A STUDY ON VISIBILITY OBSTRUCTION RELATED CRASHES DUE TO FOG AND SMOKE

Mohamed Abdel-Aty, Ph.D., P.E.

Al-Ahad Ekram

Helai Huang, Ph.D.

Department of Civil, Environmental & Construction Engineering

University of Central Florida

Orlando, FL 32816-2450

Phone: (407)823-5657

Fax: (407)823-3315

Email: mabdel@mail.ucf.edu

ABSTRACT

Research efforts on weather effects have been concentrated on snow or rain related crashes, however, there is a lack of good understanding of crashes occurring under fog/smoke (FS). This study presents a comprehensive examination on FS related crashes using crash data in Florida (2003-2007). A two-stage research strategy was implemented so as to 1) examine FS crash characteristics with respect to temporal distribution, influential factors and crash types, and 2) estimate the effects of various factors on injury severity given a FS crash has occurred. The morning hours in the months of December to February are the prevalent time for FS crashes. Compared to crashes under clear-visibility conditions, the FS crashes tend to result in more severe injuries and involve more vehicles. Head-on and rear-end crashes are the two most common crash types in terms of crash risk and severe crashes. These crashes occurred

more prevalently on higher speed, undivided, no sidewalk and two-lane rural roads. Moreover, FS crashes tend to occur more likely at night without street light, which also leads to more severe injuries.

Keywords: Fog and Smoke, Visibility, Crash risk, Injury Severity

1. INTRODUCTION

Effects of weather events on the operations and safety of transportation is a key issue in now-a-days transportation research. Previous studies discussed this key issue in a generic point of view. Some studies discussed climate changing effects on the transportation sector as a whole (Koetse and Rietveld, 2009), while others (Maze et al., 2006) showed the effect of different weather events on traffic operations, safety, traffic demand, flow and traffic intensity (Cools et al., 2008). Another study (Edwards, 1999) found a reduction of mean speed during wet and misty weather, but it does not compensate the hazard imposed by the inclement weather. Effects of weather and weather forecast on driver behavior have been researched as well (Kilpelainen and Summala, 2007), and it was concluded that drivers should be informed locally and more specifically of a weather condition rather than a forecast of a whole region.

Current records of crashes due to three major inclement weather events, i.e. rain, snow and fog/smoke (FS) (see Table 1) show that the fatal crashes in these weather conditions is certainly a major problem that need to be dealt with. These statistics show that while snowy weather, as a contributing factor of traffic crashes, is unsurprisingly more associated with some northern states, the top states in terms of rain or FS related fatal crashes are mostly located in the southern parts of the US, such as Texas, Florida and California.

Table 1: Inclement weather related fatal crashes in United States (2000-2007)

	Rain		Snow		Fog/Smoke	
Rank	State	Fatal crashes	State	Fatal crashes	State	Fatal crashes
1	Texas	1927	Michigan	572	California	380
2	Florida	1403	Pennsylvania	429	Texas	356
3	California	1340	New York	380	Florida	299
4	Pennsylvania	1060	Ohio	316	North Carolina	168
5	North Carolina	1025	Wisconsin	304	Georgia	146
Mean*		447		97		73
S.D.*		428		121		82
Total*		22813		4972		3729

Data queried from Fatality Analysis Reporting System (FARS)

* statistics for all 50 states, the District of Columbia, and Puerto Rico

Previous researches (Qin et al., 2006; Khattak and Knapp, 2001; Oh et al., 2009) have heavily focused on snow and rain related crashes in some northern states, however, there is a lack of comprehensive studies on the particular type of crashes that occur under the influence of fog or smoke. A study (Qiu and Nixon, 2008) on vehicle crashes and how weather is impacting crash rates on highways has its main focus on quantifying the weather impacts on traffic crashes. It shows meta-analysis approach to weather crashes including fog, with no conclusive result. Another research (Wanvik, 2009) studied the effect of road lighting on crashes and implied that the effect of lighting during foggy conditions may be underestimated in safety studies. Another researcher (Musk, 1991) mentioned in his study that fog is still considered the weather hazard that drivers fear most. Researches done on roadways in the UK (Moore and Cooper, 1972) concluded that despite a drop of 20% in the amount of traffic in dense fog there was an increase of 16% in the total of personal injury crashes. Some studies (Codling, 1971; Summer et al., 1977) showed that fog crashes tend to involve multiple vehicles; and another study (Perry, 1981) found that those crashes often occur in a few “black-spots”, frequently on motorways. Studies (Edwards, 1998) on the road crash severity on British motorways in fog and concluded that speed is a major contributing factor in many of the pile-up crashes in foggy conditions. Effects of fog on car following performance have been studied (Kang et al., 2008), and it concluded that drivers tend to maintain good distance headway under the highest fog condition. Another research (Cools et al., 2008) assessed the effect of weather on traffic intensity. This study had conclusive results for snowfall and rain but the effect of reduced visibility due to fog and cloudiness remains inconclusive.

Previous study results suggest that even though quite an amount of research have been done on the weather effects on traffic crashes, good and conclusive findings have been prominent only when it comes to rain and snow crashes. As for FS related crashes, there is indeed a research need to reveal the crash characteristics and potential outcomes so that proper countermeasures might be proposed. As shown in Table 1, Florida is among the top states in the United States in terms of FS related fatal crashes. This study aims at a comprehensive analysis of FS crashes in Florida. In particular, the method and major results arising from two specific analyses in this study are presented:

(1) Crash Characteristics Analysis examines the characteristics of FS crashes in comparison with crashes occurring at clear visibility conditions. Issues investigated include temporal distribution, crash types, and effects of various geometric, traffic, human and environmental factors.
(2) Injury Severity Analysis estimates the effects of various traffic and environmental factors on injury severity given a FS crash had occurred, so that appropriate countermeasures can be proposed for proactive actions to reduce the risk of severe crashes at the FS crash prone locations.

2. DATA PREPARATION

For the purpose of this study, all the state roads in Florida are taken into account. All crashes on these state roads were extracted from the crash analysis and reporting system database (CAR) maintained by the Florida Department of Transportation. Data for roadway characteristics were collected from the Roadway Characteristics Inventory database (RCI). Crash data from years 2003 to 2007 were investigated, along with the corresponding RCI data pertaining to each crash location. These two databases have been merged by the unique roadway identifier in each. Hence, the final database contains a number of different characteristics that can be associated with each specific crash, namely i) driver characteristics (e.g., age, etc.), ii) roadway characteristics (e.g., posted speed, divided/undivided, etc.) and iii) environmental characteristics (e.g., weather conditions, visibility conditions, etc.).

The FS crashes in particular were extracted based on several constraints to ensure that only those crashes that happened in foggy or smoky conditions are selected, thus they do not mingle with the other weather conditions. The "vision obstruction" variable has been used as the secondary filter variable, with "weather condition" being the primary one, so that FS crashes do not intertwine with other poor visibility conditions such as heavy rain or glare from sun or headlight (at night). As a result, a total of 994 FS crashes were identified for the period of 2003-2007. Figure 1(plotted in ArcGIS) depicts the FS crashes on the state roads of Florida overlaid on the county boundaries' map. It was justifiable to merge the fog and smoke related crashes together, given the fact that the visibility obstructions they create are virtually the same. There is no information available for the level of visibility for fog/smoke in the CAR and RCI. So only fog/smoke (FS) vs. clear visibility (CV) condition information are the attributes associated with those crashes.

Furthermore, based on the spatial locations of these FS crashes, a total of 597 road segments were manually defined, which have largely uniform road characteristics. The lengths of these segments range from 2 to 5 miles. For the purpose of comparison, a dataset which contains all the "clear-visibility (CV)" crashes (120,053 crashes) that occurred on these 597 road segments was created as a control group to FS crashes. Herein, the CV condition refers to an ambient environment where no vision obstruction is prevalent.

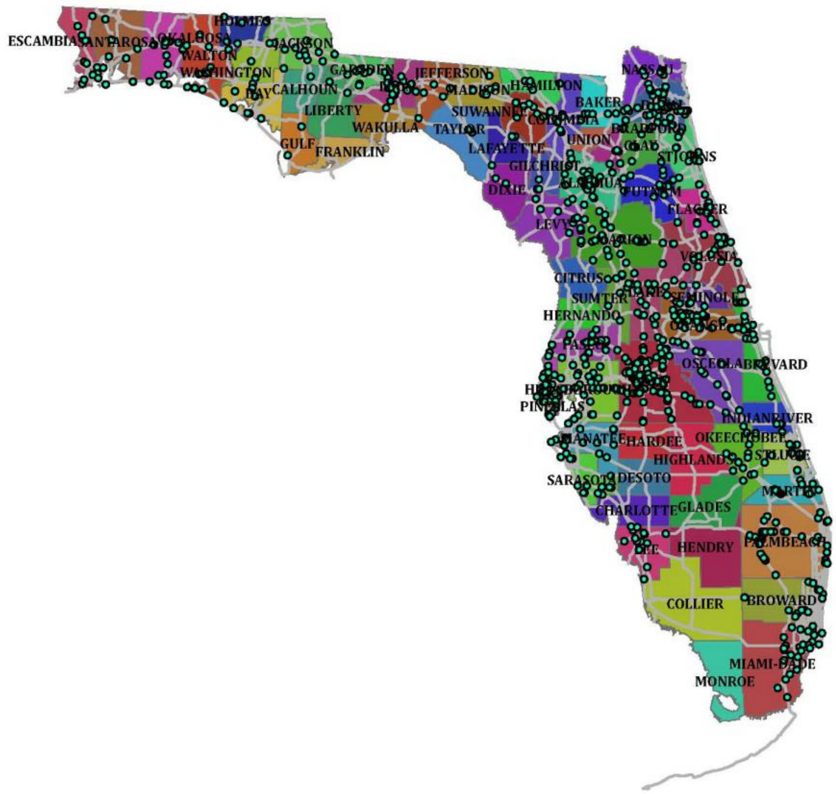

Figure 1: Fog and smoke crashes in Florida (2003-2007)

3. CRASH CHARACTERISTICS ANALYSIS

A detailed analysis of the FS crashes is provided here which focused on the temporal distribution of these crashes, comparison of FS crashes to that of CV crashes in terms of significant factors (driver, roadway and environment). Simple odds have also been introduced to compare FS crashes to CV crashes in different severity levels and/or collision types.

3.1 Temporal Distribution

Vision obstruction due to FS occurs in different times of day in different seasons. Therefore the crash frequencies in these conditions vary with time of day and seasons in a year. It is therefore worthwhile to look at the temporal distribution of FS crashes. As seen from Figure 2, it is evident that at the early hours of dawn and subsequent hours where FS is prominent, from 5am to 8am in particular, the number of crashes due to FS is on the higher side. Moreover, by the monthly variations of these crashes, the duration from December to February looks to have a high number of FS crashes. It is interesting to note that in the month of May there is a sudden inflation of the crash frequency trend.

This can be explained by the increase of smoke related crashes in particular, as the dry season prevails at that time of the year thus probably increasing the likelihood of wildfires or the propagation of fire. To surmise then, the early hours from 5am to 8am in the months of December to February are the deadliest for FS crashes.

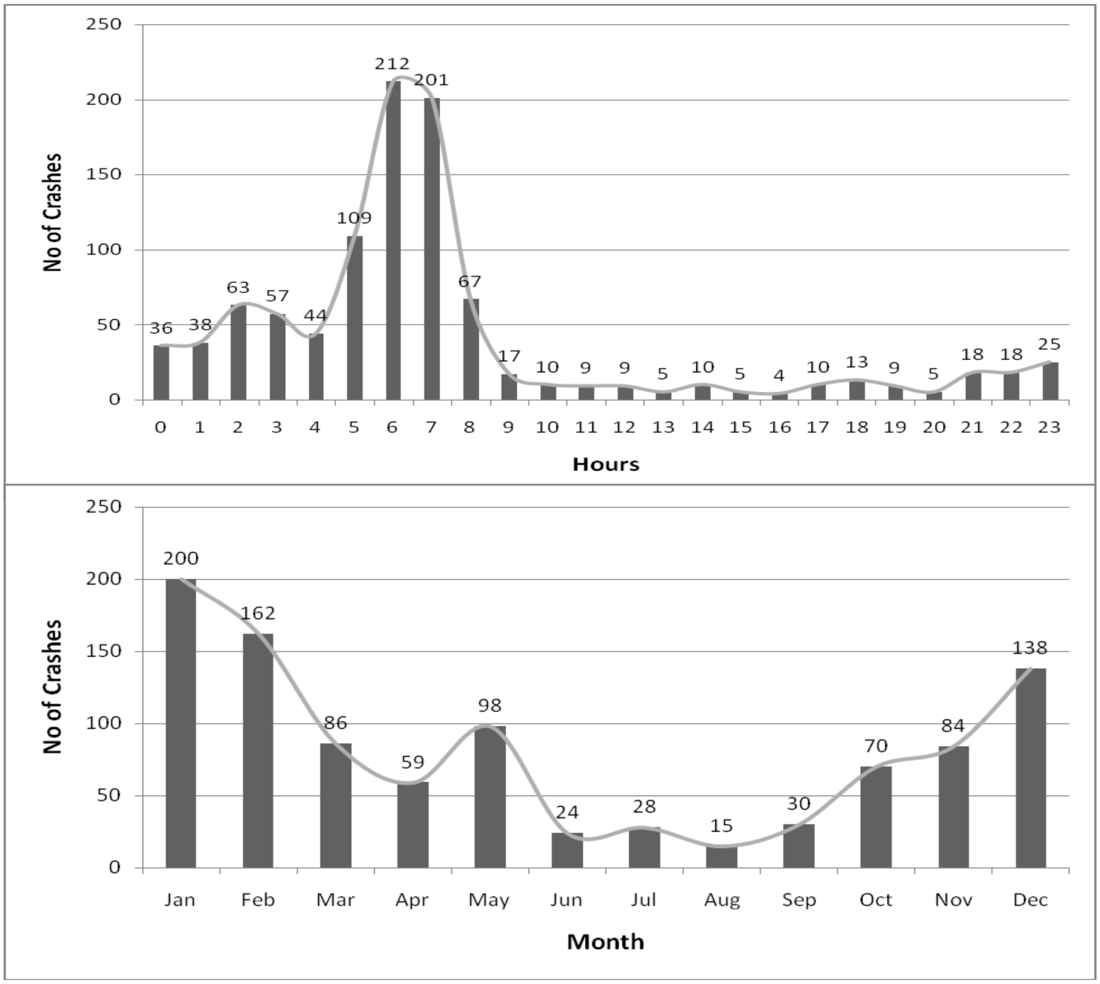

Figure 2: Temporal distributions of Fog /smoke crashes in Florida (2003-2007)

3.2 Contributing Factors

Different factors (roadway, driver and environmental factors) may have direct or indirect effect on the occurrence of FS crashes. In this analysis, the FS crash frequencies in these different conditions are compared to the CV crashes, which would give an idea about the significant factors that affect the FS crashes in particular. Figure 3 shows the effects of different factors on FS crashes compared to CV crashes.

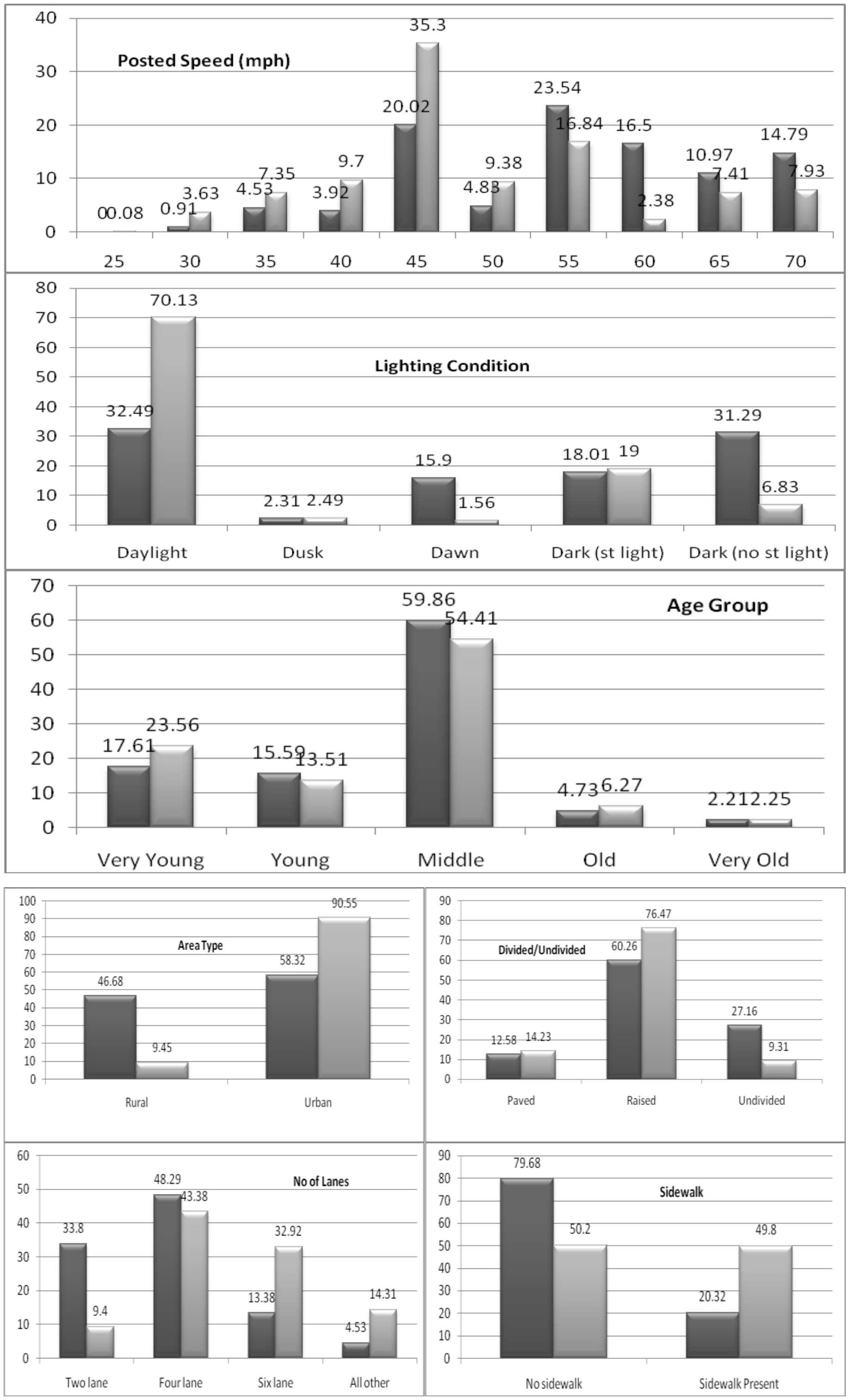

Figure 3: Comparison of the effects of contributing factors on fog /smoke crashes and clear-visibility crashes in Florida (2003 - 2007) (Black bar: % of Fog/smoke crashes; Grey bar: % of clear-visibility crashes)

Several important and interesting inferences can be made from these comparisons of crash frequencies of FS vs. CV crashes in these conditions. At posted speeds 55mph and higher there is a high number of FS crashes that are observed compared to those associated with CV conditions. Lighting condition adversely affects the FS crashes, as suggested from Figure 3 that at dawn and dark (night) with no street light the frequencies (15.9% and 31.29% of the total FS crashes respectively) are pretty high in foggy or smoky conditions, compared to CV conditions, where out of all CV crashes only 1.56% took place at dawn and 6.83% at dark (with no street light). It again confirms the findings observed from Figure 3 and is consistent with conclusions in a previous study (Wanvik, 2009). As for the age group, young and middle age drivers in particular are more prone to be involved in a crash happening in FS conditions. This might be due to the fact that at the dark hours and very early morning where fog/smoke prevails, young drivers have increased exposure. Again, at early morning it is school time for young drivers and middle age drivers going to work, thus they are being involved in high frequency of FS crashes.

As shown in Figure 3, FS is very much prevalent in rural areas, confirmed by the fact that 46.68% of FS crashes happened in rural areas compared to only 9.45% of CV crashes there. Looking at the roadway characteristics, 60.26% of FS crashes occurred on roadways with raised median compared to 76.47% of CV crashes. On undivided roadways 9.31% of CV crashes occurred, compared to 27.16% of FS crashes. Accounting for the surface width (number of lanes), most of the FS crashes occurred on four lane roadways, where the statistics is 48.29% compared to 43.38% for CV conditions. But again the key finding is the effect of two-lane roadways, where a hefty 33.8% of the total FS crashes took place, where only 9.4% crashes occurred in CV conditions. Absence of sidewalk also increases the number of FS crashes, as 79.68% of FS crashes occurred in roadways without sidewalk, whereas the statistic is 50.68% for CV crashes. This could also be related to rural highways.

3.3 Injury Severity and Collision Type

Statistics shown in table-1 reveals the startling fact that Florida is amongst the top three states for fatalities in crashes taking place in FS conditions. Injury severity of a traffic crash is a key issue. Therefore, in the absence of adequate studies of the severity of weather related crashes and FS crashes in particular, it is important to look at the severity of these crashes given the crash happened in a FS condition. In the crash database, injury severity is defined with five levels, in which, “no-injury/property damage only”, “possible injury” and “non-incapacitating injury” can be considered as non-severe crashes, and the “incapacitating injury” and “fatal (within 30 days)” can be considered as severe crashes.

Moreover, in the event of a crash, collision type can be unique given a crash happened in FS conditions. Given the fact that driver's vision is obstructed in FS conditions, collision types in these conditions can be different from those of the crashes in CV conditions. In other words, some collision type can be prominent in FS crashes. Hence, odds are introduced here to compare crashes in FS vs. CV condition in different collision types. The crash databases record has a total of forty collision types based on the first harmful event. The major collision types with an acceptable size of crash observations are investigated in this study, which includes rear-end, head-on, angle, left turn and sideswipe collisions. The investigation is also done for pile-up crashes, i.e., more than two vehicles involved (denoted by multiple vehicle crashes in this study).

To answer the questions of whether crashes in FS conditions lead to more severe injuries and which types of collisions are more associated with FS crashes, odds ratios are calculated based on equation-1 as follows,

$$O.R.(Type) = \frac{Type(FS)/Type(CV)}{All(FS)/All(CV)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,

$O.R.(Type)$ = Odds ratio of a particular type of crash (severe crash and/or collision types) in FS conditions to that in CV conditions;

$Type(FS)$ = Crash number of a particular type in FS conditions;

$Type(CV)$ = Crash number of a particular type at the segments in CV conditions;

$All(FS)$ = Total number of all types of crashes in FS conditions;

$All(CV)$ = Total number of all types of crashes at the segments in CV conditions;

Furthermore, the interaction effects of severe crash and collision types and multiple vehicle crash and collision types are introduced as well, and the odds ratios are calculated for these interactions. The important results of the analyses are summarized in Figure 4. The top plot of Figure 4 shows the odds of different crash types (including severe crashes) in fog/smoke conditions to that of CV conditions, and the bottom plot shows the odds of different collision types in fog/smoke conditions to that of CV conditions, given the crash is severe.

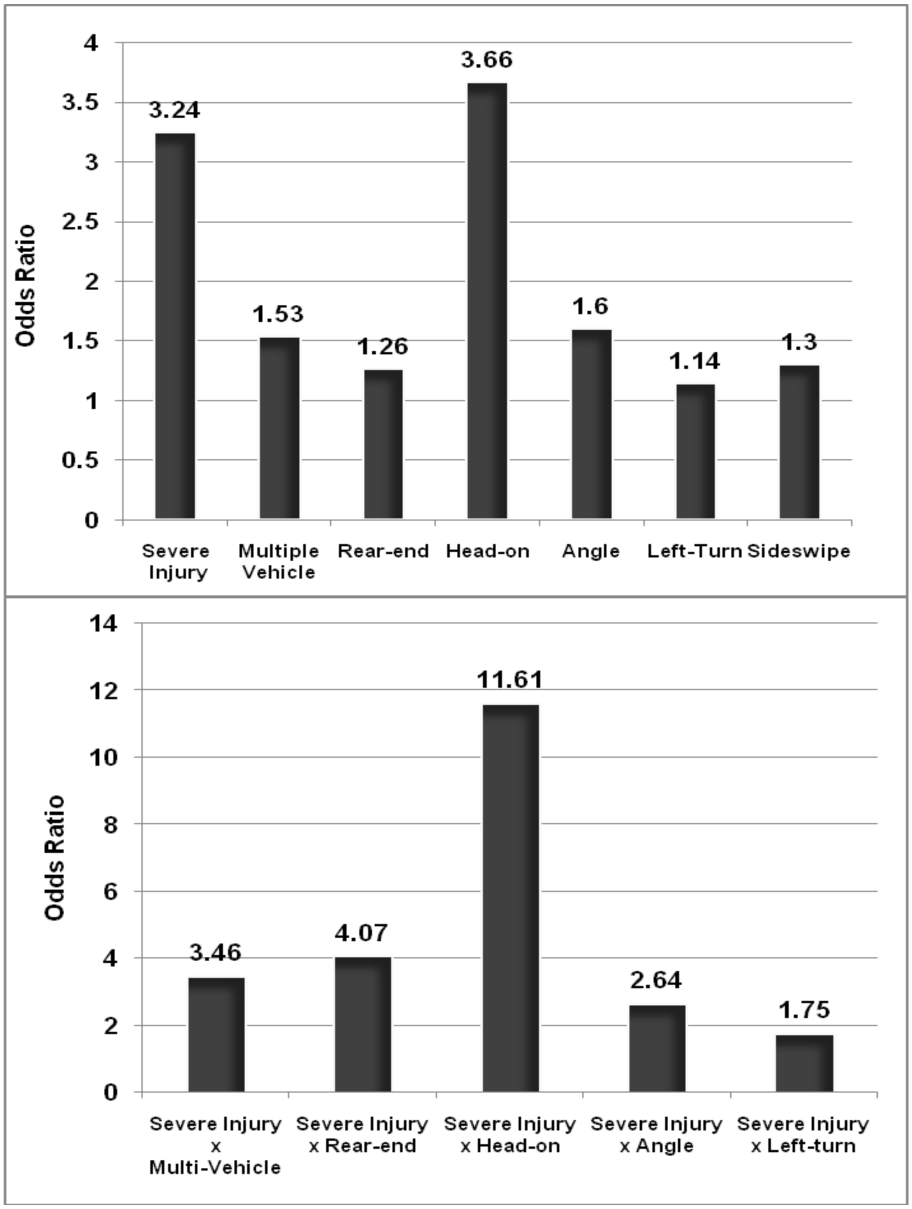

Figure 4: Odds ratios of severe crash and collision types in fog/smoke conditions to CV conditions in Florida (2003-2007)

It is quite revealing that compared to CV conditions, FS poses a deadly threat in terms of crash severity. The elevated odds are as high as 3.24 times. Moreover, a higher probability (O.R. = 1.53) of a crash involving multiple vehicles is found to be associated with FS conditions. As indicated in previous studies (Codling, 1971; Summer, 1977), pile-up crashes can be a dominant type during FS conditions due to the reduced visibility. Regarding the collision types, the likelihoods of all typical collision types investigated are higher in FS conditions than that in CV conditions. Notably, the highest odds are associated with head-on crash (O.R. = 3.66). This result is very interesting as a substantial increased proportion of FS crashes is also found on undivided roadways compared to CV crashes as discussed previously (27.16% to 9.31%). The crashes between vehicles from opposite traffic at undivided roads tend to be head-on collisions.

As suggested by the interaction effects, given a head-on, rear-end or multi-vehicle crash happens in FS conditions, there is a significantly higher probability of that crash being severe in contrast with other types of crashes. It implies that the efforts to reduce injury severity of FS crashes will be more effective by focusing on the reduction of head-on, rear-end and multiple vehicle (pile-up) crashes. These results are preliminary to more in-depth analysis of the severity of FS crashes.

4. INJURY SEVERITY ANALYSIS USING MULTILEVEL ORDERED LOGISTIC MODEL

This section presents the results of an injury severity analysis for FS crashes by developing a multilevel ordered logistic model.

4.1 Model Description

According to the CAR database, the injury severity levels of the 994 FS crashes are defined as five ordered categories:

Category 1 (C1): no injury/property damage only (PDO),
Category 2 (C2): possible injury,
Category 3 (C3): non-incapacitating injury,
Category 4 (C4): incapacitating injury, and
Category 5 (C5): traffic fatality.

For this ordinal outcome of severity, a multilevel ordered logistic model is specified to examine the effects of various risk factors. Suppose that y_{ij} is the severity level of i^{th} crashes which occurred at j^{th} segments (i = 1,…, 994; j = 1,…, 597). In an ordinal response model, a series of latent thresholds are generally formulated. Specifically, the real line is divided into five intervals by four thresholds ($\gamma_{kj}, k = 1,2,3,4$), corresponding to the five ordered categories (C_{1-5}). It is noted that differing from ordinary ordered logistic model, the multilevel model accounts for the cross-segment heterogeneities by specifying a set of variable thresholds for individual segments. The thresholds define the boundary between the intervals corresponding to observed severity outcomes. The latent response variable is denoted by y_{ij}^* and the observed categorical variable y_{ij} is related to y_{ij}^* by the “threshold model’ defined as,

$$y_{ij} = \begin{cases} 1 & \text{if } -\infty < y_{ij}^* \le \gamma_{1j} \\ k & \text{if } \gamma_{(k-1)j} < y_{ij}^* \le \gamma_{kj},\ k = 2,3,4 \\ 5 & \text{if } \gamma_{4j} < y_{ij}^* < +\infty \end{cases}$$

The ordinal models can be written as,

$$y_{ij}^* = \theta_{ij} + \varepsilon_{ij}, \quad \text{and } \theta_{ij} = \sum_{p=1}^{P} \beta_p x_{pij}$$

in which x_{pij} is the crash-level covariates and ε_{ij} is the disturbance term, which is assumed a logistic distribution with F as the cumulative density function. Thus, the cumulative response probabilities for the three categories of the ordinal outcome could be denoted as,

$$P_{ij(k)} = \Pr\left(y_{ij} \le k\right) = \mathrm{F}\left(\gamma_{kj} - \theta_{ij}\right) = \frac{\exp\left(\gamma_{kj} - \theta_{ij}\right)}{1 + \exp\left(\gamma_{kj} - \theta_{ij}\right)}, \quad k = 1, 2, 3, 4.$$

The idea of cumulative probabilities leads naturally to the cumulative logistic model

$$\mathrm{Logit}\left(P_{ij(k)}\right) = \log\left[\frac{P_{ij(k)}}{1 - P_{ij(k)}}\right] = \log\left[\frac{\Pr\left(y_{ij} \le k\right)}{\Pr\left(y_{ij} > k\right)}\right] = \gamma_{kj} - \theta_{ij},\ k = 1, 2, 3, 4.$$

In the segment level, γ_{kj} could be specified as random effects,

$$\gamma_{kj} = \gamma_k + \sum_{q=1}^{Q} \alpha_q z_{qj} + b_j,\ k = 1, 2, 3, 4.$$

where the intercept γ_k represents a constant component for thresholds for all segments. Given different segment-level covariates z_{qj}, the thresholds vary between segments. Furthermore, to accommodate for the cross-segment heterogeneities, a random effect component b_j is formulated, which is normally distributed with mean of zero and precision of $tau \sim Gamma(0.01,\ 0.01)$. z_{qz} is a covariate parameter with different segment-levels. The main idea behind the introduction of the residual term is that crashes within a segment are correlated. As for the parameter estimation (α, β), clearly a positive coefficient indicates an increase of probability of being of higher severity level given an increased value of the corresponding covariate.

4.2 Model Estimation and Results

Obtained from the CAR and RCI databases, eighteen covariates were used to explain the variations of severity of FS crashes. These variables are listed in Table 2, together with their descriptive statistics. The model was estimated via MCMC technique in Bayesian framework, which was implemented using WinBUGS software (Spiegelhalter et al., 2003).

In the model estimation, a backward procedure was employed for variable selection. Specifically, beginning with all the variables considered, each variable was tested for the statistical significance and the insignificant ones were eliminated. Table 3 shows the final results of parameter estimation in the model, in which only the statistically significant covariates are retained. The precision parameter tau is significant judged by the Bayesian Credible Interval (10.06, 145.9). This justifies the specification of the cross-segment heterogeneities and in other words, the within-segment covariance exists among crashes that occurred in a same road segment.

Table 2: Variables used in the crash severity model

Variables	Description	mean	stdev	min	max
Response variable					
Crash severity levels	C1: no injury, property damage only (PDO) C2: possible injury C3: non-incapacitating injury C4: incapacitating injury C5: traffic fatality	2.22	1.22	1	5
Covariates					
Rural area	If road at rural area = 1, otherwise = 0	0.47	0.50	0	1
Principle arterial	If road is principle arterial = 1, otherwise = 0	0.47	0.50	0	1
No. of lanes	Continuous variable: number of lanes	3.67	1.46	2	10
ADT	Continuous variable: average daily traffic (k)	28.1	27.2	0.6	197
Speed limit	Maximum speed limit on the road segment	55.17	10.12	30	70
Shoulder width	Continuous variable in feet	5.72	3.00	0	20
Truck factor	Average truck factor	13.12	8.63	0	47.3
No division	If road undivided = 1, otherwise = 0	0.27	0.44	0	1
Skid	If skid coeff. <= 30, then = 1, otherwise = 0	0.06	0.23	0	1
Curve	If crash at curve = 1, otherwise = 0	0.08	0.26	0	1
Intersection	If crash at intersection = 1, otherwise = 0	0.36	0.48	0	1
Dusk or dawn	If crash at dusk or dawn = 1, otherwise = 0	0.18	0.39	0	1
Dark with street light	If crash at night with street light =1,otherwise=0	0.18	0.38	0	1
Dark w/o street light	If crash at night w/o street light =1, otherwise =0	0.31	0.46	0	1
Vehicle type	If vehicle type is automobile = 0, otherwise =1	0.53	0.50	0	1
Young driver	If driver age < 25 then = 1, otherwise = 0	0.33	0.47	0	1
Old driver	If driver age > 65 then = 1, otherwise = 0	0.07	0.25	0	1
Alcohol use	If crash with alcohol use = 1, otherwise = 0	0.17	0.38	0	1

Table 3: Parameter estimation of multilevel ordered logistic model

Variable	mean	sd	10%	median	90%
Gamma1	-1.169	0.729	-2.116	-1.185	-0.273
Gamma2	-0.302	0.727	-1.243	-0.317	0.592
Gamma3	0.944	0.727	0.009	0.928	1.837
Gamma4	2.267	0.734	1.326	2.252	3.170
Ln(ADT)	-0.080	0.069	-0.170	-0.083	-0.005
Rural area	0.438	0.153	0.243	0.439	0.635
Dark w/o street light	0.216	0.135	0.039	0.218	0.389
Truck factor	-0.011	0.008	-0.021	-0.011	0.000
Young driver	-0.225	0.127	-0.390	-0.223	-0.064
Tau	65.82	63.15	10.06	40.83	145.9
Deviance	2824	13.79	2806	2827	2837
DIC	2844.7				

The significant covariates include Ln(ADT), Rural area, Dark without street light, Truck factor, and Young driver. As shown in Table 3, it was found that the increase of traffic volume, reflected by the ADT, has a positive effect in reducing injury severity level of FS crashes (-0.080). This result may be explained by the generally reduced speed associated with heavy traffic roads. As reported by a previous study (Edwards, 1998), speeding is a major contributing factor leading to severe crashes in pile-up crashes in foggy conditions. This result is further confirmed by the positive parameter for the variable "Rural area" (0.43). Specifically, results show that severe crashes are much more likely to occur in rural areas compared to suburban and urban areas. This might be for the fact that on the roads of rural areas, drivers are used to drive at a high speed with low level of alertness due to the low traffic volume. Traveling at a high speed, especially in reduced visibility conditions due to fog or smoke, has been widely proven to be associated with reduced capability of the driver to crash avoidance. Likewise, this problem becomes more serious at night without street light as shown in the parameter estimation (0.216). This is reasonable since drivers may have more reaction time and better perception ability in good street lighting environment (Huang et al., 2008). Previous study (Wanvik, 2009) showed the risk of crash increases by fog in unlit roads by 12%. Combined with the result of this study, therefore, it may be concluded that the installation of street lights at fog/smoke prone locations will be helpful in reducing both FS crash risk as well as the injury severity. Furthermore, it is surprising to find a negative effect for the Truck factor (-0.011) although the effect is very close to zero. There seems to be no good justification for the decrease of severity level associated with higher truck factor. It might be for the reason that overall speed is reduced while there are trucks present in the traffic stream, resulting less severe crashes. Finally, the result shows that FS crashes involving young drivers tend to be less severe (-0.225). This may be presumably due to the better vision and reaction abilities, and above all stronger physical condition, of young drivers to detect and avoid severe injury in a crash under reduced visibility conditions. Nevertheless, it is worth noting that young drivers were found to be associated with a higher crash risk in FS conditions in contrast with CV conditions as shown in Figure 3.

5. CONCLUSIONS

Fog/smoke (FS) related fatal crashes are very high in Florida, which ranks third among all states in United States in terms of FS crash fatalities. Using five-year crash data records, this paper presents a comprehensive study of FS related crashes in Florida. In terms of temporal distribution, it was found that the morning hours in the months of December to February are the deadliest for FS crashes.

Moreover, comprehensive efforts have been made to examine the effects of various factors on FS crash risk, crash types and crash severity in comparison with CV crashes, as well as variations of severity level given a FS crash has occurred. The effects of significant factors on FS crash risk and injury severity are generally consistent. Compared to CV crashes, the FS crashes tend to result in more severe injuries and involve more vehicles. Head-on and rear-end crashes are the two most prevalent crash types in terms of crash risk and severe crashes. These crashes occurred more prevalently at higher speed, undivided, non-sidewalk and two-lane rural roads. Thus the reduction of speed limits and the installation of road medians are expected to be useful to improve safety at FS prone locations. Another suggestion would be to improve road lighting at the identified hotspots as FS crashes tend to occur more likely at night without street light, which also leads to more severe injury.

Findings of this paper can also be put to some good use for engineering implementations to increase road safety in FS conditions. The analyses found that most of the FS crashes took place in undivided rural roads in dark conditions without lighting. Severity also is very high in these conditions. Hence, solar and battery powered systems can be installed for fog/smoke detection and warning in these locations, and subsequent VMS/DMSs can be installed to warn the drivers ahead based on the detection of fog/smoke.

Acknowledgement: The research is funded by District 5 of the Florida Department of Transportation.

6. REFERENCES

Codling, J. P. (1971). Thick Fog and its Effect on Traffic Flow and Accidents. Transport and Road Research Laboratory, TRRL Report LR 397, TRRL, Crowthorne.

Cools, M.; Moons, E.; Wets, G. (2008). Assessing the impact of weather on traffic intensity. In Proceedings of the 87th annual meeting of the *Transportation Research Board*. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C.

Edwards, J. B. (1998). The relationship between road accident severity and recorded weather. *Journal of Safety Research*, 29(4), pp. 249-262.

Edwards, J. B. (1999). Speed adjustment of motorway commuter traffic to inclement weather. *Transportation Research* Part F 2, pp. 1-14.

Huang H. L.; Chin H. C.; Haque M. M. (2008). Severity of driver injury and vehicle damage in traffic crashes at intersections: Bayesian hierarchical analysis. *Accident Analysis & Prevention*, 40(1), pp. 45-54.

Kang, J. J.; Ni, R.; Anderson, G. J. (2008). The effects of reduced visibility from fog on car following performance. In Proceedings of the 87th annual meeting of the *Transportation Research Board*. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C.

Khattak, A. J.; Knapp, K. K. (2001). Interstate highway crash injuries during winter snow and nonsnow events. *Transportation Research Record* 1746, pp. 30-36.

Kilpelainen, M.; Summala, H. (2007). Effects of weather and weather forecasts on driver behavior. Transportation Research Part F 10, pp. 288-299.

Koetse, M. J.; Rietveld, P. (2009). The impact of climate change and weather on transport: An overview of empirical findings. *Transportation Research* Part D 14, pp. 205-221.

Maze, H. T.; Agarwal, M.; Burchett, G. (2006). Whether weather matters to traffic demand, traffic safety, and traffic operations and flow. *Transportation Research Record* 1948, pp. 170-176.

Moore, R. L.; Cooper, L. (1972). Fog and Road Traffic. Transport and Road Research Laboratory, TRRL Report LR 446, TRRL, Crowthorne.

Musk, L. (1991). Climate as a factor in the planning and design of new roads and motorways. In: Perry, A. H., and Symons, L. J., (editors), Highway Meteorology, E&FN Spon, London.

Oh, S.; Chung, K.; Ragland, D. R.; Chan, C. (2009). Analysis of wet weather related collision concentration locations: empirical assessment of continuous risk profile. In Proceedings of the 88th annual meeting of the *Transportation Research Board*. CD-ROM. Transportation Research Board of the National Academies, Washington, D.C.

Perry, A. H. (1981). Environmental Hazards in the British Isles. George Allen & Unwin, London.

Qin, X.; Noyce, D.; Lee, C.; Kinar, J. R. (2006). Snowstorm event-based crash analysis. *Transportation Research Record* 1948, pp. 135-141.

Qiu, L.; Nixon, W. A. (2008). Effects of adverse weather on traffic crashes: systematic review and meta-analysis. In Proceedings of the 87th annual meeting of the *Transportation Research Board*. CDROM. Transportation Research Board of the National Academies, Washington, D.C.

Spiegelhalter, D. J.; Thomas, A.; Best, N. G.; Lunn, D. (2003). WinBUGS version 1.4.1 User Manual. MRC Biostatistics Unit, Cambridge, UK.

Summer, R.; Baguley, C.; Burton J. (1977). Driving in Fog on the M4. Transport and Road Research Laboratory, TRRL Report LR 281, TRRL, Crowthorne.

Wanvik, P. O. (2009). Effects of road lighting: An analysis based on Dutch accident statistics 1987-2006. *Accident Analysis and Prevention* 41, pp. 123-128.