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Examining Fatal Commercial-Truck-Involved Crashes at Work Zones

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Highway construction work zones have created a major safety concern for government agencies, legislatures, the highway industry and the traveling public. While work zone fatality data are available, data for work zone traffic volumes are generally missing and thereby the probabilities of interest cannot be directly estimated. To discover characteristics of fatal commercial-truck involved crashes at work zones without the available work zone traffic volume data, this study presents a probability ratio approach. A sample of 367 work zone fatal crashes was supplied by the Texas Department of Public Safety (DOPS) for a three-year period (1997-1999). The findings from data analysis can be of help in developing countermeasures for reducing fatalities.

JEL Codes: C12, C13, C14 and L92

1. Introduction

The U.S. Congress (1991) addressed the work zone safety issue in the Intermodal Surface Transportation Efficiency Act (ISTEA), by requiring the Secretary of Transportation to develop and implement a work zone safety program that would improve work zone safety. With the substantial increase in funding levels provided in the Transportation Equity Act for the 21st Century (TEA-21) coupled with the steady growth of traffic volumes and our aging highway system, the OPQC (1998) stated in this report that the number of work zones will increase sharply with the potential for increased fatalities. Highway construction work zones have created a major safety concern for government agencies, legislatures, the highway industry and the traveling public. Some previous studies found increased severity of accidents in work zones (Garber et al., 2002) while others found no significant difference (Chambless et al., 2002). Li et al. (2008) concluded that head-on was the dominant type for fatal accidents while the rear-end was the dominant injury accident type.

There have been a variety of methodologies used to examine characteristics of motor vehicle crashes. Descriptive statistics comprise one of the major approaches to identifying characteristics in work zone crashes (Richards et al., 1986; Garber et al., 1990; Pigman et al., 1990; Garber et al., 1994; Garber et al., 1998; Goddin, 1999;

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Wang et al., 1999). Descriptive statistics were not strong support to conclusions when questions related to factors such as weather, lighting and road conditions because traffic volumes for each of conditions were generally missing. Regression and correlation models were employed to predict roadway casualties and fatalities (Broughton, 1991; Brännäs, 1995; Guria et al., 2001; McCarthy, 2003; Miaou et al., 2003; Raeside, 2004). Regression models sometimes did not accurately assess road risks if the models were built only based on the observations of vehicles involving in crashes when observations of vehicles not involving in crashes were not available. When data for both fatal and non-fatal crashes were available, logistic regression models were used to estimate conditional probabilities of fatal crashes given that crashes had already occurred. However, the data available to this study provide only observations of fatal crashes. Further, without data of work zone traffic volumes, the probabilities of interest could not be directly estimated. This study presented a probability ratio approach to analyzing available data.

The objective of this study is to identify the characteristics of fatal commercial-truck involved crashes at work zones so that countermeasures can be developed for reducing fatalities. Work zone fatality data are analyzed to answer the following questions:

(1) Are commercial trucks more likely to be involved in fatal crashes?
(2) In what traffic control conditions are commercial trucks more likely to be involved in fatal crashes?
(3) In what lighting conditions are commercial trucks more likely to be involved in fatal crashes?
(4) In what weather conditions are commercial trucks more likely to be involved in fatal crashes?

This study designed a new probability ratio approach to analyze fatal crash data at work zone when the work zone traffic volume data were unavailable. Most previous studies concluded that commercial trucks had higher relative exposure to other vehicles at night, the result of this study showed that a commercial truck was more likely to involve in a work zone fatal crash in “daylight” condition. It might be attributed to heavier traffic in daytime.

The remainder of this paper is organized as follows: The next section provides an explanation of the data. Then two models using the probability ratio approach are presented, followed by an analysis of results and discussion. Conclusions are made in the final section.

2. Data

All work zone fatal crash data were supplied by the Texas Department of Public Safety (DOPS) for a three-year period (1997-1999). The dataset contains information on 367 fatal crashes in Texas. For convenience of presentation, Table 1 presents codes and definitions for traffic controls and Table 2 presents codes and definitions for involved vehicle types. In addition, Texas DOPS data included lighting conditions (Daylight, Dawn, Dark-Not Lighted, Dark-Lighted, and Dusk) and weather conditions (Clear, Raining, Snowing, Fog, Blowing Dust, Smoke, Sleeting, High Winds, and Other). The vehicle registration statistics were retrieved from “Highway Statistics” (FHWA, 2007) and shown in Table 3. Annualized average miles per vehicle were from Environmental Protection Agency (EPA, 2000) and shown in Table 4.

3. Methodology

Two models were employed to examine characteristics of work zone fatal crashes. Model 1 is a ratio that compares the probability of a “commercial truck” being involved in a work zone fatal crash with the probability of an “other vehicle” being involved in a work zone fatal crash. The result of Model 1 answers question 1 in the opening section. Model 2 is a ratio of two probability ratios from Model 1. For those two probability ratios from Model 1, one is computed from the fatal crashes with a certain characteristic, and another is computed from all fatal crashes or the fatal crashes with another characteristic. Model 2 answers questions 2, 3, and 4.

3.1 Model 1

Let A_1 be the event of a fatal crash involving “commercial truck(s)” and A_2 the event of a fatal crash involving “other vehicle(s).” Let N_1 and N_2 be the number of commercial trucks and the number of other vehicles passing through work zones, respectively. Let n_1 be the number of fatal crashes involving commercial trucks and n_2 the number of fatal crashes involving other vehicles. Coefficients α_1 and α_2 represent the average numbers of commercial trucks and other vehicles involved in a fatal crash. Therefore,

$$P(A_1) = \frac{\alpha_1 n_1}{N_1} \tag{1}$$

$$P(A_2) = \frac{\alpha_2 n_2}{N_2} \tag{2}$$

Table 1. Coding for Traffic Controls

Number	Name of Observation	Description
0	No control or inoperative	No sign, signal, or other instructional device
1	Officer or flagman	A person directing traffic with either a flag or light stick
2	Stop and go signal	A lighted signal controlling the flow of traffic
3	Stop sign	A type of sign designed to stop traffic in a certain direction
4	Flashing red light	A lighted signal that acts the same as a stop sign
5	Turn marks	A directional signal marked on the pavement
6	Warning sign	A type of sign designed to warn drivers of possible dangers
7	RR gates or signals	A mechanical gate, lighted signal, or sign showing the approach of a train
8	Yield sign	A type of sign instructing drivers to yield to other traffic
9	Center stripe or divider	A stripe or divider marked on the pavement, dividing the roadway into lanes
10	No passing zone	A type of sign directing drivers to not pass other vehicles
11	Other control	Any other instructional device used to direct drivers

Table 2. Coding for Vehicle Types Involved in Fatal Crashes

Number	Name of Observation
1	Commercial Truck with Commercial Truck
2	Commercial Truck with Other Vehicle
3	Commercial Truck with Motorcycle
4	Commercial Truck with Pedestrian/Worker
5	Commercial Truck with Object
6	Other Vehicle with Other Vehicle
7	Other Vehicle with Motorcycle
8	Other Vehicle with Pedestrian/Worker
9	Other Vehicle with Object
10	Other

Table 3. Vehicle Registration

Year	Texas Total	Texas Truck	Nation Total	Nation Truck	Texas Other	Nation Other	Texas Other/Truck	Nation Other/Truck
1997	12,923,253	347,172	207,753,660	3,378,625	12,576,081	204,375,035	36.2244	60.4906
1998	13,324,167	349,601	211,616,553	3,431,638	12,974,566	208,184,915	37.1125	60.6663
1999	14,068,720	353,721	216,308,623	3,427,669	13,714,999	212,880,954	38.7735	62.1066

Table 4. Annualized Average Miles Per Vehicle (1,000 Miles)

Passenger Car	Pickup	Minivan	Utility	Station Wagon	Auto Transportation	Insulated Non-refrigerated Van	Insulated Refrigerated Van
12.5	10.3	13.4	11.5	10.9	42.4	45.8	55.6

The coefficients α_1 and α_2 can be calculated using data from Texas DOPS (Table 5). The computation details are presented in the next section. Although work zone traffic volume data (N_1 and N_2) are not available, the ratio of N_1 and N_2 can be computed using vehicle registration data in Table 3 (FHWA, 2007) adjusted for road exposure by average miles per vehicle in Table 4 (EPA, 2000), assuming that the ratio remains constant. The ratio is calculated as

$$\frac{N_2}{N_1} = \frac{N_2^{'} M_2}{N_1^{'} M_1} \qquad (3)$$

where $N_1^{'}$ and $N_2^{'}$ are the numbers of the registered commercial trucks and the registered other vehicles, respectively; M_1 and M_2 are average miles per commercial truck and per other vehicle, relatively.

Table 5. Average Number of Vehicles per Fatal Crash
(Refer to Table 2 for codes of vehicle type)

Involved Vehicle Type	1	2	3	4	5	6	7	8	9	10
Mean Number of Vehicles	3.67	2.64	2.00	1.00	1.00	2.17	2	1.21	1.00	0.63
Frequency	9	50	1	2	12	118	4	43	120	8

Thus, the probability ratio is:

$$\frac{P(A_1)}{P(A_2)} = \frac{\alpha_1 n_1}{\alpha_2 n_2}\frac{N_2}{N_1} \tag{4}$$

If this ratio is greater than 1, we can conclude that a "commercial truck" is more likely to be involved in a work zone fatal crash than an "other vehicle." Based on Model 1, a statistical test on a proportion can be conducted to compare $P(A_1)$ and $P(A_2)$. If

$$\frac{P(A_1)}{P(A_2)} = \frac{\alpha_1 n_1}{\alpha_2 n_2}\frac{N_2}{N_1} > 1,$$

then

$$\frac{n_1}{n_1 + n_2} > \frac{\alpha_2 N_1}{\alpha_1 N_2 + \alpha_2 N_1} = \frac{\alpha_2 \frac{N_1}{N_2}}{\alpha_1 + \alpha_2 \frac{N_1}{N_2}}.$$

Let the right-hand side of the inequality equal a constant p_0. Thus, $\frac{P(A_1)}{P(A_2)} > 1$ can be tested by hypotheses of H_0: $p = p_0$ and H_a: $p > p_0$ using a sample proportion $p_s = n_1/(n_1+n_2)$. The Z-test of proportion is used for large-sample cases when $(n_1+n_2)\, p_0 \geq 5$ and $(n_1+n_2)\,(1-p_0) \geq 5$.

3.2 Model 2

Given condition j (traffic controls, lighting and weather conditions, etc.), let N_{1j} and N_{2j} be the number of commercial trucks and the number of other vehicles passing through work zones, respectively. Let n_{1j} and n_{2j} be the numbers of fatal crashes involving the commercial trucks and involving the other vehicles, respectively. We have the following conditional probabilities

$$P(A_{1j}) = \frac{\alpha_1 n_{1j}}{N_{1j}} \tag{5}$$

$$P(A_{2j}) = \frac{\alpha_2 n_{2j}}{N_{2j}} \tag{6}$$

Assuming that the ratio of N_{1j} and N_{2j} remains the same as N_1/N_2 in Model 1, thus

$$\frac{P(A_{1j})}{P(A_{2j})} = \frac{\alpha_1 n_{1j}}{\alpha_2 n_{2j}}\frac{N_{2j}}{N_{1j}} = \frac{\alpha_1 n_{1j}}{\alpha_2 n_{2j}}\frac{N_2}{N_1} \tag{7}$$

If $P(A_{1j})/P(A_{2j})$ is greater than 1, in condition j a "commercial truck" is more likely to be involved in a fatal crash than an "other vehicle." Then, Model 2 is constructed as a ratio of two probability ratios. If the ratio of $P(A_{1j})/P(A_{2j})$ and $P(A_1)/P(A_2)$ is greater than 1, it indicates that condition j makes a "commercial truck" more likely to be involved in a fatal crash relative to an "other vehicle." If the ratio of $P(A_{1j})/P(A_{2j})$ and $P(A_{1i})/P(A_{2i})$ is greater than 1, a "commercial truck" in condition j is more likely to be involved in a fatal crash than in condition i, relative to an "other vehicle" under the same conditions. Based on Model 2, the Z-test for two proportions can be conducted to compare the probability ratios $P(A_{1j})/ P(A_{2j})$ and $P(A_{1i})/ P(A_{2i})$. If

$$\frac{P(A_{1j})}{P(A_{2j})} = \frac{\alpha_1 n_{1j}}{\alpha_2 n_{2j}} \frac{N_{2j}}{N_{1j}} > \frac{P(A_{1i})}{P(A_{2i})} = \frac{\alpha_1 n_{1i}}{\alpha_2 n_{2i}} \frac{N_{2i}}{N_{1i}},$$

where $N_{2j}/N_{1j} = N_{2i}/N_{1i} = N_2/N_1$ we have

$$\frac{n_{1j}}{n_{2j}} > \frac{n_{1i}}{n_{2i}},$$

therefore,

$$\frac{n_{1j}}{n_{1j}+n_{2j}} > \frac{n_{1i}}{n_{1i}+n_{2i}}.$$

The hypotheses of H_0: $p_j - p_i = 0$ and H_a: $p_j - p_i > 0$ can be tested with sample proportions $p_{sj} = n_{1j}/(n_{1j}+n_{2j})$ and $p_{si} = n_{1i}/(n_{1i}+n_{2i})$.

4. Results and Discussion

4.1 Results of Model 1

In Model 1, the coefficients α_1 and α_2 can be calculated as weighted averages using information from Table 5:

$$\alpha_1 = \frac{(9)(3.67)+(50)(1)+(1)(1)+(2)(1)+(12)(1)}{9+50+1+2+12} = 1.3247$$

$$\alpha_2 = \frac{(50)(1.64)+(118)(2.17)+(4)(1)+(43)(1.21)+(120)(1)}{50+118+4+43+120} = 1.5346$$

From Table 6, 74 fatal crashes involved commercial trucks (involved vehicle types 1 to 5), and 335 fatal crashes involved other vehicles (involved vehicle type 2 and involved vehicle types 6 to 9). Therefore,

$$P(A_1) = \frac{\alpha_1 n_1}{N_1} = \frac{(1.3247)(74)}{N_1}$$

$$P(A_2) = \frac{\alpha_2 n_2}{N_2} = \frac{(1.5346)(335)}{N_2}$$

Thus,

$$P(A_1) = 0.1907 \frac{N_2}{N_1} P(A_2) = 0.1907 \frac{N_2' M_2}{N_1' M_1} P(A_2)$$

The N_2/N_1 is computed using the vehicle registration data from Highway Statistics (Table 3) adjusted for road exposure by annualized average miles per vehicle (Table 4) (EPA, 2000). If this ratio is sufficiently large, the probability of a "commercial truck" being involved in a fatal crash ($P(A_1)$) is greater than the probability of an "other vehicle" being involved ($P(A_2)$). The nationwide $N_2^{'}/N_1^{'}$ ratio is larger than the Texas ratio (Table 3). To be conservative, the smaller ratio (36.2244) is used. For the same reason, the smaller value of M_2/M_1 is chosen (Table 4). Thus,

$$\frac{N_2}{N_1} = \frac{N_2^{'}M_2}{N_1^{'}M_1} = (36.2244)\frac{10.3}{55.6} = 6.7106,$$

and

$$\frac{P(A_1)}{P(A_2)} = 1.2797.$$

This indicates that if a person drives a commercial truck through a work zone, this person is more likely to be involved in a fatal crash than if this person drives a vehicle of another type. The p-value for the test on this ratio is 0.02716, indicating that this ratio is significant ($\alpha = 0.05$).

Table 6. The n_{1j}/n_{2j} Ratios for Traffic Control j and the n1/n2 Ratio for Total (Refer to Table 1 for codes of traffic control and Table 2 for codes of vehicle type)

Fatalities (frequency)		Traffic Control												
		0	1	2	3	4	5	6	7	8	9	10	11	Total
Involved Vehicle Types	1	0	1	0	0	0	0	1	0	0	6	0	1	9
	2	3	2	3	4	1	0	4	0	1	23	3	6	50
	3	0	0	0	0	0	0	0	0	0	0	0	1	1
	4	1	0	0	0	0	0	0	0	0	0	0	1	2
	5	0	0	1	0	0	0	1	0	0	8	0	2	12
	6	20	2	11	16	1	0	8	1	1	48	6	4	118
	7	0	0	0	0	0	0	0	0	0	2	1	1	4
	8	8	2	2	0	0	0	2	0	0	22	2	5	43
	9	19	1	1	3	0	0	14	0	0	63	10	9	120
	10	0	1	0	1	0	0	0	0	1	4	0	1	8
	n_{1j}	4	3	4	4	1	0	6	0	1	37	3	11	74
	n_{2j}	50	7	17	23	2	0	28	1	2	158	22	25	335
	n_{1j}/n_{2j}	0.08	0.49	0.24	0.17	0.5	N/A	0.21	0	0.5	0.23	0.14	0.44	0.22
	p-value	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.02*	N/A	0.002*	

-: Z-test is conducted to compare traffic control j with this traffic control.
N/A: Assumptions of Z-test were not met.
*: Significant at $\alpha = 0.05$.

4.2 Results of Model 2

In Model 2, from equations (4) and (7), we have

$$\frac{P(A_{1j})/P(A_{2j})}{P(A_{1i})/P(A_{2i})} = \frac{n_{1j}/n_{2j}}{n_{1i}/n_{2i}}.$$

Let

$$\frac{P(A_{1j})/P(A_{2j})}{P(A_{1i})/P(A_{2i})} > 1,$$

we have

$$\frac{n_{1j}}{n_{2j}} > \frac{n_{1i}}{n_{2i}}.$$

If n_{1j}/n_{2j} is sufficiently large, it indicates that condition j makes a "commercial truck" more likely to be involved in a work zone fatal crash relative to an "other vehicle" in comparison with fatal crashes in condition i.

In Table 6, all traffic controls, except for "RR gates or signals" (code 7) that have only one crash in sample, show substantially larger ratios of n_{1j}/n_{2j} than "no control or inoperative" (code 0). This suggests that current traffic controls are more effective for "other vehicles" than "commercial trucks." However, the assumptions for the Z-test of two proportions can only be met for traffic controls of "center stripe or divider" (code 9) and "other control" (code 11). The results show probability ratios $P(A_{1j})/P(A_{2j})$ for both controls are significantly larger than the ratio for "no control or inoperative." In addition, Table 6 shows that the traffic control of "no passing zone" (code 10) has a smaller ratio of n_{ij}/n_{2j} (0.14) than total fatal crashes (0.22). It indicates that "no passing zone" effectively reduces fatal crashes involving "commercial trucks." This result supports the conclusion made by Wang et al. (1999).

In Table 7, all lighting conditions except for "daylight" show smaller ratios of n_{1j}/n_{2j} than total fatal crashes. A "commercial truck," in "daylight" condition, was more likely to be involved in fatal crashes relative to an "other vehicle" than in other lighting conditions. A notable result in Table 7 is that the ratio of n_{j1}/n_{j2} and, therefore, the ratio of $P(A_{1j})/P(A_{2j})$ for "dark lighted" is smaller than the probability ratio for "dark not lighted." It suggests that lighting helped "commercial trucks" more than "other vehicles." A Z-test was conducted but it was not significant (p-value = 0.2434) with available size of data.

Table 7. Distribution of Fatal Crashes by Lighting Condition and Involved Vehicle Type (Refer to Table 2 for codes of vehicle type)

Fatalities (frequency)		Involved Vehicle Types												
		1	2	3	4	5	6	7	8	9	10	n_{1j}	n_{2j}	n_{1j}/n_{2j}
Lighting Condition	Daylight	9	30	0	2	8	79	2	11	36	49	49	158	0.31
	Dawn	0	0	0	0	1	0	1	2	2	1	1	5	0.20
	Dark Not Lighted	0	15	0	0	2	19	1	20	55	17	17	110	0.15
	Dark Lighted	0	4	1	0	1	17	0	9	25	6	6	55	0.11
	Dusk	0	1	0	0	0	3	0	1	2	1	1	7	0.14
	Total	9	50	1	2	12	118	4	43	120	74	74	335	0.22

In Table 8, only “fog” and “high winds” show larger ratios of n_{1j}/n_{2j} than total fatal crashes. A “commercial truck” in those two conditions was more likely to be involved in fatal crashes relative to an “other vehicle” than in other weather conditions. No Z-tests were conducted since assumptions for the Z-test of two proportions were not met with available size of data.

Table 8. Distribution of Fatal Crashes by Weather Condition and Involved Vehicle Type (Refer to Table 2 for codes of vehicle type)

Fatalities (frequency)		Involved Vehicle Types												
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	n_{1j}	n_{2j}	n_{1j}/n_{2j}
Weather Condition	**Clear**	9	46	1	2	11	104	4	42	113	8	69	309	0.22
	Rain	0	1	0	0	1	12	0	0	6	0	2	19	0.11
	Snow	0	0	0	0	0	0	0	0	0	0	0	0	N/A
	Fog	0	2	0	0	0	2	0	0	1	0	2	5	0.40
	Blowing Dust	0	0	0	0	0	0	0	1	0	0	0	1	0.00
	Smoke	0	0	0	0	0	0	0	0	0	0	0	0	N/A
	Sleet	0	0	0	0	0	0	0	0	0	0	0	0	N/A
	High Winds	0	1	0	0	0	0	0	0	0	0	1	1	1.00
	Other	0	0	0	0	0	0	0	0	0	0	0	0	N/A
	Total	9	50	1	2	12	118	4	43	120	8	74	335	0.22

5. Conclusion

This study proposed a probability ratio approach to uncovering characteristics of fatal commercial-truck-involved crashes in work zones when non-fatal crash data and traffic volume data were not available. The major findings included

1. A commercial truck was more likely to involve in a work zone fatal crash. We recommend that work zones should have enough room for commercial trucks to maneuver.
2. The traffic control of “no passing zone” effectively reduced work zone fatalities involving commercial trucks. The controls of “center stripe or divider” alone was not effective for commercial trucks. We recommend that it should be used with other control methods.
3. Although people believed that commercial trucks have higher relative exposure to other vehicles at night, analysis showed that a commercial truck was more likely to involve in a work zone fatal crash in “daylight” condition. It might be attributed to heavier traffic in daytime. Next, light at dark helped commercial trucks more than other vehicles. We recommend that work zones should be lighted at night whenever it is possible.
4. Relative to other vehicles, commercial trucks were more likely to be involved in work zone fatal crashes in the weather conditions of “fog” and “high winds”.

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