

Article

Exploring the Determinants of School Bus Crash Severity

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Abstract: Although the school bus is considered a safe form of transportation, school bus crashes are a major safety concern. School bus crashes are a result of driver error of either the at-fault school bus or another at-fault vehicle (where the school bus is not at fault). To examine the risk factors associated with school bus related crashes and crash outcomes, this study segments and develops two binary logit models for each school bus crash type. A total of 1702 school bus related crashes recorded between 2009 and 2016 were used to estimate the model. According to the model results, sideswipe collisions were less likely to result in injury outcomes for at-fault school buses than rear-end and side-impact collisions. Speeding, driving impaired or under the influence, and negotiating a curve all have significant positive associations with injury outcomes in not-at-fault school bus crashes. This study's practical implications include enforcing the school bus safe driving guidelines, training programs for school bus drivers that include elements of nonroutine trips, training for crossing guards, and awareness programs for drivers of other vehicles to instill safe driving practices around school buses.

Keywords: school bus safety; crash severity; binary logit; driver at-fault; injury prevention; public health



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1. Introduction

Trips to and from school are made daily by over 26.7 million children in the U.S., with some 36% doing so by school bus [1]. Longer travel distances due to consolidation of schools in rural areas or not attending neighborhood schools in urban areas have been observed to be the primary reasons for children riding school buses [2]. School buses are reported as being a relatively safer mode of school travel [3,4]. Yet, between 2008 and 2017, there were 1113 fatal crashes, accounting for about 0.4% of total fatal motor vehicle crashes that were classified as school transportation related [5]. These crashes killed 1241 people, averaging 124 fatalities per year. A breakdown of the fatalities shows that 10% of the casualties were school bus occupants, 20% were non-occupants, and 70% were occupants of other vehicles. Of the 10% casualties who were school bus occupants, 55 were drivers and 71 were passengers. Furthermore, 264 (21%) of the 1241 deaths were of school-age children, of which 61 were school bus occupants, 100 were occupants of other vehicles, and 102 were either pedestrians or cyclists.

The U.S. federal government expressed concern over school transportation through a mandated examination of available crash injury data in legislation, the Transportation Equity Act for the 21st Century [6]. This was intended to potentially inform school administrators and policymakers on driver training, vehicle design requirements, and other crash contributing factors to help school districts make informed decisions about safety improvements with the various modes of school transport. Understanding the contributing factors and circumstances under which school bus crashes occur and the resulting severity outcomes is critical for improving the safety of the school children that rely on them. At the same time, it is important to acknowledge that in a multi-vehicle collision involving a school bus, the crash could be a result of the school bus being at fault or the other colliding vehicle being at fault (i.e., the school bus was not at fault). As such, the contributing factors

in these two cases are likely to be different, and it is important to realize them independently for better school travel safety. Thus, this study distinguishes the two crash types from each other and separately analyzes the factors associated with crash outcomes for each crash type. Two binary logit models are developed using crash data from the State of Alabama over the period 2009–2016. The findings of this study can help school administrators at various levels and other stakeholders in making informed decisions about countermeasures to improve school bus safety in the state.

2. Literature Review

The National Highway Traffic Safety Administration (NHTSA) characterizes a school bus related crash as one that involves, either directly or indirectly, a bus that transports children to and from school or school-related activities [7]. Many researchers have studied and explored the characteristics of school bus related crashes. Some studies have examined the biomechanics of school bus occupant injuries to reduce injury severity. For instance, NHTSA test data were analyzed to recommend that the use of combination lap and shoulder belts could reduce school bus occupant injuries [4]. However, such seat belt installations are likely to overload school buses due to the resultant loss of seating capacity [8], which could lead to more children seeking alternative modes of traveling to and from school. Alternatively, according to the school bus safety report, compartmentalization (a passive form of passenger restraint) can better serve the crash protection to the passengers of [9]. Although compartmentalization was found to be effective in frontal and rear crashes, it still had concerns in the event of a rollover collision or side impact crash [3,10]. Nevertheless, because the school bus is the safest form of school travel, using alternative modes is equivalent to exposing children to higher risks [4].

The Committee on School Transportation Safety [6] evaluated the net impact of various human, vehicular, operational, infrastructural, and environmental factors on the safety of school travel modes. The report indicates that school and other buses have the lowest injury and fatality rates and are statistically indistinguishable from each other. However, the risk per school bus trip is significantly lower than that of the other modes combined in that most fatalities to school-age children who ride school buses occur outside the vehicle. School bus drivers are also often deemed as safer drivers in that the fatality to the occupants of the school bus are comparatively lower than those of other bus drivers [11]. Other studies also show that the occupants of other vehicles quite often are the ones who are severely injured when involved in school bus crashes [11,12]. Nevertheless, there is a continuing vigilance to ensure that school buses remain a safe mode of school transportation [13]. Safety training programs for school bus drivers and drivers of other vehicles, particularly younger drivers, can be an effective tool for reducing the frequency and severity of school bus crashes [6,12,14]. Additionally, the presence of another adult in the school bus to ensure the use of seatbelts and to supervise children and keep them seated can allow bus drivers to focus on the driving task and minimize driving errors [14].

Further, nested and random-parameters logit models were also developed to obtain a prediction of seat belt usage rate in response to some proposed countermeasures, thus allowing for qualitative comparisons of various countermeasures that can contribute to school bus safety programs [15]. Eight significant influencing factors identified by this study are age, gender, home county, trip length, time of day, seat location, presence of a bus aide, and two levels of driver involvement: driver personally checking the children's belt usage and driver periodically prompting the children to wear the seat belt. A generalized ordered probit model was developed to investigate the underlying risk factors of the severity of bus crashes [16]. The results of the study showed that younger drivers (age ≤ 25), older drivers (mainly over 65 years), female drivers, high (>65 mph) or low (<20 mph) speed limits, intersections, and inattentive risky driving behavior increase school bus crash severity. A logistic regression model was developed to evaluate the probability of driver errors in fatal bus crashes [11]. Five different types of bus operations were considered in this study: school, transit, intercity, charter/tour, and others. The bus operation type, previous

violations, and previous crashes were found to be significant parameters in the model. However, because school bus drivers were found to have the best driving records with relatively few driving errors, it was concluded that school bus drivers were less likely to have contributed to the crash. Despite such results, many parents perceive driving their children to school to be safer than having their children ride the school bus, although cars account for a majority of fatal crashes involving school-age children during normal school transportation hours [17]. Amongst others, some factors influencing parents' safety concerns about their children riding the school bus are drivers' lack of supervision, drivers' speeding, and drivers' erratic behavior [18]. Further, a report by NHTSA [7] indicates that 6–8 a.m. and 3–4 p.m. are the times when a significant proportion of school bus crashes are fatal. Another study cites maximum driving exposure as the reason for the higher frequency of crashes during these periods [12].

Despite the criticality of the school bus safety issue, few studies were found in the existing body of literature that directly addressed the problem [12,16,19–21]. Kaplan and Prato [16] studied the risk factors associated with bus accident severity in general but considered the school bus as one of the bus service types. Young and older drivers, female drivers, very high and very low speed limits, intersections, and inattentive driving were some risk factors shown to increase accident severity. O'Neal et al. [19] examined school bus crash incidence by routine and nonroutine routes and concluded that the crash rate was higher on nonroutine routes. Yang et al. [12] examined school bus crashes in the state of Iowa and found school bus crash rates were mostly nonfatal. Yasmin, Anowar, and Tay [20] identified factors contributing to school bus crashes and surprisingly found that school bus drivers are more likely to commit driving violations than other drivers. Donoughe and Katz [21] evaluated fatal school bus crashes, identified school-aged pedestrians as a vulnerable user group, and hence recommended increasing awareness of school bus stop laws.

3. Research Motivation

School bus safety is a sensitive and important road safety concern. Efforts to provide adequate protection for school children riding in school buses have led to the enactment of laws and policies on safe driving behavior around school buses. Additionally, school bus driver training modules have been designed to select experienced and well-trained drivers. Although well-trained school bus drivers drive more responsibly, drivers of other vehicles are also most often cautious while driving around school buses due to federal laws that prescribe driving behavior in the vicinity of school buses. Yet, school bus related crashes do occur [5,7]. Thus, there is a need to understand the risk factors associated with these crashes to develop and target appropriate countermeasures to school bus crashes. However, the literature on school bus related crashes is limited. We found only five school bus crash related studies [12,16,19–21]. Whereas these studies have attempted to identify risk factors associated with school bus safety (e.g., [19,20]), the authors of this current study hypothesize that the contributing factors vary by the driver deemed to be at fault, i.e., the driver of the at-fault school bus and that of other vehicle that collides with the school bus. Because the crash dynamics in these two scenarios are presumably different, so are the associated risk factors, without undermining the importance of the need to know why, when, and where each of these school bus crashes occurs. Thus, it induces two distinct detailed analyses of risk factors associated with each school bus crash type. Doing so will aid in developing a unique set of countermeasures relevant to each crash type, thus increasing the effectiveness of such strategies. The contribution of this study is the identification of the factors specific to the two school bus crash types, each with different causal entities. The study investigates and compares the contributing factors that influence each type of school bus related crash severity using a binary logit analysis of some 1702 school bus crashes that occurred in Alabama between 2009 and 2016 to aid in developing countermeasures that can make school transportation safer in the state.

4. Data

School bus related crash data for the period 2009–2016 for the State of Alabama were retrieved from the Critical Analysis Reporting Environment (CARE) system developed by the Center for Advanced Public Safety at The University of Alabama. CARE is the primary database where crash records input directly by the traffic safety law enforcement officers in the State of Alabama are maintained. Each year, the data go through a rigorous QA/QC process, consistent with typical traffic safety databases maintained by state agencies throughout the U.S. Each individual crash record contains information on temporal, environmental, roadway, driver, vehicle, and crash characteristics. Crashes recorded in CARE may involve one or more motorized vehicles. The original data were filtered to make them relevant to this study. The crash was assumed to be school bus related if ‘School Bus Related’ was recorded as ‘yes’, defined when either the causal or another vehicle involved in the crash was a school bus. To ensure that the school bus was in use for transporting school children to and from school or school-related activities, only crashes that occurred between 5–9 a.m. and 2–6 p.m. were considered for the study, and crashes that occurred during the months of June and July were ignored. Observations with missing values were omitted from the dataset. This led to a total of 1702 crash records to be used for the study. It should be noted that the reported injury severities and the driver’s fault (if any) are solely based on the judgement and discretion of the reporting officer and are subject to some inaccuracies. As such, the designation of ‘at-fault’ does not connote liability but rather serves to indicate which (if more than one) the reporting officer judged to be the driver primarily contributing to the crash. Such inaccuracies, if present in the data, may result in potential biases and are a known concern in road safety research. School buses were at fault in 50% of the total number of crashes. Out of the total crashes, 14 were fatal, 71 recorded incapacitating injuries, 106 were non-incapacitating injuries, 115 resulted in possible injuries, and the remaining 1369 were property damage only (PDO) crashes. Due to the small sample size of crashes in each injury category, only two crash severity categories were considered in this study: injury crashes (consisting of fatal, incapacitating, non-incapacitating, and possible injuries) and PDO crashes, similar to other studies from the crash injury severity literature [22–26]. It should be noted that school bus crashes are generally rare occurrences, and studies that have previously been conducted in this area relied on relatively small sample sizes [12,13,19]. Table 1 shows the proportions of the different crash variables in the final dataset that were available for model building and analysis.

The summary statistics of crash data indicate that about 39% of school bus crashes happened in residential areas. Further, 25% were rear-end collisions, whereas sideswipe and side-impact were 15% and 13%, respectively. More than half of the crashes occurred at intersections. School bus crashes were prominent during their drop-off hours and during the spring season. Improper turn and following too close were among the significant contributing crash factors.

Figure 1 further shows a comparison of some key factors between when the school bus was at fault and when it was not at fault. For example, the figure shows that the proportion of injury crashes is lower than that of PDO crashes. However, while the number of school bus at-fault incidents is higher in injury crashes, it is lower compared to school bus not-at-fault incidents in case of PDO crashes. Similarly, more school bus at-fault crashes occurred in open country locales and rural areas, in contrast to urban and residential areas where school bus not-at-fault crashes were higher. In addition, more rear-end crashes were a result of at-fault school buses than sideswipe crashes. Likewise, more school buses are at fault during the morning pick-up hours than at the afternoon drop-off times.

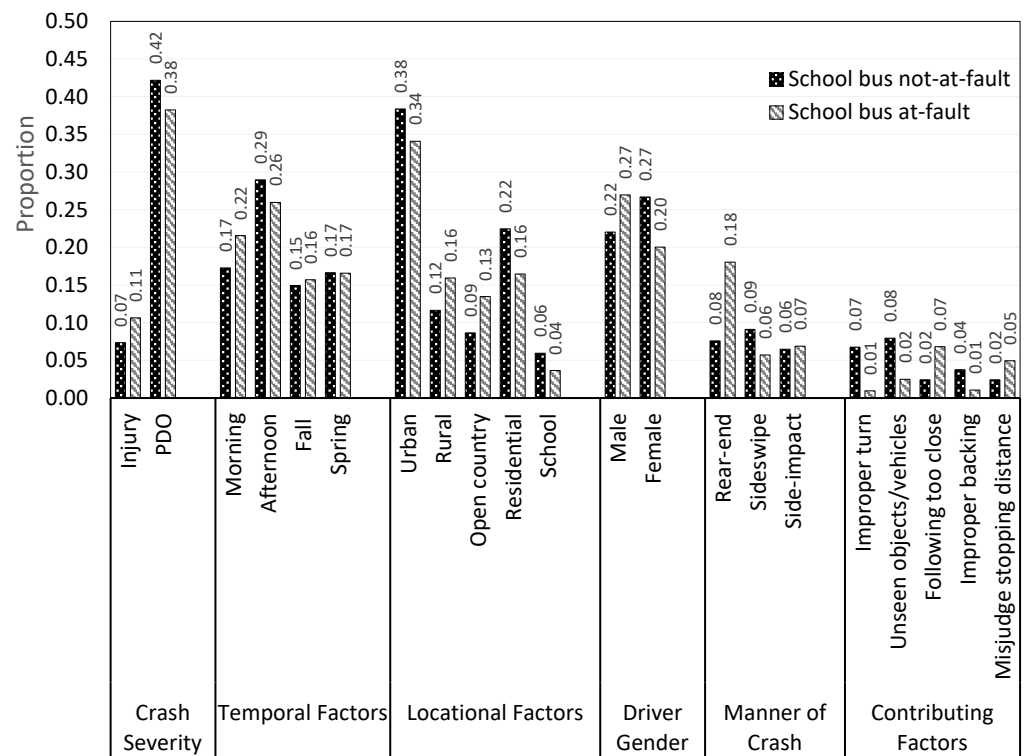


Figure 1. Proportion of crash severity and other key factors for at-fault and not-at-fault school bus crashes.

Table 1. Summary statistics of crash variables.

		Variables	Description	Freq	%
Dependent Variables		Injury	Crash severity: fatal injury 17 (1.00%) Crash severity: incapacitating injury 74 (4.35%) Crash severity: non-incapacitating injury 109 (6.40%) Crash severity: possible injury 118 (6.93%)	318	18.68
		PDO	Crash severity: property damage only	1384	81.32
Explanatory Variables	Contributing	Turn	Made improper turn (1 = Yes, 0 = No)	131	7.70
		Close	Followed too close (1 = Yes, 0 = No)	157	9.22
		Pass	Improper passing (1 = Yes, 0 = No)	27	1.59
		Lane-change	Improper lane change (1 = Yes, 0 = No)	66	3.88
			Improper backing (1 = Yes, 0 = No)	82	4.82
		Stop	Misjudge stopping distance (1 = Yes, 0 = No)	125	7.34
		ROW	Failed to yield right-of-way (1 = Yes, 0 = No)	36	2.12
		Distract	Distraction outside/inside the vehicle (1 = Yes, 0 = No)	59	3.47
		Speed	Over speed limit OR driving too fast for conditions (1 = Yes, 0 = No)	54	3.17
		Unseen	Unseen object/person/vehicle (1 = Yes, 0 = No)	177	10.40
	Side-impact	Rear	Manner of crash: rear end (1 = Yes, 0 = No)	436	25.62
		Sideswipe	Manner of crash: sideswipe (1 = Yes, 0 = No)	252	14.81
		Side-impact	Manner of crash: side impact (1 = Yes, 0 = No)	227	13.34
		Impair	Driver condition: physical impairment (1 = Yes, 0 = No)	5	0.29
		DUI	Driver condition: under the influence of alcohol/drugs (1 = Yes, 0 = No)	17	1.00
		Curve	Other vehicle maneuver: negotiating a curve (1 = Yes, 0 = No)	34	2.00
	Vehicle	Car	Causal vehicle type: passenger car (1 = Yes, 0 = No)	427	25.09
		Pick-up	Causal vehicle type: pick-up (four-tire light truck) (1 = Yes, 0 = No)	189	11.10
		Small school-bus	Other vehicle type: small school bus (seats 15 or Less) (1 = Yes, 0 = No)	88	5.17
		Single vehicle	Other vehicle type: no second vehicle (1 = Yes, 0 = No)	120	7.05
Roadway	4-way	Roadway feature: four-way intersection (1 = Yes, 0 = No)	142	8.34	
	Intersection	At intersection: crash occurred at intersection (1 = Yes, 0 = No)	899	52.82	
	Undivided	Opposing lane separation: broken painted line (1 = Yes, 0 = No)	131	7.70	
	Federal	Roadway classification: federal (1 = Yes, 0 = No)	134	7.87	
	State	Roadway classification: state (1 = Yes, 0 = No)	187	10.99	
	Municipal	Roadway classification: municipal (1 = Yes, 0 = No)	865	50.82	
	Private	Roadway classification: private property (1 = Yes, 0 = No)	30	1.76	
	Guard	Roadway curvature and grade: curve left and up grade (1 = Yes, 0 = No) Traffic control: Crossing guard (1 = Yes, 0 = No)	17 10	1.00 0.59	
Location	Rural	Crash location: rural area (1 = Yes, 0 = No)	469	27.56	
	Urban	Crash location: urban area (1 = Yes, 0 = No)	1233	72.44	
	Open country	Locale: open country (1 = Yes, 0 = No)	376	22.09	
	Residential	Locale: residential (1 = Yes, 0 = No)	662	38.90	
	School	Locale: school (1 = Yes, 0 = No)	163	9.58	

Table 1. Cont.

		Variables	Description	Freq	%
Explanatory Variables	Temporal	Morning	Time of crash: between 5 a.m. and 9 a.m. (1 = Yes, 0 = No)	661	38.84
		Afternoon	Time of crash: between 2 p.m. and 6 p.m. (1 = Yes, 0 = No)	935	54.94
		Spring	Spring season (March to May) (1 = Yes, 0 = No)	565	33.20
		Fall	Fall season (September to November) (1 = Yes, 0 = No)	521	30.61
		Winter	Winter season (December to February) (1 = Yes, 0 = No)	464	27.26
		Dawn	Lighting condition: dawn (1 = Yes, 0 = No)	21	1.23
		Dusk	Lighting condition: dusk (1 = Yes, 0 = No)	26	1.53
		August	Month of the year: August (1 = Yes, 0 = No)	118	6.93
		Driver	Younger	Driver age: less than 25 (1 = Yes, 0 = No)	266
	Old		Driver age: 65 years or more (1 = Yes, 0 = No)	311	18.27
	Female		Driver gender: female (1 = Yes, 0 = No)	795	46.71
	Male		Driver gender: male (1 = Yes, 0 = No)	834	49.00

5. Methodology

A review of injury severity methodologies suggests that several different discrete outcome modeling techniques have been used to explore the association between crash factors and injury severity outcomes [27,28]. For instance, previous injury severity analyses have used methods such as ordered probit [29], ordered logit [30], multinomial logit [31], mixed logit [32,33], random parameters with heterogeneity in means [34,35], random parameters with heterogeneity in means and variances [36], latent class analysis [37–39], Markov switching models [40], Markov switching with random parameters [41], and bivariate/multivariate models with random parameters [42,43]. In addition, several other studies have explored the relationships between crash factors and crash outcomes using a binary logit modeling approach [44–48]. As noted in the data description section, two severity categories (injury and PDO) were considered for this study. For this reason, the binary logit modeling formulation is summarized in Table 2.

Table 2. Equations used in the binary logit model formulation.

Equation	Description
$S_{in} = \beta_i X_{in} + \epsilon_{in}$	S_{in} = severity function for category i in crash n β_i = estimable severity parameters f category i , X_{in} = explanatory variables of severity category i in crash n , ϵ_{in} = error term—generalized extreme value distributed [49]
$P_n(i) = \frac{\exp(\beta_i X_{in})}{\sum \exp(\beta_i X_{in})}$	$P_n(i)$ = probability of i th outcome occurring in the n th observation [2]

Elasticities [50] were further computed to explore the effects of individual crash factors on the injury severity probabilities. Elasticities were computed from the partial derivative for each observation to investigate the effect of individual parameters on the injury-severity outcome as [50]:

$$E_{x_{ki}}^{P(i|\varphi)} = \frac{\partial P(i|\varphi)}{\partial x_{ki}} \times \frac{x_{ki}}{P(i|\varphi)} \tag{1}$$

where, $P(i|\varphi)$ is the probability of injury-severity outcome i and x_{ki} is the value of variable k for outcome i . A pseudo-elasticity is often computed for indicator variables to show the percent effect of the variable taking a value of zero to one on the injury-severity outcome probability [3,4].

For a better understanding of how different exogenous factors affect the crash severity of school buses depending on who is at fault, two binary logit analyses were performed. The development of two separate models was justified by the following transferability test:

$$\chi^2 = -2 \left[LL(\beta_{All\ crashes}) - LL(\beta_{school\ bus\ at-fault}) - LL(\beta_{other\ vehicle\ at-fault}) \right] \tag{2}$$

where χ^2 is a chi-squared distributed parameter with degrees of freedom equal to the total number of estimated parameters in the school bus at-fault and the other vehicle at-fault models minus the number of estimated parameters in the combined model; $LL(\beta_{All\ crashes})$ is the log-

likelihood at the convergence of the model estimated with all the data; $LL(\beta_{school\ bus\ at-fault})$ is the log-likelihood at the convergence of the model estimated with crashes in which the school bus was deemed to be at fault; and $LL(\beta_{other\ vehicle\ at-fault})$ is the log-likelihood at the convergence of the model estimated with the crashes in which other vehicles were deemed to be at fault. The value of $LL(\beta_{All\ crashes})$ was found to be -756.81 with 17 significant variables, $LL(\beta_{school\ bus\ at\ fault})$ was -313.63 with 10 significant variables, and $LL(\beta_{other\ vehicle\ at\ fault})$ was -429.76 with 10 significant variables. These numbers resulted in a chi-square score of 13.416 and degrees of freedom of 3. The p -value (p -value = 0.003818 < 0.05) indicates that separate models are justified.

Variables that were included in the final binary logit model had t -statistics corresponding to a confidence interval of 90% or above on a two-tailed t -test. Model estimation results are presented in Table 3.

Table 3. Binary logit model estimation results.

Variable	School Bus Not-at-Fault				School Bus At-Fault			
	Injury		PDO		Injury		PDO	
	Parameter	t-Stats	Parameter	t-Stats	Parameter	t-Stats	Parameter	t-Stats
CONSTANT	-1.551	-10.78			-2.291	-10.49		
<i>Contributing characteristics</i>								
Turn							0.871	2.19
Pass			1.943	2.18				
Lane-change			1.499	2.40				
Back			2.000	1.77			0.779	1.68
ROW			2.052	2.00				
Distract			0.878	1.71				
Unseen							1.063	2.88
Speed	0.932	3.06						
Rear					0.819	2.73		
Sideswipe							1.032	2.21
Side-impact					1.227	4.16		
Impair	2.460	2.11						
DUI	1.242	2.47						
Curve	0.952	1.82						
<i>Vehicle characteristics</i>								
Small school-bus					3.321	2.46		
Single-vehicle					1.179	3.92		
<i>Roadway characteristics</i>								
4-way					0.727	2.28		
Federal	1.022	4.08			1.307	3.72		
Private			2.583	2.37				
Left	1.796	1.96						
Guard	2.504	2.10						
<i>Location characteristics</i>								
Open country					0.987	4.17		
<i>Temporal characteristics</i>								
August							1.350	2.40
Dawn					1.730	2.56		
<i>Driver characteristics</i>								
Male	0.400	2.27						
Number of observations	851				851			
Log likelihood at constants	-464.02				-368.88			
Log likelihood at convergence	-421.08				-304.97			
McFadden Pseudo R-sq	0.076				0.159			

6. Results

Examination of the model results reveals interesting information about the factors that are associated with school bus involved crash outcomes. A total of 14 explanatory variables were found to be statistically significant at a 5% significance level for crashes where the school bus was not at fault and 13 were found significant for school bus at-fault crashes. These variables are grouped into categories describing crash-specific, roadway, vehicle, location, temporal, and driver characteristics, as shown in Table 3. Because the binary logit analysis uses crashes classified as either injury or PDO outcomes, the parameter values in Table 3 indicate the effects of the variables on a particular crash outcome relative to

each other. As hypothesized, the results in Table 3 show a unique set of factors associated with the two school bus crash types, which are separately summarized in the following sub-sections.

6.1. Factors Associated with School Bus At-Fault Crashes

The results of the binary logit models reveal that improper driving maneuvers such as turning and backing by an at-fault school bus are more likely to result in PDO. This is also true when the bus driver fails to see an object, person, or other vehicles. A sideswipe by an at-fault school bus also results in a PDO crash. In contrast, a rear-end or side-impact collision of a school bus with another vehicle is likely to record some form of injury. Although no specific vehicle characteristics were found significant in school bus not-at-fault crashes, two vehicle characteristics found significant in school bus at-fault crashes were a collision with a smaller school bus and a single-vehicle crash. This finding shows that there is not enough evidence to link school bus-involved crash severity to other at-fault vehicle types (e.g., cars, SUVs, pickup, etc.). Perhaps, this finding may be due to the small number of observations in the crash sample. Further, four-way intersections, federal highways, open country locale, and dawn were found to significantly result in injuries from crashes involving the school buses at fault. The fact that federal highways were associated with injury crashes was both expected and in line with previous findings (e.g., [16]) on the relationship between traveling speed and crash severity.

6.2. Factors Associated with School Bus Not-at-Fault Crashes

There were higher chances of multi-vehicle PDO crashes involving maneuvers such as passing, lane-changing, backing, and failing to yield right-of-way in the vicinity of a school bus where the school bus was deemed to not be at fault. Similarly, distracted driving by other motor vehicle drivers had a high likelihood of a PDO crash. However, where the at-fault driver (school bus not at fault) was engaged in speeding, driving under the influence, and negotiating a curve, the crash was likely to lead to some form of injury. The federal highway indicator variable also increased the likelihood of injury in school bus not-at-fault crashes. As with the school bus at-fault crashes, this result is reasonable, as it links crash severity to traveling speed regardless of whether the driver was cited for excessive speeding in the crash report. Additionally, making left turns on an upward graded road and traffic control by crossing guards are also associated with injuries in school bus not-at-fault crashes.

Two factors found common to school bus at-fault and not-at-fault crashes are improper backing, which results in PDO crashes, and federal highways, which results in some form of injuries. Table 4 further shows the elasticities of the variables to examine the effects of the individual factors on the probabilities of injury and PDO crashes. An elasticity of 0.25 of a variable indicates that the probability increases by 25% on average when the variable is changed from 0 to 1. A negative elasticity indicates that the variable decreases the probability of the injury category for which the variable is defined. Similar to the estimation results, elasticities in Table 4 also indicate that the set of variables that affects the probabilities of injury are unique for the school bus at-fault and not-at-fault crashes.

6.3. Elasticities of Factors Associated with School Bus At-Fault Crashes

The elasticity results indicate that single-vehicle crashes have the highest probability of injury outcomes, followed by those occurring in an open country locale. In addition, the side-impact and rear-end collision of the school bus with other vehicles can also result in significant injuries. This is intuitive, considering the impact that a large-size vehicle can have on smaller vehicles. Further, elasticities of four-way intersection and dawn are also found to lead to injury crashes where the school bus is at fault. Elasticities of other variables such as improper turning, unseen objects or vehicles, sideswipe, and August are found to increase the likelihood of PDO crashes.

Table 4. Binary logit model elasticities.

Variable	School Bus Not-at-Fault		School Bus At-Fault	
	Injury	PDO	Injury	PDO
<i>Contributing characteristics</i>				
Turn			−10.85	0.92
Pass	−4.57	0.46		
Lane-change	−6.17	0.53		
Back	−4.00	0.24	−5.31	0.55
ROW	−6.27	0.24		
Distract	−3.51	0.52		
Unseen			−15.49	1.37
Speed	3.18	−2.52		
Rear			9.62	−2.79
Sideswipe			−17.94	0.85
Side-impact			10.96	−4.90
Impair	0.29	−0.87		
DUI	1.17	−1.31		
Curve	1.34	−0.89		
<i>Vehicle characteristics</i>				
Small school-bus			0.78	−0.39
Single-vehicle			12.34	−4.3
<i>Roadway characteristics</i>				
4-way			4.53	−1.88
Federal	6.12	−3.96	4.91	−2.76
Private	0.61	−0.91		
Left	0.63	−0.63		
Guard	0.29	−0.88		
<i>Location characteristics</i>				
Open country			11.72	−5.34
<i>Temporal characteristics</i>				
August			−9.04	0.63
Dawn			1.42	−1.02
<i>Driver characteristics</i>				
Male	15.69	−5.87		

6.4. Elasticities of Factors Associated with School Bus Not-at-Fault Crashes

A male driver has the largest effect on the likelihood of an injury crash when the school bus is not at fault. This is followed by speeding, driving under influence, impaired driving, negotiating a curve, left turn, and the presence of a crossing guard, which all increase the likelihood of injury outcomes when other vehicles were deemed to be at fault in a crash with a school bus.

Except for federal highways, no other variable contributing to injuries is found common to school bus at-fault and not-at-fault crashes, supporting the hypothesis that the two crash types have a unique set of contributing factors. The following section discusses the results for each crash type and its implications in further detail.

7. Discussion

School buses are typically considered a very safe form of transportation, with crash fatalities and injury rates far lower than for other vehicles [9,12]. Typically, in school bus crashes, fatalities and injuries are more frequent among occupants of other vehicles involved in the crash than among the occupants of the school bus [5,12,19]. This study considers two school bus crash types, one resulting from the at-fault school bus and the other resulting from another at-fault vehicle. Analyses of the results of two binary logit models of school bus crashes with the Alabama data presented in this study show that the factors and its effects associated with a particular school bus crash type (at-fault and

not-at-fault) are uniquely different. Hence, the countermeasure strategies, in turn, should be imperatively different.

School buses are operated differently because of differences in their trip demands or usage, which may result in different types of crashes [20]. Among the contributing factors where the school bus is at fault, this current study finds rear-end and side-impact collisions as significant crash types that have high chances to lead to injury. It also illustrated additional consequences of the bus driver's improper maneuvering. Specifically, it showed that improper turning, backing, not seeing conflicting objects or vehicles, and sideswipe occurred more frequently but were less likely to lead to injury. These findings are consistent with other previous studies [19,20,51] that attributed such collisions to the size of school buses and their operational characteristics, such as decelerating or accelerating to and from stops more frequently than other drivers.

Further, the study also finds that single-vehicle, open country locale, four-way intersections, federal highways, and dawn are also associated with injuries in a school bus at-fault crash. Of these, intersection, single-vehicle, and dawn are consistent with the results of a past study [12,20]. Yang et al. [12] finds that the main factors associated with a single bus crash were a collision with a fixed object (e.g., bridge, poles, tree, ditch, mailbox, etc.), over-turn/rollover, and collision with an animal, whereas Yasmin, Anowar, and Tay [20] finds that single-vehicle school bus crashes are more prevalent than multiple vehicle collisions. As with the school bus at-fault crashes, the federal highway variable is reasonable, as it links crash severity to traveling speed regardless of whether the driver was cited for excessive speeding in the crash report. The extent to which the dawn variable is associated with crashes agrees with the literature (e.g., [20]) and is intuitive, as the morning school commute is the most common time for school buses to be traveling, and in some cases may also correlate to lower lighting conditions and higher levels of background commuter traffic. Such contributing factors could be a result of either faulty driving or poorly built environments around school zones. Whereas the built environments around school zones could be improved by simple measures [21,52], guidelines disseminated by NHTSA could also be helpful to drivers for the safe operation of school buses [53,54]. The guidelines provide a review of important aspects of driving a school bus and covers diverse topics, such as driver attitude, safety, vehicle training, route familiarity, emergency evacuation, and driving under adverse conditions. With such guidelines already in place, sustained enforcement efforts can achieve improved school bus safety. Further detailed investigation of the characteristics of school bus crashes at intersections should also be carried out to learn more about pre-crash, crash, and post-crash events that may have contributed to the crash occurrence. Additionally, licensing and driver training requirements of school bus drivers should be regularly reviewed. Reduced travel speeds in open country locales can also lead to reduction in injury crashes.

Further, some studies examined the seasonal distribution of school bus crashes and found summer as a period of the fewest crashes [12,20]. The current study, however, found no particular season to be significantly overrepresented—the single month of August, however, exhibited a relatively higher proportion of crashes, although the chance of no injury was high. This may be due to the unfamiliarity of the drivers with the new routes and pick-up and drop-off points, given that August is the start of a new school year. Indeed, more frequent crashes have been observed on nonroutine routes compared to routine routes in a previous study [19]. As a countermeasure, policies should be put in place to assign drivers to routine routes until they gain experience, as this might help to reduce crashes on nonroutine routes [19]. In the case of newer school bus drivers, the training programs should be improved to include scenarios of bus crashes on nonroutine trips, which could alert drivers to this issue and potentially provide insight into ways to avoid these crashes [19].

For the crashes where the school bus is not at fault, the results indicate speeding, impaired driving, DUI, negotiating curves, and left turns are some of the significant contributing characteristics associated with injury crashes, whereas improper passing,

lane-changing, backing, failing to yield right-of-way, distracted driving by drivers of other vehicles leads to PDO crashes. To an extent, such improper maneuvers by drivers of other vehicles significantly contributing to crashes involving school buses is consistent with findings of other past studies. For example, a research study found that drivers of other vehicles were more likely than the bus driver to contribute to or cause a crash, indicating that light-vehicle drivers are most often at fault in crashes [11,55]. Similarly, another study found that it is usually other vehicles and mainly those traveling in the opposing lane that makes a significant amount of illegal passing maneuvers [21]. In addition, contributing causes related to major driving violations (e.g., reckless or aggressive driving and disregard for traffic control) were found to be more frequently exhibited by other vehicles that crashed with buses [19]. However, unlike other studies, this study specifically found improper passing, lane-changing, backing, failing to yield right-of-way, and distracted driving on the part of other vehicles to be significant contributors to school bus related crashes. Further, speeding associated with injury crashes is both expected and in line with previous findings on the relationship between traveling speed and crash severity. Other factors such as driving impaired or under influence, turning left on upward graded roads, and male drivers have already been established in the literature as risky crash factors [5,12,16,19,22]. These findings have implications for reducing school bus crashes and suggest that school bus safety programs need to include drivers of other vehicles [12]. Incorporating education for drivers of other vehicles in school zones about safe driving around school buses into driver's education programs may help reduce school bus crashes.

Interestingly, although increased crossing guard presence around school zones should increase safe behavior [56], this study finds an increased likelihood of injury crashes by other vehicles at locations where crossing guards controlled the traffic. This finding certainly raises concerns about the competencies and/or effectiveness of crossing guard placements in school zones. A proper training program for the crossing guards to improve their competency and effectiveness should be instituted to improve safety in the vicinity of school zones. It also implies the need for educating drivers of other vehicles about maneuvering at crossings with guards present and proper training of the guards to improve their competency and effectiveness.

Overall, in terms of policy implications, this study suggests a two-pronged approach—one for the school bus drivers and another for other drivers regarding driving around the school bus. For the school bus drivers, more improved training, enforcement of guidelines for the safe operation of school buses, and updates in policies (such as assigning drivers to routine routes) is suggested. Whereas for the other generic drivers, educating them on driving in and around school zones and buses, and navigating at crossings manned by a guard is recommended. Additionally, improved training programs for crossing guards and the inclusion of crash scenarios on nonroutine routes for bus drivers could also be helpful.

8. Conclusions

Although school buses are often touted as one of the safest modes of transportation, many serious injuries and fatalities result from school bus related crashes [21] whether or not the bus driver is at fault. School buses experience low crash rates, and the majority of crashes do not lead to injury [9,12]. This study used the 2009–2016 crash data for Alabama to investigate the exogenous factors that contribute to such school bus crash outcomes. The research contribution of this study is the investigation of the school bus crash data by each causal entity type—school bus at-fault and not-at-fault (i.e., another vehicle at-fault) crashes and development of two binary logit models to independently examine the factors associated with injury and PDO outcomes for each school bus crash type. Segmentation of the crashes by the manner of collision helped to unravel further details about school bus crash injury severity. Our model results suggest that improper driving maneuvers such as improper turning, backing, passing, lane-changing, failing to yield right-of-way, failing to see objects, and driving distracted significantly contributed to crashes involving school buses. Federal roadways, private property, left turns on upward graded roads,

traffic control with crossing guards, and male drivers are related to crashes more prone to injury outcomes when drivers of other vehicles are at fault. Similarly, speeding, driving impaired, under the influence, or negotiating a curve by drivers of other vehicles lead to injury crashes, whereas rear-end and side-impact collisions do so when the school bus is at fault. Additionally, four-way intersections, federal roads, open country locale, and dawn are associated with school bus at-fault crash injuries. A single-vehicle crash could be riskier than any other crash when the school bus is at fault. School bus at-fault PDO crashes are also more significant in August, the first month of the school season, probably due to the unfamiliarity of the drivers with the newer neighborhoods, routes, and pickup locations.

The highlights of the implications discussed in the study include separate strategies for each school bus crash type. Enforcement of safe school bus driving guidelines, review of licensing and driver training requirements, improvements in school bus driver's training program, and assignment of drivers to the familiar local neighborhoods at least in the first month of the school season are the countermeasures discussed for the at-fault school bus crashes. Further, the countermeasures to mitigate school bus not-at-fault crashes include training programs for the crossing guards and an improved education and awareness program for other drivers.

As such, school buses make up only a small proportion of annual crashes due to their rarity. The small sample size of these crashes hinders the development of models to investigate crash factors associated with each crash severity. The grouping of all injury outcome categories in a single category leads to loss of information on the individual injury severity categories. The limitation of the study is that it lacks information on the factors that contribute to the severity of the injury crashes. With the availability of more school bus crash data, perhaps this possibility could be explored in the future.

Overall, this study looked at school bus related crashes in Alabama and found that crash contributing factors and roadway characteristics are the most frequent correlates of these crashes, regardless of whether the school bus is at fault. As suggested by the results, the implementation of school bus safety awareness programs should be supplemented by traffic regulation enforcement programs at high-risk locations to minimize traffic violations by drivers of other vehicles. The implications discussed hitherto can aid in improving policies related to school bus transportation, thereby creating a safer environment for school travel. However, school bus crashes, like all crashes, are fortunately rare events. School bus drivers require and receive specific training and perform their driving tasks in a specialized environment [57]. A Safe system approach to understanding crashes and developing road safety countermeasures is more informative for all situations. Explicitly examining school bus crashes in such a way could be very informative as understanding the interactions among driver workload, roadway characteristics, speed limits, and traffic volume and composition would lead to more effective driver training and other countermeasures to prevent and reduce the severity of school bus crashes.

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