USDOT Region V Regional University Transportation Center Final Report

NEXTRANS Project No 015WY01

Investigation of Emergency Vehicle Crashes in the State of Michigan

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DISCLAIMER

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TECHNICAL SUMMARY

NEXTRANS Project No 015WY01 Final Report, October 2009

Investigation of Emergency Vehicle Crashes in the State of Michigan

Introduction

Crashes involving emergency vehicles, including ambulances, fire trucks, and police cars, are a substantial problem nationwide. The national traffic fatality rates for emergency medical service personnel, police officers, and firefighters have been estimated to be 2.5 to 4.8 times the national average among all occupations. Emergency vehicle crashes have been shown to be particularly problematic in the State of Michigan, which is among four states that were previously shown to account for 37.5% of the country's ambulance-involved fatalities. Over the five-year period from 2004 to 2008, a total of 12,966 emergency vehicles were involved in traffic crashes in the State of Michigan and, among these crash-involved vehicles, approximately 28.6 percent were on an emergency run at the time the crash occurred. The objectives of this research were to identify critical factors associated with the occurrence of emergency vehicle crashes, to distinguish among the characteristics of crashes involving different types of emergency vehicles, and to determine those factors affecting the injury severity resulting from emergency vehicle crashes.

Findings

Crashes occurring during emergency response were more likely to occur near intersections or driveways, under dark lighting conditions, and during the PM peak period and the most prevalent types of crashes were angle, head-on, and sideswipe collisions. These emergency response crashes were also characterized by high risk driving behaviors, such as speeding, overtaking, passing, and non-use of safety restraint devices.

Injuries tended to be most severe at high speeds, when emergency or non-emergency drivers exhibited high risk driving behaviors, when angle collisions occurred, and when crashes involved police cars. Crashes were least severe at locations with lower posted speed limits, under darkness, when male drivers were involved, and particularly when safety belts were utilized.

Recommendations

Efforts to improve the knowledge, skills, and abilities of emergency vehicle drivers is warranted, including targeted training and educational programs aimed at reducing the frequency of high-risk driving behaviors, such as speeding, unsafe passage through signalized intersections, and the non-use of safety restraint devices.

Initiatives should also be aimed at increasing the awareness of emergency vehicle safety issues among the general public as crash data indicates that hazardous actions by other drivers, including speeding, disregarding traffic control, and other careless driving behaviors present a substantial problem for emergency vehicle operators.

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CHAPTER 1. INTRODUCTION

1.1 Background

Crashes involving in-service emergency vehicles, including ambulances, fire trucks, and police cars, are a substantial problem nationwide as evidenced by the 160 fatalities resulting from such crashes during the period from 2004 to 2008 (National Highway Traffic Safety Administration, 2009). While these fatalities represent a small percentage of all annual traffic fatalities, the risk of emergency vehicle crashes, injuries, and fatalities is considerably higher when accounting for the degree of exposure for these types of vehicles. In fact, the national traffic fatality rates for emergency medical service personnel, police officers, and firefighters have been estimated to be 2.5 to 4.8 times the national average among all occupations (Maguire et al., 2002).

Emergency vehicle crashes have been shown to be particularly problematic in the State of Michigan, which is among four states that were previously shown to account for 37.5% of the country's ambulance-involved fatalities (Pirrallo and Swor, 1994). Over the five-year period from 2004 to 2008, a total of 12,966 emergency vehicles were involved in traffic crashes in the State of Michigan as shown in Table 1.1. Among these crash-involved vehicles, approximately 28.6 percent were on an emergency run, with lights and sirens activated, while the remaining 71.4 percent were being used for other non-emergency purposes. While the frequency of emergency vehicle crashes has begun to decline in recent years, mirroring the statewide trend in overall crashes, the rate of emergency vehicle crashes remains high given the relatively small proportion of total vehicle miles of travel contributed by these vehicles.

Table 1.1. Emergency Vehicle Crash Data by Response Status and Vehicle Type

Response Status	Type of Vehicle	Year 2004	2005	2006	2007	2008	5-Year Total
Non-emergency	EMS	210	227	200	221	239	1,097
	Fire	206	184	177	156	158	881
	Police	1,879	1,561	1,493	1,488	1,495	7,916
	Total	2,295	1,972	1,870	1,865	1,892	9,894
Emergency	EMS	90	110	104	81	96	481
	Fire	113	94	75	94	87	463
	Police	496	430	403	397	402	2,128
	Total	699	634	582	572	585	3,072
Total	EMS	300	337	304	302	335	1,578
	Fire	319	278	252	250	245	1,344
	Police	2,375	1,991	1,896	1,885	1,897	10,044
	Total	2,994	2,606	2,452	2,437	2,477	12,966

In response to this public safety dilemma, various emergency vehicle safety studies have been conducted in recent years. These studies have focused on a broad range of topics, including the impacts of the use of lights and sirens on emergency response times, the effectiveness and degree of use of safety restraint devices by emergency vehicle occupants, and the effects of numerous factors on the level of occupant injury severity, among others. The majority of recent emergency vehicle safety studies have focused specifically on ambulance-involved crashes, with one exception being a study by Becker et al (2003) which compared the relative risk of injury and death among emergency vehicle occupants based upon seating position, restraint use, and vehicle response status. While a growing body of literature is becoming available regarding ambulance crashes, a broader examination of emergency vehicle crashes of all types is warranted as illustrated by the crash data presented in Table 1.1. From 2004 to 2008, police cars were the type of emergency vehicle most frequently involved in traffic crashes, comprising 80.0 percent of crashes that occurred under non-emergency situations and 69.3 percent of crashes that occurred during emergency response. Fire trucks were also involved in a substantial number of crashes, totaling 11.1 percent of all non-emergency crashes and 8.9 percent of crashes during emergency runs. Collectively, these statistics indicate that all three types of emergency services warrant further research into those factors contributing to emergency vehicle crashes.

1.2 Study objectives

The objectives of this research are to identify critical factors associated with the occurrence of emergency vehicle crashes, to distinguish among the characteristics of crashes involving different types of emergency vehicles, and to determine those factors affecting the injury severity resulting from emergency vehicle crashes. In order to accomplish these objectives, logistic (logit) regression techniques are utilized in order to develop models to aid in improving the understanding of emergency vehicle crashes. In particular, four models are developed:

1. a binary logit model to compare the characteristics of emergency vehicle crashes which occurred during an emergency run (i.e., with lights and sirens activated) versus those that occurred while the emergency vehicle was not on an emergency run;
2. a multinomial logit model to identify differences between crashes involving police, fire, and emergency medical service vehicles;
3. an ordered logit models to identify those factors which impact the injury severity sustained by emergency vehicle drivers involved in single-vehicle crashes during emergency runs; and
4. an ordered logit models to identify those factors which impact the injury severity sustained by emergency vehicle drivers in crashes involving two vehicles during emergency runs.

1.3 Organization of the research

The remainder of the research is organized as follows. Chapter 2 provides background on emergency vehicle safety in the State of Michigan and presents a review of previous research in this area. Chapter 3 describes the statistical methodology utilized to develop the four models alluded to previously. Chapter 4 presents the results of these models and discusses the implications of the findings and Chapter 5 summarizes the research and provides direction for future research.

CHAPTER 2. BACKGROUND ON EMERGENCY VEHICLE SAFETY

This chapter provides background regarding emergency vehicle safety, beginning with an overview of previous emergency vehicle safety research in Section 2.1, followed by a presentation of Michigan emergency vehicle crash data in Section 2.2, and a discussion of the preparation of the analysis database in Section 2.3

2.1 Literature Review

Previous studies of emergency vehicle-involved crashes show that driver error is the primary cause of up to 93 percent of such crashes in urban environments and 75 percent of emergency vehicle crashes in rural environments (Ray and Kupas, 2005). There are a wide variety of factors that contribute to these crashes and among the most widely publicized are errors made on the part of non-emergency vehicle drivers who fail to yield the right-of-way to approaching emergency vehicles, particularly at intersections (Maio et al, 1992; Kahn et al, 2001). Savolainen and Datta (2009) recently completed a study which found that approximately 25 percent of drivers at five intersections in suburban Detroit, Michigan violated the right-of-way of an approaching emergency vehicle during a series of emergency runs. Clarke et al (2009) found emergency vehicle drivers to exhibit a low 'blameworthiness ratio' in their collision involvement, indicating that the non-emergency vehicle driver was more likely to commit a mistake leading to the crash and subsequent injuries. However, emergency vehicle drivers were also found to exhibit blameworthy behaviors, the most common of which was classified as 'failing to take account of a restricted view'. Nearly all such cases involved travelling through a red light at a signalized intersection while on an emergency call and failing to see another vehicle that was hidden by a vehicle which had already stopped and given way for the emergency vehicle. Past research has also identified certain groups of drivers to be more prone to crash involvement.

Among the crash-involved emergency vehicle drivers in their study, Clarke et al (2009) found that nearly all were male and that crash involvement peaked in the 26 to 30-year old age group. Further, fatal injuries were more likely to result in the cases where the emergency driver was judged to be at fault. Custalow and Gravitz (2004) examined 9 years of data from the Paramedic Division of the Denver Health and Hospital Authority and found that in 71 percent of crashes, the emergency vehicle operator had a record of multiple collisions. They noted that 91 percent of these crashes occurred while the vehicle was operating with lights and sirens activated.

Interestingly, the literature regarding the use of lights and sirens has shown only marginal benefits in terms of reductions in door-to-door response times in comparison to non-emergency operation (Hunt et. al, 1995; Ho and Casey, 1998; O'Brien et al., 1999). Becker et al (2003) found that occupants were more likely to be seriously injured in emergency situations as compared to non-emergencies while Kahn et al (2001) found that the location of the crash relative to an intersection and the type of collision were the only significantly different factors in an analysis of eleven years of data from the Fatality Analysis Reporting System (FARS) which compared ambulance use in emergency and non-emergency situations.

One of the most critical errors committed by emergency vehicle drivers and occupants is the failure to use appropriate safety restraint devices. The Centers for Disease Control and Prevention (2003) analyzed 11 years of data from the FARS database, including 300 fatal crashes involving ambulances., and found that one-third of the fatalities sustained in ambulances occurred in the front seat where safety belts were available, but not used. In the aforementioned study by Becker et al (2003), restraint use was found to significantly reduce the likelihood of being killed or seriously injured in an analysis which used data from both FARS and the General Estimates System (GES). In one of the earliest studies focusing on emergency vehicle crashes, Auerbach et al (1987) also found that the use of a safety belt was the most significant factor affecting injury severity. They also found that most fatalities occurred when the occupants of the emergency vehicles were in the drivers' seat, followed by the patient compartment and passenger side seats. Other researchers have showed that the rear patient compartment is the most dangerous part of the ambulance (Levick et al, 2001a; Levick et al, 2001b).

A recent study by Ray and Kupas (2005) compared the characteristics of crashes involving ambulances with those involving non-emergency vehicles of similar sizes using Pennsylvania Department of Transportation data from 1997 to 2001. Road surface and weather conditions at the time of the crash were found to be similar among the vehicle groups while ambulance crashes were more likely to occur at intersections, particularly where traffic signals were present. Ambulance crashes were also found to occur more frequently during evening and weekend hours.

In a subsequent study using the same data, Ray and Kupas (2007) compared urban and rural ambulance crashes. The time of day, lighting conditions, and road type were generally similar between the urban and rural environments, though rural crashes were more likely to occur on snowy roads and under darkness. Operator error was found to be the most common cause of crashes, particularly in urban areas while other external factors, such as vehicle defects and environmental conditions were more frequently to contribute to rural crashes. Urban crashes were more pronounced at intersections, particularly angle collisions stop-controlled and signalized intersections. The distribution of injury severities was similar in the urban and rural environments, thought the authors note that rural crashes more frequently resulted in property damage only.

2.2 Emergency Vehicle Crash Data

Clearly, there are numerous factors which contribute to emergency vehicle crashes, injuries, and fatalities. Tables 2.1 and 2.2 provide summary data regarding all emergency vehicle crashes which have occurred in the State of Michigan between 2004 and 2008, as well as reference data for all non-emergency vehicle crashes which occurred during this same period.

Table 2.1 presents summary data on the environmental conditions and other crash-specific details for all crashes. In general, the characteristics of the emergency vehicle-involved crashes are not substantially different from those which did not involve emergency vehicles. Surprisingly, emergency vehicle crashes were more likely to occur during daylight, under clear weather conditions, and on dry pavement. It is possible that the reasons for such findings may be due to drivers exercising less caution under such favorable weather conditions. When examining crash types, angle collisions are more prevalent in emergency vehicle crashes, as are sideswipe collisions, which frequently occur when emergency vehicles are trying to pass other vehicles en route to an incident. Emergency vehicle crashes also occurred more regularly on lower speed roads, where a large percentage of their travel occurs and more frequent access points present opportunities for collisions with conflicting traffic streams.

Table 2.2 presents data related to the drivers and vehicles involved in all crashes in the State of Michigan from 2004 to 2008, categorized by whether the crash involved an emergency vehicle. The majority of emergency vehicle drivers are between the ages of 25 and 44 and there are substantially fewer very young and very old drivers. This is to be expected since emergency vehicle drivers are generally required to take specific courses and meet minimum standards, which inhibit younger, inexperienced drivers and older drivers with deteriorating reflexes and driving skills. The majority of emergency vehicle drivers were males, similar to the results reported in a study by Clarke et al (2009). One of the unfortunate discrepancies that is apparent from the crash data is the fact that restraint use is alarmingly low among emergency vehicle drivers, whose restraint use rate was 3.3 percentage points lower than other crash-involved drivers. When examining the injury severity distributions, there is little difference between the emergency-vehicle involved crashes and other crashes. The last characteristics shown in Table 2.2 are drawn from the "Vehicle Use" and "Special Vehicle" fields of the Michigan State Police UD-10 Crash Report Form. Interestingly, 617 non-emergency vehicles were classified as being "In Pursuit/On Emergency". This discrepancy is explained further in the following section.

Table 2.1. Environmental Conditions from Michigan Crash Database

Environmental Conditions	EV involved cases		Non-EV involved cases	
Weather	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Clear/Cloudy	10,038	80.1%	1,303,814	78.2%
Rain	1,071	8.6%	148,773	8.9%
Snow/Sleet/Hail	1,143	9.1%	163,570	9.8%
Fog/smoke	86	0.7%	10,462	0.6%
Other/unknown	187	1.5%	40,275	2.4%
Total	12,525	100.0%	1,666,894	100.0%
Road Surface	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Dry	8,322	66.4%	1,066,181	64.0%
Wet	2,045	16.3%	285,212	17.1%
Snowy/Icy/Slushy	1,888	15.1%	269,659	16.2%
Other/Unknown	270	2.2%	45,842	2.8%
Total	12,525	100.0%	1,666,894	100.0%
Lighting	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Daylight	6,340	50.6%	999,422	60.0%
Dawn	227	1.8%	59,301	3.6%
Dusk	329	2.6%	50,547	3.0%
Dark lighted	2,537	20.3%	197,868	11.9%
Dark unlighted	3,013	24.1%	338,132	20.3%
Other/unknown	79	0.6%	21,624	1.3%
Total	12,525	100.0%	1,666,894	100.0%
Crash Type	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Single motor vehicle	3,970	31.7%	621,723	37.3%
Head-on	249	2.0%	25,780	1.6%
Head-on / left turn	198	1.6%	41,063	2.5%
Angle	2,517	20.1%	295,869	17.8%
Rear-end	2,631	21.0%	421,102	25.3%
Sideswipe same direction	1,585	12.7%	144,018	8.6%
Sideswipe opposite direction	497	4.0%	39,222	2.4%
Other/unknown	878	7.0%	78,117	4.7%
Total	12,525	100.0%	1,666,894	100.0%
Day Of Week	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Sunday	1,487	11.9%	178,420	10.7%
Monday	1,726	13.8%	239,459	14.4%
Tuesday	1,793	14.3%	244,131	14.7%
Wednesday	1,906	15.2%	255,067	15.3%
Thursday	1,897	15.2%	247,535	14.9%
Friday	1,964	15.7%	282,462	17.0%
Saturday	1,752	14.0%	219,820	13.2%
Total	12,525	100.0%	1,666,894	100.0%
Speed Limit	**Frequency**	**Percentage**	**Frequency**	**Percentage**
<= 30 mph	3,755	30.0%	354,961	21.3%
35-45 mph	3,920	31.3%	556,712	33.4%
50-60 mph	3,553	28.4%	557,365	33.4%
>=65 mph	1,297	10.4%	197,856	11.9%
Total	12,525	100.0%	1,666,894	100.0%

Table 2.2. Driver and Vehicle Characteristics from Michigan Crash Database

Driver/Vehicle Characteristic	EV involved cases		Non-EV involved cases	
Driver Age	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Less than 25 yrs	3,167	14.4%	662,092	23.5%
25 yrs to 34 yrs	5,903	26.9%	489,518	17.4%
35 yrs to 44 yrs	5,497	25.0%	490,215	17.4%
45 yrs to 54 yrs	2,988	13.6%	440,507	15.7%
Greater than 54 yrs	2,143	9.8%	468,727	16.7%
Unknown	2,257	10.3%	263,730	9.4%
Total	21,955	100.0%	2,814,789	100.0%
Driver Gender	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Male	14,938	68.0%	1,460,772	51.9%
Female	5,068	23.1%	1,139,731	40.5%
Unknown	1,949	8.9%	214,286	7.6%
Total	21,955	100.0%	2,814,789	100.0%
Driver Restraint Use	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Driver Belted	17,831	81.2%	2,379,047	84.5%
Driver Not Belted	632	2.9%	35,151	1.3%
Other/Unknown	3,492	15.9%	400,591	14.2%
Total	21,955	100.0%	2,814,789	100.0%
Airbag Deployment	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Airbag Deployed	1,367	6.2%	203,145	7.2%
Airbag Not Deployed	16,363	74.5%	1,985,319	70.5%
Airbag Not Equipped	4,225	19.2%	626,325	22.3%
Total	21,955	100.0%	2,814,789	100.0%
Driver Degree Of Injury	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Killed	22	0.1%	4,192	0.2%
Incapacitating injury	209	1.0%	29,846	1.1%
Nonincapacitating injury	585	2.7%	72,968	2.6%
Possible injury	1,859	8.5%	219,981	7.8%
No injury	17,294	78.8%	2,233,828	79.4%
Unknown	1,986	9.1%	253,974	9.0%
Total	21,955	100.0%	2,814,789	100.0%
Vehicle Use	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Private	9,106	41.5%	2,469,027	87.7%
Commercial	1,143	5.2%	129,399	4.6%
In pursuit / on emergency	3,091	14.1%	617	0.0%
Other government use	6,905	31.5%	10,130	0.4%
Other/Unknown	1,710	7.8%	205,616	7.3%
Total	21,955	100.0%	2,814,789	100.0%
Special Vehicle	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Not special vehicle	8,515	38.8%	2,688,974	95.5%
Police vehicle	10,044	45.8%	0	0.0%
Fire vehicle	1,344	6.1%	0	0.0%
Bus (commercial/ private/ school)	44	0.2%	6,133	0.2%
Ambulance	1,578	7.2%	0	0.0%
Equipment	41	0.2%	5,689	0.2%
Unknown	389	1.8%	113,993	4.1%
Total	21,955	100.0%	2,814,789	100.0%

2.3 *Preparation of Emergency Vehicle Crash Database*

For the purposes of this study, the Michigan State Police crash database was used to identify emergency vehicle-involved crashes occurring in the State of Michigan from 2004 to 2008 and to extract all relevant data for the subsequent statistical analysis. This analysis required these 12,525 crashes to be aggregated into several groups based upon specific crash characteristics.

There are two fields on the Michigan UD-10 Traffic Crash Report Form that are particularly important when examining emergency vehicle crashes. The first field is "Special Vehicle Type", which allows for the identification of non-standard vehicles, such as emergency vehicles, buses, farm equipment, and construction equipment. Emergency vehicles are designated by Special Vehicle Type codes 1 (Police), 2 (Fire), and 4 (EMS). Anytime a governmentally controlled fire, EMS, or police vehicle is involved in a crash, their special vehicle coding will take one of these three values. For private business-controlled or hospital ambulances, they also apply under this special vehicle coding, which also includes under-cover police vehicles or responding unit commanders of fire departments in departmentally controlled vehicles.

The second field of relevance is "Primary Vehicle Use", which documents the investigating officer's description of the trip purpose for each crash-involved vehicle at the time of the crash. Vehicles responding to an emergency are assigned a Primary Vehicle Use code of 3 "In Pursuit/On Emergency", though a manual examination of various UD-10 report forms shows that some such crashes may also be coded as "Other Government Use" (code 8), or various other codes.

In order to identify an appropriate sample of crashes to meet the needs of this study, several data queries were developed and compared to determine which provided the greatest accuracy in identifying emergency-vehicle involved crashes and determining whether the vehicles were being used for emergency or non-emergency purposes. To examine the extent of coding accuracy, three query combinations were compared using one year of data from the Michigan Office of Highway Safety Planning (OHSP) Michigan Traffic Crash Facts website. One hundred UD-10 crash report forms were randomly selected after running each query and were investigated to determine coding accuracy, in terms of (a) whether the crash actually involved an emergency vehicle and (b) whether the vehicle use variable was coded correctly. The three queries developed were as follows:

- Query 1 – Primary Vehicle Use Code = 3 (In Pursuit/On Emergency) and Special Vehicle Type Code = 1 (Police), 2 (Fire), or 4 (EMS)
    - All 100 randomly selected crash reports involved at least one emergency vehicle that was engaged in an emergency run.
- Query 2 – Primary Vehicle Use Code = 3 (In Pursuit/On Emergency) and Special Vehicle Type Code = 0 (Not Applicable), 3 (Bus), 5 (Farm Equipment), or 6 (Construction Equipment)
    - Out of the 100 crash report forms, 55 crashes were found to actually involve an emergency vehicle involved, of which 50 were engaged in an emergency run. These crashes were "missed" by the system because the Special Vehicle Type data was missing on the actual UD-10 form. Of the 45 crashes that did not involve an emergency vehicle, 36 were miscoded as vehicles in pursuit while sufficient data was unavailable on the UD-10 forms to reach a conclusion regarding the other 9 forms.
- Query 3 – Primary Vehicle Use Code = any value other than 3 (In Pursuit/On Emergency) and Special Vehicle Type Code = 1 (Police), 2 (Fire), or 4 (EMS)
    - The primary vehicle use on all 100 UD-10 forms was coded as either private, commercial, school/education, other government use, or other. Among these crashes, three crashes involved miscoded reports for which the emergency vehicle was actually on an emergency run and three additional crashes were incorrectly coded as emergency vehicle-involved crash.

Based upon these results, those crashes identified by Query 1 and Query 3 were retained for the purpose of this analysis. While Query 3 incorrectly identified the vehicle use for three crashes and special vehicle type for three other crashes, there is no systematic means to isolate out such instances without manually examining each of the

18,864 such crashes. As this was not practical and the error rate was relatively small, all crashes meeting this criteria were included in the subsequent analysis. However, for crashes identified through Query 2, the UD-10 forms were manually examined and included in the database in instances where an accurate determination could be made as to the correct vehicle type and vehicle use codes. For the purposes of the subsequent statistical analysis, the resulting full database was subdivided into a series of four smaller analysis datasets as described here:

1. The binary logit model used to compare vehicles under emergency and non-emergency use required separating the crash data into two groups. The first group (emergency use) included all crashes with Special Vehicle Type Codes of 1, 2, or 4 and Primary Vehicle Use Code of 3 while the second group (non-emergency use) included all crashes with Special Vehicle Type Codes of 1, 2, or 4 and Primary Vehicle Use codes not equal to 3.

2. The multinomial logit model used to identify differences between crashes involving police, fire, and emergency medical service vehicles required separating the data into three groups. Each group was selected based upon the appropriate Special Vehicle Type code: 1 for Police, 2 for Fire, 4 for EMS.

3. The ordered logit models used to identify those factors which impact the injury severity sustained by emergency vehicle drivers involved in single-vehicle crashes involved the extraction of all crashes with Special Vehicle Type codes of 1, 2, and 4 for which exactly one vehicle was involved in the crash.

4. The ordered logit models used to identify those factors which impact the injury severity sustained by emergency vehicle drivers in crashes involving two vehicles involved the extraction of all crashes with Special Vehicle Type codes of 1, 2, and 4 for which exactly two vehicles were involved in the crash. Data for both the emergency and non-emergency vehicles and drivers were extracted and included in the analysis dataset.

CHAPTER 3. METHODOLOGY

Chapter 3 provides an overview of the methodological framework used to analyze the emergency vehicle crash data described in Chapter 2. The aim of the statistical models developed as a part of this research is to isolate the driver-, vehicle-, and environment-, and crash-related factors affecting emergency vehicle crashes. Specifically, the intent is to determine those factors which:

- are different between those crashes that occur while emergency vehicles are on emergency runs (i.e., with lights and sirens activated) and those crashes occurring while emergency vehicles are being used for other purposes;
- are different between crashes involving police cars, fire trucks, and ambulances; and
- affect the level of injury severity that results from the occurrence of an emergency vehicle crash.

As each of these research questions involves the analysis of a discrete dependent variable (type of vehicle use, type of emergency vehicle, and level of injury), logistic regression techniques can be used to examine the impacts of covariates on such variables. Section 3.1 provides background on binary logit models, Section 3.2 details multinomial logit models, and Section 3.3 describes ordered logit models as they apply to the analysis of emergency vehicle crash data conducted as a part of this study.

3.1 Binary Logit Model

A logistic regression, or logit, model is a generalized linear model used to analyze a dependent variable which can take one of a finite number of values. In the simplest case where only two potential outcomes are being compared, a binary logit model is appropriate for determining what factors increase the likelihood of either of the outcomes. For example, all emergency vehicle crashes can be classified into one of two discrete scenarios in terms of vehicle use at the time of the crash: (1) the crash occurred while the vehicle was on an emergency run with lights and sirens activated or (2) the crash occurred while the vehicle was being used for a non-emergency activity. It is expected that the characteristics associated with each of these scenarios may vary substantially in terms of the vehicular, roadway, and environmental factors associated with each type of crash.

Within the terms of this research problem, a binary logit regression model is structured as follows:

$$P_n(i) = \frac{1}{1 + EXP(\beta_i X_{in})},$$

where $P_n(i)$ is the probability of outcome i (an emergency vehicle being on an emergency run at the time a crash occurred), β_i is a vector of estimable parameters indicating the change in this probability due to X_{in}, which is a vector of the observable characteristics (covariates) associated with vehicle n. A positive parameter estimate indicates that a particular characteristic will, on average, be overrepresented among crashes involving vehicles that are on emergency runs. Conversely, a negative parameter estimate indicates a characteristic that is underrepresented or more likely to occur among crash-involved emergency vehicles that are being used for other purposes. Maximum-likelihood techniques are used to estimate the coefficients for those covariates which are found to be significantly different between those crash-involved vehicles that are on emergency runs and those that are not.

3.2 *Multinomial Logit Model*

In situations where more than two discrete outcomes are possible, the binary logit model can be generalized in the form of a multinomial logit (MNL) model, which is defined as:

$$P_n(i) = \frac{EXP[\beta_i X_{in}]}{\sum_{\forall I} EXP(\beta_I X_{In})}.$$

For this study, an MNL model is developed in order to identify differences between crashes involving the three different types of emergency vehicles: police cars, fire trucks, and ambulances. Within this context, $P_n(i)$ is the probability of an emergency vehicle being of a particular type (fire, EMS, or police), β_i is a vector of estimable parameters indicating the change in this probability due to X_{in}, which is a vector of the observable characteristics (covariates) associated with emergency vehicle n.

3.3 *Ordered Logit Model*

In some situations, discrete data may follow a natural ordering process. For example, crash-related injury severity data are generally represented as one of five discrete categories: property damage only (PDO), possible injury, non-incapacitating injury, incapacitating injury, and fatal injury. Each of these five categories can be are ordered from least severe (PDO) to most severe (fatal injury). Application of the standard MNL model does not account for the ordinal nature of such data. In such instances, the parameter estimates remain consistent, but there is a loss in efficiency (Washington et al., 2006).

To mitigate this issue, ordered probability models can be developed by defining an unobserved variable, z, which can be specified as a linear function of the form: $z = \beta X_n + \varepsilon_n$, where X_n is a vector of variables determining the discrete ordering for observation n, β is a vector of estimable parameters, and ε_n is a random disturbance term. Using this equation, observed ordinal data, y, for each observation are defined as:

$$
\begin{array}{ll}
y = 1 & \text{if } z \leq \mu_0 \\
y = 2 & \text{if } \mu_0 < z \leq \mu_1 \\
y = 3 & \text{if } \mu_1 < z \leq \mu_2 \\
y = \ldots & \\
y = I & \text{if } z \geq \mu_{I-2},
\end{array}
$$

where the μ are threshold parameters that define y and correspond to integer ordering, with I being the highest integer ordered response. Within the context of injury severity models, y = 1 corresponds to a PDO/no injury crash while y = 5 corresponds to a crash resulting in a fatal injury (Washington et al, 2006). By assuming that the error terms are distributed as a standard normal variable, the selection probabilities for the ordered logit model are as follows:

$$
\begin{aligned}
&P(Y = 1) = \Phi(-\beta X) \\
&P(Y = 2) = \Phi(\mu_1 - \beta X) - \Phi(\beta X) \\
&P(Y = 3) = \Phi(\mu_2 - \beta X) - \Phi(\mu_1 - \beta X) \\
&.. \\
&.. \\
&.. \\
&P(Y = 3) = 1 - \Phi(\mu_{I-2} - \beta X)
\end{aligned}
$$

When interpreting the parameter estimates of such an ordered logit model, a positive β is indicative of a parameter which increases the likelihood of the highest ordered response (fatal injuries in this instance) and decreases the likelihood of the lowest ordered response (PDO/no injury in this case).

CHAPTER 4. MODEL RESULTS AND DISCUSSION

Chapter 4 presents the results of the four regression models developed as a part of this research. Sections 4.1 presents a binary logit model used to isolate the differences between emergency vehicle crashes that occur during emergency runs versus those that occur while vehicles are used for other non-emergency purposes. Section 4.2 compares and contrasts the characteristics associated with crashes involving police cars, fire trucks, and ambulances using a multinomial logit model. Sections 4.3 and 4.4 present the results of the injury severity model for single-vehicle and two-vehicle crashes involving emergency vehicles, respectively.

4.1 Binary logit model for emergency vehicle in pursuit versus not in pursuit

Table 4.1 presents the results of the binary logit model developed to isolate those factors associated with emergency vehicle crashes that occur under emergency and non-emergency situations. Positive coefficients indicate a particular parameter is overrepresented among emergency use crashes while negative coefficient indicate that parameter is underrepresented among such crashes. It should be cautioned that, due to a lack of exposure data indicating the frequency with which certain groups of drivers or types of vehicles are utilized for emergency versus non-emergency situations, it is unclear in some cases whether these effects are systematic or simply due to more or less frequent exposure. For example, ambulance and fire trucks were overrepresented among those crashes occurring during emergency response. However, this is due at least in part to the fact that these types of vehicles are generally used much less frequency in non-emergency situations than police cars.

Table 4.1. Binary Logit Model for Vehicles in Emergency versus Non-Emergency Use

Parameter	β	SE(β)	P-value
Intercept	-1.4374	0.1484	<0.0001
Weekday	-0.3655	0.0531	<0.0001
Male Driver	0.2149	0.0632	0.0007
Crash Occurs Between 6 AM and 10 AM	-0.3695	0.0815	<0.0001
Crash Occurs Between 4 PM and 7 PM	0.2195	0.0666	0.0010
Ambulance	0.5280	0.0675	<0.0001
Fire Truck	0.9173	0.0760	<0.0001
Airbag Deployed	0.3737	0.0957	0.0001
Safety Belt Used	-0.4691	0.1094	<0.0001
Speed Limit Greater than 50 mph	0.1403	0.0634	0.0268
Single Vehicle Crash Type	-0.8259	0.0808	<0.0001
Angle Crash Type	0.5337	0.0684	<0.0001
Head-On Crash Type	0.5872	0.1529	0.0001
Sideswipe Crash Type	0.5432	0.0745	<0.0001
Speeding Involved	0.8182	0.1210	<0.0001
Other Illegal Driving Behaviors	-0.3231	0.1004	0.0013
Failure to Yield or Unable to Stop	-0.1528	0.0790	0.0532
Wet Pavement	-0.1117	0.0651	0.0859
Darkness, Lighting Present	0.4466	0.0631	<0.0001
Darkness, No Lighting Present	0.3101	0.0744	<0.0001
Divided Highway, Up to 3 Lanes per Direction	0.2186	0.0594	0.0002
Driver Age 25 or Under	-0.2097	0.0772	0.0066
Stop-control	-0.3721	0.0875	<0.0001
Intersection or Driveway	0.1975	0.0585	0.0007
Overtaking, Passing, or Changing Lanes	1.1155	0.1203	<0.0001
Avoidance Maneuver	0.7920	0.1271	<0.0001
Alcohol-Involved	-2.0107	0.7273	0.0057

Younger emergency vehicle drivers (age 25 or less) were underrepresented among those crashes that occurred during emergency vehicle runs. As no exposure data is available regarding the number of emergency vehicle drivers within each age category or the frequency with which such drivers are tasked with driving on emergency runs, this may be simply due to the fact that younger, inexperienced drivers are less likely to be used in such runs, resulting in an overrepresentation of this group in non-emergency scenarios.

Male emergency vehicle drivers were overrepresented in crashes that occurred during emergency use, consistent with previous findings from Clark et al (2009). Past research has found that when controlling for exposure, male drivers exhibit a higher risk of crash involvement than female drivers regardless of crash severity (Massie, Green, and

Campbell, 1997). It is possible that the risk-taking behavior of male drivers is further exacerbated en route to an emergency.

As expected, crashes that occur while an emergency vehicle driver attempts passing another vehicle, changing lanes, or avoiding another vehicle or other obstacle, are more likely to occur under emergency situations. Such crashes generally involve higher travel speeds as drivers attempt to arrive at their destinations sooner in response to an incident. While the use of lights and sirens should make emergency vehicles more distinguishable to other motorists, this increased frequency of crashes may be due to increased risk-taking on the emergency vehicle driver, as well as a lack of awareness of its approach on the part of the general public. As past research has shown the use of lights and sirens to provide only moderate savings in term of reduced travel times, this provides further reinforcement that emergency vehicle drivers should exercise due caution, particularly at intersections and other high-risk locations. Speeding was more likely during emergency runs, which is also likely due to the fact that drivers are generally attempting to travel between destinations as quickly as possible under such situations. Higher speeds during emergency runs also provides an explanation as to the increased likelihood of airbag deployment during emergency runs due to the increased impact forces created with higher speeds.

Conversely, failure to yield, an inability to stop, and other illegal driving behaviors taken by the EV driver, are less likely to occur under emergency operation. While this may seem somewhat counterintuitive, emergency situations require greater concentration on the part of the drivers, whereas drivers in non-emergency scenarios may be less focused on the driving task. In addition, the use of lights and sirens during emergency runs serves to alert others motorists, which may further reduce the likelihood of collisions under these conditions. The reduced likelihood of alcohol involvement during emergency operation may also be due in part to the use of lights and sirens.

Belt use among emergency vehicle drivers was lower while responding to an emergency. While drivers may be making a conscious decision to not wear a safety belt in these types of situations in order to reduce the response time to an emergency, the time required to buckle up is relatively miniscule in comparison to the total response time. Based on previous research which has shown the use of lights and sirens to produce only marginal improvements in response time, educational efforts and other measures aimed at improving belt use among emergency vehicle drivers appears warranted. Research by Levick (2005) found that the use of an onboard computer-monitoring device, which activates an auditory alert signal and penalizes driver for non-compliance was found to reduce the number of front seat belt use violations from 13,500 pre-deployment to only four post-deployment. Such a system, similar to the auditory alarms of many of today's passenger vehicles, may be an appropriate countermeasure to improve use among all emergency vehicle drivers, as well.

Emergency use crashes were more likely to occur under dark lighting conditions, which may be due to reduced conspicuity of approaching emergency vehicles to other drivers, as well as other problems which are prevalent during dark periods, such as drowsy or drunk driving. Crashes involving emergency response were also more prevalent on weekends, which could be due to increase demand for such services or systematic problems, such as increased drinking and driving during these periods.

Crashes occurred at intersections and driveways on a more frequent basis during emergency runs as driver recognition of approaching emergency vehicles at such locations is reduced due to limited sight distances. A recent study by Savolainen and Datta (2009) showed that driver compliance, in terms of vehicles yielding to an emergency vehicle that is within 150 feet of the intersection, was only 75 percent at intersection locations. This problem of late or non-recognition of approaching emergency vehicles is also evidenced by the fact that angle, head-on, and sideswipe crashes were overrepresented during emergency runs.

Wet pavement was less prevalent among crashes that occurred during emergency response and this finding may be due increased caution on the part of emergency vehicle drivers under such conditions. Stop-controlled intersections were also less likely to sustain crashes during emergency runs. Such locations generally exhibit lower traffic volumes and lower approach speeds, which may serve to aid driver recognition of an approaching emergency vehicle and reduce the opportunity for conflicts.

4.2 Comparison model by type of crash involved emergency vehicle

While the literature regarding those factors associated with ambulance-involved crashes is becoming more well-developed, less is known about the factors impacting crashes involving police cars and fire trucks. To provide insight regarding these types of vehicles, a multinomial logit (MNL) model was developed and is presented in Table 4.2. The parameter estimates for this model indicate whether particular factors are more (positive coefficient) or less (negative coefficient) strongly associated with crashes involving a particular type of emergency vehicle. For example, the positive coefficients shown under both the “Police” and “Fire” categories for male drivers indicates that crash-involved drivers are more likely to be males in comparison to crash-involved ambulance drivers. This is another finding that may be simply due to larger numbers of male drivers in these types of agencies. Similarly, drivers under age 25 were more prevalent in crashes involving police cars and fire trucks. A discussion of the implications of other parameter estimates follows.

Police cars were more likely to be stopped or moving slowly at the time of the crash. Police cars were also more likely to have taken evasive actions to avoid another vehicle or obstacle prior to the crash occurring, which is due in part to high-speed pursuits that require officers to swerve around oncoming vehicles and may also be due to officers attempting to navigate the smaller police cars through gaps in traffic that ambulances and fire trucks would be unable to fit through.

Fire trucks were more likely to be crash-involved during the AM and PM peak travel periods, which could be related to the higher traffic volumes and reduced maneuverability of such large vehicles in dense traffic. Similarly, fire trucks were also less likely to be involved in single vehicle crashes. In addition to being larger in size, fire trucks are also less capable of accelerating or decelerating quickly or of taking evasive actions, which contributes to the increased incidence of angle and sideswipe crashes. Ambulances were also found to be more likely to be involved in these types of crashes.

Table 4.2. MNL Model for Type of Crash-Involved Emergency Vehicle

Type of Vehicle	Parameter	β	SE(β)	P-value
POLICE	Intercept	1.4693	0.1316	<0.0001
	Darkness, No Lighting Present	-0.2454	0.1037	0.0180
	Male Driver	0.7509	0.0857	<0.0001
	Airbag Deployed	1.0918	0.2197	<0.0001
	Emergency Run	-0.5908	0.0839	<0.0001
	Speed Limit Over 50 mph	-0.2546	0.0956	0.0078
	Driver Age 25 or Under	-1.1381	0.0942	<0.0001
	Fatal Crash	-1.3110	0.5527	0.0177
	Rainy Weather	-0.2576	0.1311	0.0494
	Stop-Controlled	0.8312	0.1783	<0.0001
	Single Vehicle Crash	0.0876	0.1258	0.4861
	Angle Crash	-0.2909	0.1249	0.0198
	Sideswipe Crash	-0.7496	0.1243	<0.0001
	Avoidance Maneuver	1.0859	0.3099	0.0005
	Stopped or Slowing on Roadway	0.3506	0.1232	0.0044
	Divided Highway, Up to 3 Lanes per Direction	0.2392	0.0955	0.0123
	Safety Belts Not Used	1.4390	0.5293	0.0066
	AM or PM Peak Traffic Period	-0.0126	0.0875	0.8855
FIRE	Intercept	-0.8443	0.1933	<0.0001
	Darkness, No Lighting Present	-0.4284	0.1641	0.0091
	Male Driver	0.6632	0.1302	<0.0001
	Airbag Deployed	-0.0586	0.3540	0.8685
	Emergency Run	0.2434	0.1165	0.0367
	Speed Limit Over 50 mph	-0.5047	0.1427	0.0004
	Driver Age 25 or Less	-0.9980	0.1592	<0.0001
	Fatal Crash	-0.3477	0.8392	0.6787
	Rainy Weather	0.0983	0.1844	0.5940
	Stop-Controlled	0.8307	0.2232	0.0002
	Single Vehicle Crash	-0.3040	0.1842	0.0988
	Angle Crash	-0.2388	0.1743	0.1705
	Sideswipe Crash	-0.0424	0.1674	0.7998
	Avoidance Maneuver	-0.4965	0.5396	0.3575
	Stopped or Slowing on Roadway	0.0016	0.1717	0.9924
	Divided Highway, Up to 3 Lanes per Direction	0.2621	0.1345	0.0514
	Safety Belts Not Used	0.0668	0.7791	0.9317
	AM or PM Peak Traffic Period	0.4002	0.1207	0.0009

Police cars were more likely to be involved in crashes that involve speeding, airbag deployment, and non-use of safety belts, which collectively explain why police vehicles were also prone to more severe injuries as a result of a crash. Conversely, police crashes were less likely under rainy weather conditions, a finding that is likely due to a combination of factors including the better handling performance and reduced stopping distances required of police cars.

4.3 Driver Injury Severity Model for Single Vehicle Crashes

While responding to an emergency, drivers of police cars, fire trucks, and ambulances are subjected to substantial risks as they attempt to travel between locations in as timely a manner as possible. Traffic crashes are a serious concern, particularly as these vehicles may be responding to other crashes, further taxing emergency service resources. Table 4.3 presents the results of an ordered logit model which examines those factors which impact the degree of injury severity sustained by the driver in single-vehicle emergency vehicle crashes. The parameter estimates for this model indicate the relative impacts of each factor, with positive signs indicating parameters which generally increase injury severity and negative signs indicating those parameters which decrease injury severity.

Table 4.3. Driver Injury Severity Model for Single-Vehicle Crashes

Parameter	β	SE(β)	P-value
μ_1	2.3292	0.9327	0.0125
μ_2	3.7455	0.9526	0.0001
μ_3	5.6810	1.0159	<0.0001
μ_4	7.0667	1.1893	<0.0001
Rainy Weather	1.0064	0.3631	0.0056
Icy, Snowy, or Slushy Weather	0.9108	0.3175	0.0041
Darkness, No Lighting Present	-0.5635	0.2828	0.0463
Vehicle Turning at Time of Crash	-1.3157	0.6834	0.0542
Airbag Deployed	3.3307	0.3349	<0.0001
Safety Belt Used	-2.1012	0.6702	0.0017
Police Car	2.0796	0.6399	0.0012
Fire Truck	1.5267	0.8277	0.0651
Posted Speed Limit Less than 30 mph	-1.2009	0.5114	0.0189
Driver Unable to Stop	1.4777	0.7101	0.0374

When emergency vehicle drivers were turning prior to the crash, injuries tended to be less severe, which may be due to reduced speeds at impact or to glancing collisions which avoided the brunt force of frontal impacts. Similarly, drivers who were unable to stop may frequently result in airbag deployments due to frontal impacts. Regardless of the type of crash, airbags deployment was generally found to increase the level of injury severity.

Under dark, unlighted conditions, injuries tended to be less severe. This may be a result of increased caution on the part of the emergency vehicle drivers as various studies have found that drivers generally drive more slowly under dark conditions (Kilpeläinen and Summala, 2007; Eluru and Bhat, 2007). In general, roads with posted speed limits of 25 mph or less were most likely to result in no injury, which is due to a confluence of factors that include reduced impact forces and greater available reaction time.

Rain and wintry road conditions were found to increase the likelihood of severe injuries. Wet, snowy, or icy pavement reduce the traction between the tires and the pavement and require drivers to maintain lower speeds in order to safely navigate their vehicles, particularly around horizontal curves. Under such conditions, drivers may misjudge the pavement condition, resulting in a more severe crash due to excessive speeds.

Drivers of police cars and fire trucks tended to suffer more severe injuries than ambulance drivers. Police cars are generally more vulnerable due to their smaller size and the higher travel speeds that occur during high speed chases and other incidents for which police are generally first responders. Another contributing factors may be that the drivers of police cars and fire trucks are prone to greater risk taking in general as these groups were both found to be less likely to wear safety belts than ambulance drivers as explained in the previous section. Safety belt use was again found to be the most effective countermeasure for reducing injury severity, which is consistent with several previous emergency vehicle studies (Auerbach et al, 1987; Levick et al, 2001a, Levick et al, 2001b; Becker et al, 2003, Centers for Disease Control and Prevention, 2003).

4.4 Driver Injury Severity Model for Two-Vehicle Crashes

While the previous section focused on single-vehicle crashes, this section presents the results of an ordered logit model which assesses the impact of several factors on the level of injury severity sustained by the emergency vehicle driver in crashes involving two vehicles. Characteristics associated with both the emergency and non-emergency vehicles and drivers were included in the development of the statistical models. Table 4.4 presents the final model and a discussion of the parameters follows.

Table 4.4. Driver Injury Severity Model for Two-Vehicle Crashes

Parameter	β	SE(β)	P-value
μ_1	0.6627	0.4040	0.1009
μ_2	2.3558	0.4161	<0.0001
μ_3	3.9259	0.4547	<0.0001
μ_4	7.2372	1.0544	<0.0001
No Traffic Control	-0.4921	0.1969	0.0125
Speed Limit Less than 30 mph	-0.4164	0.2155	0.0534
Speed Limit More than 55 mph	0.9730	0.2745	0.0004
Sideswipe Crash Type	-0.5611	0.2552	0.0279
Angle Crash Type	0.5920	0.2064	0.0041
Male Emergency Vehicle Driver	-0.6104	0.1956	0.0018
Emergency Vehicle Airbag Deployed	2.5913	0.2319	<0.0001
Belt Use in Emergency Vehicle	-1.0876	0.2532	<0.0001
Emergency Vehicle Turning Prior to Crash	-0.6832	0.3070	0.0260
Emergency Vehicle Overtaking/Passing/Changing Lanes	0.7048	0.2937	0.0164
Speeding by Emergency Vehicle	0.9683	0.5537	0.0803
Police Car	0.7257	0.2517	0.0039
Fire Truck	-0.6445	0.3877	0.0965
Other Driver is Male	-0.3094	0.1782	0.0825
Other Vehicle Bus or Truck	-1.6487	0.8079	0.0413
Other Driver Speeding	0.7921	0.3520	0.0244
Other Driver Disregards Traffic Control	0.9793	0.4034	0.0152
Other Driver Unable to Stop	1.0661	0.2984	0.0004
Other Driver Cited as Careless/Negligent	1.0652	0.3494	0.0023

Male emergency vehicle drivers were less likely to sustain severe compared to female drivers, which could be due to physiological or behavioral differences and is consistent with previous research (Islam and Mannering, 2006). Interestingly, if the driver of the other vehicle was male, injuries also tended to be less severe. This could be due to differences in the awareness or driving abilities of male drivers or to some other factor that is correlated with gender.

High-risk driving behaviors by both the emergency and non-emergency vehicle drivers were shown to substantially increase the likelihood of more severe injuries.

Speeding, overtaking, passing, and changing lanes on the part of the emergency vehicle driver were all shown to increase the level of injury severity. Similarly, hazardous actions by the other driver, such as speeding, disregarding traffic control devices, and other careless driving practices were also found to increase the degree of injury sustained by the driver of the emergency vehicle. Collectively, these behaviors of both drivers tend to results in reduced reaction times, higher speeds upon impact, and greater impact forces, each of which is likely to result in more severe injuries.

Other findings were consistent with prior expectations. Injuries tended to be less severe at locations where the posted speed limit was lower and more severe where posted speed limits were higher. Angle crashes tended to result in the most severe injuries while sideswipe crashes were least severe. Drivers of police cars were at the greatest risk of injury in two-vehicle collisions while drivers of fire trucks were at the least risk. These findings are likely due to the relative sizes of these vehicles as fire trucks are able to sustain much higher impact forces than smaller police cars. In addition, the speeds of fire trucks responding to emergencies are generally substantially lower than the speeds of police cars on emergency runs.

As in the case of single-vehicle crashes, safety belt use was again found to be the most effective means of reducing injury severity while airbag deployment was associated with greater degrees of injury. However, it should be noted that this finding is likely due to the increased speeds and impact forces which lead to airbag deployment, rather than the actual deployment itself.

CHAPTER 5. CONCLUSIONS

This chapter summarizes the research, highlights its contributions, and proposes directions for future research.

5.1 Summary

The objectives of this research were to identify critical factors associated with the occurrence of emergency vehicle crashes, to distinguish among the characteristics of crashes involving different types of emergency vehicles, and to determine those factors affecting the injury severity resulting from emergency vehicle crashes.

When comparing emergency vehicle crash characteristics and trends to those of all traffic crashes throughout the State of Michigan, many of the factors are quite similar. Emergency vehicle involved crashes were slightly more likely to occur under favorable weather and pavement conditions and on low-speed roads. Certain types of crashes involving emergency vehicles were overrepresented in comparison to non-emergency vehicle crashes, particularly angle and sideswipe collisions. Crash-involved emergency vehicle drivers were more likely to be male and between the ages of 25 and 44, which is a byproduct of the general demographics of the emergency service industry. An in-depth analysis of emergency vehicle crash characteristics was conducted in order to:

1. Differentiate those factors associated with emergency vehicle crashes occurring during emergency runs versus crashes involving out-of-service emergency vehicles. Crashes occurring during emergency response were more likely to occur near intersections or driveways, under dark lighting conditions, and during the PM peak period and the most prevalent types of crashes were angle, head-on, and sideswipe collisions.

These emergency response crashes were also characterized by high risk driving behaviors, such as speeding, overtaking, passing, and non-use of safety restraint devices.

2. Identify differences between crashes involving police cars, fire trucks, and ambulances. Drivers of police cars were less likely to be on an emergency run, use their safety belts, be involved in crashes during rainy weather conditions or under darkness. Police officers were more likely to be males, to attempt avoidance maneuvers prior to a crash occurring, and to be involved in high-speed crashes resulting in airbag deployment. Fire truck operators were also more likely to be males and were more prone to involvement in crashes under rainy weather conditions, during peak traffic periods, and at stop-controlled intersections. Drivers of both police and fire vehicles were less likely to sustain fatal injuries than ambulance drivers.

3. Determine those factors affecting the injury severity resulting from emergency vehicle crashes that occur during emergency response. Injuries tended to be most severe at high speeds, when emergency or non-emergency drivers exhibited high risk driving behaviors, when angle collisions occurred, and when crashes involved police cars. Crashes were least severe at locations with lower posted speed limits, under darkness, when male drivers were involved, and particularly when safety belts were utilized.

5.2 Future Research Directions

Collectively, this research identified numerous factors associated with emergency vehicle crashes in the State of Michigan. In broad terms, emergency vehicle crashes tended to occur when emergency vehicle drivers were either unable to properly assess the risk at a given location, such as determining the actions of other drivers at intersections and driveways, or when they themselves exhibited high risk behaviors in attempting to reach their destinations, such as driving too fast for conditions. These problems are compounded by the fact that emergency vehicle drivers are less likely than the general public to wear an appropriate safety restraint. Emergency vehicle crashes also tended to occur when mistakes were made by the non-emergency drivers, including reckless driving behaviors or failing to identify an approaching emergency vehicle.

Moving forward, some of these conclusions point to areas of opportunity for future research. Efforts to educate the public as to the particular hazards associated with emergency vehicle crashes may be warranted. This may include emphasizing interactions with emergency vehicles as a part of the driver training curriculum or through targeted public awareness campaigns. Providing further advance warning of an emergency vehicle's approach may also lead to reductions in crashes where the other driver is unable to stop in time to avoid a collision. Signal preemption has proven effective in past studies at reducing the opportunity for emergency vehicle crashes and several newly developed technologies are also aimed at providing advance warning to drivers, either directly in the vehicle or through external warning devices on the signal infrastructure. An assessment of driver training programs aimed at emergency vehicle drivers may provide benefits, as would the development of initiatives aimed at increasing the degree of safety belt use among emergency vehicle drivers.

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