and environmental characteristics, as well as chance. While theoretical work on vehicle dynamics, laboratory simulation and vehicle testing have greatly enhanced the knowledge concerning the factors that lead to lack of stability of trucks in wet conditions, past accident records of these heavy trucks have not been thoroughly analyzed to provide evidence in support of these theories.

Ivey, Tonda, Horne, and Chira-Chavala (1) reported that the following elements, independently or interactively, had been identified by past studies as possible causes for combination trucks losing control in wet conditions.

a) low tire pavement friction
b) brake system characteristics
c) speed
d) reduced visibility
e) hydroplaning

Loss of control of combination trucks may result in reported accidents such as jackknife, overturn, run-off-road, and separation of units. These four types of accidents are collectively referred to in this report as single-truck accidents.

It was not until very recently that dynamic hydroplaning was believed to contribute to loss of control of lightly loaded combination trucks (2). The accident analysis presented here will systematically identify factors that affect the probability of single-truck accidents in general first. Then an in-depth analysis of truck accident records will be performed to determine and to compare single-truck accident propensity on wet pavements for empty and for loaded trucks. In this way, past accident experience of these trucks may be used to provide a supporting evidence (or otherwise) to the hydroplaning hypothesis of Horne (2).

III. LITERATURE REVIEW

Horne (2) was the first to predict that, contrary to conventional wisdom, truck tires were subject to dynamic hydroplaning at highway speeds when empty or lightly loaded. A verification of Horne's prediction was carried out by Ivey (2) using a test trailer in simulated highway environments and recording the speeds at which the tires began to spin down. In reporting these results in support of Horne's prediction, Ivey also explained the following:

> "In the early 60's, Horne and his fellow engineers in NASA discovered and studied the phenomenon of hydroplaning as it related to aircraft tires. Because of the way aircraft tires are constructed, the shape of the contact patch (that portion of the tire actually in contact with the ground) remains much the same for a fairly wide variation of tire load. The NASA group found that one could predict hydroplaning speed as a simple function of tire pressure. This relationship predicted hydroplaning speeds of tires with 60 to 100 psi inflation pressure well above what could be achieved by highway vehicles. Since truck tires normally required pressures in this range, it was felt that they would not be subjected to speeds high enough to hydroplane. Further work in the late 60's on automobile tires confirmed that hydroplaning speeds would be extremely high at high levels of tire pressure. These studies of automobile tires, including testing by A. J. Stocker, B. M. Gallaway and D. L. Ivey at TTI, pointed to tire loads as being an unimportant variable. The following was not

appreciated. While an automobile tire for a 4000 lb. vehicle may have a normal range of loads from 800 to 1200 lbs., a truck tire may be operated with loads varying from 600 to 6000 lbs. With this extremely wide load variation, the aspect ratio of a truck tire surface contact zones varies spectacularly, leading to hydroplaning conditions for a lightly-loaded, albeit normally inflated, truck tire at speeds common to highway vehicles. The aspect ratio is the ratio of the surface contact zone width to length."

A recent study based on analyses of accident data of combination trucks by Chira-Chavala (3) revealed that for empty trucks on rural highways, the proportion of total truck accident involvements that were single-truck (as opposed to collisions with at least another vehicle) substantially increased in wet conditions (up to 3 times of that on dry pavements). The single truck accident proportion for loaded van, flatbed, and tanker semitrailers in wet conditions, however, was only 1.5 times or less of that in dry conditions.

IV. CONCEPTUAL BASIS FOR ACCIDENT ANALYSIS

The analysis of accident data consists of two parts: a preliminary analysis of factors influencing the types of truck accident involvements (i.e., single-truck or multi-vehicle accidents) in general and an in-depth analysis of single-truck accident propensity on wet pavements for empty and for loaded trucks. The preliminary analysis is required because:

(a) it provides a quick screening to see whether the subsequent in-depth analysis is warranted. To be warranted, the preliminary analysis should indicate that pavement condition (wet or dry) and empty/loaded, were among the significant variables influencing the probability of single-truck accidents.

(b) The propensity for single-truck accidents on wet pavements may be influenced by a number of other factors. The preliminary analysis will serve as a variable selection step to determine which significant variables, out of a very large number of potential variables, are to be included for the in-depth analysis. In this way, a multivariate analysis can be effectively conducted without serious sample size problems, which may have arisen otherwise.

V. PRELIMINARY DATA ANALYSIS OF ACCIDENT TYPES

Truck accident involvements fall mostly into one of the following accident types:

(a) non-collision

(b) collision with fixed object

(c) collision with passenger vehicle

(d) collision with large commercial vehicle

According to the BMCS, about 25 percent of the annually reported truck accident involvements were non-collisions, 10 percent collisions with fixed objects, 45 percent collisions with passenger vehicles, 15 percent collisions with large commercial vehicles, and 5 percent other accident types. For the non-collisions, about 90 percent were reported as run-off-road, jackknife, overturn, or separation of units.

Given that a combination truck is involved in an acident, the probability that it will be a non-collision accident, a fixed object collision, or a multi-vehicle collision is likely to be influenced by factors such as vehicle, operational, driver, roadway, and environmental characteristics. Such a probability can be expressed as:

$$P\left[\text{A Specific Accident Type} \mid \text{An Involvement}\right] = f(\text{vehicle, operation, driver, road, environment})$$

To identify those significant variables influencing this probability, and to discard those non-significant variables, the 1981 BMCS data for all ICC-authorized truck accident involvements was analyzed. Sixteen potential variables were initially examined. Table 1 shows these variables and their levels.

The procedure to determine the significant variables of accident types was based on the tests developed by Landis, Heyman, and Koch (<u>4</u>), using two measures of association for contingency-table analyses: Q_{CMH} and Q_T. This procedure had been applied in a recent study concerning accident severity of combination-truck accidents (5). Only the result of the variable-selection analysis is reported here.

Of the 16 variables considered, those which were found to be significant were:

a. trip length
b. road class
c. dry/wet pavements
d. ramps
e. empty/loaded
f. day/night
g. driver experience
h. driver age
i. vehicle configuration
j. trailer body style

As expected, wet/dry pavements and empty/loaded were among the significant variables identified by the variable selection analysis. The subsequent in-depth analyses will determine single-truck accident propensity on wet pavements and the factors affecting this propensity.

VI. ANALYSIS OF SINGLE-TRUCK ACCIDENT PROPENSITY ON WET PAVEMENTS

This analysis is aimed at determining single-truck accident propensity on wet pavements, particularly that which may be attributable to dynamic hydroplaning of truck tires. Specifically, single-truck accident propensity on wet pavements for empty trucks and for loaded trucks will be determined and compared. To this end, the BMCS-reported accidents involving at least one combination truck on 4-or-more-lane highways in Texas were analyzed. The analysis was also restricted to the reported accidents involving ICC-authorized trucks in over-the-road service. This restriction was due to the relatively high under-coverage of the BMCS-reported accidents involving private carriers.

For the accident data to be supportive of the hydroplaning theory by Horne, one would expect to see a significantly higher ratio of single-truck accidents (i.e. run-off-road, jackknife, overturn, and separation of units) on wet pavements to those on dry pavements for empty trucks than for loaded trucks. To ensure that this higher ratio was not an artifact of the truck exposure (e.g. empty trucks happened to travel more in wet weather than did loaded trucks, or empty trucks tended to travel faster than did loaded trucks), heavy-truck involvements in multi-vehicle collisions were used as a comparison group.

All the significant variables that were identified in the preliminary data analysis, were closely examined here. Trip length, road class, and ramps were incorporated into the analysis by considering only the accident involvements of over-the-road carriers and on 4-or-more-lane highways. Driver age and experience were not included because their effect on the proportion of truck accident involvements that were single-truck was relatively small (3). Furthermore, within the same truck type, their effect on single-truck accident probability was found to be similar between wet and dry pavements, as well as between empty and loaded trucks (3).

Data Source

The BMCS file contains information on accidents involving interstate motor carriers that are subject to the U. S. Department of Transportation Act of 1966 (49 U. S. C. 1655). With few exceptions, these carriers are required to report to the BMCS any accident involving their vehicles that resulted in death, injury, or property damage exceeding $2000. Exempted are occurrences that involve any boardings and alightings from stationary vehicles, loading and unloading of cargo, or farm-to-market agricultural transportation. The accident information is reported to the BMCS by the carriers themselves on standard forms.

There are altogether 74 variables describing the place and time of accident, events leading to the accident, accident consequences, driver and occupant characteristics, vehicle characteristics, road and environment. Over 30,000 accident involvements are reported to the BMCS each year. Of these, about 80 percent are by the ICC-authorized carriers and the other 20 percent are by private or other non-ICC-authorized carriers.

Data Input

Table 2 is a contingency table of the BMCS-reported truck accident involvements for Texas between 1979 and 1981, cross classified by wet or dry pavements (V1), empty or loaded trucks (V2), truck type (V3), day/night (V4), and accident type (V5). Five truck types were defined: single-unit trucks (also included tractor-only), combination trucks pulling van trailers, combination trucks pulling flatbed trailers, combination trucks pulling tankers, and combination trucks pulling other types of trailers. The variable day/night was defined so that "night" included dawn, dusk, dark, and artificial light conditions. Accident type was a dichotomous variable: single-truck accidents (run-off-road, jackknife, overturn, separation of units) or multi-vehicle collisions involving at least one heavy truck.

Table 2 also shows two useful descriptive statistics: the cross-product ratios (τ) between wet/dry and empty/loaded and the standardized cross-product ratios (Z).

A cross-product ratio expresses the odds of wet-pavement accident involvements for empty trucks to the odds of wet-pavement accident involvements for loaded trucks, or

$$\tau = \frac{X_{11}X_{22}}{X_{12}X_{21}}$$

where

X_{11} = the number of wet-pavement accident involvements for empty trucks,

X_{12} = the number of dry-pavement accident involvements for empty trucks,

X_{21} = the number of wet-pavement accident involvements for loaded trucks, and

X_{22} = the number of dry-pavement accident involvements for loaded trucks.

A cross-product ratio of 1 therefore indicates that the wet-pavement-accident propensity is the same for empty and for loaded trucks. A ratio of higher than 1 indicates a higher likelihood of wet-pavement accident involvements for empty trucks than for loaded trucks, and vice versa.

The values of cross-product ratios alone are not usually reliable measures for comparison due to their difference in standard errors. These standard errors, in turn, are influenced by the sample size (i.e. $X_{11} + X_{12} + X_{21} + X_{22}$). Standardized cross-product ratios, which take into account the magnitude of standard errors, are usually more useful as descriptive statistics.

A standardized cross-product ratio is defined by Griffin (6) as:

$$Z = \frac{\ln \tau}{\sqrt{\frac{1}{X_{11}} + \frac{1}{X_{12}} + \frac{1}{X_{21}} + \frac{1}{X_{22}}}}$$

A τ value of 1 corresponds to a Z value of zero. A τ value less than 1 corresponds to a negative Z value, and a τ value greater than 1 results in a positive Z value.

To obtain the significant effect of the independent variables on the single-truck accident propensity on wet pavements, the following modeling method is used.

Analysis Method

In order to analyze and compare the ratios single-truck accidents on wet pavements to those on dry pavements for empty and for loaded trucks, a discrete-multivariate model with a control group was used. The purpose of the modeling was to account for the significant effect of truck type, day/night, and chance variation so that the true effect of empty/loaded on the ratios of wet-to-dry single-truck accident involvements could be obtained. The control group of multi-vehicle collisions involving at least one heavy truck was also employed in the analysis to further enhance the credibility of the results. In this way, the effect due to confounding variables would be minimized and the estimates of wet-to-dry accident ratios might then be stable.

The model can be expressed as follows:

$$\ln\left[\frac{p}{1 - p}\right] = w + w_2 + w_3 + w_4 + w_5 + w_{23} + w_{24} + \ldots$$

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where p is the proportion of accident involvements that occurred on wet pavements.

Therefore, (1 - p) is the proportion of accident involvements occurring on dry pavements.

w is the overall mean.

w_2 is the main effect of empty/loaded.

w_3 is the main effect of truck type.

w_4 is the main effect of day/night.

w_5 is the main effect of accident type.

w_{23} is the interaction between empty/loaded and truck type,

and so on.

Analysis Result

The model estimation was carried out using the FUNCAT program (7). The "best" model was found to be:

$$\mathrm{Ln}\left[\frac{p}{1 - p}\right] = w + w_2 + w_3 + w_5 + w_{25}$$

The chi-square goodness-of-fit statistic for this model was 17.28 for 12 degrees of freedom (p-value = 0.1394), which indicates a good fit.

The estimated model indicates that the ratios of wet-pavement to dry-pavement accident involvements, $\frac{p}{1 - p}$, were significantly influenced by load status (empty/loaded), truck type, accident type (single-truck/multi-vehicle), and the interaction between load status and accident type. However, the ratios of wet-pavement to dry-pavement accident involvements were not significantly influenced by day/night. Tables 3(a) and 3(b) show the summary of the modeling results. Table 4 shows the estimated ratios of wet-pavement to dry-pavement accident involvements by truck type and empty/loaded separately for single-truck accidents and for multi-vehicle collisions.

Interpretation of Modeling Results

Figures 1 (a) and (b) are the plots of the estimated ratios of wet-to-dry accident involvements for single-truck accidents and for multi-vehicle collisions, respectively. It can be seen that the ratios of wet-to-dry accident involvements were consistently higher for empty than for loaded trucks regardless of the accident type or the truck type. However, this difference between empty and loaded trucks was far more pronounced for single-truck accidents than for multi-vehicle collisions. This differential finding was the result of the interaction between load status and accident type.

To illustrate this interaction graphically, Figure 2 shows a plot of the means of the ratios of wet-to-dry accident involvements for single-truck accidents and for multi-vehicle collisions, weighted by appropriate accident involvement frequencies. If the effect of wet pavements was not particularly pronounced for empty trucks in single-truck accidents, the two lines representing single-truck accidents and multi-vehicle collisions would be parallel as indicated by the dotted line.

Figure 2 indicates that the ratios of wet-to-dry accident involvements for empty trucks on 4-or-more-lane highways in Texas was, on the average, about 3 times higher than expected, when heavy-truck involvements in multi-vehicle collisions were used as a comparison group. This immediately suggests a very strong influence of wet pavements on single-truck accident involvements for empty trucks that was not observed for loaded trucks.

CONCLUSIONS

The foregoing analysis results clearly indicate that empty trucks had a considerably higher estimated propensity for single-truck accident involvements than did loaded trucks in wet conditions. This higher propensity was indicated for all 5 truck types considered: single-unit trucks, combination trucks with van trailers, with flatbed trailers, with tankers, and with other trailer styles. Day/night did not have significant influence on such propensity.

Whether the higher single-truck accident propensity of empty trucks in wet conditions was attributable to dynamic hydroplaning problems or whether some other factors were the primary causes warrants further research and investigation. Nevertheless, the accident analysis thus far appears to strongly support the prediction by Horne and the recent laboratory findings by Ivey (2) concerning the dynamic hydroplaning of truck tires at highway speeds.

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Table 1

Potential Variables for Analysis of Accident Types

Variable	Level
Vehicle Configuration	single-unit, single, double
Trailer Style	van, flatbed, tanker
No. of Axles of Power Unit	2-or-3 (tandem) axle
Load Status	empty, loaded
Gross Vehicle Weight	
Trip Length	over-the-road, local
Cargo Type	general cargo, other
Road Class	undivided rural, divided rural, urban roads
Road Surface Condition	dry, wet
Ramps	yes, no
Day/Night	day, night
Weather	clear, rain or snow
Driver Experience	≤1 year, 2-4 years, 4+ years
Driver Age	18-30, 31-45, 45+
Hours on Duty	<2 hours, 2-5 hours, 5+ hours
Region of the Country	Northeast, North, South

Table 2

ICC-Authorized Truck Accident Involvements on 4-or-More-Lane Highways in Texas (1979-1981)

ACC-TYPE (V5)	LIGHT (V4)	TRUCK TYPE (V3)	EMPTY/ LOADED (V2)	PAVEMENT CONDITION (V1)		CROSS-PRODUCT RATIO (τ)	STANDARDIZED CPR (Z)
				WET	DRY		
SINGLE-TRUCK	DAY	SU	E L	2 2	4 1	.25	- 0.92
		VAN	E L	42 76	7 50	3.95	3.07
		FLATBED	E L	8 12	2 22	7.33	2.29
		TANKER	E L	16 6	5 20	10.67	3.42
		OTHER	E L	10 4	4 6	3.75	1.51
	NIGHT	SU	E L	3 3	1 2	2.00	0.47
		VAN	E L	33 80	10 81	3.34	3.06
		FLATBED	E L	1 6	3 29	1.61	0.39
		TANKER	E L	9 4	3 10	7.50	2.26
		OTHER	E L	2 2	1 5	5.00	1.09
MULTI-VEHICLE COLLISIONS	DAY	SU	E L	5 2	43 9	.52	- 0.71
		VAN	E L	44 102	99 303	1.32	1.30
		FLATBED	E L	27 31	86 133	1.35	1.00
		TANKER	E L	15 11	49 55	1.53	0.96
		OTHER	E L	13 8	22 37	2.73	1.92
	NIGHT	SU	E L	13 2	24 5	1.35	0.34
		VAN	E L	27 90	59 299	1.52	1.60
		FLATBED	E L	9 21	52 149	1.23	0.48
		TANKER	E L	13 11	23 45	2.31	1.73
		OTHER	E L	8 7	13 34	2.98	1.79

SOURCE: BMCS 1979, 1980, 1981

Table 3(a)

Summary of Modeling Results

VARIABLE	CHI-SQUARE	DEGREE OF FREEDOM	P-VALUES
LOAD STATUS	55.16	1	0
TRUCK TYPE	38.03	4	.0001
ACCIDENT TYPE	178.65	1	0
LOAD STATUS x ACCIDENT TYPE	14.22	1	.0002

Table 3(b)

Parameter Estimates and Standard Errors

TERM	ESTIMATE	STANDARD ERROR
W	-.4815	.0755
W_2	.4445	.0617
W_3	-.1785	.1819
	.3883	.0851
	-.3072	.1066
	-.0545	.1267
W_5	.7905	.0599
W_{25}	.2169	.0598

Table 4

Estimated Ratios of Wet-to-Dry Accident Involvements

TRUCK TYPE	LOAD STATUS	WET/DRY RATIO	
		SINGLE-TRUCK	COLLISIONS
SINGLE-UNIT	EMPTY	2.21	0.29
	LOADED	0.59	0.19
VAN	EMPTY	3.89	0.52
	LOADED	1.04	0.33
FLATBED	EMPTY	1.94	0.26
	LOADED	0.52	0.16
TANKER	EMPTY	2.50	0.33
	LOADED	0.67	0.21
OTHER	EMPTY	3.07	0.41
	LOADED	0.82	0.26

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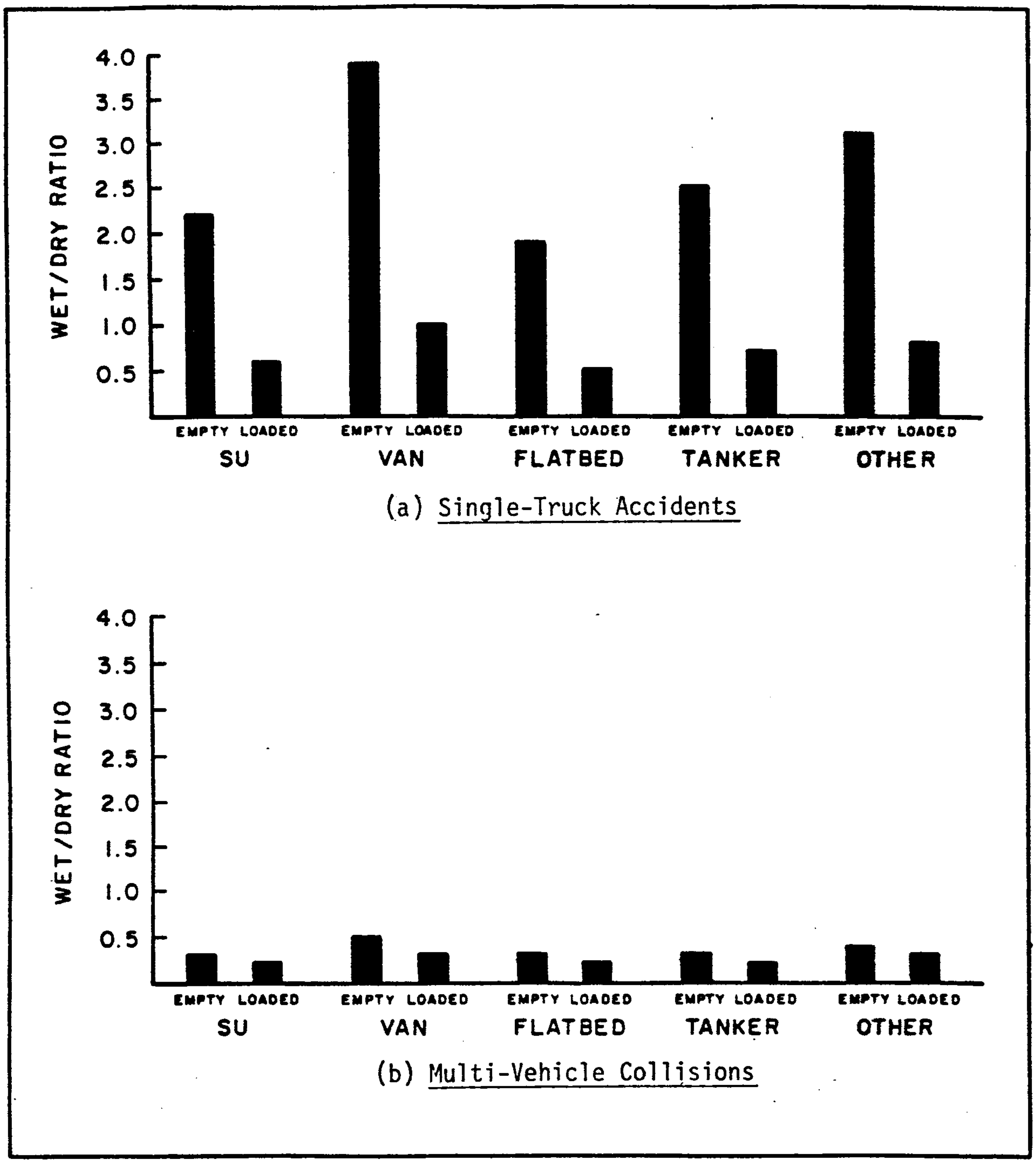

FIGURE 1: ESTIMATED RATIOS OF WET-TO-DRY ACCIDENT INVOLVEMENTS

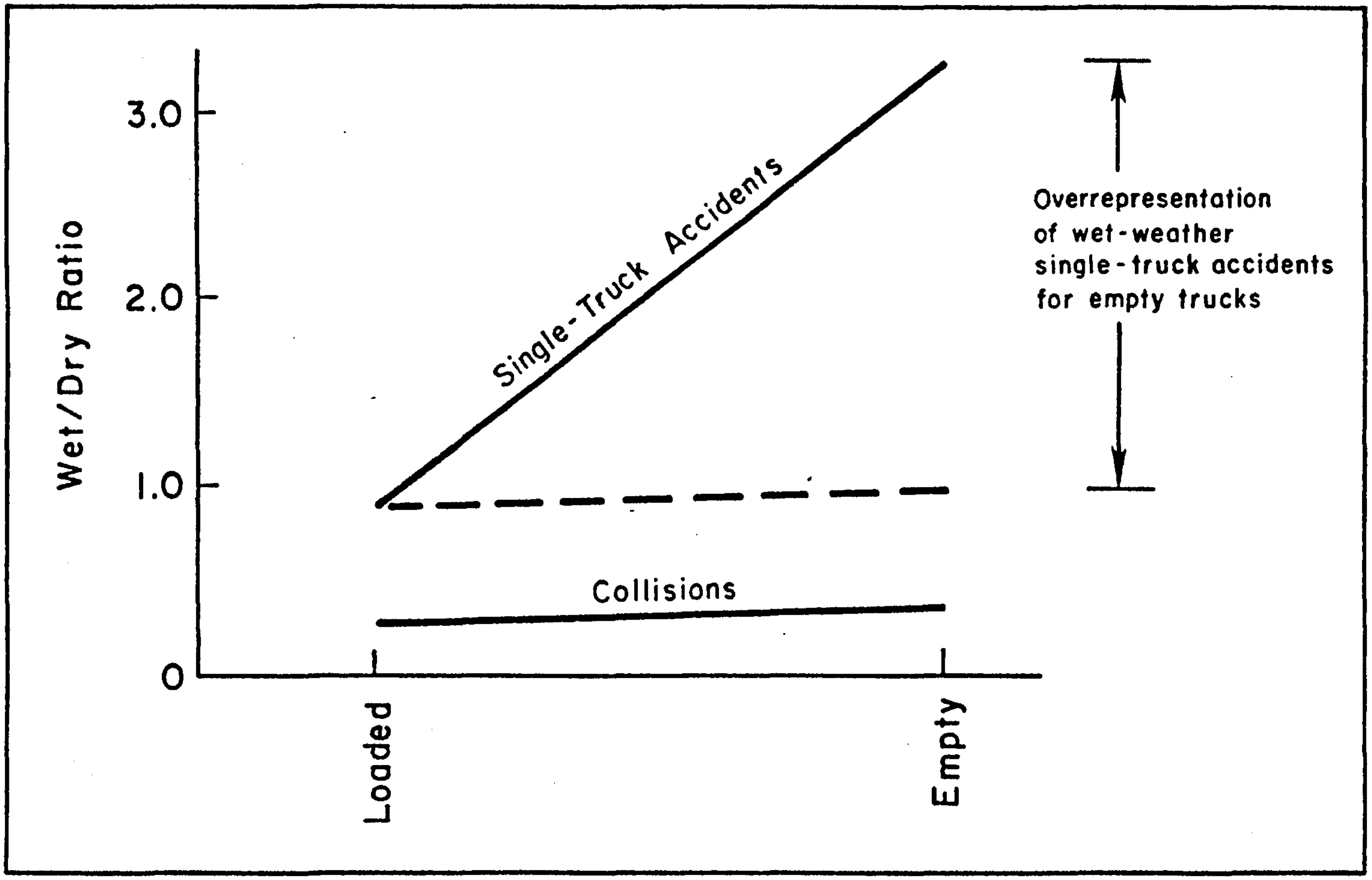

FIGURE 2 WEIGHTED MEANS OF WET-TO-DRY TRUCK ACCIDENT INVOLVEMENT RATIOS