Final Report

Contract BDK78 977-11

Synthesis of Visibility Detection Systems

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DISCLAIMER

"The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation."

UNITS CONVERSION

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
in^2	squareinches	645.2	square millimeters	mm^2
ft^2	squarefeet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: volumes greater than 1000 L shall be shown in m^3				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in

m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

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16. Abstract

Visibility is a critical component to the task of driving on all types of roads. The visibility detection and warning systems provide real-time, automated detection as well as appropriate responses to counteract reduced visibility conditions due to fog, heavy rain, snow, smoke, dust or haze by informing drivers of present conditions and lowering the speed limits to match the reduced visibility condition. The objective of this research project is to provide a synthesis of visibility detection systems and traffic control techniques that are developed and/or implemented in the U.S. and around the world. This report provides an overview of the best practices of fixed visibility systems at areas of recurrent dense fog and mobile systems for seasonal visibility reduction for areas of predicted seasonal fog or smoke from wildfires. Ongoing research efforts of developing new camera-based visibility detection systems are also discussed.

In addition, a preliminary analysis of Fog/Smoke (FS) crashes in Florida, including detailed two-way analysis capturing interactions between various factors and fog and/or smoke related crashes is provided in this report. To identify and prioritize areas for treatment, an update of the statewide map with increased granularity of reduced visibility related crashes is generated.

The visibility detection systems can help to mitigate the increased hazard of limited-visibility, however such systems are not widely implemented and many locations with no systems are experiencing considerable number of fatal crashes due to reduction in visibility caused by fog and inclement weather. On the other hand, airports' weather stations continuously monitor all climate parameters in real-time, the gathered data may be utilized to mitigate the increased risk for the adjacent roadways. An additional research effort is also provided to examine primarily the possibility of using weather information collected by weather stations at airports within the vicinity of fog-prone areas . Bayesian logistic regression was utilized to link 6-year (2005-2010) of historical crash data to real-time weather information collected from 8 airports in the State of Florida, roadway characteristics and aggregate traffic parameters. The results from this research depicts that real-time weather data collected from adjacent airports may be good predictors to assess increased risk on highways.

17. Key Word Reduced Visibility; Safety; Fog; Smoke; Real-time Weather Data; Airport Weather Information	18. Distribution Statement

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EXECUTIVE SUMMARY

Florida is among the top states in the United States regarding traffic safety problems resulting from adverse visibility conditions due to fog/smoke (FS) and heavy rain (HR). Florida was the third after California and Texas, with 299 fatal crashes occurring due to FS between 2002 and 2007. The most recent example for visibility related crashes in Florida was the pileup involving a dozen cars and six tractor-trailers on I-75 near Gainesville in January, 2012. At least 10 people were killed, and another 18 were taken to a nearby hospital. The poor visibility also made it extremely difficult for rescuers to find victims, and the segment was shut down for an extended time.

The problem derives from the inadequacy of traffic control techniques to provide guidance for drivers and the unpredictability of locations and times of reduced visibility on highways. Therefore, the main goal of this research project is to provide an up to-date synthesis of reduced visibility countermeasures implemented by other states and agencies in the area of traffic safety as well as other areas, such as aviation. Moreover, an evaluation of both fixed and mobile existing systems was conducted. This research project identified the unpredictability of when and where these systems are needed and prioritized areas in the state of Florida for treatment using Geographic Information Systems (GIS) and other traffic safety analyses.

In addition, this report discusses a comprehensive study of FS crashes in Florida using eight-year crash data records between 2003 and 2010. Eleven areas were identified with frequent fog/smoke related crashes on Florida state highways using Kernel Density Estimation (KDE) in macroscopic analysis. We also magnified these areas and divided all state highways into one mile

segments and thus FS crashes were counted based on the segments. All segments with two or more FS crashes were defined as hotspots in the analysis.

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. Compared to crashes under clear-visibility (CV) 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.

Additional research effort of this study were to primarily investigate whether airports' weather data can be used to provide indications about weather conditions in general and visibility levels in particular to roadways close to these airports and hence the gathered data may be utilized to mitigate the increased risk for the adjacent roadways. A potential benefit of existing visibility systems at airports in Florida was depicted from the preliminary analysis. More investigation is needed to prove the benefits of linking airport systems to traffic management centers. The possible implications would be substantial with respect to more coverage and huge savings.

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ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
AWSS	Automated Weather Sensor System
CAR	Crash Analysis and Reporting
CCTV	Closed Circuit Television
CV	Clear Vision
DMS	Dynamic Message Signs
DOD	Department of Defense
DOT	Department of Transportation
DUST	Dual Use Safety Technology
ESS	Environmental Sensor Stations
FAA	Federal Aviation Administration
FDWS	Fog Detection and Warning System
FS	Fog/Smoke
FWS	Fog Warning System
GIS	Geographic Information Systems
HARS	Highway Advisory Radio Service
ITS	Intelligent Transportation Systems
KDE	Kernel Density Estimation
LED	Light Emitting Diode
METAR	Routine Aviation Weather Observation (in French)
NOTAM	Notice to Airmen

NWS	National Weather Service
RPU	Remote Processing Unit
RTMS	Remote Traffic Microwave Sensor
RWIS	Road Weather Information Systems
TMC	Traffic Management Center
UCF	University of Central Florida
VSL	Variable Speed Limit

1. INTRODUCTION

Florida is among the top states in the United States regarding traffic safety problems resulting from adverse visibility conditions due to fog/smoke (FS) and heavy rain. Florida was the third after California and Texas, with 299 fatal crashes occurred due to FS between 2002 and 2007. The most recent example for visibility related crashes in Florida was the pileup involving a dozen cars and six tractor-trailers on I-75 near Gainesville in January, 2012. At least 10 people were killed, and another 18 were taken to a nearby hospital. The poor visibility also made it extremely difficult for rescuers to find victims, and the segment was shut down for an extended time. Figure 1-1 illustrates the distribution of injury severity for crashes related to vision obstruction. It depicts the increased severity levels of vision obstruction related crashes compared to crashes that are not related to vision obstruction.

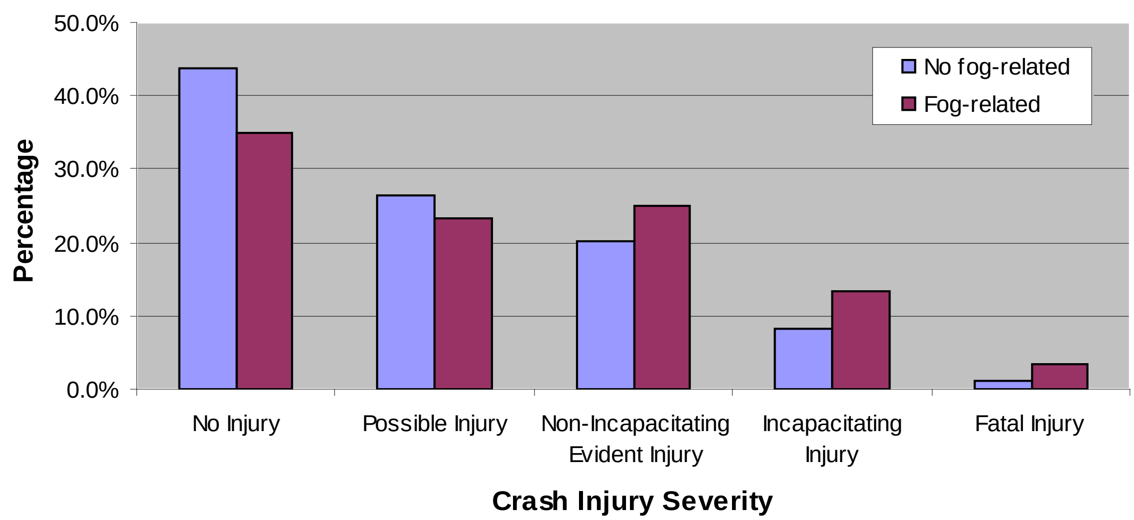

Figure 1-1: Distribution of Crash Injury Severity for Vision and Non Vision Obstruction

The problem derives from the inadequacy of traffic control techniques to provide guidance for drivers and the unpredictability of locations and times of reduced visibility on highways. Therefore, the main goal of this research project is to provide an up to-date synthesis of reduced visibility countermeasures implemented by other states and agencies in the area of traffic safety as well as other areas, such as aviation. Moreover, an evaluation of both fixed and mobile existing systems was conducted. This research project identified the unpredictability of when and where these systems are needed and prioritized areas in the state of Florida for treatment using Geographic Information Systems (GIS) and other traffic safety analyses.

This report is divided into five Chapters. A synthesis of existing visibility detection systems and emerging visibility detection technique are provided in Chapter 2. Chapter 3 provides a preliminary analysis of Fog/Smoke (FS) crashes in Florida, including detailed two-way analysis capturing interactions between various factors and fog and/or smoke related crashes. Data collection and preparation and an update of the statewide map with increased granularity of reduced visibility related crashes are given in Chapter 4. The identification of priority areas for treatment is presented in Chapter 5. Exploring the feasibility of using airports' weather stations data as part of visibility detection systems is provided in Chapter 6. Finally, the conclusions and recommendations are provided in Chapter 7.

2. SYNTHESIS OF APPLICATION AND RESEARCH OF VISIBILITY DETECTION SYSTEMS

The synthesis of application of visibility detection systems is divided into 3 sections. Section 1 reviews all developed systems in the United States of America. Section 2 presents systems implemented in Europe. Types of visibility detection systems that are used for aviation are provided in Section 3. Followed by the synthesis of existing visibility detection systems, researchers in emerging technique (camera-based visibility detection) is also introduced, which is promising for future application.

2.1. Visibility Detection Systems in the U.S.A.

Nowadays, there are many fog warning systems to warn drivers of sudden drops in visibility especially due to fog. Visibility warning systems should be able to estimate the safe travel speed for drivers based on visibility conditions to reduce fog-related crashes. There are two main countermeasures to account for reduction in visibility; active and passive systems. Active systems comprise visibility, weather and traffic detection sensors in combination with driver warning systems, e.g., flashing lights, dynamic message signs and variable speed limit signs. Active systems may be as simple as flashing lights and advisory/warning signs to warn motorists that the roadway is susceptible to reduction in visibility due to various weather events or advanced Intelligent Transportation Systems (ITS) providing dynamic advisory messages based on the visibility level and traffic flow parameters. Passive systems provide measures to help warn and delineate traffic, such as delineators, reflectors, stripping, etc.

With the help of Florida Department of Transportation (FDOT) and USDOT, information regarding the state of the practice of visibility detection systems in the U.S. have been collected.

Eighteen states with visibility detection systems were identified as indicated in Figure 2-1; Alabama, Arizona, California, Florida, Georgia, Idaho, Indiana, Louisiana, Nevada, New Jersey, North Carolina, Pennsylvania, South Carolina, Tennessee, Utah, Virginia, Washington, and Wisconsin. This section presents a synthesis of the existing fog warning and detection systems.

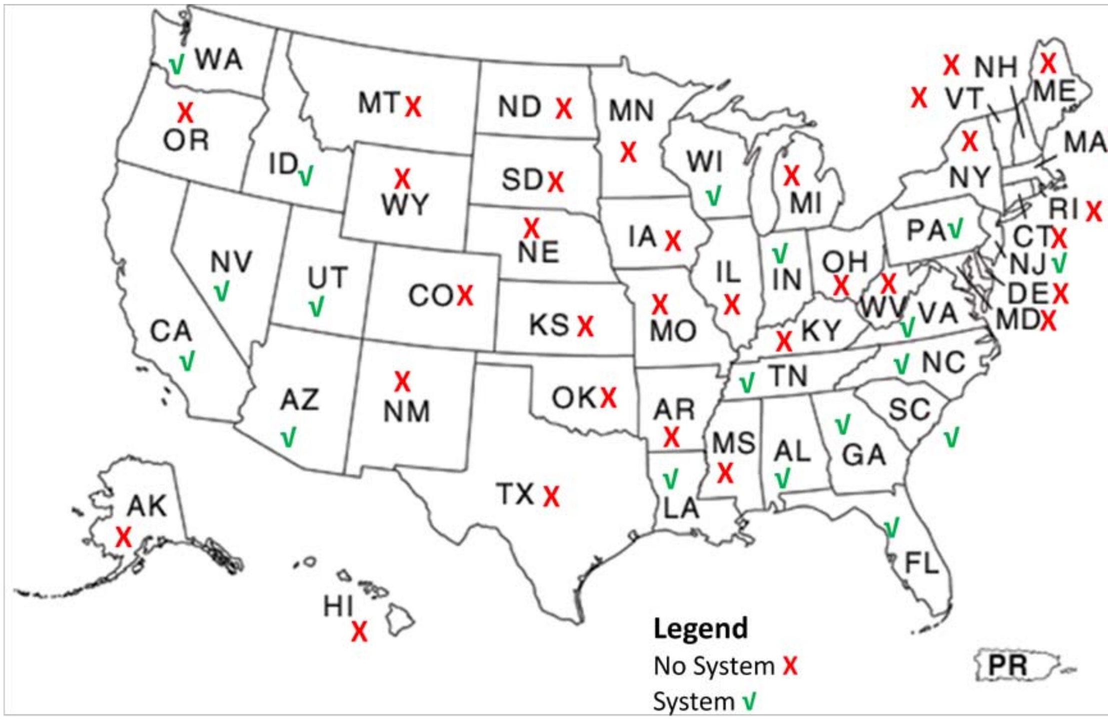

Figure 2-1: Visibility Detection Systems in the U.S.A.

<u>Alabama DOT Low Visibility Warning System</u>

In fall 1999, the Alabama DOT (ADOT) deployed a low visibility warning system on a fog-prone area near Mobile, Alabama. This system consisted of 6 visibility sensors with forward-scatter technology that are spaced roughly at ¾ of a mile to a mile. It is worth mentioning that ADOT switched from the unsuccessful backscatter fog detectors because of the inaccuracy of their readings. About 25 Closed Circuit Television (CCTV) cameras were used for monitoring traffic data, the cameras are spaced ¾ of a mile apart. Via a fiber optic cable communication system, field sensor data were transmitted to a central computer in the control room. Also to display advisories or regulations to drivers, 24 Variable Speed Limit (VSL) signs and 5 Dynamic Message Signs (DMS) were used.

At least two Automated Transportation System (ATS) Operators staff the Traffic Management Center (TMC) twenty-four hours a day. When fog is observed via CCTV, ATS Operators consult the central computer, which displays visibility sensor measurements by zone. The warning system is divided into six zones which can operate independently as shown in Figure2-2. Depending on visibility conditions in each zone, operators may display messages on DMS and alter speed limits with VSL signs (as shown in Table 2-1).

Table 2-1 : Alabama DOT Low Visibility Warning System Strategies (Goodwin 2003).

Visibility Distance	Advisories on DMS	Other Strategies
Less than 900 feet (274.3 meters)	"FOG WARNING"	Speed limit at 65 mph (104.5 kph)
Less than 660 feet (201.2 meters)	"FOG" alternating with "SLOW, USE LOW BEAMS"	• "55 MPH" (88.4 kph) on VSL signs • "TRUCKS KEEP RIGHT" on DMS
Less than 450 feet (137.2 meters)	"FOG" alternating with "SLOW, USE LOW BEAMS"	• "45 MPH" (72.4 kph) on VSL signs • "TRUCKS KEEP RIGHT" on DMS
Less than 280 feet (85.3 meters)	"DENSE FOG" alternating with "SLOW, USE LOW BEAMS"	• "35 MPH" (56.3 kph) on VSL signs • "TRUCKS KEEP RIGHT" on DMS • Street lighting extinguished
Less than 175 feet (53.3 meters)	I-10 CLOSED, KEEP RIGHT, EXIT ½ MILE	Road Closure by Highway Patrol

It was found that Alabama's low visibility system was effective in improving safety, reducing average speed and minimizing crash risk in low visibility conditions (Goodwin 2003).

One of the major problems however with the older Alabama's system is that the fog sensors are made for airports and only require a determination of visibility of 2,400 feet. Moreover, they are not capable to distinguish between finer gradations of fog and therefore the margin of error is quite large, these fog detectors have a 25% margin of error in visibility distance determination.

In 2008, a system upgrade was performed to the fog system. These upgrades included updating devices, improving the method of communication with these devices by going from a point-to-point system to Ethernet, and the addition of Radar Vehicle Detection (RVD) devices every one-third of a mile along the Bayway.

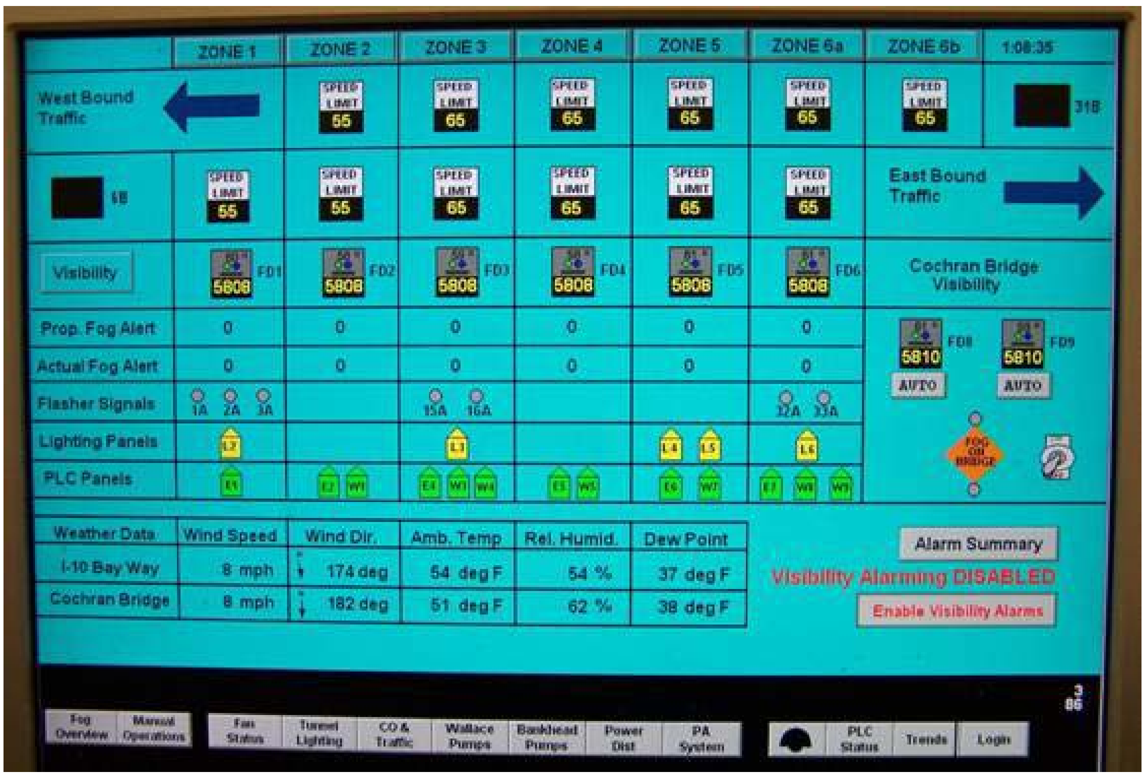

Figure 2-2: Screen Shot of Low Visibility Warning System (Source: USDOT 2001)

Alaska Increased Delineators

Although Alaska suffers from reduction in visibility due to fog and snow, there are no detection systems in place. The only countermeasure is increased delineators on the side of the road. One of the main reasons of not having any systems in place is the fact that in the fog-prone areas, there are no power lines to operate any fixed visibility detection systems; therefore a mobile detection system that relies on rechargeable car batteries could be a good alternative.

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Arizona Dual Use Safety Technology (DUST) Warning System

While reduced visibility due to fog is not a problem in Arizona, the state suffers from unpredictable dust storms during the spring season. Dust storms are an important safety concern that can reduce visibility to extremely low levels, causing multiple-vehicle crashes. With the difficulty of the nature of dust storms, visibility and metrological technologies are needed to deal with the much localized storms (a ½ mile wide dust storm occurring anywhere within a 30 mile stretch of roadway). The Arizona DOT (ADOT) has developed and implemented the DUST Warning System to help mitigate the dust storms problem (Figure 2-3). The proposed system has been designed to focus on dual challenges:

1. Visibility hazards caused by blowing dust on a sixty mile segment of I-10 between Bowie and the New Mexico Stateline.

2. Unexpected snow and ice in the Texas Canyon area of I-10.

The DUST Warning System provides an early warning and detection for icy conditions in Texas Canyon as well as wind borne dust along I-10 using several Environmental Sensor Stations (ESS) and a comprehensive sensor array. Each ESS site is equipped with a snapshot Closed Caption Television (CCTV) camera to visually confirm any potential low visibility conditions.

The system consists of Wireless Ethernet Networks - Based on the WIMAX IEEE 802.16 standard, the wireless network solution is integrated to serve as a cost-effective and reliable long-range communications backbone for the DUST Warning System.

Photovoltaic Cells - Power for the remote telemetry sites are derived from renewable solar energy generated using photovoltaic cells. Initially developed to power satellites, the technology has gained recent widespread acceptance for solar powered remote telemetry and warning applications.

Anemometers - These devices measure wind speed to predict the potential for on-set of high wind conditions which may lead to reduced visibility conditions.

Forward Scatter Visibility Sensors Technology - it uses the forward scatter principle of light in the presence of atmospheric particles to measure the extinction coefficient and visibility. A high-intensity infra-red light emitting diode (LEDs) transmitter is used to illuminate the sensor's scatter volume. This results in a high signal-to-noise ratio and reduces the effects of background light variations. Visibility measurements are possible over a standard range up to more than 10 miles.

Light Emitting Diodes - LEDs have been in use as indicators for decades. As the reliability, heat tolerance, brightness and efficiency have increased, LED technology has gained widespread acceptance for application as traffic signal or warning beacon indications.

CCTV camera – Each ESS site is equipped with a snapshot CCTV camera to visually confirm any potential low visibility conditions.

Figure 2-3: Visibility Sensor in ADOT Dust Warning System

The overall concept of operations for the DUST warning system is simple. Sensors will be used to detect high winds and low visibility conditions. In addition, CCTV cameras will be providing snapshots for visual confirmation of low visibility conditions, so that ADOT and Department of Public Safety (DPS) can make informed decisions regarding roadway closures and detours as needed.

The DUST warning will use Programmable Logic Controllers (PLC) to trigger various warning devices when wind speed thresholds are exceeded or when sensors detect that minimum visibility thresholds are not met at any of the monitored sites. The components of the warning system will include:

Roadside mounted “Zero Visibility Possible” signs equipped with radio controlled flashing beacons. The beacons will be switched on when the user-set wind gust speed threshold is exceeded or when the nearest visibility sensor indicates that a user-set minimum visibility threshold is not met. The “Zero Visibility Possible” beacons will remain on for a user-settable period as determined by an “off delay timer”.

Figure 2-4: Dynamic Message Sign with Warning Message

- The DUST Warning System hardware is connected to the nearby ADOT DMS and will be able to post messages from a set of stored DMS messages based on sensor inputs, as seen in Figure 2-4 above.
- The DUST Warning System will enable Highway Advisory Radio Service (HARS) and play from a set of up to eight locally stored messages based on sensor inputs.
- The DUST warning systems will also send sensor alerts to a group of programmable e-mail addresses to alert highway operations and law enforcement staff of high wind and/or low visibility conditions.

Benefits:

ADOT has implemented the DUST warning system in an effort to reduce the number of crashes on I-10 caused by the limited visibility experienced during certain weather conditions. Instrumentation detects adverse weather conditions and then alerts travelers to high winds and limited visibility. Additionally, the system notifies ADOT operational personnel of these conditions and records certain parameters for future review. Video equipment also assists ADOT personnel in quickly assessing field conditions remotely. Although there are additional components located at the Texas Canyon Mountain pass further west between Benson and Wilcox, that system monitors for snow and ice conditions but does not trigger any public alerts.

Under certain conditions, alert and informational messages are automatically delivered to the public through a variety of field components. Messages are scripted and vary with instrumentation input. The combination of static and dynamic signing plus the HARS broadcasts present drivers with immediately important and usable information when needed in order to help prevent driver distraction and information overload.

Operational personnel can access data and live video feed in addition to email notifications. This allows the quick assessment, confirmation, and subsequent sharing of information with law enforcement and New Mexico DOT counterparts. Decisions regarding highway closures and remote traveler notification are expedited and become more reliable.

Implementation Issues:

ADOT's DUST warning system is not a new technology but rather a second generation prototype which expands the capabilities of an older, smaller system. There are issues which should be addressed as the technology evolves, and consideration given to deploying similar systems elsewhere. Although not mutually exclusive, these issues can be segregated into administrative and technical areas in nature.

The administrative issues highlighted here could be considered typical in any weather warning project:

- The Department must commit operating and maintenance funds to sustain the system, not just the first cost for installation. Training on how to operate and maintain the system must be reflected in the funding allocated.
- The integration of other measures and stakeholders, and the degree of integration must be considered. For example, allowing New Mexico DOT to view Arizona weather data is fairly simple via the Internet. However, ensuring than an appropriate and coordinated multiagency, multistate response is provided for a large-scale, sustained weather event takes much more than hanging a few blinking lights along the highway.

Technical issues discovered so far (and others will surely manifest themselves over time) include the following:

- Specifying, procuring, and installing the system requires a team with specialized experience. Using a qualified consultant greatly helps. A warranty period should be included in any agreement as well as training and field shadowing to facilitate the knowledge transfer from the vendor to Department personnel. Vendor technical support should include both hardware and software.
- Determining what data to collect, its significance, how to store and review it, and how long to keep it will take time. There has been some discussion that none of the data should be recorded due to potential liability concerns; however, that issue has not been fully resolved within ADOT.
- The initial calibration and set points for parameters takes time to discern. There may be some variability in wind speed versus soil type versus dryness, etc, that can make each

site unique from other locations. There is a growing body of knowledge but in the end the operator will need to adjust the system sensitivity until false alarms are minimized and the alerts delivered to the public are accurate (so dust storm messages are not displayed during a calm day and vice versa).

- The HARS does have serious limitations due to Federal Communications Commission transmission power and frequency assignment restrictions. Although the immediate vicinity may be covered, the signal becomes essentially imperceptible in less than a mile's distance. HARS is not an effective long-distance warning device; it is only good for delivering instructions to travelers in the immediate area. Many question its cost effectiveness.
- Email overload is one of the first observations made by new users, especially before the system set points are dialed in to minimize false alarms. Several users first excited about participating in the new system chose to later unsubscribe from the email warning distribution list because of the high volume of repetitive warnings. Operational personnel in the field typically do not have access to email, especially after working hours. Typically, law enforcement has no interest in receiving automated email messages but rather rely on ADOT notification or personal field observations.
- Sensory instrumentation and subsequent alerts are just snap shots of conditions in the immediate vicinity within a long corridor that in reality may be experiencing a wide variety of conditions. It would be cost prohibitive to place a continuous array of sensors and warning devices along any corridor so any proposed effort should focus on segments of highway where weather-related problems have already been demonstrated. Because this segment of I-10 in southeastern Arizona had a history of crashes and a larger-than-

normal number of fatalities due to weather-caused visibility problems, it was deemed an appropriate location for deployment of this technology.

- ADOT has struggled whether to periodically review weather, crash, and system performance data with the goal of validating whether the system is worth the cost. It is noted that both weather events and crashes are highly random in nature and it can be expected to take several years for enough data to be collected to make a meaningful assessment. However, we know that a single fatality has both a very high emotional as well as financial cost to society. If the Department can reduce the number of crashes then the system cost could be justified in a traditional business sense. It may be difficult to analytically demonstrate a reduction in crashes attributed to this warning system. Nevertheless, system reliability will always be an issue and maintenance programs have real costs that need to be justified so this particular question remains open.
- All involved would do well to remember that a certain portion of the traveling public will either be confused by the warning messages or choose to ignore them and attempt to pass through an area experiencing bad weather while hoping for the best. Technology will not help them.

Arkansas

No Visibility detection systems.

California DOT Motorist Warning System

In 1996, California DOT (Caltrans), District 10, implemented a low visibility warning system to warn drivers of adverse visibility on I-5, Stockton, CA. To collect traffic and weather data, the system includes 36 traffic speed monitoring sites, 9 complete ESS, and 9 DMS for warning drivers (see Table 2-2). Figure 2-5 shows one of the California's ESS. Each ESS includes a forward-scatter visibility sensor, a rain gauge, wind speed and direction sensors, a relative humidity sensor, a thermometer, a barometer, and a remote processing unit.

Figure 2-5: California DOT ESS (Goodwin 2003)

Table 2-2: California DOT Motorist Warning System Messages (Goodwin 2003)

Conditions	Displayed Message
Average speed between 11 and 35 mph (56.3 kph)	"SLOW TRAFFIC AHEAD"
Average speed less than 11 mph (17.7 kph)	"STOPPED TRAFFIC AHEAD"
Visibility distance between 200 and 500 feet (152.4 meters)	"FOGGY CONDITIONS AHEAD"
Visibility distance less than 200 feet (61.0 meters)	"DENSE FOG AHEAD"
Wind speed greater than 35 mph	"HIGH WIND WARNING"

Traffic and environmental data were transmitted from the field to Traffic Management Center (TMC) via dedicated, leased telephone lines. The evaluation of this system showed that it improved highway safety by reducing the number of visibility related crashes (MacCarley 1998, 1999).

General Description:

California's Central Valley suffers from Tule fog, which reduces visibility to one hundred feet or less and has caused severe traffic crashes. In response the Caltrans contracted ICx Transportation to build and integrate a fog detection and warning system along a 13-mile section of the California Highway 99 corridor in the central part of the state. The system was completed in 2009.

California's Central Valley—extending from Bakersfield in the south to Redding in the north—is one of the country's largest agricultural regions. It is also a major transportation corridor, with Interstate 5 and California Highway 99 (CA-99) running through the valley. CA-99 in Fresno in the project area carries more than 100,000 vehicles per day. The region is subject to a particularly dense kind of fog, known as Tule fog, during the winter. In fog season, which runs roughly from November 1 to March 31, Tule fog can form overnight and reduce visibility to less than an eighth of a mile, and in some cases to nearly zero. Drivers along the corridor routinely would continue to drive at unsafe speeds despite the low visibility, which has led to large, multiple-car crashes. In November 2007, Tule fog caused a 108 car pileup. There were two deaths and nearly forty injuries. The pileup, which included 18 semi-trailer trucks, extended for nearly a mile and closed CA-99 for over twelve hours. The last vehicle collided ten minutes after the initial crash.

In addition to the threat to life and property, these major pileups have an enormous effect on the economy of the Central Valley. In order to reduce the likelihood of future multivehicle crashes, District 6 of Caltrans is implementing a pilot project to automatically detect fog and warn motorists of hazardous conditions. Construction of the Fog Detection and Warning System (FDWS) began in October 2008.

Phase 1 was completed in February 2009 and Phase 2 was completed before the beginning of the 2009-2010 fog season on November 1, 2009. The project covers a thirteen-mile stretch of CA-99 south of Fresno, California.

System Components: The FDWS system consists of visibility sensors, speed detectors and cameras to detect congestion and visibility problems that could affect driver and passenger safety.

The installation is forty percent solar powered and uses both point-to-point and point-to-multipoint wireless radios to provide network connectivity. Local field controllers allow the field equipment to work autonomously if there is a break in communications to the central system.

System Operations:

Through intelligence built into the ICx Cameleon™ ITS product, the system alerts motorists automatically of dangerous weather conditions and slow speeds by using Changeable Message Signs (DMSs) and Highway Advisory Radio Service (HARS). The system will soon be incorporated into a 511 traffic web page and telephone system.

Speed detectors have been deployed every quarter of a mile, and fog sensors and DMSs deployed every half mile. Using the data collected from the sensors, the DMSs warn drivers of the presence of fog downstream and instruct them to slow down when they are in dense fog. When slower speeds are detected downstream, the DMSs warn drivers of the slower traffic ahead. HARs, roadside weather stations, cameras and multicolor changeable message signs are included.

The FDWS will use sensors to detect both visibility and speed on CA-99 in the project area. To measure visibility, the team selected the PWD10 forward scatter sensor developed by

Vaisala. The sensors have been installed every half-mile covering both directions of the freeway. They are installed at driver eye level to ensure the system is reporting the current conditions as seen by the driver. In addition, the project team has installed SmartSensor HD radar spot speed sensors from Wavetronix every quarter-mile through the project area. These radars are capable of measuring traffic volume, classification, speed, lane occupancy and presence in both directions of travel. Figure 2-6 shows the sensors on the roadside. These two sensing technologies combine to provide a more complete picture of traffic and visibility conditions than has ever been attempted on a large scale.

Figure 2-6: Sensor Array

The data from the sensors will be used to assess both visibility conditions and, equally importantly from the perspective of both travelers and traffic managers, speed differential at downstream locations on the freeway.

Due to the relatively rural nature of the project area, dedicated wire line communications are not available. Moreover, even if they were, the cost of trenching to connect into such systems would be prohibitive. As a result, all system communications are wireless. The communications system uses Proxim wireless devices to communicate between devices in the corridor. Backhaul communications to Caltrans' TMC is done using Verizon Wireless EVDO modems. Also due to the scarcity of fixed infrastructure, forty percent of the field equipment runs on solar power.

Data processing ensures that the data collected in the field is available in a useful format to travelers and to traffic managers. The system was developed with two levels of data processing.

Under normal system operations, all data are collected in the field and transmitted wirelessly to the TMC. There it is processed using the Cameleon™ ITS platform developed by ICx 360 Surveillance. If there are significant speed differentials on the freeway or if there is fog, Cameleon automatically generates messages for the data dissemination systems. If an incident has occurred, the DMSs will warn drivers of slower traffic ahead in order to prevent chain-reaction collisions.

Planned enhancements include providing the speed and visibility data from the system to the new 511 traveler information system for the southern Central Valley. The 511 system will inform travelers of problems in the project area via the telephone and the Internet before they reach it, possibly before they even leave their home or office. This will help reduce the impact of severe fog by minimizing the number of vehicles on the roadway.

As the system is further refined and enhanced, Caltrans envisions that it will have some or all of the following features:

- Full Matrix Color DMS to provide better information
- Road Weather Information Systems (RWIS) at various locations to monitor the full range of weather conditions, including rain, wind, humidity and temperature. The data from these sensors could potentially be used to predict fog.

- HARS reports, with alerts to travelers using extinguishable message signs
- CCTV cameras to provide more detailed information to the TMC and to the public over the Internet
- Pulsing in-pavement lighting to be used to slow traffic down under certain conditions (such as when there is an incident ahead). The lights would not be used during low visibility until an incident has occurred for fear the lights would guide drivers to move at unsafe speeds.
- Thermal Cameras
- Incident detection using advanced radar detection

Benefits:

The system alerts motorists automatically of dangerous weather conditions and slow speeds by using DMSs and HARS. When slower speeds are detected downstream, the DMSs warn drivers of the slower traffic ahead. If an incident has occurred, the DMSs will warn drivers of slower traffic ahead in order to prevent chain-reaction collisions.

Presently, the system only employs DMSs and HARS to communicate road conditions to travelers. Both of these methods are very effective. The addition of the 511 system addresses the shift to mobile data devices and the increased reliance by the motorist on receiving this information while traveling. Once the fog detection data is integrated with the 511 system, it will help reduce the impact of severe fog by minimizing the number of vehicles on the roadway.

Implementation Issues:

The FDWS installation involved a very short design-build cycle and innovative uses of existing technology. A number of issues were encountered in the implementation of the FDWS:

- Internal controls needed to be reconciled with the aggressive schedule and cost constraints of the FDWS.
- Existing infrastructure had to be reconfigured in order to merge the old and new components into a unified system, under the control of the Cameleon software.
- Evaluations of new technologies, such as Color DMSs, took time and resources to complete.
- User interfaces to the TMC needed to be developed around existing procedures, policies, and systems.
- Caltrans policies regarding information technology security issues needed to be addressed due to the nature of the communication systems deployed by the FDWS.

Additionally, the density of detectors was limited by funding. In general, more detection capability equates with a more robust coverage of fog events. However, the nature of the funding for this project did not allow for even small deviations from the allotted and agreed upon budget. Finally, there were concerns regarding the aesthetics of the project, due to the perceived clutter that the number of proposed field elements would present to the motorist.

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Colorado

The COTrip system has been developed by Colorado DOT (CDOT) to provide the traveler with important information about travel time, congestion, adverse weather conditions, road condition, and lane closure due to occasional avalanche danger, maintenance on the road and/or road crashes. The system consists of Cameras, Streaming Cameras, Weather Stations, Remote Traffic Microwave Sensors, Automatic Vehicle Identification Systems and Variable

Message Boards. This system serves more than 20 interstates and arterials, including I-25, I-70, and I-76.

In the past, fog-related crashes were prevalent at I-25 where the road runs through a low-lying area bordered by water and wetlands. CDOT installed LED and Flip Fiber overhead and ground-mounted Variable Message Signs (DMSs). Out of 12 DMSs, only 4 to 6 were used for fog problems. The system however is not fully automated and requires human interaction and decision-making. The system is activated using dial-up phone connection to display appropriate warning. Messages such as a “FOG CONDITIONS MAY EXIST” can be displayed when conditions are favorable for fog even if fog has not been reported.

Connecticut

Connecticut has few DMSs located at certain fog-prone bridges, but they never have been used to display fog-related warning messages because the state believe that the DMSs would not be easy to see in foggy conditions. Also, Connecticut has made no provisions for fog surveillance systems.

Delaware

No visibility systems.

Florida Tampa Bay Area Motorist Warning Systems for Fog-Related Incidents

The analysis of traffic crashes at Tampa Bay revealed that it has a history of fog-related problems, and has an average of 22 "heavy fog" days every year. Fog events in this area are not site-specific, and there are no established trends by location, therefore no automated fog detection systems have been installed.

In 2010, the researchers at University of Central Florida (UCF) developed an Early Detection System for Reduced Visibility. This system can detect any reduction in visibility below certain acceptable levels and respond accordingly in real-time to convey specific warning messages to drivers in an effective way and report this information to the appropriate TMC. The innovation in this system is that it was developed from components that are inexpensive and available commercially. Also, this system can be employed as portable or fixed system. A fixed system might be useful in areas that tend to have dense fog (for example, rural sections of freeways). However, the portable system can be used every time a wildfire occurs close to a highway. Furthermore, the system can be powered using regular car batteries so it does not depend on AC power supply.

2.1.1. System Components and Operation

Low visibility scenarios can occur due to a variety of conditions such as fog, rain, smoke, and smog. They can occur anywhere, and are especially dangerous on freeways and in rural areas. To cope with a variety of operational scenarios, a visibility detection system needs careful consideration for mobility, power, and communication technologies.

In this regard, the researchers at UCF deployed a low visibility warning system (Abdel-Aty et al., 2010). This visibility detection system consists of several components that are illustrated in more detail in this section. Initially for the prototype, the hardware is composed of four stations, each is connected to a visibility sensor; and each of these four stations will be monitored and controlled by a micro controller installed in a unit attached to it. The proposed structure of the system is shown in Figure 2-7. One of the stations performs as a base station which carries out all the communication processes between the different stations and the TMC and DMS. The components of the base and the station are shown in Figure 2-8 and Figure 2-9, respectively.

Each station contains the following components:

- Radio antenna
- GPS
- Visibility sensor
- XBee Radio (Receiver and Transmitter)
- Mini Computer
- USB hub
- Power regulator
- Power distributor
- Battery

Each station continuously detects highway visibility distances and save them on a flash memory attached to the mini computer. Then every station sends this information as messages to the base station. These messages contain the visibility distance (measured by the visibility sensor), coordinates of a station (estimated by GPS), and time and date of each message. In addition to the components mentioned above, base station contains XTend radio for communication between base and DMS. It also contains a cellular modem for communication between the base and TMC.

Therefore, the visibility system is designed to be autonomous in its operation and decision-making. It continuously monitors visibility distances. Whenever hazardous conditions are detected, it automatically generates warning messages that can be displayed to motorists on DMS and/or VSL signs.

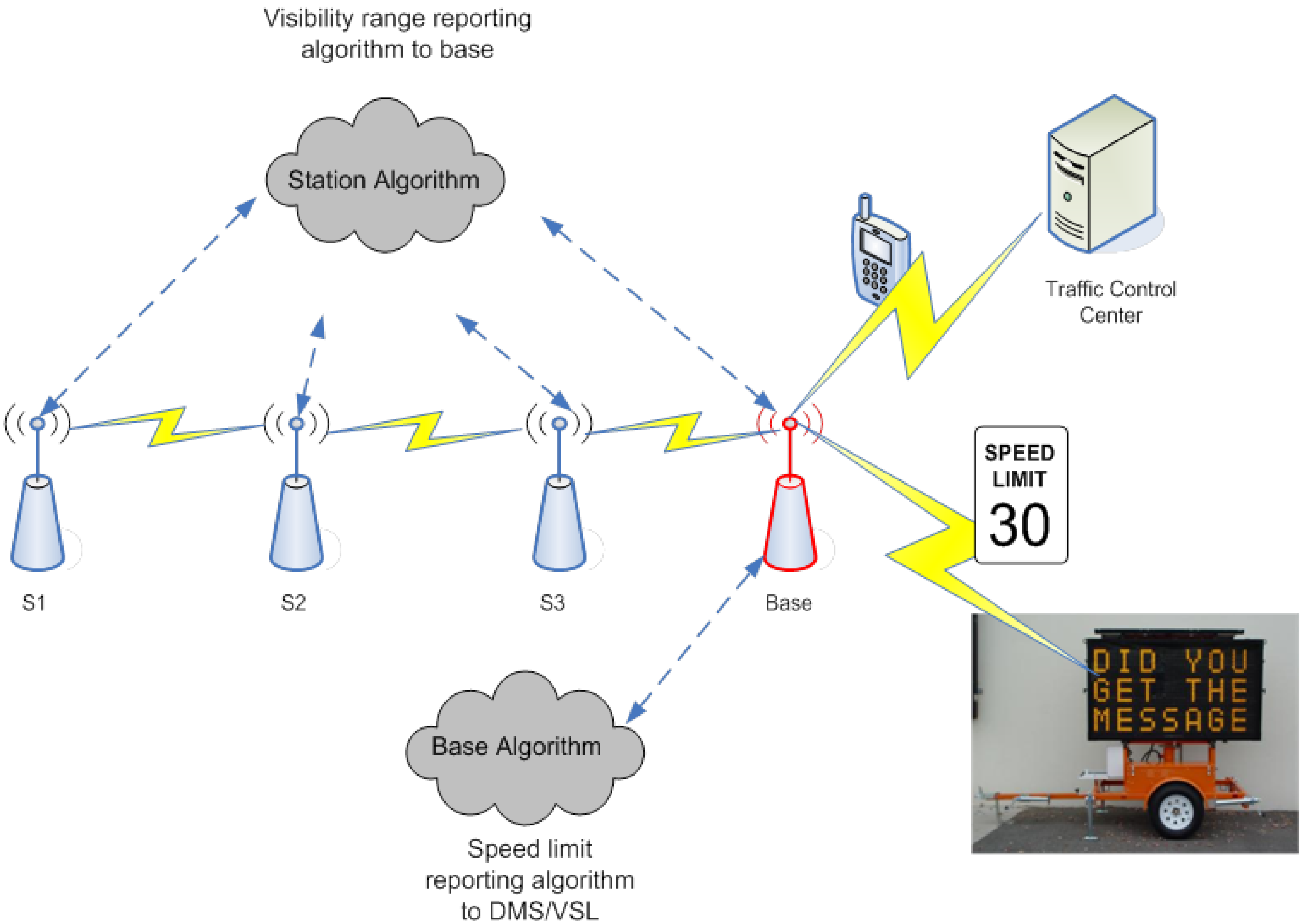
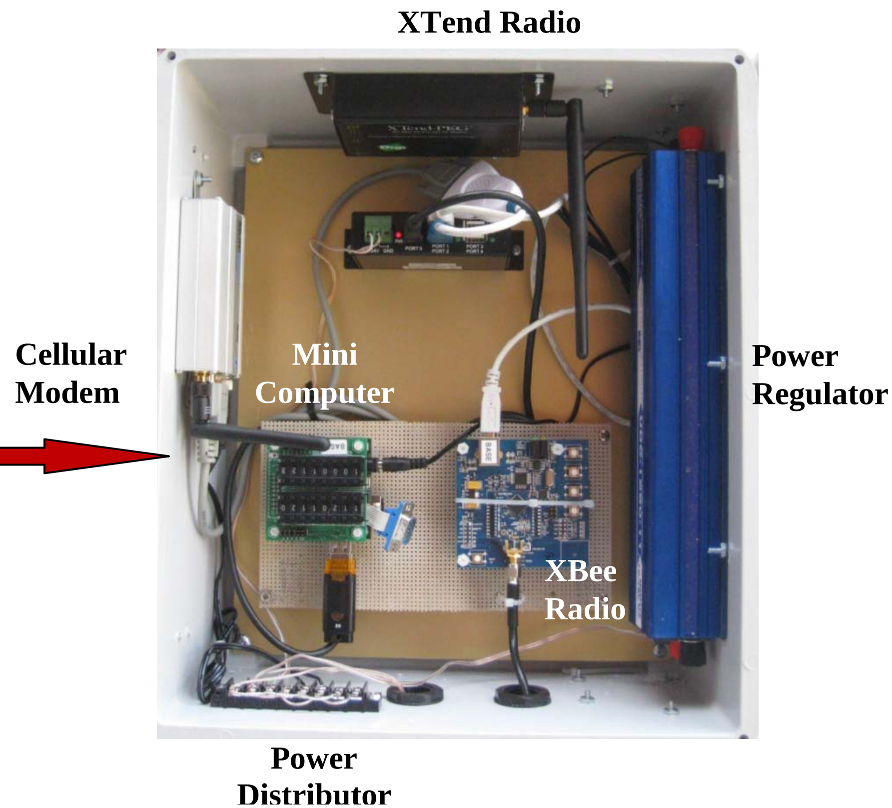
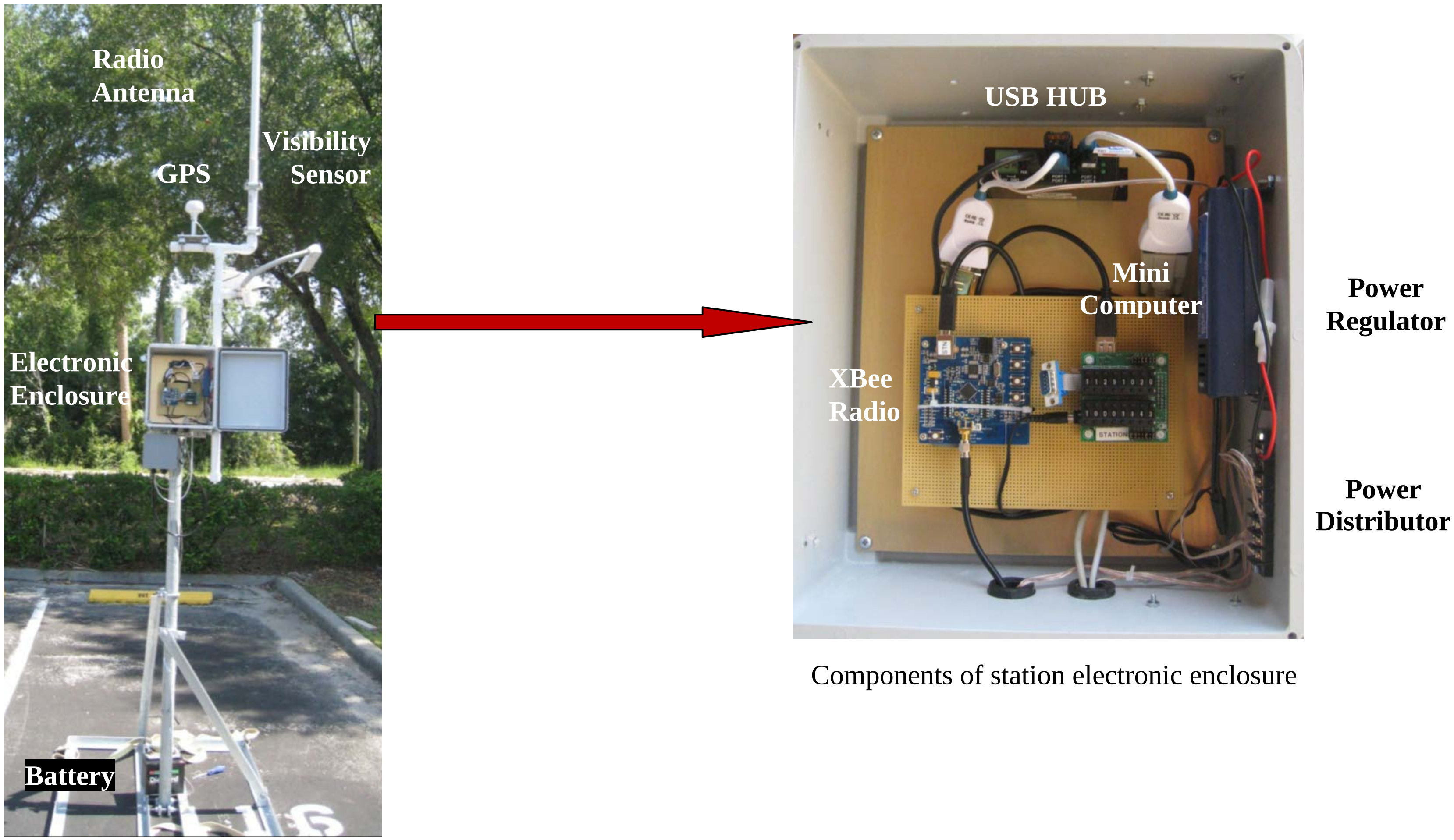


Figure 2-7: Visibility System Components



Components of base electronic enclosure

Figure 2-8: Base Components



Components of station electronic enclosure

Figure 2-9: Station Components

2.1.2. Communications

Communication is the important part of the system; the system includes two types of communication links. First, the internal communication link (data from sensors and base station) is a 900 MHz radio. The second type is cellular communication which is used to exchange information from the base station to the TMC. Any system is useless if it cannot report real-time visibility conditions for warning drivers and TMC about adverse visibility conditions. For this reason, the selection of a reliable communication system is of utmost importance. Thus, to avoid typical line of sight limitations inherent in communication technologies such as WiFi, the spread spectrum, etc., researches at UCF proposed the use of cell-based communication. This communication mode guarantees national coverage and reduces hardware costs. Also, since this system is designed to report on exceptional bases, data costs should be minimal.

2.1.3. System Operation

The visibility system is designed to be autonomous in its operation and decision-making. It continuously monitors visibility. Whenever hazardous conditions are detected, it automatically generates warning messages that can be displayed to motorists. Two types of messages are generated; speed advisories and warning messages of poor visibility. The automatic messages are selected by a computer algorithms based on the measured visibility distance and the maximum safe speed.

2.1.4. Software Design and Algorithms

The system's software control runs on a micro controller attached to the base station and executes a real-time operating structure. The system controls the entire baseline functions necessary to operate the overall system, including data acquisition, data storage, system control, and self monitoring. Specifically, the system reads from 4 fog sensors, while controlling up to four DMSs. This overall functionality is obtained through individual software modules, which are illustrated in the diagram shown in Figure 2-10. The design of the system is extendible to include additional fog sensors, VSL signs, flashing lights and DMS to expand the capability of the system to cover longer segments of roads in fog-prone areas.

There are two main algorithms that have been designed to control the communications process and data reporting frequencies. One of these algorithms controls the communications between the stations and the base, while the other controls the communication between the base and both DMS and TMC.

As mentioned earlier, each station detects the visibility distance and reports it to the base station. At normal conditions (highway visibility range > 250 m), the base station receives messages from each station showing the current visibility distance every 15 minutes. Although it is not needed to take any action at normal visibility conditions, it was decided to receive messages from each station to make sure that all stations are working properly. However, once the visibility distance drops below hazardous visibility levels (<250 m), the reporting frequency reduces to 1 minute.

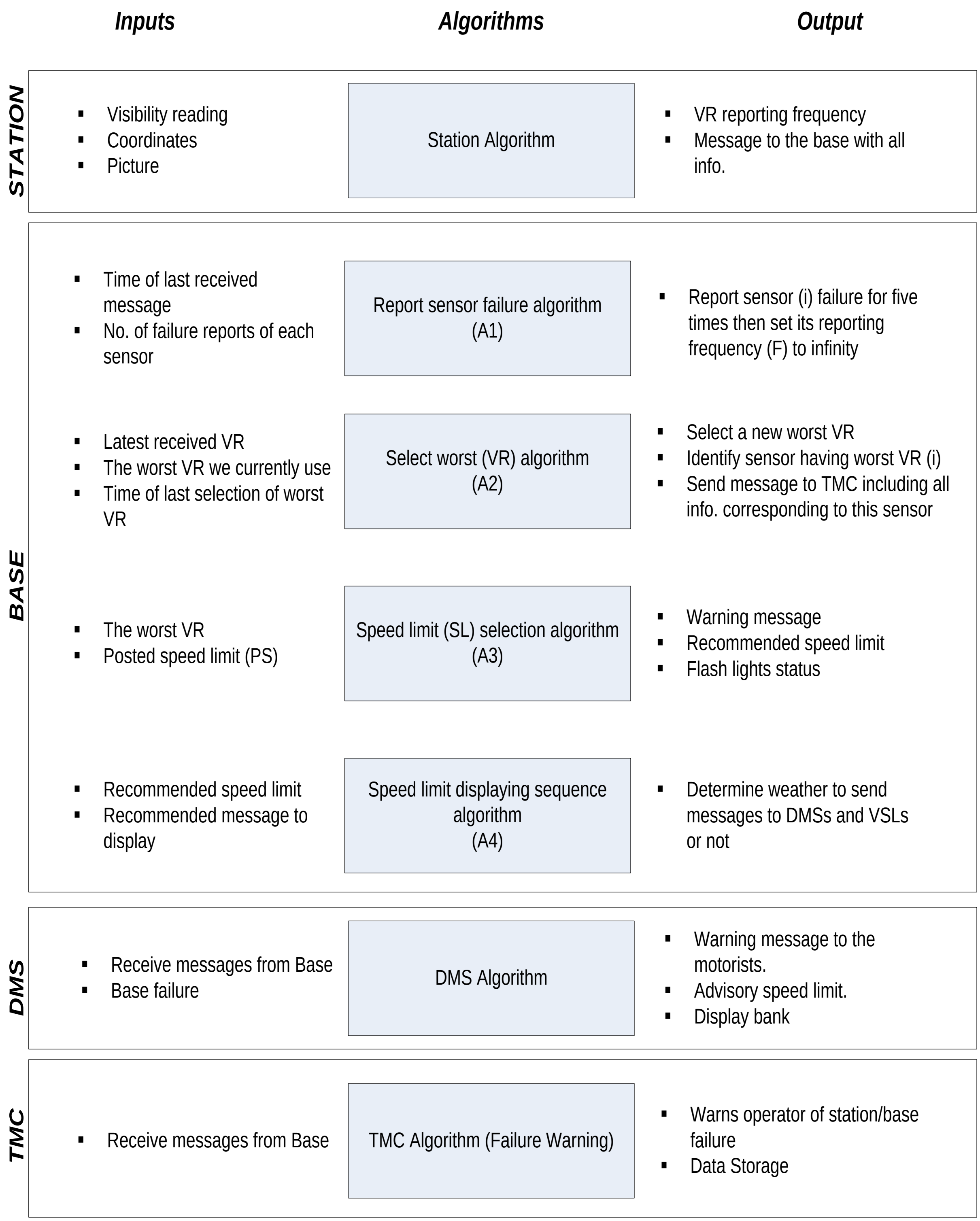


Figure 2-10: Structure of the System Algorithms

The proposed operators displayed messages on DMS and changed speed limits with VSL signs, based on the current visibility conditions (as shown in Table 2-3).

Table 2-3: E-mail Message Titles and Frequency of Reporting Messages to TMC

	E-mail Title	**Highway Visibility Range**
1	EMERGENCY: No Visibility	< 20ft
2	URGENT: Extremely low Visibility	< 200ft
3	WARNING: Moderate visibility	If visibility is between 200-500 ft
4	WARNING: Fog or Smoke Conditions affecting visibility	If visibility is between 500-800 ft
5	NORMAL CONDITIONS	Visibility greater than 800 ft
Frequency of reporting to TMC		
Every hour		Normal conditions.
Every 1 Minute		in Emergency
Every 5 minutes		Otherwise

The preliminary testing of this visibility system indicated that it can detect any reduction in visibility in a timely manner and respond accordingly in real-time to convey specific warning messages, either by reporting these messages to TMC/FDOT through e-mails or by displaying a warning message and an advisory safe speed at each visibility level using DMS and VSL signs, respectively. However, before reaching a final conclusion about the performance of this visibility detection system, conducting a traffic engineering study in real fog condition is still needed.

Georgia Automated Adverse Visibility Warning and Control System

In 2001, at a site known for fog problems on Interstate Highway 75 in South Georgia, Georgia Tech and the Georgia DOT (GDOT) jointly developed an automated Adverse Visibility Warning and Control System (AVWCS) along 14-mile section of I-75 to warn drivers about adverse visibility conditions.

This system consists of 19 Vaisala visibility sensors, five CCTVs, two DMSs, and five sets of traffic loops monitor speed and headway for northbound and southbound moving traffic lanes. The data collected by sensors are transmitted to an on-site computer using a fiber-optics communications network. The total project cost for system development and installation was $4 million. In addition, the cost needed to duplicate the system would be approximately $1.7 million (Gimmestad et al. 2004).

Hawaii

No visibility systems.

Idaho DOT Motorist Warning System

Between 1988 and 1993, 18 major weather related crashes (due to sudden drops in visibility) involving 91 vehicles and resulting in nine fatalities and 46 injuries occurred on a 45-mile stretch of Interstate 84 in southeast Idaho. Therefore, in 1993, to improve the safety in this area, Idaho Transportation Department (ITD) installed weather and visibility warning system at that site to measure three kinds of data: traffic, visibility, and weather data. Furthermore, to measure driver behavior during normal clear days and visibility event periods, automatic traffic counters were used to observe and record the lane number, time, speed, and length of each vehicle passing by the sensor site (Liang et al. 1998).

The system consists of three visibility sensors to measure reduced visibility conditions and a video camera to provide visual verification of the visibility sensors. The data collected by these sensors are transmitted to a master computer which records readings every five minutes.
This project was conducted in two phases. The objective of Phase I was to determine if the visibility sensors provide accurate visibility measurements, while the objective of Phase II was to

assess whether the DMSs would reduce vehicle speed during periods of low visibility (Kyte et al. 2000).

Figure 2-11: Idaho DOT Visibility Sensor

In this regards, Liang et al. (1998) studied the effects of visibility and other environmental factors on driver speed. The major purpose of this study was to determine the efficacy of using Idaho Visibility Warning System to warn motorists of inclement weather conditions and to quantify the nature of the speed-visibility relationship.

The results indicated that drivers responded to adverse environmental conditions by reducing their speeds by about 5.0 mph during the fog events and approximately 12 mph during the snow events (Table 2-4). Also, it was found that the primary factors affecting driver speed were reduced visibility and winds exceeding 25 mph. Also, Table 2-5 indicates an initial set of recommended speed levels based on the findings of the above mentioned study.

Table 2-4: Vehicle Speed Characteristics (mph) by Vehicle Type (Liang et al. 1998)

	Number of Events Evaluated	Car/trucks Combined		Passenger Cars Only		Trucks only	
		Mean Speed	Standard Deviation	Mean Speed	Standard Deviation	Mean Speed	Standard Deviation
Base Conditions	3	65.8	2.3	68.4	3.6	63.5	2.6
Fog Events	2	60.8	4.6	64.8	7.2	59.2	4.4
Snow Events	11	53.9	6.3	55.3	7.6	52.5	6.4

Table 2-5: Day and Night Vehicle Speed Characteristics (mph) by Visibility Level (Liang et al. 1998)

Visibility (miles)	Night Time Speed	Day Time Speed
0-1	60	62
>1	63	64

Illinois

No systems.

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Indiana

Indiana has a roadway visibility system on a ½ to ¾ mile stretch on I-69 that is not designed for fog detection. Although the system can be used for visibility, it mainly used for snow and white out conditions. The system consists of one JayCor 1200 visibility sensor, LED DMSs, a local controller, and wireless communications. The system cost was $100,000 without the DMSs. The sensor reads ambient visibility and temperature every 30 seconds and calculate the average over 5-minute. When the visibility is dropped below 500 feet, the system will report roadway location, mile marker, and direction. The Advanced Traveler Information System (ATIS) Expert System servers will then determine the message to be displayed on the DMSs. The message will continue being displayed until the field processor calls again to cancel or terminate the incident.

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Iowa

No fog detection system. Only DMSs are used to warn motorists of reduced visibility conditions, the DMSs are operated manually.

Contact: Sandra Larson, Sandra.Larson@dot.iowa.gov 515-239-1205

Kansas

No visibility systems.

Kentucky

In mid 1980s, Kentucky dismantled an automatic visibility detection system that was installed in the late 1970's on a bridge over Kentucky River because of its frequent malfunctions. The system used backscatter fog detector linked to static signs. Currently, Kentucky has 7 RWIS systems around the state for weather condition reporting and warning.

Louisiana

No visibility systems.

Contact: Harold Paul, Harold.Paul@LA.GOV

Maine

No systems. Only static signs to warn motorists.

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Maryland I-68 Fog Detection System, 2005

In 2005, a fog detection system was installed on I-68, Big Savage Mt. The system consists of 4 ground-mounted signs with solar powered flashers, 2 upgraded RWIS (camera, radio, remote processing unit, fog sensor), 6 Yagi directional antennas, 3 omnidirectional antennas, and 10 spread – spectrum radios (shelf item) (Sabra, Wang & Associates 2003).

Massachusetts

Massachusetts has static signs to warn travelers that they are entering a fog area.

Michigan

Michigan has 11 RWISs in use, the state had one fog visibility sensor installed and used without much success between 1992 and 1994.

Minnesota

No visibility systems.

Contact: Sue Lodahl, sue.lodahl@state.mn.us 320-223-6608

Mississippi

No visibility systems.

Contact: Mike Stokes, MStokes@mdot.state.ms.us 601-359-9710

Missouri

Missouri DOT (MODOT) and City of St. Peters operate 26 RWIS located throughout the state of Missouri. The system provides temporal observation of air temperature, relative humidity, dew point, wind speed, wind direction, visibility and precipitation. The only countermeasure in place is a static flashing light sign warning drivers of fog at fog-prone areas.

Montana

Montana uses only static warning signs and HARS that transmit a weather warning every 15 minutes.

Nebraska

No systems.

Nevada

Nevada has one visibility sensor within RWIS on I-80 east of Reno. The sensor is linked to 4 VSL (2 in each direction).

New Hampshire

No systems.

New Jersey

New Jersey DOT (NJDOT) has a long-term plan to develop and implement tools to provide accurate and dependable weather information to all travelers in New Jersey. In 2003 NJDOT tested the feasibility of a fog detection system on Route 287, the system consisted of pavement sensors imbedded in the pavement that measure temperature, moisture, form of moisture (snow/ice), and amount of deicing chemical present as well as atmospheric sensors that determine air temperature, relative humidity, wind speed and direction, precipitation and visibility. All sensors connect to a Remote Processing Unit (RPU) that transmits information to a server located at the main offices. Still frame video cameras also transmit images back to the operators.

Figure 2-12: NJDOT Visibility Sensor (Ozbay et al. 2003)

NJDOT decided not to use the deployed fog detection system to disseminate real-time data to the drivers using DMS's, only the system is used to collect and archive weather and traffic data from the sensors.

New Mexico

No systems.

New York

No systems.

North Carolina

North Carolina has a visibility system on a 5-mile stretch of I-40. The system consists of three Belfort visibility sensors, two DMSs, and a remote processor that control the DMSs and communicates with the central office. Fiber optics and dial-up connections are used to link the remote processor to central office. The DMSs are located 1-mile before a fog-prone area based on 15 years of accident data. The DMSs can automatically display different messages according to the visibility level. A "Low visibility, slow speed" will be displayed when the first visibility threshold is crossed. The operators monitor the visibility conditions and they can make different decisions. The visibility sensors cost $30,000 each, and the DMSs cost $125,000 a piece, including the structure, required poles, etc.

North Dakota

No systems.

Ohio

Ohio DOT (ODOT)'s RWIS has 172 visibility sensors deployed across all major highway corridors and in all counties. These sensors have a maximum range of 1.1 miles and are capable of detecting a range of present weather conditions, including low visibility situations.

Currently, Ohio's RWIS is not configured to alert in low visibility situations, but it is a possibility.

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Oklahoma

No systems.

Oregon

There is no system in place yet. The Oregon DOT (ODOT) is planning for a system to warn motorists about dust storm on I-84 new Pendleton.

Contact: Barine Jones, Barnie.P.JONES@odot.state.or.us 503-986-4486

Pennsylvania

In 1996, Pennsylvania DOT (PennDOT) acted immediately to a 24-car pileup involving four fatalities that occurred during white-out conditions on 2-mile segment on US 22 by implementing a visibility detection system. The system consisted of an Surface System Inc. (SSI) RWIS, DMSs, and HARS. The system requires manual operation and each component operates independently. Later the PennDOT moved to more automated system and installed CCTV systems and connected the components using fiber optic.

The Pennsylvania Turnpike Commission (PTS) commissioned a turnkey Fog Warning System (FWS) to eliminate fog-related crashes and reduce secondary crashes along 12 mile stretch on the Turnpike. The FWS provides real-time, automated detection as well as appropriate responses to counteract reduced visibility conditions by informing drivers of conditions present and lowering the speed limits to match the reduced visibility conditions.

Rhode Island

No systems.

South Carolina DOT Low Visibility Warning System

In 1992, South Carolina DOT (SCDOT) deployed a low visibility warning system on 7 miles (11.3 kilometers) on Interstate 526 to warn drivers of dense fog conditions, reduce traffic speeds, and guide vehicles safely through the fog-prone area.

The system consists of 5 forward-scatter visibility sensors spaced at 500-foot (152.4-meter) intervals, pavement lights installed at 110-foot spacing (33.5-meter), adjustable street light controls, 8 CCTV cameras, 8 DMSs, an RPU, a central control computer, and a fiber optic cable communication system. Table 2-6 shows the advisory and control strategies the system.

The South Carolina Low Visibility Warning System improved both mobility and safety on I-526. No fog-related crashes have occurred since the system was deployed (Goodwin 2003; Schreiner 2000; Center for Urban Transportation Research 1997).

Table 2-6: South Carolina DOT Low Visibility Warning System Strategies (Goodwin 2003)

Visibility Conditions	Advisory Strategies	Control Strategies
700 to 900 feet (213.4 to 274.3 meters)	"POTENTIAL FOR FOG" and "LIGHT FOG CAUTION" on DMS	"LIGHT FOG TRUCKS 45 MPH" and "TRUCKS KEEP RIGHT" on DMS
450 to 700 feet (137.2 to 213.4 meters)	"FOG CAUTION" and "FOG REDUCE SPEED" on DMS	Pavement lights illuminated
		"FOG REDUCE SPEED 45 MPH" and "TRUCKS KEEP RIGHT" on DMS
300 to 450 feet (91.4 to 137.2 meters)	"FOG CAUTION" on DMS	Pavement lights illuminated and overhead street lighting extinguished
		"FOG REDUCE SPEED 35 MPH" and "TRUCKS KEEP RIGHT" on DMS
Less than 300 feet	N/A	Pavement lights illuminated and overhead street lighting extinguished
		"DENSE FOG REDUCE SPEED 25 MPH" and "TRUCKS KEEP RIGHT" on DMS
		If warranted, "PREPARE TO STOP", "I-526 BRIDGE CLOSED AHEAD USE I 26/US 17", and "ALL TRAFFIC MUST EXIT" on DMS

The system had some minor problems and false detection. At the beginning the used electronic components were not suitable for the hot, humid environment. The microwave communication system failed because of lightning and was replaced by fiber optics to link the visibility sensors and weather stations. Also SCDOT had to install air conditioning units in the cabinets where the electronic were stored because of the extremely high temperature inside the cabinets. Another lesson that can be learned from SCDOT system is that fog detectors have to be cleaned every month which resulted in a very high maintenance cost. The initial cost of the system was $5 million, but it is unclear whether that figure includes construction items for the bridge.

South Dakota

No systems.

Tennessee

In 1990, chain-reaction collisions involving 99 vehicles, 42 injuries, and 12 fatalities had occurred on I-75 in southeastern Tennessee due to reduced visibility (less than 10 ft or 3.1 m). Therefore in 1994, Tennessee DOT (TDOT) and the Tennessee Department of Safety implemented a low visibility warning system on I-75, Tennessee. The system covered 19 miles (30.6 kilometers) and it consisted of 2 ESS, 8 forward-scatter visibility sensors, 44 vehicle detectors, 10 DMS, 10 VSL signs (as shown in Figure 2-13), and two highway advisory radio transmitters. Traffic and environmental data were transmitted from the sensors to on-site computer for processing through underground fiber optic cables then the data were submitted to the central computer in the Highway Patrol office in Tiftonia via a microwave communication system.

Figure 2-13: Tennessee VSL Sign (Goodwin 2003)

Table 2-7 shows the control strategies, while Table 2-8 shows the system strategies of Tennessee visibility warning system.

Table 2-7: Control Strategies of Tennessee Low Visibility Warning (Dahlinger 2001)

Visibility Distance	Control strategies
From 480 feet (146.3 kph) to 1,320 feet	The speed limit is reduced from 65 to 50 mph
From 240 to 480 feet.	The speed limit is lowered to 35 mph (56.3 kph)
Less than 240 feet or 73.2 meters	Road close due to Fog

Table 2-8: System Strategies of Tennessee Low Visibility Warning (Dahlinger 2001)

Conditions	Advisories on DMS	Other Strategies
Speed Reduced	"CAUTION" alternating with "SLOW TRAFFIC AHEAD"	N/A
Fog Detected	"CAUTION" alternating with "FOG AHEAD TURN ON LOW BEAMS"	• "FOG" displayed on VSL signs
Speed Limit Reduced	"FOG AHEAD" alternating with "ADVISORY RADIO TUNE TO XXXX AM"	• "FOG" & Reduced Speed Limits displayed on VSL signs • HARS messages broadcasted
	"FOG AHEAD" alternating with "REDUCE SPEED TURN ON LOW BEAMS"	
	"FOG" alternating with "SPEED LIMIT XX MPH"	
Roadway Closed	"DETOUR AHEAD" alternating with "REDUCE SPEED MERGE RIGHT"	• "FOG" displayed on VSL signs • HARS messages broadcasted • Ramp Gates closed
	"I-75 CLOSED" alternating with "DETOUR"	
	"FOG AHEAD" alternating with "ADVISORY RADIO TUNE TO XXXX AM"	

After deployment of the warning system in 1994, safety improved significantly as only one visibility related crash has occurred due to fog (Dahlinger and McCombs, 1995; Dahlinger, 2001; Tennessee ITS State Status Report, 2000).

Texas

No systems.

Utah DOT Low Visibility Warning System

In 1988 there was a 66-vehicle crash and in 1991 ten crashes, with three fatalities, occurred on one day due to dense fog on I-215 above the Jordan River in Salt Lake City, Utah. Therefore, during 1995 and 2000, the Utah DOT (UDOT) deployed a low visibility warning system on a two-mile (three-kilometer) segment of Interstate 215 to notify drivers of safe travel speeds and to achieve more uniform traffic flow in cases of reduction of visibilities.

The warning system consisted of 4 forward scatter visibility sensors and 6 vehicle detection sites to collect data on prevailing conditions. The speed, length, and lane of each vehicle were measured by inductive loop detectors' record. Traffic and Environmental data were transmitted to a central computer through Ultra-High Frequency radio modems. Two DMSs were used to post advisories to drivers. Table 2-9 shows Utah DOT Low Visibility Warning System Messages (Perrin, 2000; Perrin et al., 2002).

Table 2-9: Utah DOT Low Visibility Warning System Message (Perrin 2000)

Visibility Conditions	Displayed Messages
656 to 820 feet (200 to 250 meters)	"FOG AHEAD"
492 to 656 feet (150 to 200 meters)	"DENSE FOG" alternating with "ADVISE 50 MPH"
328 to 492 feet (100 to 150 meters)	"DENSE FOG" alternating with "ADVISE 40 MPH"
197 to 328 feet (60 to 100 meters)	"DENSE FOG" alternating with "ADVISE 30 MPH"
Less than 197 feet (60 meters)	"DENSE FOG" alternating with "ADVISE 25 MPH"

Perrin et al. (2002) measured the efficacy of Utah Low Visibility Warning System in reducing the variation between speeds which is the most important factor in reducing fog-related crashes. To achieve this goal, they tested a fog-prone area of I-215 in Salt Lake City, Utah during three phases. Phase I was the base case, no DMSs were used in this phase. In phase II, the warning system was implemented and DMSs were used. Phase III data was collected following DMS installation during the winter of 1999-2000. The displayed DMSs, based on measured visibility, are listed below in Table 2-10.

The results of this research showed that Utah FWS successfully reduced speed variation by an average 22%. This finding supports a prior idea that informing drivers of a safe speed during adverse visibility conditions is much better than leaving each driver to decide their own safe speed. In summary, Utah Fog Warning Stations, failed to reduce mean speed, but it succeeded in reducing the variation between vehicle speeds.

Table 2-10: Highway Visibility Range Criteria for Changeable Message Signs (Rockwell 1997)

Highway Visibility Range	Message
> 250 meters	No message
200 – 250 meters	"Fog Ahead"
150 – 200 meters	"Dense Fog" alternating with " advise 50 mph
100 – 150 meters	"Dense Fog" alternating with " advise 40 mph
60 – 100 meters	"Dense Fog" alternating with " advise 30 mph
< 60 meters	"Dense Fog" alternating with " advise 25 mph

Vermont

Vermont has a fixed sign with flashing lights to warn motorists to reduce speed during fog or snow on a 2-3 mile segment. The system is activated by remote dispatch.

Washington

No systems.

West Virginia

West Virginia DOT (WVDOT) has installed fog delineators on US 19. There is an ongoing research project looking into fog detection and warning system.

Contact: Donald L. Williams, Donald.L.Williams@wv.gov 304-677-4000.

Wisconsin

Wisconsin has two FWS in the Green Bay area on I-43 and US 41. The two systems are simple static signs with attached flashers that are manually activated through a dial-up phone line connection.

Wyoming

The VSL system (Layton and Young, 2011) in Wyoming adjust speed limits according to the recommended speed limit decided by Highway Patrol based on the existing weather and roadway conditions.

Summary of the U.S. Visibility Detection Systems and their Cost

The cost of fog mitigation systems depends upon many factors such as the type and amount of fog detection sensors, DMSs, and VSL signs, communication between fog sensors, etc. Table 2-11 provides detailed information about systems' components, length, locations, communication, power source, type of system, and system cost.

Table 2-11: U.S. Visibility Detection Systems

State	Type/Length	Visibility Reduction Due to	Visibility Sensors/ Weather Stations	Traffic/Speed Detectors	Warning Systems	Communications	Power	Management Strategy	Cost
Alabama /I-10 (Mobile)	Fixed/ 6.2 miles	Fog	6 Forward Scatter Visibility Sensors , 25 CCTV	Loop detectors/ Radars	24 DMSs/ 5 DMSs	Fiber Optics	Power Lines	Automatic	$18,000 excluding DMSs and loops
Arizona/ I-10 (Bowie, Texas Canyon)	Fixed/ 30 miles	Dual Snow and Dust (DUST)	Environmental Sensor Stations (ESS), Forward Scatter Visibility Sensors, Anemometers, CCTV	None	DMSs/ HARS	Wireless Ethernet	Solar Photovoltaic Cells	Manual/ Partial Automatic	Unknown
California/ Rt. 99/I-5 (San Joaquin Valley)	Fixed/ 13 miles	Fog	9 Full ESS (Vaisala Forward Scatter Visibility Sensors, rain gauges, wind speed and direction, humidity, thermometer, barometer and remote processing unit, CCTV, Thermal Cameras	Wavetronix SmartSensor HD radars	80 DMSs/ 9 DMSs / HARs	Proxim Wireless/ Verizon Wireless EVDO modems	40% Solar	Automatic	$3,600,000
Colorado/ 20 Interstates and arterials including (I-25, I-70, I-76, etc.)	Fixed/ Unknown	Fog and Snow	Weather Stations, Cameras, Streaming Cameras	RTMS and Automatic Vehicle Identification	6 LED Roadside DMSs, overhead DMSs	Dial-up Phone	Power Lines	Manual	$275,000
Florida/ Central Florida I-4	Prototype Mobile System/ Variable	Fog and Smog	4 Vaisala Forward Scatter Visibility Sensor, Cameras	Based on the Location	Variable LED DMSs/ VSL	XTend Radios/ Cellular Wireless Modems	100% Solar/ Car Batteries	Fully Automated/ Manual Override	$25,000/ 2 miles
Georgia/ I-75 (Florida border)	Fixed/ 14 miles	Fog	19 Vaisala Forward Scatter Visibility Sensors, 5 CCTVs	5 Loop Detectors	2 Light Emitting Diode (LED) DMSs	Fiber Optics	Unknown	Fully Automated	$4,000,000
Idaho/ I-84	Fixed/ 45 miles	Fog	3 Visibility Forward Scatter Sensors, Weather Station, Video Camera	Automatic Traffic Counters	DMSs	Unknown	Unknown	Unknown	Unknown
Indiana/ I-69 (Fort Wayne)	Fixed/ ¾ mile	Snow and White Out Conditions	1JayCor 1200 Visibility Sensor	None	LED DMSs	Wireless	Unknown	Automatic	$100,000
Kentucky/ Bridge over Kentucky River	Dismantled Fixed/ Unknown	Fog	7 RWIS, Backscatter Visibility Sensor	None	Static Signs	Unknown	Power Lines	Automatic	Unknown
Maryland/ I-68	Fixed/ Unknown	Fog	2 RWIS, Forward Scatter Visibility Sensor, Cameras	Unknown	4 Ground-mounted Signs with Solar Powered Flasher	Unknown	Power Lines/ Solar	Unknown	Unknown
Michigan	Dismantled	Fog	11 RWIS, 1 Fog Visibility	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown

Table 2-11, continued

	Fixed/ Unknown		Sensor						
Missouri/ City of St. Peters	Fixed/ Unknown	Fog	26 RWIS	None	Static Flashing Light Sign	Unknown	Unknown	Unknown	Unknown
Nevada/ I-80	Fixed/ One location	Fog	1 Visibility Sensor	None	4 VSLs (2 in each direction)	Unknown	Unknown	Unknown	Unknown
New Jersey/ Route 287	Fixed/ Unknown	Fog	RWIS, Visibility Sensors, , rain gauges, wind speed and direction, humidity, thermometer, barometer and remote processing unit, Still frame Video Cameras	Loop Detectors	DMSs	Cellular Digital Packaged Data (CDPD) Modem	Power Lines	Inactive/ Data Collection Only	Unknown
North Carolina/ I-40 (Haywood County)	Fixed/ 5 miles	Fog	3 Belfort Forward scatter Visibility Sensors	None	2 DMSs	Fiber Optics and Dial-up Connections	Power Lines	Automatic	$1,100,000
Ohio	Fixed/ Multiple Highway Corridors	Fog	172 Visibility Sensors	Unknown	Unknown	Unknown	Power Lines	Inactive	Unknown
Pennsylvania/ Rt. 22 (Crescent Mountain)	Fixed/ 2 miles	Fog	1 RWIS, CCTV	None	DMSs, Highway Advisory Radio	Fiber Optics	Power lines	Manual/ Upgraded to Automatic	$411,010 plus $1,200,000 in upgrades
South Carolina/ I-526	Fixed/ 7 miles	Fog	5 Forward Scatter Visibility Sensors, 8 CCTVs, RPU	Loop Detectors	8 DMSs, Pavement Lights, Adjustable Street Lights	Fiber Optics	Power Lines	Automatic	$5,000,000
Tennessee/ I-75 (Calhoun)	Fixed/ 19 miles	Fog	8 Forward Scatter Visibility Sensors , 2 ESS RWIS stations	44 Traffic Detectors	10 DMSs, 10 VSLs, 2 HARS	Fiber Optics/ Microwave Communication	Power Lines	Automatic	$4,460,580
Utah/ I-215 (Salt Lake City)	Fixed/ 2 miles	Fog	4 Forward Scatter Visibility Sensors	6 Loop Detectors	2 DMSs	Ultra-High Frequency Radio Modems			$461,000
Vermont	Fixed/ 2 miles	Fog	Highway Patrol	None	Fixed Signs with Flashing Lights	None	Power Lines	Remote Dispatch	Unknown
Wisconsin/ I-43 and US 41 (Green Bay area)	Fixed/ 2 locations	Fog	Manual	None	Static Signs with Flashing Lights	Dial-up Phone	Power Lines	Manual	Unknown
Wyoming	Fixed/ Unknown	Fog and Adverse Weather	Highway Patrol	Unknown	VSL	None		Manual	Unknown

2.2. Visibility Detection Systems in Europe and other Countries

England: M25 London Automatic Fog-Warning System

In 1990, an automatic FWS was designed by Traffic Control and Communications Division of the Department of Transport, London. This system was installed on the M25 London orbital motorway to warn drivers about formation of fog by displaying “Fog” legend on roadside matrix signals.

Transport Research Laboratory (TRL), United Kingdom, evaluated the effectiveness of the system in reducing the variation in vehicles’ speeds during inclement visibility conditions due to fog. The results indicated that there was about a 1.8 mph reduction in mean vehicle speeds when the signals were switched on based on data measured from 6 test sites.

The speed reductions indicated that drivers are alerted to the presence of fog ahead together with a credible automatic system means that drivers are more likely to respond more quickly to the hazard itself. In addition, operational benefits would be expected to accrue to the police. Control office staffs were notified of the presence of fog, but were relieved of the difficult task of operating motorway signals in response to fog whose density and location is likely to be continuously changing (Cooper and Sawyer, 1993; MacCarley, 1999).

Austria: A1 West Motorway Advanced Traffic Management System

The Austrian Motorway Administration (ASFINAG) is considered one of the leading agencies to equip a large portion of their motorway network with an advanced traffic management system (Intelligent Line Control System) that combines variable speed limits for congestion, incident detection and warning system, and weather information (i.e. black ice, fog, etc.). Moreover, in order to prevent mass pileups as a result of quickly developed thick fog, a pilot fog warning system was installed on the A1 West motorway in the area around the Upper Austrian lakes. Five visibility sensors were installed in each direction on a 6.2-mile section (one sensor every 0.62 mile). In addition to the variable speed limits based on visibility levels, a further measure to reduce fog-related crashes was the introduction of fog reflectors. The fog-prone roadway sections were equipped with fog reflectors to delineate the roadway edges for better visibility. These sections were selected by motorway organizations, meteorologists, and operating personnel. The system was proven to reduce 19% of injuries and up to 25% of fatal crashes.

Netherlands: A16 Automatic Fog-Signaling System

The Dutch Ministry of Transport implemented an automatic FWS to elicit safer driving behavior during adverse visibility conditions along 12-km (7.4 mile) section of the A16 Motorway in the Netherlands. The system consists of 20 visibility sensors to continuously measure the visibility range. This system warns drivers of reduced visibility due to fog by displaying an explicit fog warning on overhead matrix signs, together with a maximum speed limit that depends on the actual measured visibility distance.

Hogema and Horst (1997) evaluated the Dutch FWS in terms of driving behavior for a period of more than 2 years after implementing the system. Using inductive loop detectors at six locations (four experimental and two control locations), continuous traffic measurements for individual vehicles were obtained. Data on the local visibility conditions and on the messages displayed on the matrix signs were available on a 1-min basis.

The results showed that the system had a positive effect on speed choice in fog as it resulted in an additional decrease of speed of about 8 to 10 kph (Hogema and Horst, 1997).

For A16 in the Netherlands, the displayed speed limits are based on the visibility conditions captured by 20 visibility sensors along the road. If the visibility drops below 140 m (456 ft), then the speed limit will drop to 80 km/h (49 mph). If visibility drops below 70 m (228 ft), the speed limit will be dropped to 60 km/h (37 mph). Besides, if an incident is detected, 50 km/h (31 mph) on the first sign upstream and 70 km/h (43 mph) on second sign upstream will be displayed.

Studies in Finland

Finland's VSL algorithm is a discrete simple one; it only depends on the road conditions. Displayed speed limits can be 120 km/h (74 mph) for good road conditions, 100 km/h (62 mph) for moderate road conditions or 80 km/h (49 mph) for poor road conditions.

Saudi Arabia:

Saudi Arabia has installed a low visibility warning system on a 2-km section of a two-lane, rural highway in the Al-Baha region. The system consisted of a visibility sensor, a point detection device that utilizes infrared technology to measure visibility, and a DMS. In addition, NC-97, an advanced traffic counter classifier, was used to measure traffic data (i.e., speed, headway, vehicle classification, and volume). Only one message was used during the project and the DMS was activated once the sensor detects a reduction in visibility less than 200 m. The main result from this study indicated the system was ineffective in reducing speed variability.

However, the system reduced mean speed throughout the experimental sections by about 6.5 kph (Al-Ghamdi, 2004).

2.3. Aviation Visibility Detection Systems

In modern aviation, visibility detection is core to the management and operation of the airports. Automated airport weather stations are prevalent in the United States and Canada. They are automated sensor suites which are designed to serve aviation and meteorological observing needs for safe and efficient aviation operations and weather forecasting. Three major automated weather detection systems are in application, namely are the Automated Weather Observing System (AWOS), Automated Surface Observing System (ASOS), and Automated Weather Sensor System (AWSS). All of these three systems are equipped with forward scatter visibility sensors to provide visibility information. The principle for visibility measurement behind the sensors is determining the amount of light scattered by particles in the air that passes through the optical sample volume. Considering the different operational agencies of these systems and the corresponding weather report format, the visibility output can be slightly different.

2.3.1. Automated Weather Observing System (AWOS)

The Automated Weather Observing System (AWOS) (as shown in Figure 2-15) units are operated and controlled by the Federal Aviation Administration (FAA) in the United States, as well as by state and local governments and some private agencies. The American National Weather Service (NWS) and Department of Defense (DOD) play no role in their operation or deployment.

Visibility in AWOS is a ten-minute average calculated each minute from sensor readings taken at ten-second intervals. Visibility is measured by the forward scatter visibility sensor

(Figure 2-14), and is reported in statute miles (sm). The sensor also performs self-checks of communications, window condition, and a number of operational functions, and reports any errors in its status word(s).

The precision of visibility detection depends on how many heads that a sensor has, the more heads the more accurate.

Figure 2-14: Forward Scatter Visibility Sensor

The reported visibility values are from <1/4 mile up to 10 miles. If a present weather sensor and a visibility sensor are installed and reporting properly, the following (Table 2-12) will be reported when the present weather sensor is reporting "No Precipitation":

Table 2-12: Reported Weather Condition by AWOS

Reported Weather Condition	Individual Weather Parameters
Haze	Visibility < 7 sm and dew point depression > 4°F
Mist	Visibility > 1/2 sm and <7 sm, and dew point depression −4°F, and temperature > 32°F
Freezing Fog	Visibility < 1/2 sm, dew point depression −4°F, and temperature −32 °F

Six standard categories of AWOSs have been developed since its first introduction:

AWOS I: wind speed and direction in knots, wind gust, variable wind direction, temperature, dew point in degrees Celsius, altimeter setting, density altitude.

AWOS II: AWOS I + visibility, and variable visibility.

AWOS III: AWOS II + sky condition, and cloud coverage and ceiling up to twelve thousand feet.

AWOS III-P: AWOS III + present weather, and precipitation identification.

AWOS III-T: AWOS III + thunderstorm and lightning detection.

AWOS III-P-T: AWOS III + present weather, and lightning detection.

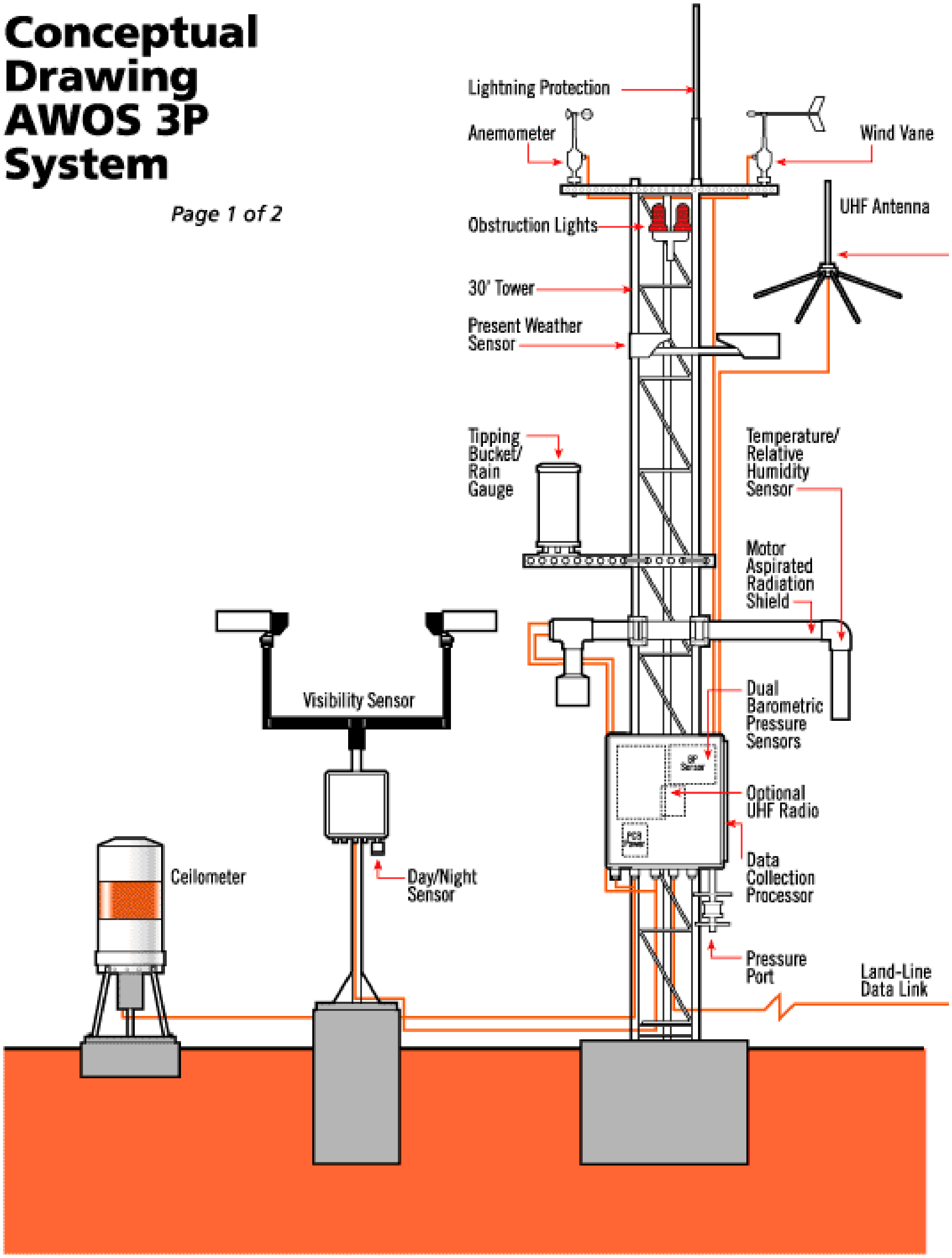

Figure 2-15: Configuration of AWOS System

The output of the AWOS weather observation is controlled by one of four modes of operation. Mode 1 is applicable to all systems; modes 2, 3, and 4 are applicable only to systems configured with an operator terminal. Modes 3 and 4 require an agreement with the NWS to maintain a Non-Federal Observer program to augment and back up the AWOS system.

Mode 1 – Full-time Automated Operation. In this mode the AWOS operates 24 hours/day without any manual input. The automated weather observations are updated on a minute-by-minute basis. There is no weather observer input to the AWOS.

Mode 2 – Full-time Automated Operation with Local Notice to Airmen (NOTAM). Operation in this mode is the same as Mode 1, with the addition of the capability to append a manually recorded NOTAM to the automated voice reports. The voice synthesizer system is installed in the PC together with a microphone that allows input of two voice remarks, each up to 90 seconds in duration. These NOTAM messages are automatically broadcast with the synthesized data from the AWOS.

Mode 3 – Full-time Automated Operation with Manual Weather Augmentation and Local NOTAM Option. Operation in this mode provides the capability for a weather observer to manually augment the automated observation by appending a weather entry to the observation during the weather observer duty hours.

Mode 4 – Part-time Manual Operation. This mode is normally used for backup. It permits a weather observer to enter a complete manual observation into the system.

2.3.2. Automated Surface Observing System (ASOS)

The Automated Surface Observing System (ASOS) (as shown in Figure 2-16) units are operated and controlled cooperatively in the United States by the NWS, FAA and DOD. After many years of research and development, the deployment of ASOS units began in 1991 and was completed in 2004. A basic strength of ASOS is that critical aviation weather parameters are measured where they are needed most: airport runway touchdown zone(s).

Figure 2-16: Automated Surface Observing System (ASOS)

The primary function of the ASOS is to provide minute-by-minute observations and generate the basic Aviation Routine Weather Report (METAR) and Aviation Selected Special Weather (SPECI) report.

The ASOS will automatically report the following surface weather elements in the METAR:

- Wind: Direction (tens of degrees - true), Speed(knots), and Character (gusts)
- Visibility up to and including 10 statute miles

- Runway Visual Range (RVR) at selected sites
- Basic Present Weather Information (type and intensity): Rain, Snow, Freezing Rain, Squalls
- Obstructions: Fog, Mist, Haze, and Freezing Fog
- Sky Condition: Cloud height and amount up to 12,000 ft above ground level; amount is characterized in METAR reports as clear (CLR), few clouds (FEW), scattered clouds (SC), broken clouds (BKN), and overcast (OVC
- Ambient Temperature, Dew Point Temperature (degrees Celsius)
- Pressure: Altimeter Setting in inches of mercury (Hg), and Sea-level Pressure (SLP) in Hectopascals (hPa) in Remarks
- Automated, Manual, and Plain Language Remarks (depending on service level) including: Volcanic Eruption (plain language), Tornadic Activity (plain language), Wind Shift, Tower Visibility, Beginning and Ending of Precipitation, Virga (plain language), Significant Cloud Types (plain language), SLP, and Other Significant (Plain Language) Information
- Additive and Automated Maintenance Data including: 3, 6, 24-hour Precipitation Amount, Hourly Temperature and Dew Point, 6-hour Maximum and Minimum Temperatures, 3-hour Pressure Tendency, various sensor status indicators, and maintenance check indicator ($).

The range of visibility recorded is up to and including 10 statute miles. The visibility derived is not measured directly but is inferred by measuring other physical characteristics and properties of the air.

Visibility in METAR is reported in statute miles (sm). The reportable increments are: M1/4 sm (less than ¼ sm), ¼ sm, ½ sm, ¾ sm, 1 sm, 1¼ sm, 1½ sm, 1¾ sm, 2 sm, 2½ sm, 3 sm, 4 sm, 5 sm, 6 sm, 7 sm, 8 sm, 9 sm and 10 sm.

Note that visibilities between zero and less than 1/4 mile are reported as M1/4 sm. Measured visibilities exactly half way between reportable values are rounded down. Visibilities of 10 miles or greater are reported as "10 sm."

Main advantages of the visibility sensor is its location at the touchdown zone of the primary instrument runway where it provides a precise visibility value appropriate for that location. Another strength of the sensor is consistency of observations. Variations introduced by human observers from such limitations as perspective, sun angle, day and night and night differences and poor locations are eliminated.

2.3.3. Automated Weather Sensor System (AWSS)

As with the AWOS, the Automated Weather Sensor System (AWSS) (as shown in Figure 2-17) units are operated and controlled by the FAA in the United States; the NWS and DOD play no role in their operation or deployment.

Figure 2-17: Automated Weather Sensor System (AWSS)

The AWSS is a modular system, designed to automatically collect, process, disseminate, and archive weather sensor measurement data. Ten individual weather parameters are recorded.

The individual weather parameter data monitored and processed consist of:

- Sky Condition
- Cloud Height
- Visibility
- Present weather type and intensity
- Obscurations
- Pressure (altimeter, station, density altitude, pressure altitude and sea level)
- Temperature, relative humidity, and dew point
- Wind (speed, direction, gust character, and variability)
- Precipitation amount
- Freezing rain (Optional)

The visibility sensor must provide an extinction coefficient equivalent to up to at least 10 miles. Forward scatter visibility sensor is still used in AWSS. The reportable increments of visibility must be (in statute miles): <¼, ¼, ½, ¾, 1, 1¼, 1½, 1¾, 2, 2 ½, 3, 4, 5, 7, and 10.

2.3.4. System Cost

The cost of these systems is not fixed. It varies based on the scale and requirement of the system. Examination of some existing programs can give an impression on the cost of these systems. The FAA AWSS for 17 airports costs $4.3 million. State of Alaska AWSS provides 24 AWSS systems in Alaska and costs $3.0 million. The State of Texas ordered 11 domestic AWOS systems by $0.8 million. The FAA ACE-IDS program distributed ASOS (All Weather Inc., formerly Systems Management Inc.) to over 800 air traffic positions at a cost of $33 million. (Allweather Inc.).

2.4. <u>Summary of Existing Fog Warning Systems</u>

Reviewing the existing visibility warning systems revealed that they have many limitations. First, most of these systems were designed specifically for one road location (fixed systems); thus it is not possible to reinstall them in other locations. Second, they are not cost-effective in terms of system's components, management, and maintenance. Finally, most of them depend on AC power supply and fiber optic cable for internal communication; thus, they are not suitable in the absence of AC power. The only portable visibility detection and portable system that is consisted from components that are inexpensive and available commercially was developed at University of Central Florida for FDOT. Another advantage is that the system can be powered using car batteries instead of AC power.

2.5. <u>Researches on Camera-Based Visibility Detection</u>

2.5.1. Introduction

While traditional visibility detection techniques are now prevailing at airports and weather stations operated by meteorological agencies. They can handle the visibility at night, in fog, smoke, glare and other weather conditions. Generally speaking, the optical visibility detection methods have been in existence for a long time, the technique proven in real application field. Nevertheless, the cost of optical transmission and scattering equipment is expensive. Recent years also see a trend in researches exploring the potential of utilizing the cameras as alternative visibility detection tools. Roadside cameras have acted as a critical component in the ITS for a long time and their number still growing. According to Hallowell et al.'s (2007) research, there are over 10,000 cameras continuously monitoring major roadways in the U.S. only by considering State DOT and TMC camera assets. In-vehicle cameras, though not common currently, appeal to researchers due to their superior mobility. Both the ready roadside and the promising in-vehicle cameras, if utilized for visibility detection, can have a major impact on the traffic safety at marginal cost.

2.5.2. Camera-Based Visibility Detection

The basic issue with camera-based visibility detection is that images compress the road and environmental information from a 3-D space to a two dimensional space. As a result, the depth of object in the image is unavailable. Current researches mostly employ image processing technique and concentrate on algorithms to determine the visibility distance.

1. **Image Processing**

Without information about the depth of object, images obtained by cameras have to be processed first for visibility detection algorithms. When judging whether an object is visible or not, researchers need to compare the contrast of the target with a reference value used as threshold (normally 5% is defined as the threshold value). Most of the existing researches will conduct edge detection on the images to keep the necessary information (road and shoulder boundaries, lane markings, etc.) for visibility distance calculation. Wavelet transform algorithm (Busch and Debes, 1998), Sobel edge detection algorithm (Kwon, 1998; Hallowell et al., 2007; Bäumer et al., 2008; Chen et al., 2009; Babari et al., 2011; Babari et al., 2012), Canny edge detection algorithm (Hautière et al., 2006b; An et al., 2010) are frequently used. From An et al.'s (2010) test results they concluded that Canny algorithm retains more image details closer to the truth, and can effectively extract the edge than the Sobel algorithm.

The edge detection algorithms mentioned above are commonly adopted in researches where cameras are installed at fixed location along roadside or over travel lanes. For studies investigating into the onboard cameras, because of the always-changing background, researchers raised a variety of methods to get the depth information. Hautière et al. (2006a) employed "v-disparity" approach to extract the three-dimensional (3-D) road surface in their research. Boussard et al.'s (2008) used only one in-vehicle camera; however, they aligned two successive images with the knowledge of the motion of the camera to construct a pseudo-depth map. Kidono and Ninomiya (2007) instead of creating a 3-D map, they used a multiband onboard camera which could obtain a visible monochrome image and infrared image simultaneously. The principle lies in the difference between wavelength bands. In Pomerleau's (1997) research, his system named RALPH (Rapidly Adapting Lateral Position Handler) used the algorithm to find road features based on the observation that when viewed from above, a road resembles a ribbon of parallel bands formed by lane markings and other road features.

2. Visibility Distance Algorithm

Visibility distance algorithms do not vary due to the camera location. Two general approaches to measure meteorological visibility with a camera are prevalent based on recent studies: the first is to detect a selected object at the maximum distance based on the definition of visibility; the second method correlates the contrast in the scene with the visual range estimated by reference additional sensors, and a learning phase is necessary (Babari et al., 2011). Below (Table 2-13) are some representative studies conducted.

Table 2-13: Visibility Distance Algorithm Classification

Type1: Based on maximum distance at which a selected target can be detected	China: Chen et al., 2009; An et al., 2010; France: Hautière et al., 2006a; Hautière et al., 2006b; Boussard et al., 2008; Hautière et al., 2008; Germany: Busch and Debes, 1998; Bäumer et al., 2008; Japan: Kidono and Ninomiya, 2007; U.S.: Pomerleau, 1997; Kwon, 1998.
Type2: Based on additional sensors and learning phase	France: Babari et al., 2011; Babari et al., 2012; Japan: Hagiwara et al., 2006; U.S.: Hallowell et al., 2007; Xie et al., 2008.

If meteorological visibility measurement is based on the definition of visibility (in Type 1 researches), then visibility detection algorithms are most likely to be based on the classical Koschmieder equation or Duntley's attenuation law of atmospheric contrasts derived from Koschmieder's equation (Busch and Debes, 1998; Hautière et al., 2006a; Hautière et al., 2006b; Bäumer et al., 2008; Hautière et al., 2008; Chen et al., 2009; An et al., 2010). Yet some researchers (Pomerleau, 1997; Kwon, 1998; Kidono and Ninomiya, 2007) still developed and verified their own visibility algorithms. In all, Koschmieder's equation or Duntley's equation are still the most popular principles on which visibility algorithms built in Type 1 studies.

With the development of machine learning techniques, we see some research findings which incorporate a learning phase in their visibility detection methods. In addition, other sensors served as reference are also essential (Type 2 researches). Hallowell et al. (2007) used visibility data from ASOS as the reference and utilized fuzzy logic integration in his algorithm. The test showed an overall satisfying performance of this method. Babari et al. (2011, 2012) in their two papers applied a model-driven approach, and a robust gradient-based approach respectively. In both of these two papers, Koschmieder's model were selected as reference.

3. Issues with Visibility Detection

While developing detection techniques and algorithms, researchers also paid attention to the weather factors causing the reduction of visibility. Many of the current studies explored the visibility detection in fog, at night time, or in glare.

The presence of fog makes it hard to detect the edges in camera images. The topic of fog detection has been covered in most of current studies. Among these researchers, the majority focuses on visibility detection with daytime fog and they achieved decent accuracy in visibility distance detection.

Night visibility detection is rather different. According to Kwon (1998), for night time a constant light source is required to evaluate visibility; also passing vehicles at night can distort the illumination of test targets. Thus making night visibility detection really sensitive to interference. Bearing the problems in mind, researchers still come up with some solutions. Kwon developed a new diffusion model that could effectively fitted into an image with a constant light source. Kidono and Ninomiya (2007) used multiband camera, deriving both visible monochrome image and infrared image, and detected visibility distance based on the wavelength bands.

The issue of glare is omitted in a lot of researches. From the available studies addressing this problem, the source of glare can be the sun or the headlights of vehicles. Bäumer et al. (2008) reasoned that the elevation of the sun would have direct effect on the visibility detection, since the aperture automatically decreased when the camera looked towards the sun. Pomerleau (1997) tested six different weather conditions, and he found that the lowest estimated visibility of these tested was in the early morning glare condition. Kwon (1998) suggested to deal with the glaring issue, cameras selected for taking images should have the back light compensation feature. An automatic back light compensation function was desirable to minimize the drastic contrast drop at the objects when the camera was against sunlight.

2.5.3. Conclusion on Camera-Based Visibility Detection Technique

Existing studies nowadays stress the development of visibility detection methods in different type adverse weather conditions. Image processing technique and visibility distance algorithm are the focus points. Daytime fog visibility have been investigated recurrently and researchers claim that relatively good detection accuracy can be achieved. However, researches about night visibility, glare and some are weather types are still inadequate or have not yet gained enough attention. For visibility distance measurement, most algorithms are developed based on the concept of visibility. With the introduction of machine learning techniques, we will surely see more novel algorithms developed in future.

3. ANALYSIS OF FOG/SMOKE RELATED CRASHES IN FLORIDA

3.1. Introduction

In terms of crash frequencies in the three major inclement weather events, i.e. rain, snow and Fog/Smoke (FS), there are revealing statistics (Table 3-1) that show the fatal crashes in these weather conditions. Table 3-1 shows that while snow weather, as a contributing factor for 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 U.S., such as Texas, California, and Florida.

Table 3-1: Incremental Weather-Related Fatal Crashes in United States (2001-2010)

	Rain		Snow		Fog/Smoke	
Rank	State	Fatal crashes	State	Fatal crashes	State	Fatal crashes

1	Texas	2236	Michigan	646	Texas	428
2	Florida	1726	Pennsylvania	500	California	424
3	California	1597	New York	430	Florida	326
4	Pennsylvania	1263	Ohio	384	North Carolina	194
5	North Carolina	1243	Illinois	327	Pennsylvania	181
Mean*		363		115		84
S.D.*		344		137		94
Total*		14520		5851		4265

Data queried from Fatality Analysis Reporting System (FARS)

* statistics for all 50 states and District of Columbia

The literature reviewed suggests that even though quite an amount of researches 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 3-1, Florida is among the top states in the United States in terms of FS related fatal crashes. This chapter presents a comprehensive analysis of FS crashes in Florida. In particular, the method and major results arising from three specific analyses in this chapter are presented as follows:

(1) Crash characteristics analysis examines the characteristics of FS crashes in comparison with crashes occurring at non vision obstruction conditions. Issues investigated include temporal distribution, crash types, and effects of various geometric, traffic 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 could be proposed for proactive actions to reduce the risk of severe crashes at the FS crash prone locations.

3.2. Fog- and smoke-related Crashes in Florida

To achieve the above mentioned objectives, all on-state and off-state roads in Florida were taken into account (34,432 miles in total). All crashes on these roads were extracted from the Crash Analysis and Reporting (CAR) system database maintained by the FDOT. Crash data on all roadways in Florida from years 2005 to 2010 were investigated. There were 1,492,446 crashes occurred without any vision obstructions. Among them, 2,078 crashes were fog-related and 278 crashes were smoke-related crashes.

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 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.).

3.3. Crash Characteristics Analysis

This section provides a detailed examination of the characteristics of FS crashes, which include temporal distribution, effects of influential factors, injury severity and collision types.

3.3.1. Temporal Distribution

Visibility obstruction due to FS prevails based on weather conditions. Therefore in the absence of detailed meteorology statistics, it is worthwhile to look at the temporal distribution of FS crashes for the daily and seasonable variations on the prevalence of vision obstruction by fog or smoke. As seen from Figure 3-1, it is evident that at the early hours of dawn and subsequent hours where fog is prominent, from 5am to 8am in particular, the number of crashes due to fog is on the higher side while crashes due to smoke do not occur at specific time period (Figure 3-2). The curves for Clear Vision (CV) crashes have also been given. Moreover, by the monthly variations of these crashes, the duration from December to February looks to have a high number of fog crashes (Figure 3-3). In contrast, May seems to have the highest number of smoke crashes and it is thought that the dry season prevails at that time of the year increasing the likelihood of wildfires or the propagation of fire (Figure 3-4).

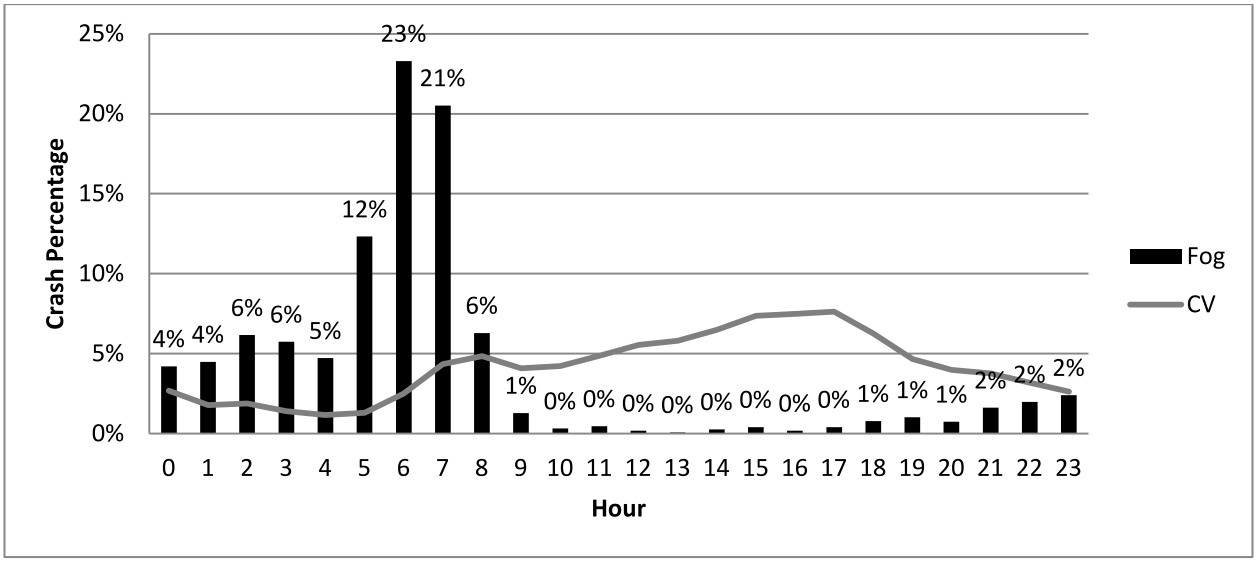

Figure 3-1: Hourly Distribution of Fog-Related Crashes

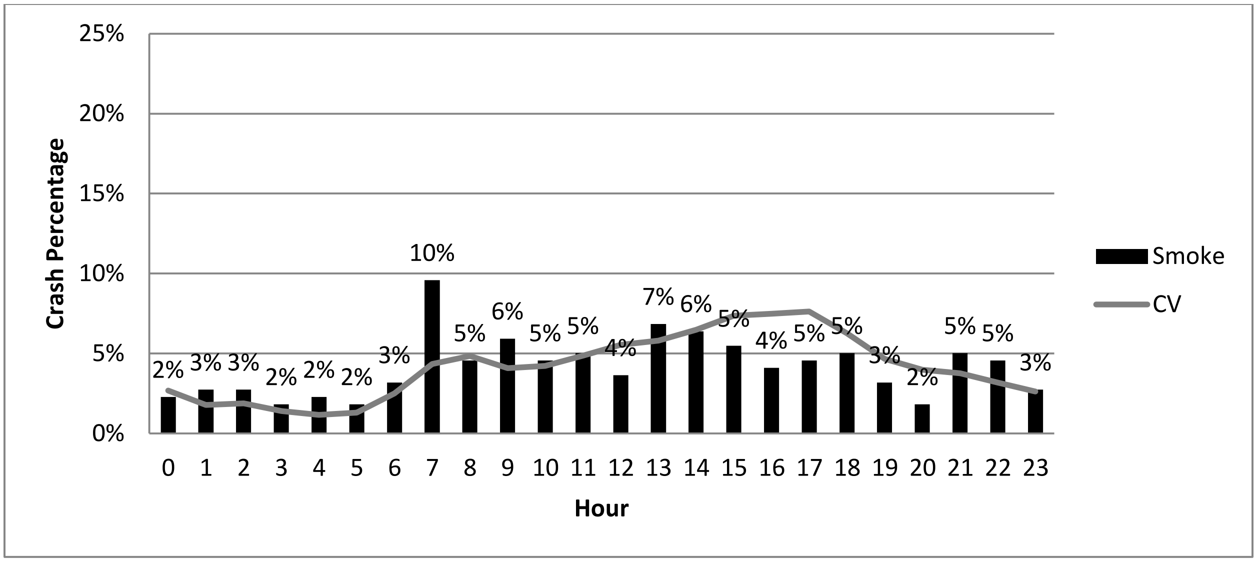

Figure 3-2: Hourly Distribution of Smoke-Related Crashes

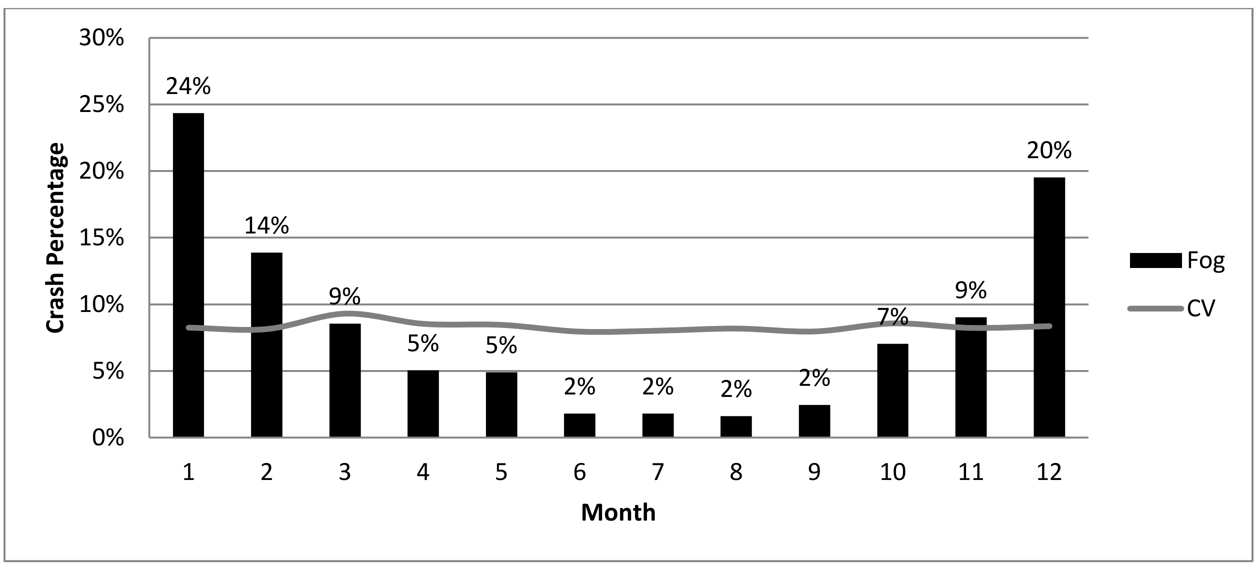

Figure 3-3: Monthly Distribution of Fog-Related Crashes

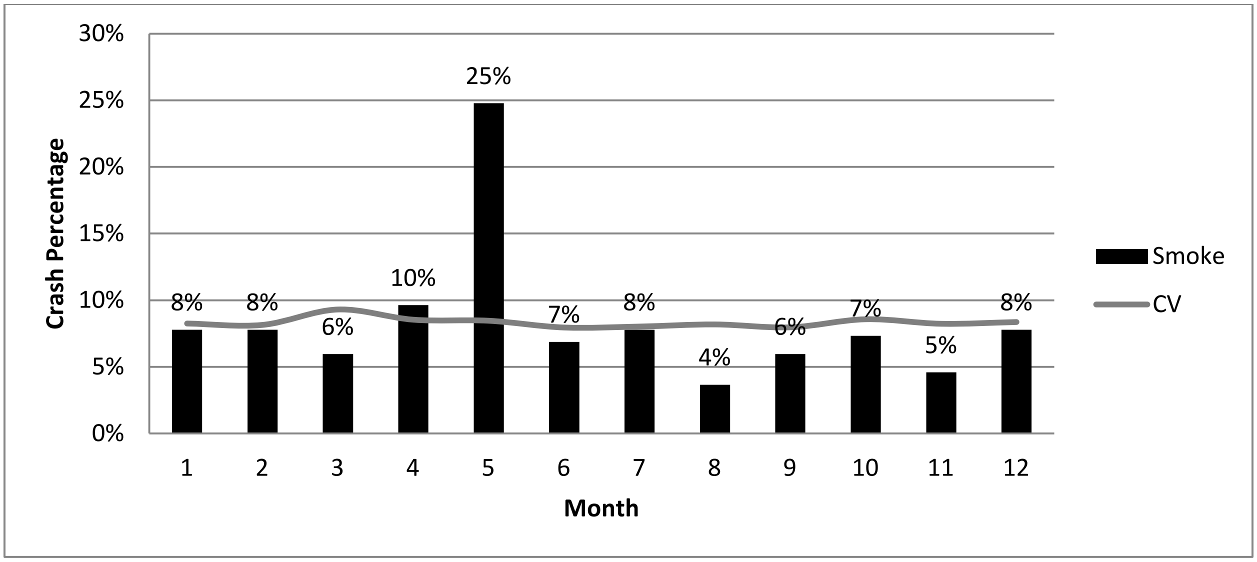

Figure 3-4: Monthly Distribution of Smoke-Related Crashes

3.3.2. Contributing Factors

Different factors (roadway, driver, and environmental factors) may have direct or indirect effect on the occurrence of fog- and smoke-related crashes. These factors, when compared to the CV crashes, would give an idea about the significant factors that affect the fog crashes in particular. Figure 3-5 shows the effects of different factors on fog crashes compared to CV crashes.

Focusing only on the important aspects of the contributing factors, there are some interesting findings from these observations. At posted speeds 55mph and higher, there are a high number of fog crashes that are observed compared to those associated with CV conditions. Lighting condition adversely affects the fog crashes, as suggested from Figure 3-5 that at dawn and dark (night) with no street light the frequencies (17.8% and 36.1% of the total fog crashes, respectively) are pretty high in foggy conditions, compared to CV conditions, where out of all CV crashes only 1.3% took place at dawn and 7.1% at dark (with no street light). It again confirms the findings observed from Figure 3-5 and is consistent with conclusions in Wanvik (2009).

As shown in Figure 3-5, fog is very much prevalent in rural areas ($p < 0.001$), confirmed by the fact that 52% of fog crashes happened in rural areas compared to only 15% of CV crashes there. Looking at the roadway characteristics, 59% of fog crashes occurred on divided roadways to 45% of CV crashes ($p < 0.001$). Furthermore, fog crashes occurs less frequently at intersection or at influenced by intersection, 47% of CV crashes occurred, compared to 39% of fog crashes ($p < 0.001$).

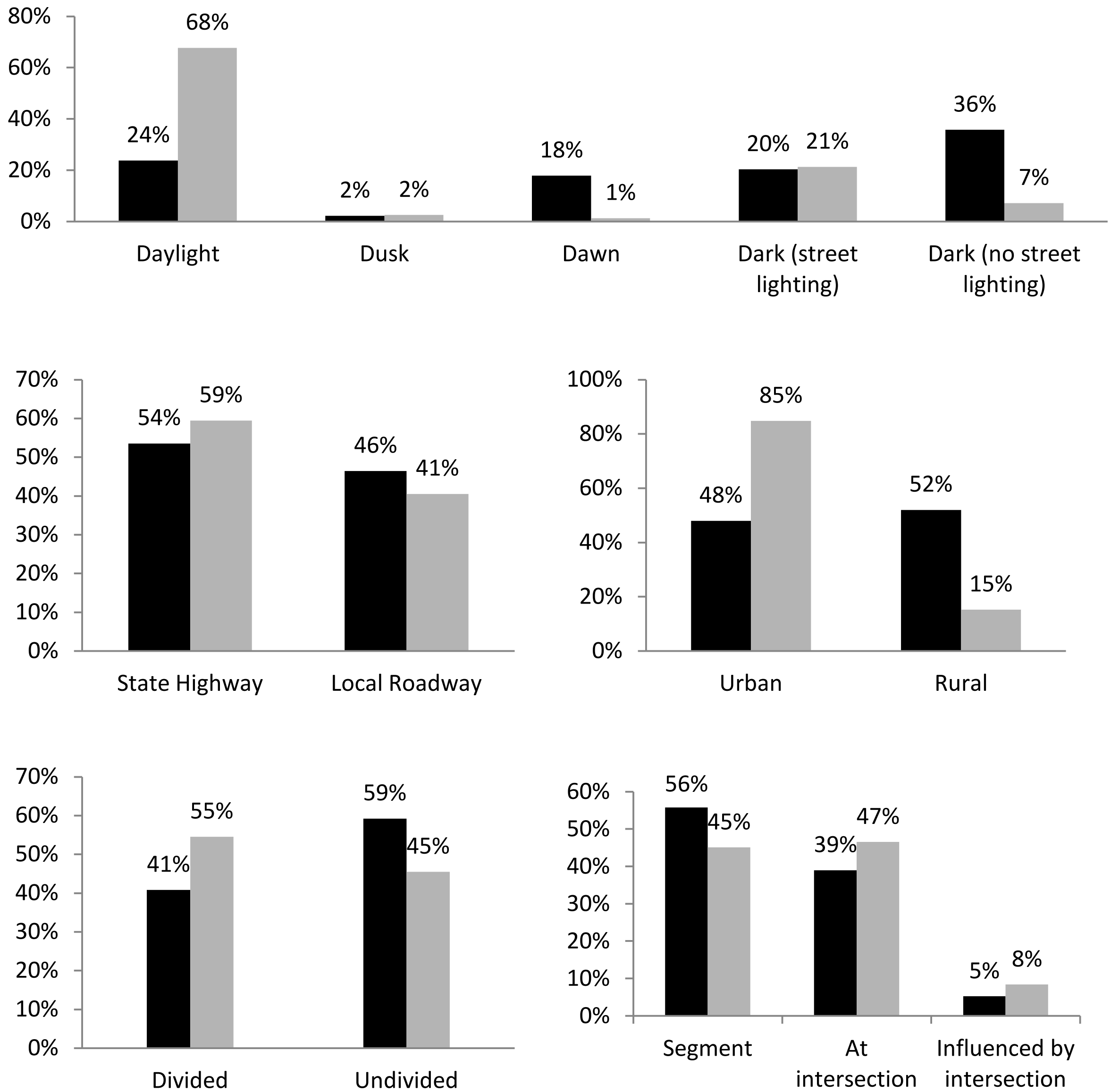

Figure 3-5: Comparison of the Effects of Contributing Factors on Fog Crashes and Clear-Visibility Crashes in Florida (2005 - 2010) (Black bar: % of Fog crashes; Gray bar: % of clear-visibility crashes)

As to smoke related crashes, it was found that lighting condition also affects the smoke crashes ($p < 0.001$) as suggested in Figure 3-6. The figure 3-5 shows that smoke crashes on the local roadway are less commonly observed compared to those associated with CV conditions, however, it was not statistically significant ($p = 0.093$). As shown in Figure 3-6, smoke is also prevalent like fog in rural areas ($p < 0.001$), confirmed by the fact that 51% of smoke related crashes occurred in rural areas compared to only 15% of CV crashes there.

Concerning the roadway characteristics, no association from the divided/undivided highway section was found between smoke crashes and CV crashes ($p = 0.250$). Lastly, smoke crashes occurs less frequently at intersection or at influenced by intersection, 25% of CV crashes occurred, compared to 47% of fog crashes ($p < 0.001$).

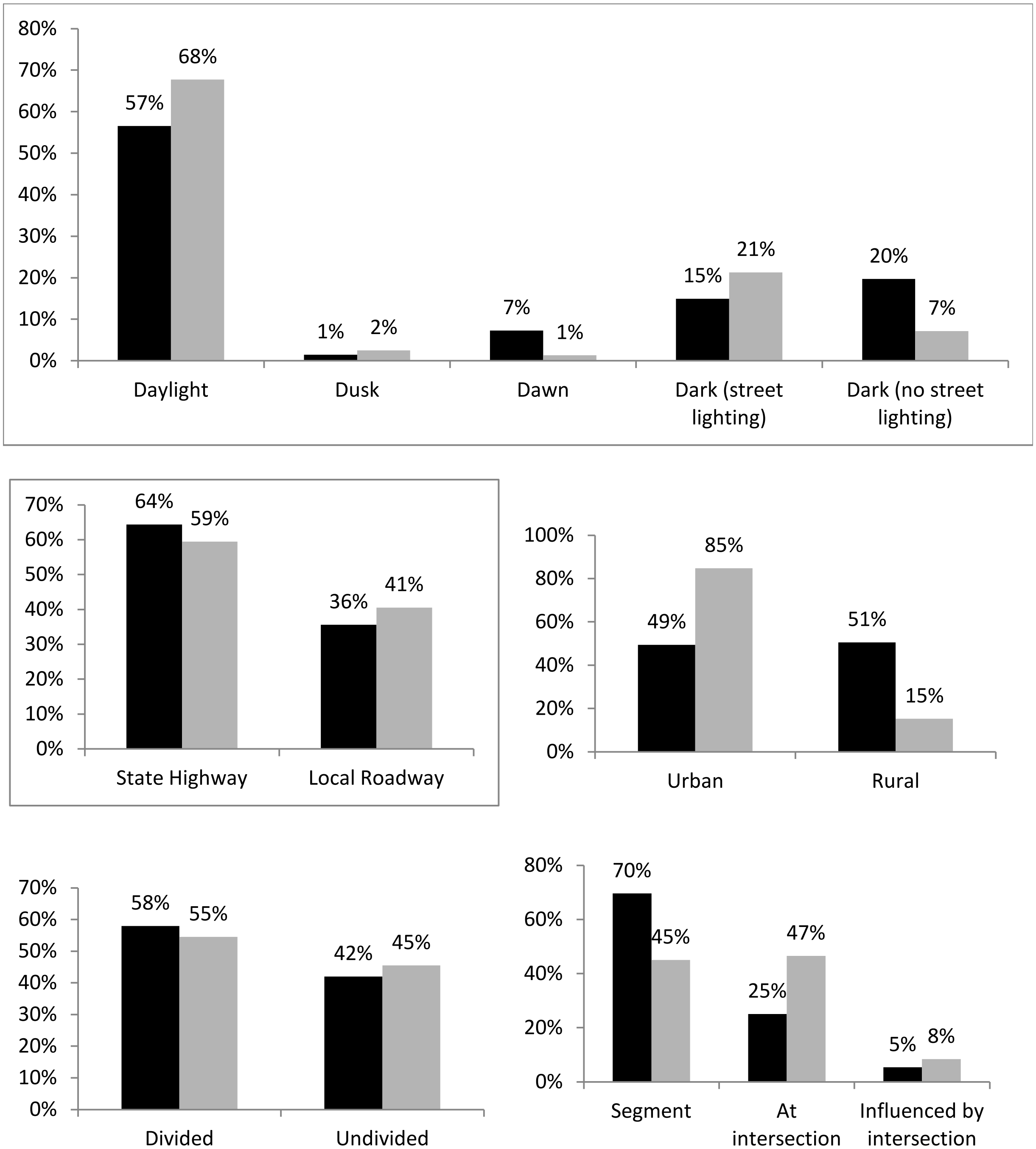

Figure 3-6: Comparison of the Effects of Contributing Factors on Smoke Crashes and Clear-Visibility Crashes in Florida (2005 - 2010) (Black bar: % of Smoke crashes; Gray bar: % of clear-visibility crashes)

3.3.3. Injury Severity and Collision Type

In order to gain a better understanding of the FS crashes in comparison with CV crashes, it is necessary to delve into more specific analyses. Injury severity of a traffic crash is a key issue. 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, "none injury", "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. The crash databases record 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 include rear-end, head-on, angle, left turn and sideswipe. The investigation is also done for multiple vehicle crashes, i.e., more than two vehicles involved.

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 the equation as follows,

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

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 3-7 and Figure 3-8.

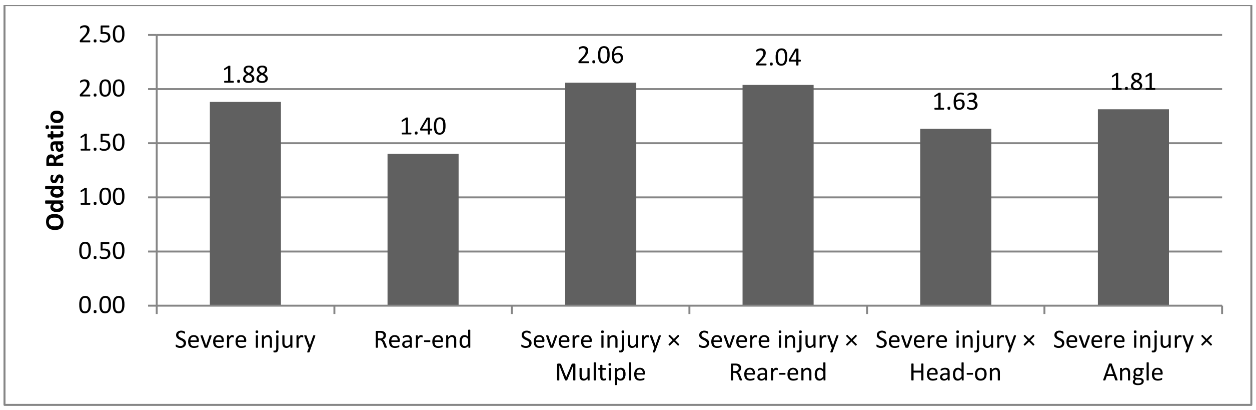

Figure 3-7: Odds Ratios of Severe Crash, Collision Types, and their Interactions in Fog Conditions to CV Conditions in Florida (2003-2010)

It is quite revealing that compared to CV conditions, fog crashes poses a deadly threat in terms of crash severity. The elevated odds are as high as 1.88 times. Moreover, a higher probability (O.R. = 1.40) of a rear-end crash is found to be associated with foggy conditions.

As suggested by the interaction effects, given a multivehicle, rear-end head-on or angle crash happening in foggy conditions, there is a significantly higher probability to result in severe injuries in contrast with other types of crash. It implies that the efforts to reduce injury severity of fog crashes will be more effective by focusing on the reduction of head-on, rear-end, angle and multiple vehicle crashes.

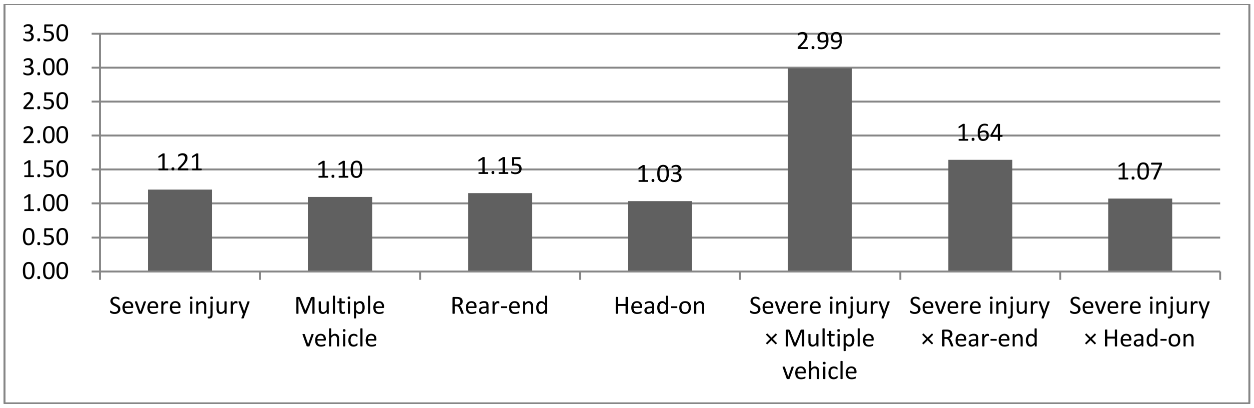

Figure 3-8: Odds Ratios of Severe Crash, Collision Types and their Interactions in Smoke Conditions to CV Conditions in Florida (2003-2010)

With respect to smoke crashes, a higher probability of a severe injury, multiple vehicle, rear-end and head-on crash are found to be associated with smoke conditions. As indicated in previous studies (Codling 1971 and Summer et al. 1977), pileup crashes can be a dominant type during adverse weather conditions due to the reduced visibility. Regarding the collision types, the likelihoods of rear-end and head-on collision types investigated are higher in smoke conditions than that in CV conditions.

As presented by the interaction effects, given a head-on, rear-end or multivehicle crash happening in smoky conditions, there is a significantly higher probability to result in severe injuries compared to other types of crash.

Notably, the highest odds are associated with head-on severe crash (O.R. = 2.99). This result is very interesting as we also found a substantial increased proportion of smoke crashes on undivided roadways compared to CV crashes as discussed previously (26.3% to 10.3%). The crashes between vehicles from opposite traffic at undivided roads tend to be head-on collisions and causes severe injuries.

3.4. Conclusions

Florida is among the top states in the United States for traffic safety problems resulting from reduced visibility conditions due to fog and smoke. Using eight-year crash data records, a comprehensive study of FS related crashes in Florida was developed. 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, efforts have been made to comprehensively 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, 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 is 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.

4. UPDATE THE STATEWIDE MAP WITH INCREASED GRANULARITY

4.1. Data Collection and Preparation

In order to conduct hotspot identification and priority area identification analysis, fog/smoke related crashes in 2005-2010 were collected from Crash Analysis Reporting (CAR) system of Florida Department of Transportation (FDOT). It is very difficult to locate FS hotspots on local roads since they do not have Roadway ID. Only FS crashes that have occurred on the state highway system including interstate highways, US routes and state roads were gathered for the analysis. Overall 1,634 FS crashes were prepared, among them 1,411 crashes were only fog-related, 155 crashes were only smoke related and 68 crashes were due to both fog and smoke. They are summarized by each year in Table 4-1.

Table 4-1: Number of FS Crashes on the State Highway System in Florida (2003-2010)

Year	Number of crashes			
	Fog only	Smoke only	Both fog and smoke	Total
2003	170	21	3	194
2004	172	18	2	192
2005	207	7	4	218
2006	211	23	19	253
2007	213	53	13	279
2008	165	14	17	196
2009	191	4	8	203
2010	82	15	2	99
Total	**1,411 (86.35%)**	**155 (9.49%)**	**68 (4.16%)**	**1,634 (100%)**

4.2. Hotspot Identification Analysis

The first step of investigating the FS crashes is to examine the spatial distribution and as such the crash hotspots could be identified and focused on for further safety treatments. The statewide map with frequent FS crash clusters was also presented for better visualization and understanding of the spatial distribution of FS crashes. Each cluster was zoomed in for microscopically investigating the roadway segments with frequent FS crashes.

4.2.1. Macroscopic Analysis

First of all, priority areas with frequent FS crashes for treatment were identified in macroscopic analysis. The Kernel Density Estimation (KDE, see Chainey and Ratcliffe 2005) was used to serve the purpose of clustering the crashes and identifying the hotspots. The KDE defines the spread of risk as an area around a defined cluster in which there is an increased likelihood of a crash to occur based on spatial dependency. It places a symmetrical surface over each point and then evaluates the distance from the point to a reference location based on a mathematical function and then sums the value for all the surfaces for that reference location. This procedure is repeated for successive points, which allows us to place a kernel over each observation, and summing these individual kernels gives us the density estimate for the distribution of crash points (Fotheringham et al. 2000).

$$f(x, y) = \frac{1}{nh^2} \sum_{i=1}^{n} K\left(\frac{d_i}{h}\right)$$

where f (x, y) is the density estimate at the location (x, y); n is the number of observations, h is the bandwidth or kernel size; K is the kernel function; and d_i is the distance between the location (x, y) and the location of the i^{th} observation. The main objective of placing these kernels over the crash points is to create a smooth, continuous surface. Around each point at which the indicator is observed, a circular area (the kernel) of defined bandwidth is created. This takes the value of the particular indicator at that particular point spread into it according to some appropriate function. Then it sums up all of these values at all places, including those at which no incidences of the indicator variable were recorded, and gives a surface of density estimates.

The ArcGIS spatial analyst tool provides the features needed to do the cluster analysis by density estimation methods. The KDE process needs that the data points be spatially jointed. For the points to be joined spatially, a fishnet of square cells was created using the “create fishnet” tool. The cell size (cell width and height) was selected in such a way that the area under consideration is divided in a finite number of cells that can be calculated. Since the FS crashes are sparsely populated, the fishnet cells were created such that the number of cells on each side does not exceed 100. The kernel density function was applied to calculate the boundaries of each cluster, with more number of points (crashes) within the center of each cluster.

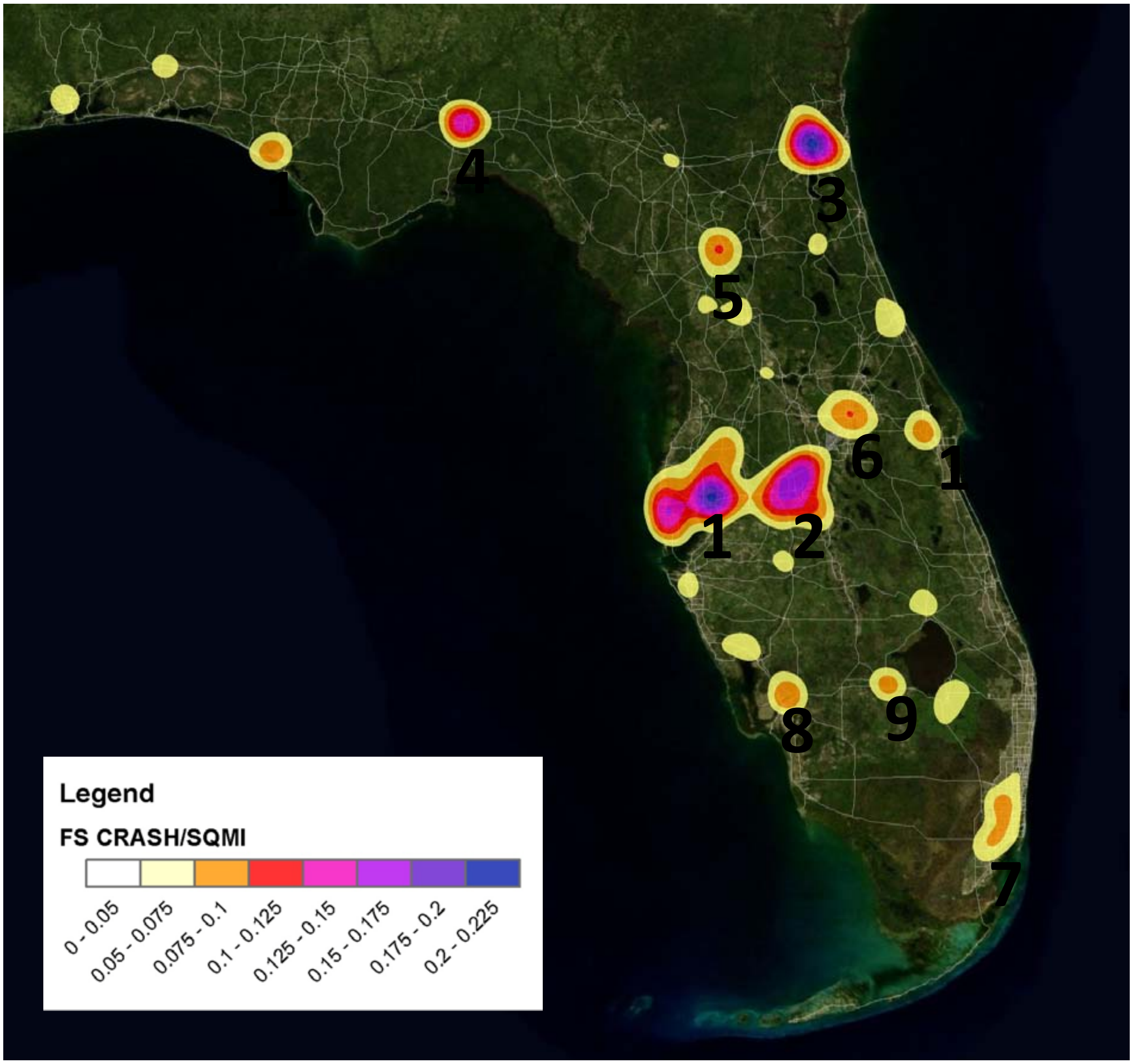

Figure 4-1: Cluster Analysis of Fog- and Smoke-Related Crashes on Florida State Highway System (2003-2010)

Figure 4-1 shows the statewide map with clustering output from the GIS analysis and Table 4-2 illustrates the locations of FS crash hotspots. The KDE technique presents eleven distinct FS crash hotspot areas on Florida road network. The colors represent the density of crashes per square mile area. From the figure, the eleven clusters identified are associated with crash densities above 0.075 crashes per square mile. It is notable that several most hazardous areas have crash densities higher 0.20 crashes per square mile.

Table 4-2: Areas for Fog/Smoke Crashes in Florida State Highway System

Cluster No.	County	Area
1	Pinellas, Hillsborough and Pasco	The almost whole of Pinellas and Connects from center of Hillsborough to center of Pasco
2	Polk and Osceola	Extends from the center to the northeast corner of Polk and a very small portion in the northwest corner of Osceola County
3	Duval	Center of Duval County (Jacksonville)
4	Leon	Center of Leon County (Tallahassee)
5	Alachua	Center of Alachua County (Gainesville)
6	Orange	Center of Orange County (Orlando)
7	Miami-Dade and Broward	North seaside of Miami-Dade County and small portion in the south of Broward County
8	Lee and Charlotte	North part of Lee County and small portion in the south of Charlotte County
9	Glades and Hendry	Southeastern corner of Glades County and northeastern corner of Hendry County
10	Bay	South center seaside of Bay County
11	Brevard and Orange	West part of Brevard County and small portion in the east side of Eastern part of Orange County

5. IDENTIFICATION OF PRIORITY AREAS FOR TREATMENT

Eleven areas were identified with frequent fog/smoke related crashes on Florida state highways using KDE in macroscopic analysis. We also magnified these areas and divided all state highways into one mile segments and thus FS crashes were counted based on the segments. All segments with two or more FS crashes were defined as hotspots in the analysis.

Cluster 1: Pinellas, Hillsborough and Pasco County

Cluster 1 covers considerably large area including Pinellas, Hillsborough and Pasco Counties. Overall 24 segments were discovered as hotspots in Cluster 1. Three segments have 3 FS crashes and 22 segments have 2 FS crashes per mile.

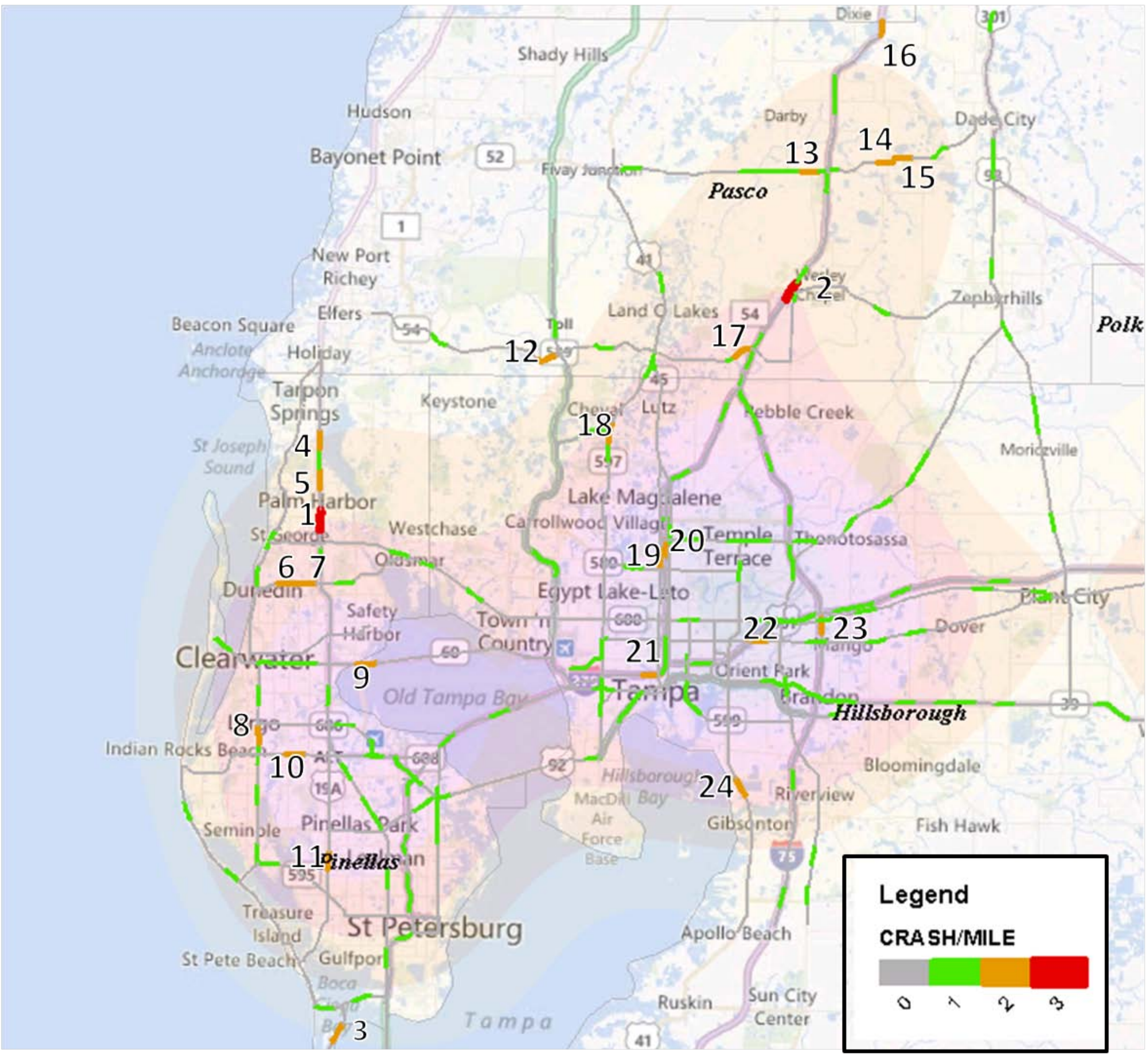

Figure 5-1: Microscopic Analysis of FS Crashes in Cluster 1

Table 5-1: Segments with Frequent FS Crashes in Cluster 1

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	3	Pinellas	Tarpon Springs	US 19	15150000	25.539	15150000	26.123
2	3	Pasco	Wesley Chapel	I 75	14140000	4.835	14140000	5.104
3	2	Pinellas	St. Petersburg	SR 679	15200000	8.366	15200000	8.555
4	2	Pinellas	Tarpon Springs	US 19	15150000	29.422	15150000	30.184
5	2	Pinellas	Palm Harbor	US 19	15150000	27.405	15150000	27.56
6	2	Pinellas	Dunedin	SR 580	15070000	1.283	15070000	1.756
7	2	Pinellas	Dunedin	SR 580	15070000	2.443	15070000	3.119
8	2	Pinellas	Largo	US 19A	15010000	16.052	15010000	16.37
9	2	Pinellas	Clearwater	SR 60	15040000	6.114	15040000	6.289
10	2	Pinellas	Largo	SR 688	15120000	6.053	15120000	6.057
11	2	Pinellas	Kenneth City	SR 693	15230000	3.501	15230000	4.139
12	2	Pasco	Land O Lakes	SR 54	14571000	2.264	14571000	2.264
13	2	Pasco	San Antonio	SR 52	14120000	22.675	14120000	22.677
14	2	Pasco	San Antonio	SR 52	14120000	26.134	14120000	26.634
15	2	Pasco	St. Leo	SR 52	14120000	27.102	14120000	27.971
16	2	Pasco	Dade City	I 75	14140000	19.882	14140000	20.082
17	2	Pasco	Lutz	SR 56	14091000	0.788	14091000	0.845
18	2	Hillsborough	Tampa	SR 597	10160000	9.16	10160000	9.49
19	2	Hillsborough	Tampa	SR 685	10020000	6.172	10020000	6.365
20	2	Hillsborough	Tampa	I 275	10320000	5.992	10320000	6.092
21	2	Hillsborough	Brandon	I 275	10190000	6.34	10190000	6.34
22	2	Hillsborough	Tampa	SR 574	10340000	7.496	10340000	7.496
23	2	Hillsborough	Tampa	I 75	10075000	26.038	10075000	26.699
24	2	Hillsborough	Tampa	US 41	10060000	19.967	10060000	20.267

Cluster 2: Polk and Osceola County

Cluster 2 extends from the center to the northeast corner of Polk County and a very small portion in the northwest corner of Osceola County. Twenty-four (24) segments were identified as hotspots. Three segments on I-4 have 4 or more FS crashes in a short distance. This is as a result of the massive pileup crash that occurred on January 9, 2008. According to the crash data, 78 vehicles were involved, and 4 people were killed in the multivehicle crash.

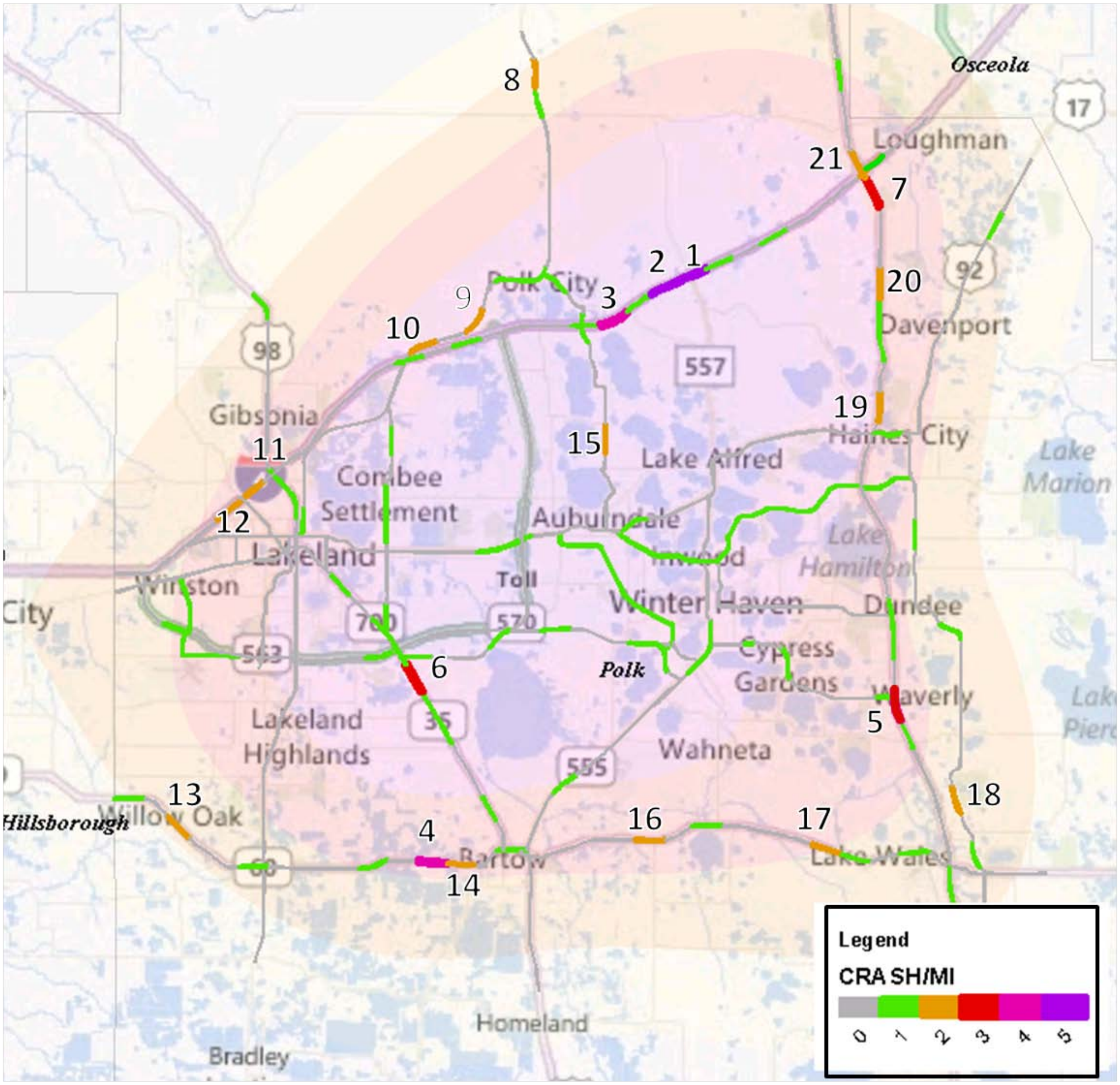

Figure 5-2: Microscopic Analysis of FS Crashes in Cluster 2

Table 5-2: Segments with Frequent FS Crashes in Cluster 2

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	5	Polk	Lake Alfred	I 4	16320000	22.528	16320000	22.628
2	5	Polk	Lake Alfred	I 4	16320000	21.426	16320000	21.928
3	4	Polk	Auburndale	I 4	16320000	19.426	16320000	19.994
4	4	Polk	Bartow	SR 60	16110000	11.069	16110000	11.645
5	3	Polk	Lake Wales	US 27	16180000	5.547	16180000	5.944

6	3	Polk	Lakeland	US 98	16060000	6.525	16060000	6.697
7	3	Polk	Haines City	US 27	16180000	23.346	16180000	23.357
8	2	Polk	Polk City	SR 33	16070000	21.534	16070000	21.534
9	2	Polk	Polk City	SR 33	16070000	10.805	16070000	11.391
10	2	Polk	Polk City	SR 33	16070000	9.452	16070000	9.729
11	2	Polk	Lakeland	I 4	16320000	5.165	16320000	5.387
12	2	Polk	Lakeland	I 4	16320000	4.663	16320000	4.887
13	2	Polk	Mulberry	SR 60	16110000	2.311	16110000	3
14	2	Polk	Bartow	SR 60	16110000	12.135	16110000	12.896
15	2	Polk	Auburndale	SR 559	16160000	3.188	16160000	3.341
16	2	Polk	Bartow	SR 60	16110000	18.697	16110000	18.974
17	2	Polk	Lake Wales	SR 60	16110000	25.187	16110000	25.187
18	2	Polk	Lake Wales	SR 17	16090000	21.086	16090000	21.486
19	2	Polk	Haines City	SR 25	16180000	15.777	16180000	16.485
20	2	Polk	Haines City	SR 25	16180000	20.126	16180000	20.154
21	2	Polk	Haines City	SR 25	16180000	23.753	16180000	23.884

Cluster 3: Duval County

Cluster 3 is located in the heart of Duval County. It covers almost whole of Jacksonville. There are 11 segments with 2 or more FS crashes. Three segments have 3 FS crashes.

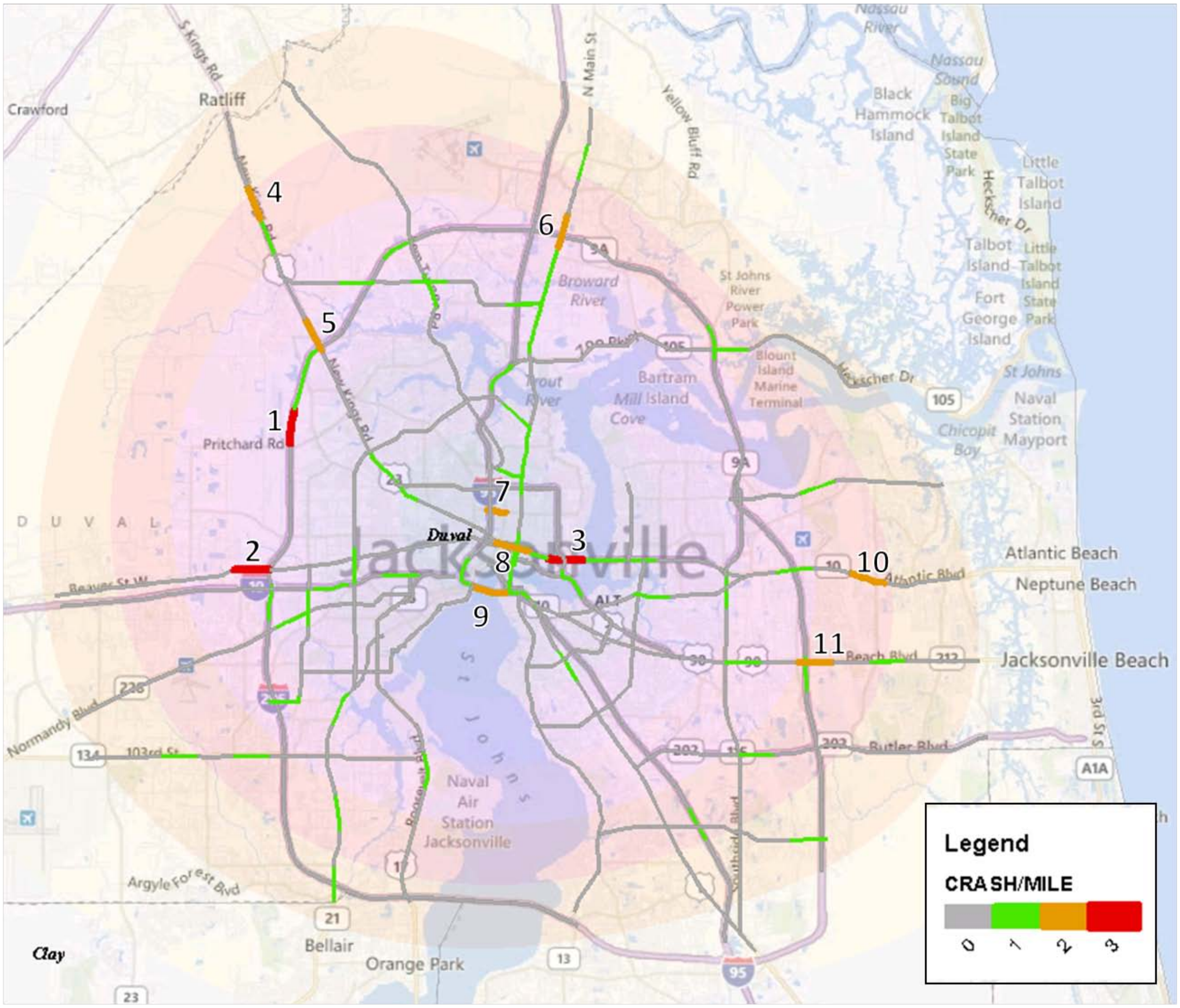

Figure 5-3: Microscopic Analysis of FS Crashes in Cluster 3

Table 5-3: Segments with Frequent FS Crashes in Cluster 3

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	3	Duval	Jacksonville	I 295	72001000	25.189	72001000	25.689
2	3	Duval	Jacksonville	US 90	72010000	14.741	72010000	14.741
3	3	Duval	Jacksonville	US 90A	72040000	14.025	72040000	14.035
4	2	Duval	Jacksonville	US 1	72080000	12.299	72080000	12.711
5	2	Duval	Jacksonville	US 1	72080000	8.437	72080000	8.456
6	2	Duval	Jacksonville	US 17	72060000	2.13	72060000	2.13
7	2	Duval	Jacksonville	SR 114	72005000	0.51	72005000	0.543
8	2	Duval	Jacksonville	SR 139	72040101	0.067	72040101	0.146
9	2	Duval	Jacksonville	I 95	72020000	1.26	72020000	1.377
10	2	Duval	Jacksonville	SR 10	72100000	10.034	72100000	10.053
11	2	Duval	Jacksonville	US 90	72190000	7.011	72190000	7.699

Cluster 4: Leon County

Cluster 4 covers entire Tallahassee, the center of Leon County. Four segments were identified as hotspots in the cluster. Nevertheless, since many segments have one FS crash per mile, the total number of FS crashes in the cluster should not be ignored.

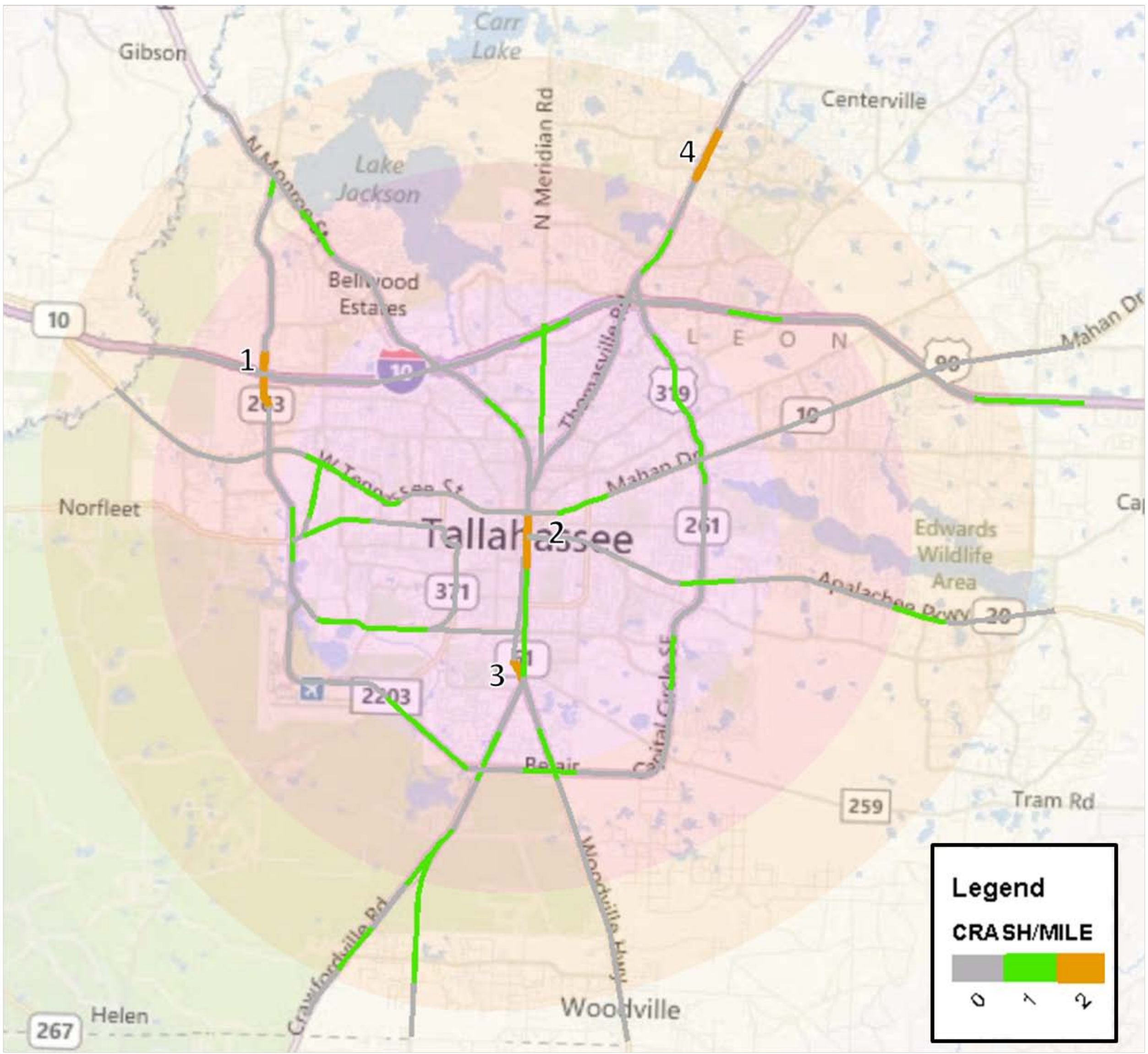

Figure 5-4: Microscopic Analysis of FS Crashes in Cluster 4

Table 5-4: Segments with Frequent FS Crashes in Cluster 4

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	2	Leon	Tallahassee	SR 263	55002000	11.048	55002000	11.353
2	2	Leon	Tallahassee	SR 61	55040000	10.606	55040000	11.24
3	2	Leon	Tallahassee	SR 61	55120000	7.175	55120000	7.408
4	2	Leon	Tallahassee	US 319	55050000	7.176	55050000	7.176

Cluster 5: Alachua County

Cluster 5 is located in the center of Alachua County, Gainesville. Similar to Cluster 4, despite of considerable number of segments with FS crashes, it was found that only two segments have 2 FS crashes and only they were marked as hotspots.

On January 29, 2012, the pileup crash was occurred due to fog and smoke involving large trucks in Segment 2 on I-75. As a result of the crash, 10 drivers were killed and 18 were injured in the crash. Although 2012 crashes were not considered in this study, Segment 2 could be identified as a hotspot using only previous crash data.

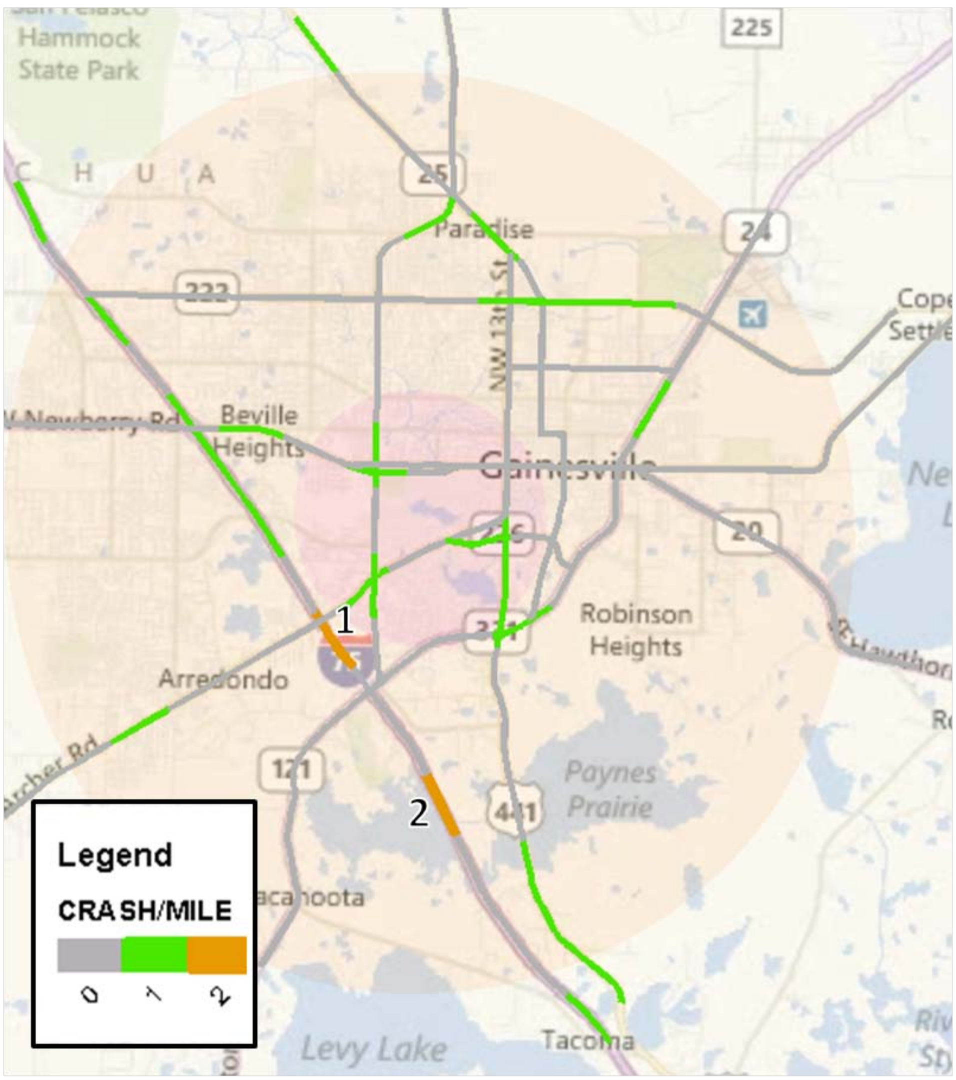

Figure 5-5: Microscopic Analysis of FS Crashes in Cluster 5

Table 5-5: Segments with Frequent FS Crashes in Cluster 5

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	2	Alachua	Gainesville	I 75	26260000	10.738	26260000	10.738
2	2	Alachua	Gainesville	I 75	26260000	7.601	26260000	7.717

Cluster 6: Orange County

Cluster 6 is located in the center of Orange County, Orlando. It has four hotspots and they have two FS crashes per mile.

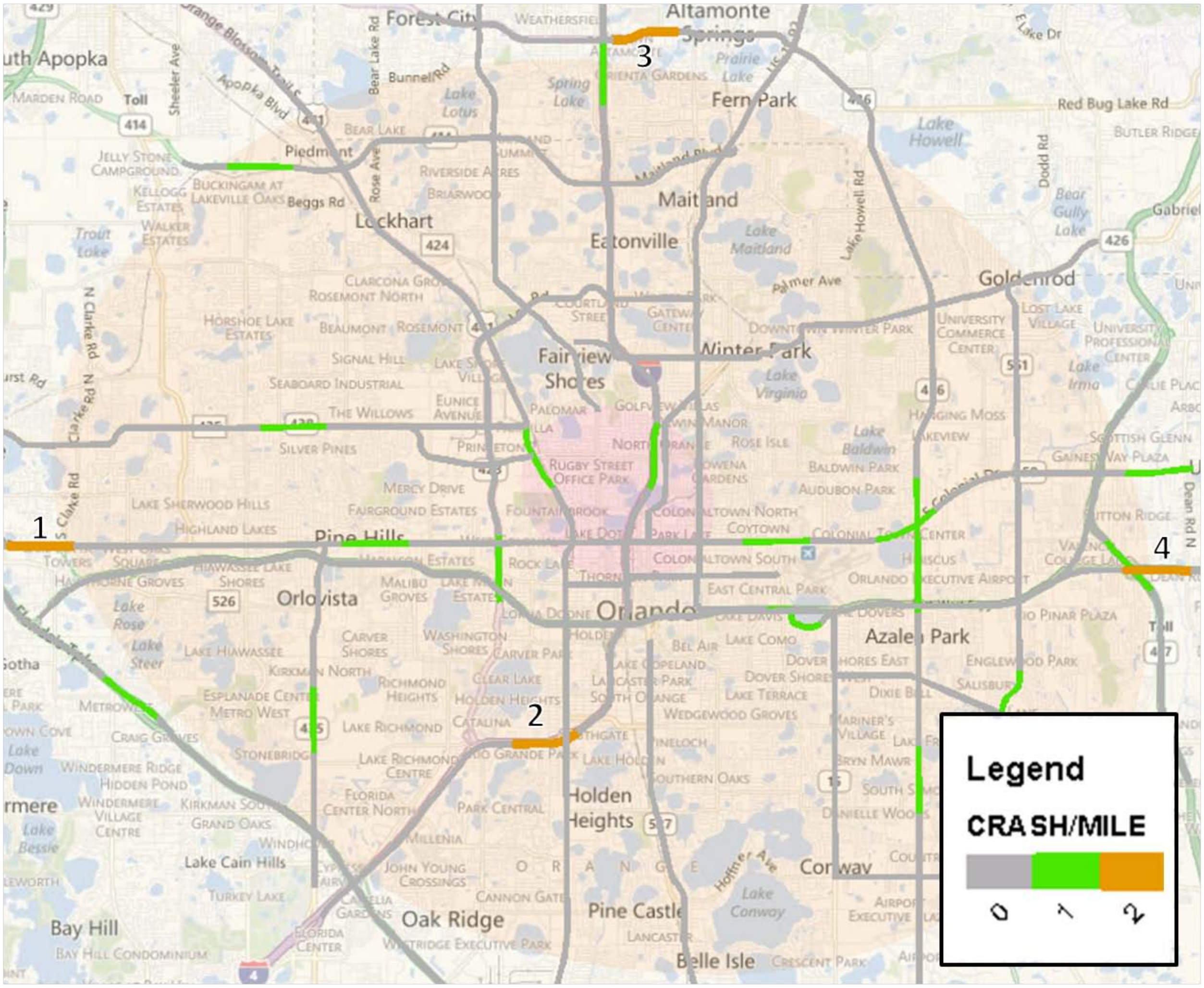

Figure 5-6: Microscopic Analysis of FS Crashes in Cluster 6

Table 5-6: Segments with Frequent FS Crashes in Cluster 6

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	2	Orange	Ocoee	SR 50	75050000	7.646	75050000	7.835
2	2	Orange	Orlando	I 4	75280000	14.202	75280000	15.068
3	2	Seminole	Altamonte Springs	SR 436	77080000	5.412	77080000	5.609
4	2	Orange	Orlando	SR 408	75008160	1.162	75008160	1.771

Cluster 7: Miami-Dade and Broward County

Cluster 7 covers North seaside of Miami-Dade county and small portion in the south of Broward County. It has three hotspots and they have two FS crashes per mile.

Figure 5-7: Microscopic Analysis of FS Crashes in Cluster 7

Table 5-7: Segments with Frequent FS Crashes in Cluster 7

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	2	Miami-Dade	Kendall	SR 94	87001000	4.907	87001000	4.916
2	2	Miami-Dade	Miramar	SR 821	86471000	2.958	86471071	0.296
3	2	Miami-Dade	Miami	US 1	87030000	6.534	87030000	7.093

Cluster 8: Lee and Charlotte County

Cluster 8 embraces the north coastal region of Lee county and a small portion in south Charlotte County. It has only two hotspots; however, their FS crash frequencies are noticeably high. Two segments have 12 FS crashes, and among them, 11 FS crashes occurred at the same time on January 21, 2003. Thirty-four vehicles were involved, and ten people were injured. Fortunately, no one died in this crash.

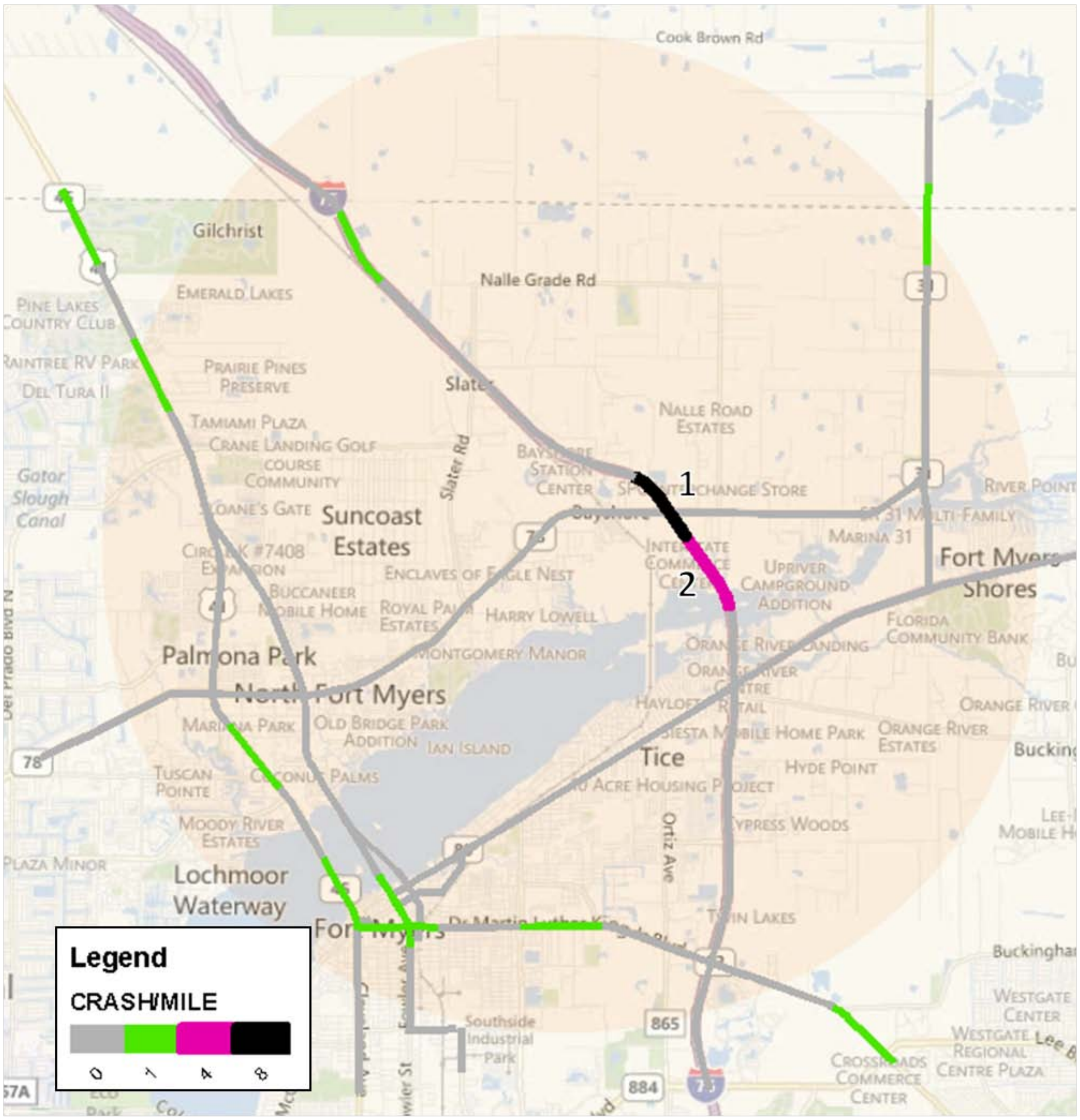

Figure 5-8: Microscopic Analysis of FS Crashes in Cluster 8

Table 5-8: Segments with Frequent FS Crashes in Cluster 8

Segment	FS crashes / Mile	County	Town	Route	Crash points Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	8	Lee	Fort Myers	I 75	12075000	28.116	12075000	28.3
2	4	Lee	Fort Myers	I 75	12075000	27.4	12075000	27.946

Cluster 9: Glades and Hendry County

Cluster 9 covers Southeastern corner of Glades County and northeastern corner of Hendry County. Four hotspots were identified and one segment on US 27 has 3 FS crash records.

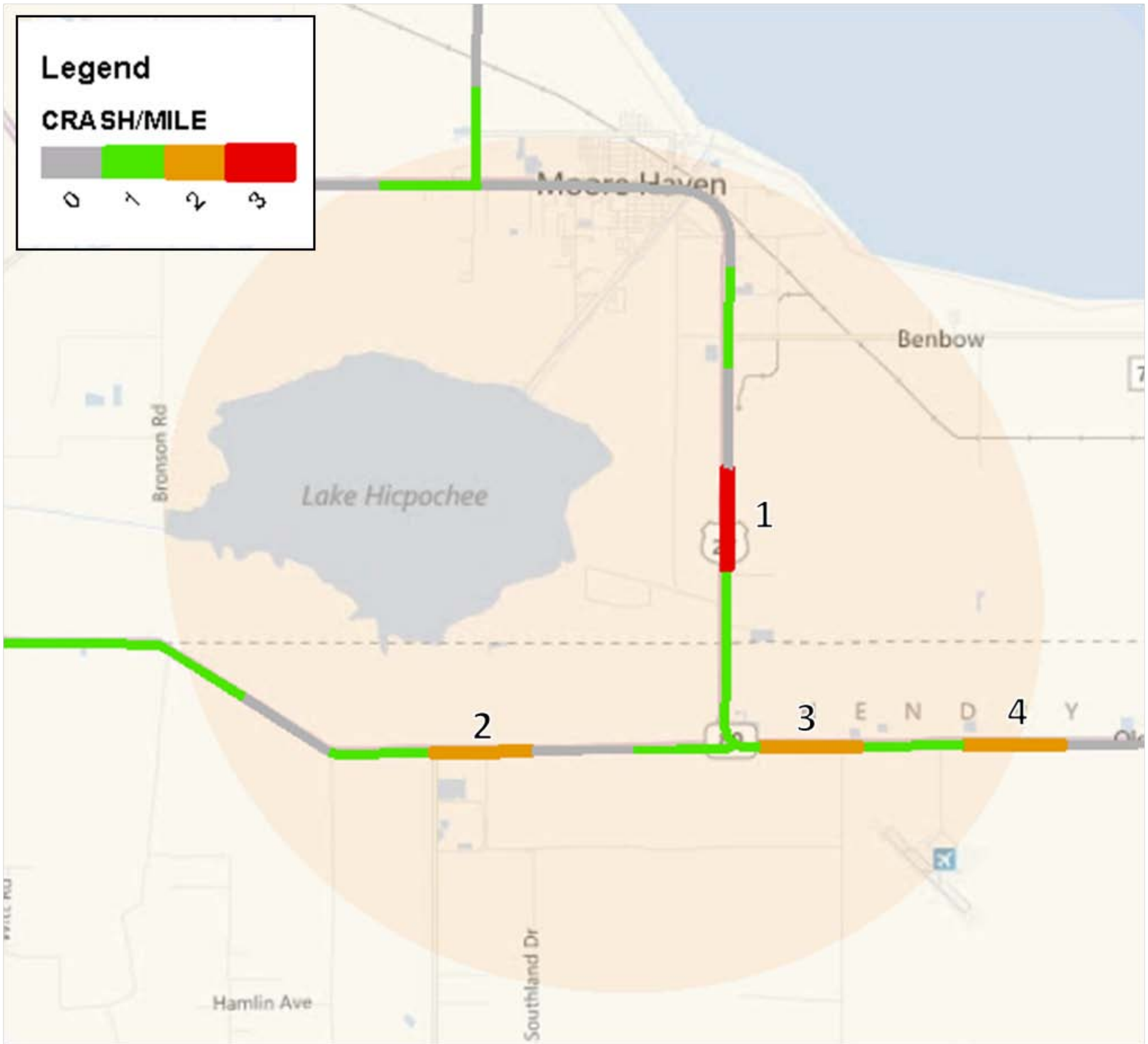

Figure 5-9: Microscopic Analysis of FS Crashes in Cluster 9

Table 5-9: Segments with Frequent FS Crashes in Cluster 9

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	3	Glades	Moore Haven	US 27	05010000	1.001	05010000	1.003
2	2	Hendry	Clewiston	SR 80	07010000	28.854	07010000	28.856
3	2	Hendry	Clewiston	US 27	07030000	11.173	07030000	11.173
4	2	Hendry	Clewiston	US 27	07030000	9.195	07030000	9.195

Cluster 10: Bay County

Cluster 10 is located in South center seaside of Bay County. Four hotspots were identified and one of them had 4 FS crashes.

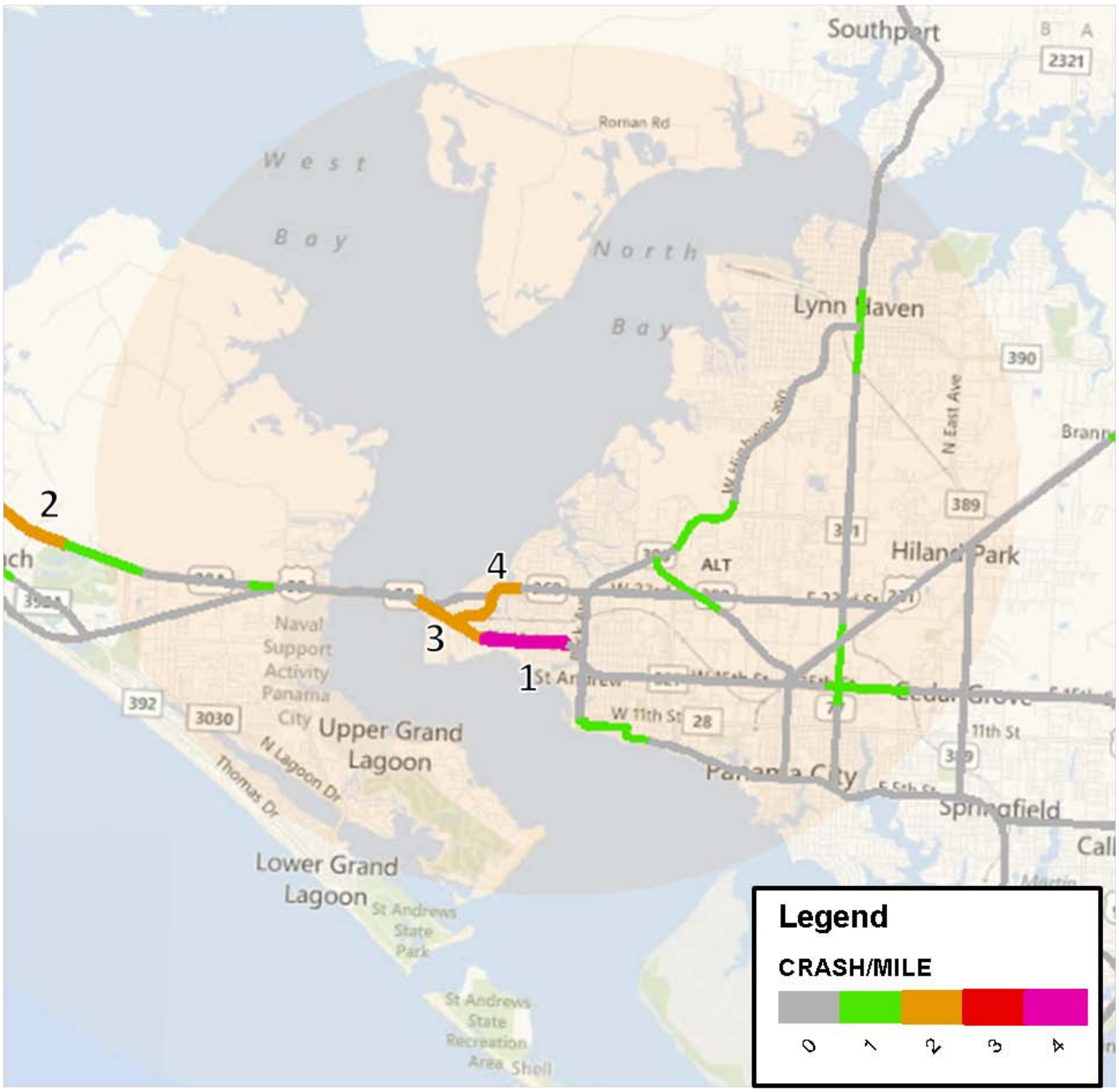

Figure 5-10: Microscopic Analysis of FS Crashes in Cluster 10

Table 5-10: Segments with Frequent FS Crashes in Cluster 10

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	4	Bay	Panama City	US 98	46020000	2.009	46020000	2.507
2	2	Bay	Panama City Beach	US 98	46160000	11.29	46160000	11.574
3	2	Bay	Panama City	US 98	46020000	1.295	46020000	1.314
4	2	Bay	Panama City	SR 368	46140001	0.629	46140001	0.97

Cluster 11: Brevard and Orange County

Cluster 11 covers the West part of Brevard County and small portion in the east side of Eastern part of Orange County. Five segments were discovered as hotspots in the cluster. One segment on I-95 had 4 FS crashes.

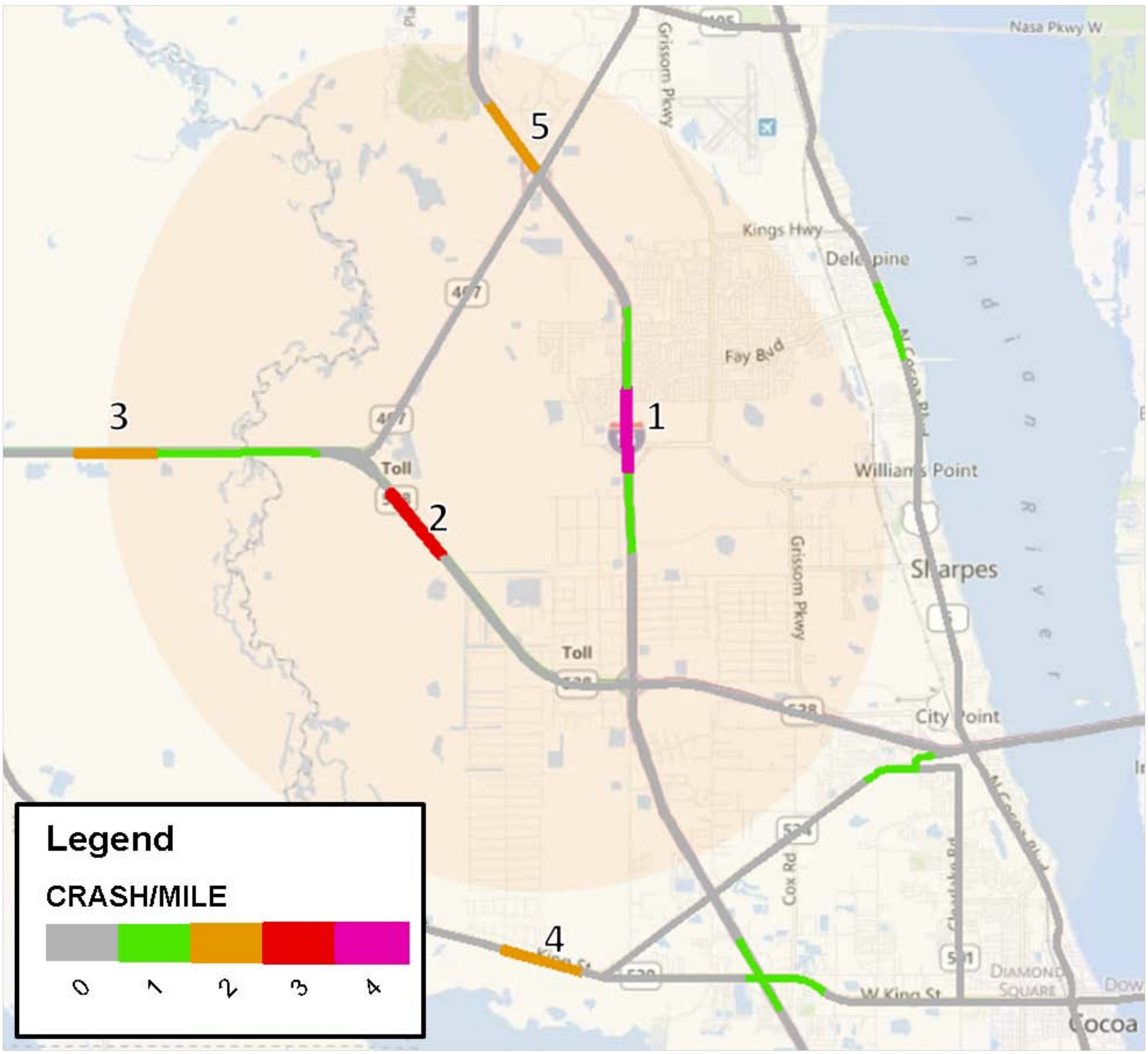

Figure 5-11: Microscopic Analysis of FS Crashes in Cluster 11

Table 5-11: Segments with Frequent FS Crashes in Cluster 11

Segment	FS crashes / Mile	County	Town	Route	Crash points			
					Roadway ID (Begin)	Milepost (Begin)	Roadway ID (End)	Milepost (End)
1	4	Brevard	Cocoa	I 95	70225000	6.72	70225000	6.933
2	3	Brevard	Cocoa	SR 528	70007000	2.429	70007000	2.925
3	2	Orange	Orlando	SR 528	75005000	3.041	75005000	3.882
4	2	Brevard	Cocoa	SR 520	70100000	1.724	70100000	2.444
5	2	Brevard	Titusville	I 95	70225000	10.957	70225000	10.957

5.1. Conclusion

Areas with frequent FS crashes were identified using the KDE technique in macroscopic analysis. Eleven areas with FS crashes densities per square miles above 0.075 were identified as hotspots. The statewide map was updated with magnifying those eleven frequent FS crash areas. Finally specific roadway segments were found as hotspots at the network level. It was found that clusters such as Cluster 2 (Polk and Osceola County) and Cluster 8 (Lee and Charlotte County) experienced massive multivehicle crashes between in 2008 and 2003, respectively.

6. Exploring the Viability of using Airport Weather Data as Part of Visibility Detection Systems

Although visibility detection systems can help to mitigate the increased hazard of limited-visibility, such systems are not widely implemented and many locations with no systems are experiencing considerable number of fatal crashes due to reduction in visibility caused by fog and inclement weather. On the other hand, airports' weather stations continuously monitor all climate parameters in real-time, the question arises here whether these data can be used to provide indications about weather conditions in general and visibility levels in particular to roadways close to these airports and hence the gathered data may be utilized to mitigate the increased risk for the adjacent roadways. As discussed earlier that visibility detection systems comprises of two main components; 1) visibility detection sensors and 2) DMS for warning, the first main component might be substituted by airports' weather stations. This chapter provides an added effort (outside the scope of this study) to examine primarily the possibility of using weather information collected by weather stations at airports within the vicinity of fog-prone areas.

There are a variety of methods that have been used for collecting weather data on highways. Crash and weather data can be collected from the long form crash reports; however, recorded weather conditions may be mistakenly reported (Shinar et al., 1983). Other studies collected data from weather stations installed within Advanced Traffic and Information System (ATIS) (Ahmed et al., 2012). Andrey et al. (2003) gathered weather data from the Meteorological Service of Canada (MSC), but found it difficult to compare MSC data with the weather data from crash reports and one study collected weather data from airports in the vicinity of the locations of the crashes (Abdel-Aty and Pemmanabonia, 2006).

To investigate the feasibility of using airports' weather data, crash data were collected from Florida Department of Transportation's (FDOT) Crash Analysis Reporting (CAR) system. Airport weather data were collected from the National Climate Data Center (NCDC) under the umbrella of the National Oceanic and Atmospheric Administration (NOAA). NCDC archives weather data from various weather stations nationwide, including radar, satellites, airport weather stations, U.S. Navy, U.S. Air Force, and etc.

As shown in Figure 6-1, there are 76 airports, U.S. Air Force/Navy bases and one space center in Florida. Airports' automated weather stations that monitor the weather conditions continuously, and the weather parameters are recorded according to a specific change in the reading threshold, and hence, they do not follow a specific time pattern. The stations report frequent readings as the weather conditions change within short time; if the weather conditions remain the same, the station would not update the readings. These weather data include visibility, temperature, humidity, wind speed and direction, precipitation, etc. Among all these parameters, visibility is considered one of the most critical factors affecting crash occurrence. Visibility in general can be described as the maximum distance (in mile) that an object can be clearly perceived against the background sky; visibility impairment can be a result of both natural (e.g., fog, mist, haze, snow, rain, windblown dust, etc.) and human-induced activities (transportation, agricultural activities, and fuel combustion). The automated weather stations do not directly measure the visibility but rather calculate it from a measurement of light extinction, which includes the scattering and absorption of light by particles and gases. All airports' weather data are collected and maintained by NCDC.

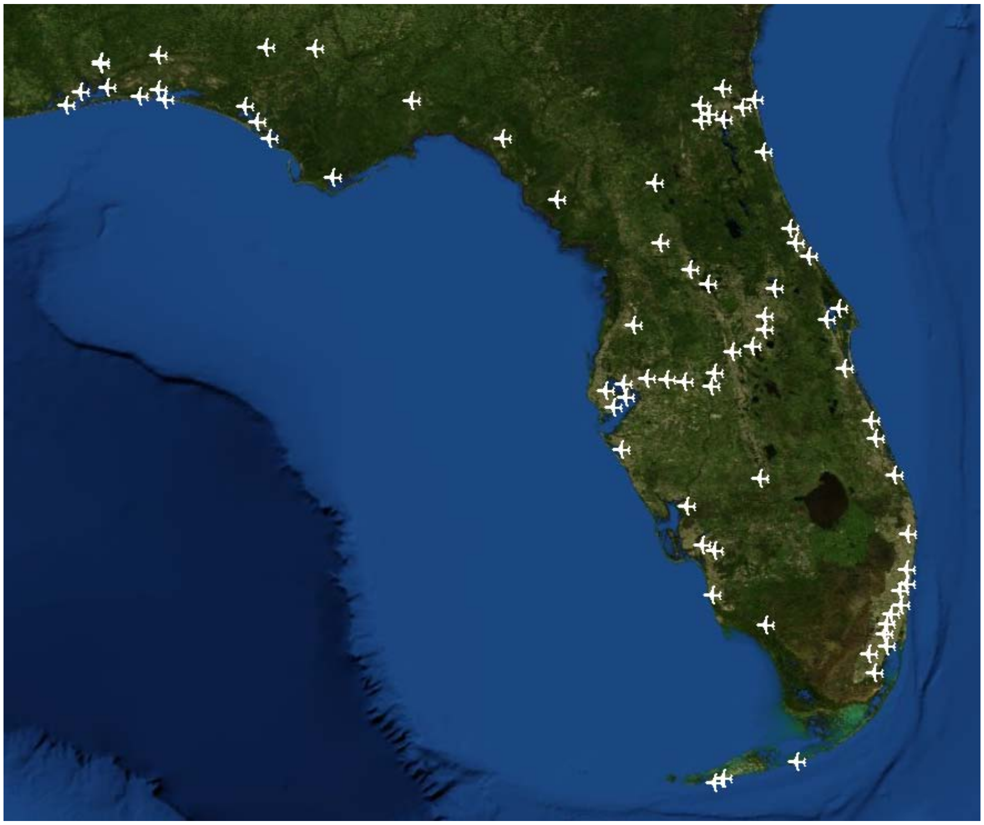

Figure 6-1: **Locations of Airports, Air Force Base, Navy Airbases, and a Space Center in Florida**

In order to examine the valid coverage of airport data for limited-visibility crashes (Fog and Smoke FS), the following indices were calculated; 1) percentage of Spatial Coverage (SC%), 2) percentage of Temporal Coverage (TC%) and 3) percentage of Overall Valid Coverage (OVC%). SC% as shown in Figure 6-2 can be defined as the proportion of FS crashes that are located within specific radius of airports' buffer zones SC% = b / (a+b).

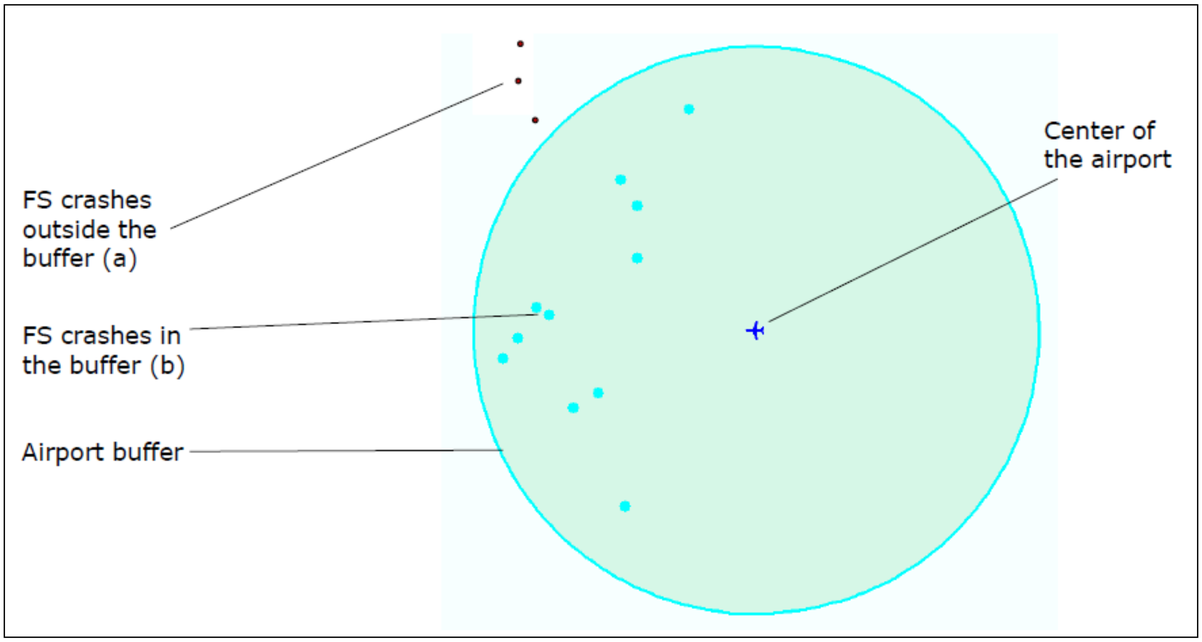

Figure 6-2: Percentage of Spatial Coverage (SC%)

The percentage of temporal coverage (TC%) can be defined as the percentage of limited-visibility crashes (determined according to crash reports) that had occurred within airports' buffer zones that happened during reduction in visibility due to fog, smoke, or haze (reported by airports' weather stations) as indicated in Figure 6-3.

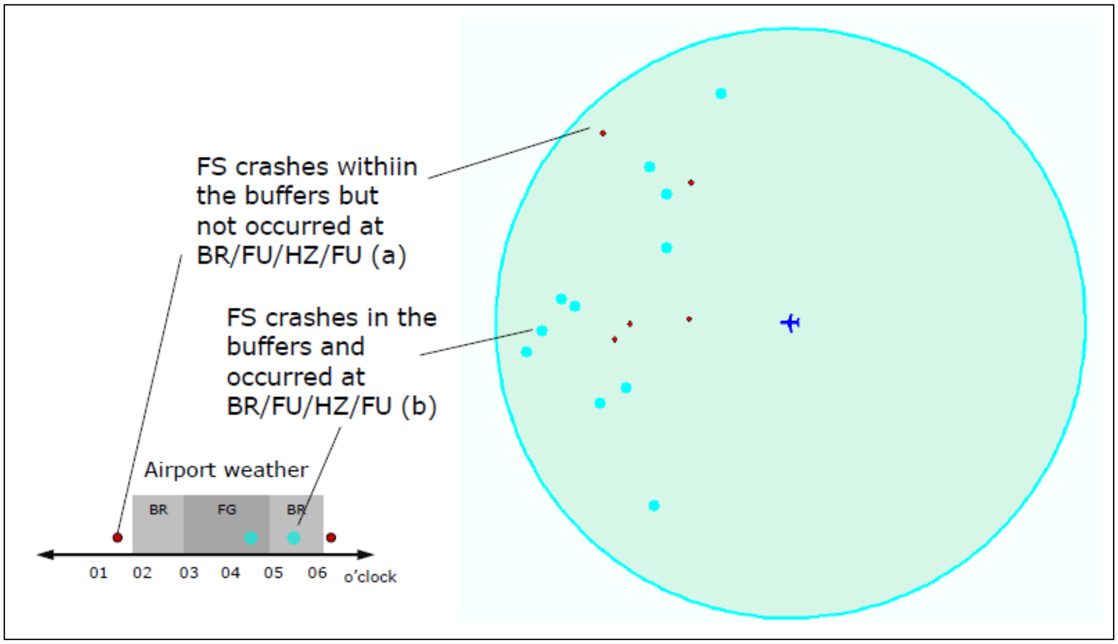

Figure 6-3: Percentage of Spatial Coverage (SC%)

The percentage of the overall valid coverage (OVC%) can be defined as the proportion of all limited-visibility crashes (determined according to crash reports) occurring within the airports' buffer zones that happened during reduction in visibility due to fog, smoke, or haze (reported by airports' weather stations) as indicated in Figure 6-4, the OVC% combines both the spatial and temporal coverage.

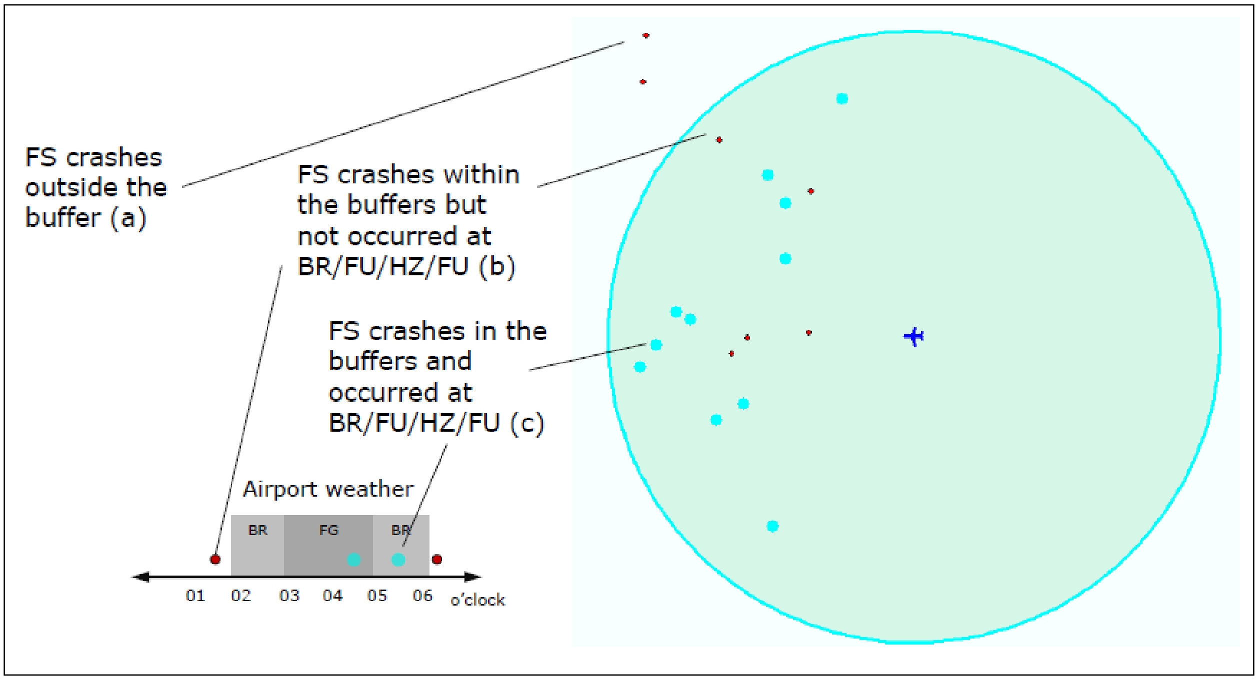

Figure 6-4: Percentage of Spatial Coverage (SC%)

As mentioned earlier that crash data are collected from FDOT's CAR system, crashes within the vicinity of 7 airports in Pinellas and Hillsborough were identified using Geographic Information System (GIS) from 2007 through 2010. Fog/ smoke crashes were extracted from the crash reports and were matched with airport weather data closest time just before the crash. Total number of 170 FS crashes that occurred within the two counties were extracted, buffer sizes of 1-mile to 15-mile were considered in the analysis. Figure 6-5 shows an example of limited-visibility crashes within 6-mile airports buffers (blue dots), limited-visibility crashes outside the buffer zones (red dots), airports locations and the 6-mile buffer circles.

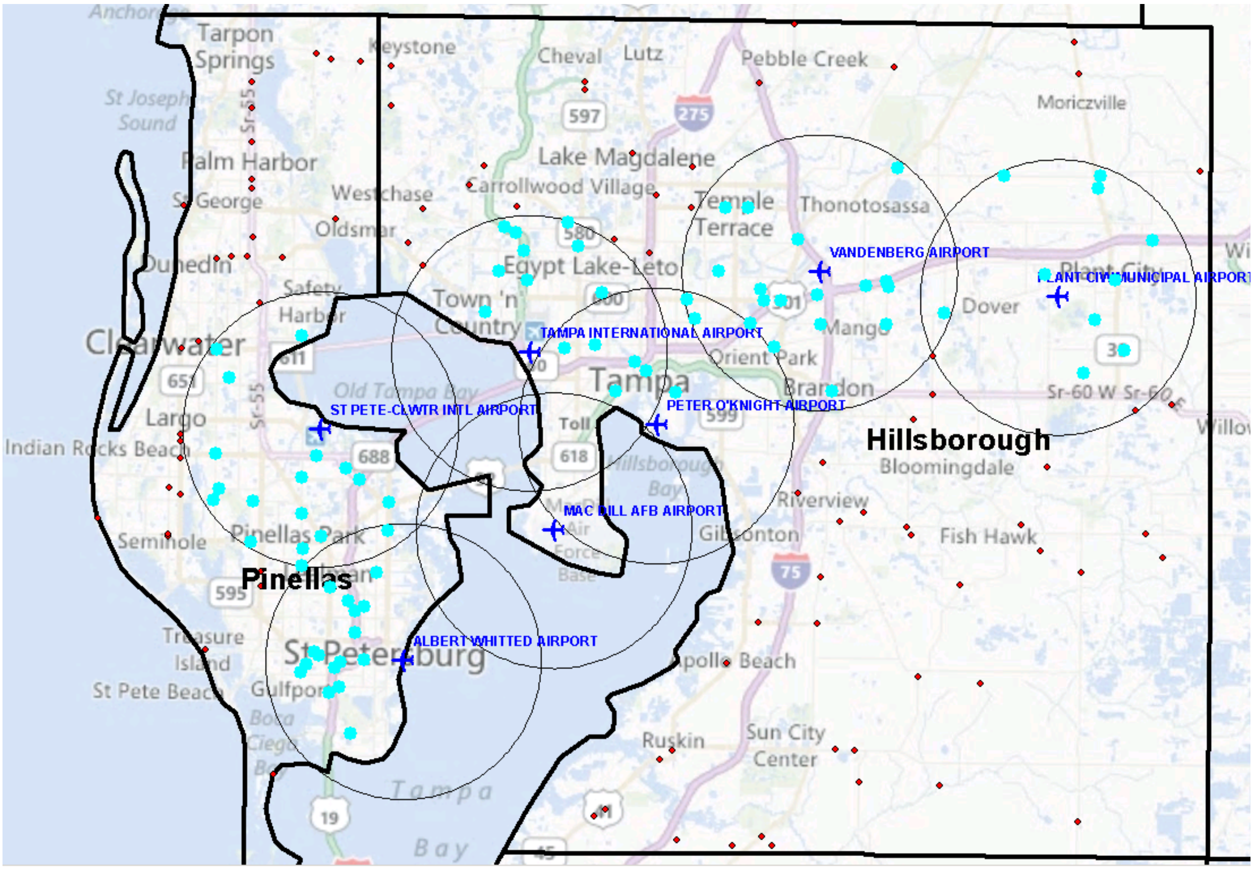

Figure 6-5: Pinellas and Hillsborough Limited-Visibility Crashes (6-mile buffer circles)

Table 6-1 summarizes the total number of spatially/ temporally, SC%, TC%, and OVC% for limited-visibility crashes within various buffer zone radii, 1 to 15-mile. Additionally, the TC% were plotted by airport against the buffer zone radii to determine the optimum buffer zone radius, as indicated in Figure 6-6. For example, 6-mile radius was found to provide the highest TC% of 93.3% for Tampa international airport.

Table 6-1: Buffer Zones Coverage Summary

Buffer size	Number of SC/ TC Crash es	SC%	OVC%	TC%
1 mile	0/ 0	0.0%	0.0%	0.0%
2 mile	8/ 8	4.7%	3.5%	75.0%
3 mile	29/ 24	17.1%	14.1%	82.8%
4 mile	46/ 38	27.1%	22.4%	82.6%
5 mile	64/ 50	37.6%	29.4%	78.1%
6 mile	81/ 64	47.6%	37.6%	79.0%
7 mile	99/ 85	58.2%	50.0%	85.9%
8 mile	111/ 94	65.3%	55.3%	84.7%
9 mile	121/ 105	71.2%	61.8%	86.8%
10 mile	130/ 113	76.5%	66.5%	86.9%
11 mile	137/ 117	80.6%	68.8%	85.4%
12 mile	146/ 125	85.9%	73.5%	85.6%
13 mile	152/ 131	89.4%	77.1%	86.2%
14 mile	154/ 133	90.6%	78.2%	86.4%
15 mile	157/ 135	92.4%	79.4%	86.0%

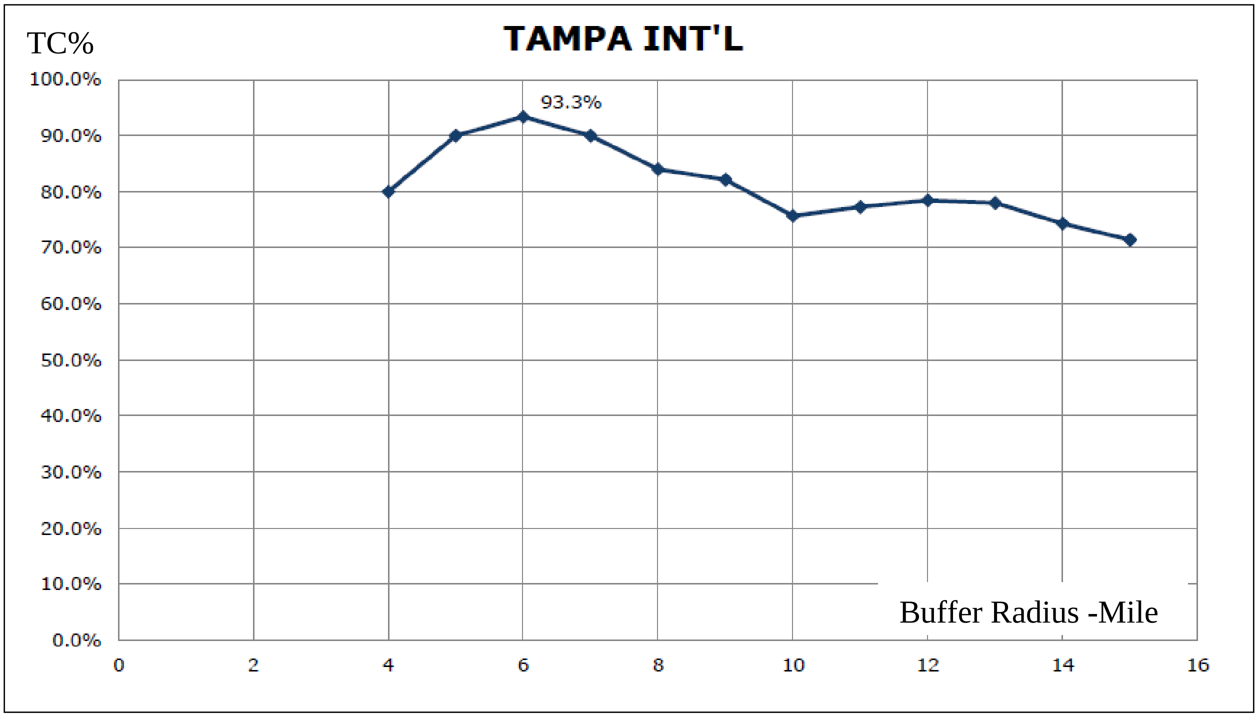

Figure 6-6: TC% Tampa International Airport

The optimum buffer sizes were determined for each airport based on the TC%, Table 6-2 provides the TC% and the optimum buffer size.

Table 6-2: Airport-Specific Optimum Buffer Size

Airports	**TC%**	**Optimum Buffer Size**
ALBERT WHITTED	76.9%	4MI
ST PETERSBURG-CLEARWATER	90.9%	5MI
TAMPA INT'L	93.3%	6MI
PETER O'KNIGHT	92.9%	7MI
VANDENBERG	78.4%	10MI
PLANT CITY	92.9%	7MI

MACDILL Air Force Base	84.2%	10MI

Utilizing airport-specific optimum buffer sizes, 77 crashes were identified correctly within the buffer zones that occurred at reduced visibility conditions determined from crash reports and confirmed by the airports' weather stations in Pinellas and Hillsborough counties during the 4 years study period (2007-2010). Figure 6-7 shows the buffer zones radii for the 7 airports, captured limited-visibility crashes within the buffer zones (blue dots), and the limited-visibility crashes outside the coverage areas. It was concluded that about 52% and 88% of these crashes were spatially and temporally covered with overall valid coverage of 45%.

The results from this study depicts that the available real-time airport weather data can be utilized by traffic management centers (TMC) to mitigate the increased risk of limited-visibility. Airport weather stations can be a reliable source to determine visibility conditions of the roadways within 5 nautical miles radius around airports, and may be more depending on the location, type and overlap of buffers around airports. TMCs can benefit from the availability of real-time weather data from airports and utilize it with relatively negligible cost. More research might be needed to address other issues such as the comparison between data reported at different airports and the overlap between airports coverage. Moreover, weather data collected by airports' weather stations could be utilized to statistically link various weather parameters to crash occurrence, these models can be used to assess and mitigate the increased risk during inclement weather conditions in real-time.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Visibility is critical to the task of driving and reduction in visibility due to fog, smoke or other weather events such as heavy rain is a major traffic operation and safety concern. In Florida, these conditions could be a result of sudden dense fog, fires (whether wild or controlled), and heavy pockets of rain or hail. Real-time measurement of visibility may help in warning the drivers when the visibility falls below certain acceptable levels. The credibility of visibility detection and warning systems is essential to ensure the drivers' compliance with the system.

With the help of FDOT and USDOT to get information on the state of the practice of visibility detection systems in the U.S., this report provides synthesis of the visibility warning and detection systems that were developed and/or implemented in the U.S. and other countries. By examining the configurations and management strategies of these systems, it shows that some of these systems can detect reduction in visibility below certain acceptable levels and respond accordingly in real-time to convey specific warning messages to drivers in an effective way and report this information to the appropriate TMC. DMSs, LED DMSs, and HARSs are the major channels to inform drivers of the reduced visibility conditions. VSLs also suggest or mandate drivers to slow down their speed in case of adverse weather reducing visibility.

New visibility detection systems from existing affordable technologies such as roadway side cameras are also discussed. Camera-based visibility detection is still in its infancy stage. Image processing and algorithm construction are the focus points. Different types of weather can result in different requirements for the visibility detection system. Nevertheless, the idea of a low-cost and mobile real-time camera-based visibility detection system is so appealing that we will surely see more novel and advanced techniques and models in the future.

Florida has been experiencing visibility-related crashes in which a majority was caused by fog/smoke. The identification of FS crash hotspot is therefore of paramount importance for crash mitigation. Through GIS analysis at macro and micro level, eleven FS crash hotspot areas and specific road segments within the areas have been pinpointed across the state. Corresponding countermeasures should be considered for these identified hotspots.

In all, visibility detection systems have been in existence in the U.S. and other countries to bring down visibility-related crashes. This report offers synthesis of visibility systems and traffic control techniques that are deployed and/or implemented in the U.S. and around the world. Aviation visibility detection is also studied to shed some light on the development of road visibility systems. Along with these existing systems, new trend such as utilizing camera as visibility detection tools is also investigated. They show promising potential to be a part of the visibility detection system in the future. To implement the visibility detection systems in Florida, FS crash hotspots have first been identified. Installing the visibility detection system for specific road segments can serve as good means to test the effectiveness of the systems on visibility related crashes.

We have also highlighted the potential benefit of existing visibility systems at airports in Florida. More investigation is needed to prove the benefits of linking airport systems to traffic management centers. The possible implications would be substantial with respect to more coverage and huge savings.

REFERENCES

Abdel-Aty M., and Pemmanabonia R., *Calibrating a Real-Time Traffic Crash-Prediction Model Using Archived Weather and ITS Traffic Data*. *IEEE Transactions on Intelligent Transportation Systems*, Vol. 7(2), pp.167–174, 2006.

Abdel-Aty, M., A. Oloufa, H. Hassan, M. Ahmed, C. Siddiqui, A. Ekram, and H. Huang, *Developing an Early Detection System for Reduced Visibility*. (FDOT Report BDK78 562-1) University of Central Florida, Orlando, FL, 2010.

Ahmed, M., Abdel-Aty, M., Yu, R., Assessment of the *Interaction Between Crash Occurrence, Mountainous Freeway Geometry, Real-Time Weather and AVI Traffic Data*. Journal of the Transportation Research Board, Washington, D.C (In Press 2012).

Al-Ghamdi, A., *Experimental Evaluation of Fog Warning System, Transportation Research Board, TRB Annual Meeting CD-ROM*, Paper no. 002136, 2004.

Allweather Inc. "*Historic Large Program Experience*", July 2012, http://www.allweatherinc.com/home/large_program.html

An, M., Guo, Z., Li, J., and Zhou, T., "*Visibility Detection Based on Traffic Camera Imagery*". In: 3rd International Conference on Proceedings of the Information Sciences and Interaction Sciences (ICIS), 2010, pp. 411-414.

Andrey, J., B. Mills, M. Leahy, J. Suggett. *Weather as a Chronic Hazard for Road Transportation in Canadian Cities*. *Natural Hazards*, Vol. 28, 2003, pp.319-343.

Babari, R., Hautière, N., Dumont, É., Brémond, and R., Paparoditis, N., "*A Model-Driven Approach to Estimate Atmospheric Visibility with Ordinary Cameras*". *Atmospheric Environment*, Vol.45, No.30, 2011, pp. 5316-5324.

Babari, R., Hautière, N., Dumont, É., Paparoditis, N., and Misener, J., "Visibility *Monitoring using Conventional Roadside Cameras–Emerging Applications*". *Transportation Research Part C*: Emerging Technologies, Vol.22, 2012, pp. 17-28.

Bäumer, D., Versick, S., and Vogel, B., "*Determination of the Visibility using a Digital Panorama Camera*". *Atmospheric Environment*, Vol.42, No.11, 2008, pp. 2593-2602.

Boussard, C., Hautiere, N., and d'andrea-Novel, B., "Vehicle *Dynamics Estimation for Camera-Based Visibility Distance Estimation*". In: *IEEE/RSJ International Conference on Proceedings of Intelligent Robots and Systems,* 2008, pp. 600-605.

Busch, C., and Debes, E., "Wavelet *Transform for Analyzing Fog Visibility*". *Intelligent Systems and their Applications*, Vol.13, No.6, 1998, pp. 66-71.

Center for Urban Transportation Research, "*Evaluation of Motorist Warning Systems for Fog-Related Incidents in the Tampa Bay Area*" *University of South Florida*, p. 25, June 1997, http://www.cutr.eng.usf.edu/research/fog.pdf.

Chainey, S., and Ratcliffe, J. *GIS and Crime Mapping, John Wiley and Sons*, UK, 2005.

Chen, Z, Li, J., and Chen, Q., "*Real-Time Video Detection of Road Visibility Conditions*". In: WRI World Congress on Proceedings of the Computer Science and Information Engineering, 2009, pp. 472-476.

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

Cooper, B., Sawyer, H. *Assessment of M25 Automatic Fog-Warning System* - Final Report, *Transport Research Laboratory*, Old Wokingham Road, Crowthorne, Berkshire, Rg11 6au, United Kingdom, TRL Project Report, Issue Number: PR 16, IRRD Document Number: 858269, 1993.

Dahlinger, D. "*Tennessee Fog Detection and Warning System*," Public Works, presented at the Southern Rural Transportation Workshop, May 2001.

Dahlinger, D. and McCombs, B. *Fog Warning System Provides a Safety Net for Motorist*, Public Works, December 1995.

Fotheringham, S., Brunsdon, C., and Charlton, M. *Quantitative Geography: Perspectives on Spatial Data Analysis*. Sage, Thousand Oaks, CA, 2000.

Gimmestad, G., Daley, W., Carey, R., Moses, M., and Usher, C. *Georgia Automated Adverse Visibility Warning and Control System, GDOT Research Project* No. 9304, Final Report, September 2004.

Goodwin, L. *Best Practices for Road Weather Management*, Version 2.0, report no. FHWA-OP-03-081, May 2003.

Hagiwara, T., Ota, Y., Kaneda, Y., Nagata, Y., and Araki, K., "*Method Of Processing Closed-Circuit Television Digital Images For Poor Visibility Identification*". *Transportation Research Record: Journal of the Transportation Research Board*, Vol.1973, No.1, 2006, pp. 95-104.

Hallowell, R., Matthews, M., and Pisano, P., "An automated visibility detection algorithm utilizing camera imagery". In: 23rd Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology (IIPS), San Antonio, TX, 2007.

Hautière, N., Bigorgne, E., and Aubert, D., "Daytime visibility range monitoring through use of a roadside camera". In: IEEE Intelligent Vehicles Symposium, 2008, pp. 470-475.

Hautière, N., Labayrade, R., and Aubert, D., "Real-time disparity contrast combination for onboard estimation of the visibility distance". IEEE Transactions on Intelligent Transportation Systems, Vol.7, No.2, 2006a, pp. 201-212.

Hautière, N., Tarel, J.P., Lavenant, J., and Aubert, D., "Automatic fog detection and estimation of visibility distance through use of an onboard camera". Machine Vision and Applications, Vol.17, No.1, 2006b, pp. 8-20.

Hogema, J., and Horst, R. Evaluation of A16 Motorway Fog-Signaling System with Respect to Driving Behavior. *Journal of Transportation Research Board*, Vol. 1573, pp. 63-67, 1997.

Kidono, K., and Ninomiya, Y., "Visibility estimation under night-time conditions using a multiband camera". In: IEEE Intelligent Vehicles Symposium, 2007, pp. 1013-1018.

Kwon, T., "An automatic visibility measurement system based on video cameras". Publication MN/RC-1998-25. Minnesota Department of Transportation, 1998.

Kyte, M., Shannon, P., and Kitchener, F. Idaho Storm Warning System Operational Test, Final Report, ITD No. IVH9316 (601), NIATT Report No. N00-04, December 2000.

Layton, E.C., and Young, R. Effects on Speed of a Rural Variable Speed Limit System. Presented at the 18th World Congress on ITS, Octorber 2011, Orlando, Florida.

Liang, W., Kitchener, F., Kyte, M., and Shannon, P., The Effect of Environmental Factors on Driver Speed: A Case Study, *presented at Transportation Research Board, 77th Annual Meeting*, January, 1998.

MacCarley, A. Evaluation of Caltrans District 10 Automated Warning System, Cal Poly Transportation Electronics Laboratory, year one progress report, June 10, 1998.

MacCarley, A. Evaluation of Caltrans District 10 Automated Warning System, Year Two Progress Report, California PATH Research Report, UCB-ITS-PRR-99-28, August 1999.

Ozbay, K., Ozmen-Ertekin, D., Berechman, J. Empirical analysis of the relationship between accessibility and economic development, J. of Urban Planning and Development, Vol. 129, No.2, pp. 97-119, 2003.

Perrin J. Effects of Variable Speed Limit Signs on Driver Behavior during Inclement Weather," *presented at Institute of Transportation Engineers (ITE) Annual Meeting*, August 2000.

Perrin, J., Martin, P., and Coleman B. Testing the Adverse Visibility Information System Evaluation (ADVISE) – Safer Driving in Fog. *Presented at Annual meeting of the Transportation Research Board, TRB*, Paper no. 02-3140, 2002.

Pomerleau, D., "Visibility estimation from a moving vehicle using the ralph vision system". In IEEE Conference on Intelligent Transportation System, 1997, pp. 906-911.

Rockwell Transportation Systems, Anaheim, CA. Adverse Visibility Information System Evaluation (ADVISE), System Design Document, *Prepared for Utah Department of Transportation*, January 14, 1997.

Sabra, Wang & Associates, I-68 Fog Detection System Planning Report, Research and Innovative Technology Administration (RITA), U.S. Department of Transportation (US DOT), 2003.

Schreiner, C. State of the Practice and Review of the Literature: Survey of Fog Countermeasures Planned or in Use by Other States, Virginia Tech Research Council, October 2000.

Shinar, D., J.R. Treat, S.T. McDonald. The Validity of Police Reported Accident Data. Accidents Analysis and Prevention, Vol. 15, Issue, 3, pp. 175-191, 1983.

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

Tennessee ITS State Status Report, "Fog Project on I-75 between Chattanooga and Knoxville," October 2000, www.its.dot.gov/staterpt/tn.htm.

U.S. DOT, "Mobile, Alabama Fog Detection System," Intelligent Transportation Systems (ITS) Projects Book, FHWA, ITS Joint Program Office, 2001.

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

Xie, L., Chiu, A., and Newsam, S., "Estimating atmospheric visibility using general-purpose cameras". Advances in Visual Computing, Vol.5359, 2008, pp. 356-367