Evaluation of Motorist Warning Systems for Fog-Related Incidents in the Tampa Bay Area

prepared by
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The opinions, findings, and recommendations expressed in this report are those of the Center for Urban Transportation Research (CUTR) and the University of South Florida and not necessarily those of the Florida Department of Transportation. This report has been prepared in cooperation with the Florida Department of Transportation-District VII Office, in fulfillment of ENC No. ESC-DOT-96/97-7007-TO, Journal Trans. 49-20-2-655006-489007-0050, and CUTR Account No. 21-17-255-L.O. CUTR Principal Investigator has been Michael C. Pietrzyk (ITS Program Manager), with assistance provided by Patricia A. Turner (Research Associate), Sandra L. Geahr (ITS Program Assistant) and Ramakrishna Apparaju (Graduate Research Assistant).

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Executive Summary

In February 1997, the Center for Urban Transportation Research (CUTR) was retained by the Florida Department of Transportation-District VII Office to conduct a four-month investigation to determine: (1) the extent of unique and recurring patterns of fog and fog-related incidents in the Tampa Bay area (defined as Hillsborough and Pinellas counties), and (2) suitable countermeasures to detect and warn motorists of fog conditions.

The Tampa Bay area typically has about 22 "heavy fog" days annually when visibility is 1/4 mile or less. Comparatively, the foggiest location in the U.S. is located at Cape Disappointment, Washington, with 106 heavy fog days per year. Fog tends to form on clear, cool nights when moist air accumulates just above the ground or water. Light winds mix this shallow air to form condensation, which dissipates as the sun rises. This condition generally tends to occur between December and February in the Tampa Bay area. However, fog prediction is difficult because of the variability in density, location, development and dissipation rates, and area of coverage at a given point in time. Indeed, according to the National Weather Service in Ruskin, there is no favorite location for fog to form in the Tampa Bay area. Thus, only the typical "fog season" can be identified.

Between 1987-1995, 829 fog-related crashes were reported in the Tampa Bay area and 6,323 statewide. This represents 0.30 and 0.32 percent of the total reported crashes in Tampa Bay and the state, respectively. Crash report sites have been scattered throughout the Tampa Bay area, and, thus, historically, there have been no particular fog-prone crash locations. Over the last decade, Hillsborough County has had a fog crash rate somewhat above the state average, while Pinellas County's fog crash rate has been well below the state's average. Hillsborough County has never been ranked higher than 16th, and Pinellas County has not ranked higher than 47th among all 67 Florida counties over this same period of time (see Appendix). Those drivers who are most likely to be involved in fog-related crashes in the Tampa Bay area are residents of the county where the crash occurs, driving passenger cars, between the ages of 20-29, driving during the a.m. commute hours and traveling on local and county roads in rural locations.

About 12 states have been formally engaged in detection and warning system evaluation related to fog, and several have invested $2-$4 million for integrated visibility/weather and motorist warning systems. However, the benefits for deployment of such systems have not been documented. Even though a recurring theme in all fog crash evaluations conducted by the states and National Transportation Safety Board recommends the development of a driver awareness campaign (to assure driver behavior is uniform in times of limited visibility), only California has

followed through in this endeavor.

This report recommends and describes a focused driver awareness campaign as the most cost-effective measure to reduce fog-related crashes, since the Tampa Bay area exhibits no particular fog-prone or fog-crash-prone areas. This awareness campaign should share information related to the fog season, fog crash history, and driving tips in fog.

II. Background

On December 27, 1996, at 11:30 a.m., a fog-related incident occurred on the Sunshine Skyway Bridge involving a 54-vehicle incident in both travel directions. This single event, although very uncharacteristic of historical fog-related crashes in the Tampa Bay area, piqued local interest and concern about fog detection and motorist warning systems that may be needed for the area (Hillsborough and Pinellas counties). Fog-related crashes, like crashes in general, are difficult to predict but may exhibit some tendencies associated with their occurrence. It has been generally concluded from National Transportation Safety Board (NTSB) investigations of major fog incidents that fog-related crashes result because drivers have not maintained uniform reduced speeds during times of limited visibility. However, just because drivers do not maintain uniform reduced speeds during periods of reduced visibility does not guarantee that a crash will occur. For example, according to FDOT, 5,700 total vehicles successfully crossed the Sunshine Skyway bridge in heavy fog conditions on the morning of the December 27th.

Dense fog is a threat to the safe and efficient operation of motor vehicles. Attempts are being made to prevent, abate, and disperse fog and to improve visibility and guidance through fog. Restricted driver visibility due to fog and its relationship to safe traffic operation, particularly on high-speed freeways, has been a national concern. However, it is important to note that in Florida, from 1987-1995, the percentage of fog-related crashes to all crashes was 0.32 percent.[1] This statistic includes only crashes where fog was the primary environmental contributing cause. According to 1994 FARS data, fog weather conditions existed in 1.6 percent of all fatal crashes nationwide. Compared to the1994 national average, Florida was 2.2 percent and South Dakota (having the highest percentage) was 5.0.[2] Although fog crashes account for a relatively small portion of all crashes, when fog was a contributing cause or the prevailing weather condition at

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1 Florida Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

2 1994 Fatal Accident Reporting System (FARS) Data, National Center for Statistics and Analysis.

the time of fatal crashes, they can involve many vehicles in a chain-reaction pileup which attracts much public attention. These poor visibility conditions increase stress on drivers and reduce their ability to react appropriately to sudden changes in roadway and traffic conditions.

Two very important aspects of fog crashes needed to be determined. First, the extent of unique and recurring patterns of fog and fog-related incidents in the Tampa Bay area were not fully documented. Second, suitable measures being utilized throughout the country to systematically and effectively detect fog and fog-related incidents and warn motorists in real-time of these conditions were not known. Consequently, the Center for Urban Transportation Research was retained by the Florida Department of Transportation-District VII Office in February 1997 to conduct a four-month investigation to determine a basic definition of these aspects.

III. Purpose

The purpose of this evaluation is to investigate and define the specific Tampa Bay area conditions for fog and fog-related crashes that may exist and recommend an area-wide plan based on these findings to ensure that drivers react more consistently and safely during times of limited visibility. This recommended plan will focus on the most appropriate techniques for detection, warning, and related driver education and awareness programs. This report is structured to address four primary questions:

(1) *What are the recurring patterns (if any) of fog and fog-related crashes in Tampa Bay?*
(2) *How does the rate of fog crashes in Tampa Bay compare with <u>other</u> Florida counties?*
(3) *What are other states doing (in general) to address fog-related incidents?*
(4) *Which countermeasure technique, or combination of techniques, would be justified for Tampa Bay given the findings of (1) and (2) above?*

IV. Meteorological Data Review

Fog is one of the most serious meteorological limitations to visibility. The extreme variability of fog, especially in its density and location, make it difficult for motorists to perceive and react quickly. Fog can affect both day and night driving conditions because light, both natural and manmade, is retro-reflected, (refracted and deflected by the water droplets of the fog) and will veil objects from sight. Fog is measured by visibility in mile, and is considered severe (or "heavy") when visibility is 1/4 mile or less. If this condition persists for at least several hours during the day, a heavy fog day is recorded. According to *TouchWeather Wisdom*, the foggiest location in the U.S. is located at Cape Disappointment, Washington, at the mouth of the Columbia River, with an average of 106 heavy fog days per year. Eastport, Maine is the foggiest area on the eastern U.S. coast with 65 heavy fog days annually. Elkins, West Virginia is the foggiest inland area in the U.S., with about 81 days annually with heavy fog. Many people assume that the San Francisco Bay area gets a lot of fog, but it averages only 18 heavy fog days a year (slightly less than the average for the Tampa Bay area at 22 heavy fog days a year).

Informal surveys conducted with the National Weather Service in Ruskin, Florida, and several local meteorologists provided the basic characteristics of fog and fog forms. Fog can be defined as a cloud in contact with the ground composed of tiny droplets of water or ice crystals. These droplets form spherical shapes, and their diameters may range from two to 100 microns. Fog usually forms in two ways: (1) by air cooling to its saturation point, and (2) by air parcels mixing with different temperatures and humidities.

There are four prevalent types of fog. The earth's radiational cooling produces ***radiation fog.*** It forms when drier air has overlain a layer of moist air near the ground during late fall and winter. The moist lower layer, chilled rapidly by the cold ground, quickly becomes saturated, and fog forms. When a high pressure system becomes stagnant over an area, radiation fog may form on many consecutive days. This fog is also known as "valley fog" because the cold, heavy air drains downhill and collects in low-lying areas. ***Advection fog*** is the fog that arises from the movement of humid air over a surface that is already cool. This type of fog is most prevalent in the regions of Pacific coasts, and the southern and central United States and tends to form over large grassy areas. ***Upslope fog*** forms when moist air flows up along an elevated plain, hill or mountain. ***Evaporation fog*** or ***Sea fog*** forms when cold air moves over warm water. When rain drops fall through into a cold layer, these rain drops will be under a high vapor pressure and the water from rain drops evaporate. When the cold air becomes sufficiently moist, fog forms. ***Sea fog*** is much thicker than advection fog and takes longer to dissipate when it comes off the warm gulf waters. Radiation, advection, and evaporation (sea) fog are all common to the Tampa Bay area.

Fog is something we have to learn to cope with. Basically, if we did not have cooler air masses (or cold fronts) moving over warmer land and water, fog would not form. The U.S. Air Force has experimented with fog dissipation on a small scale with silver iodine generators (which "rain-out" the air's moisture), but success of this project has not been documented. Also, large fans have been used to stir-up the air over small areas, but not on a larger scale. Consequently, when fog does form, real-time information on the presence and density of fog is necessary for effective traffic control. Presently, fog-related information is available from several sources. For example, the National Oceanic and Atmospheric Administration (NOAA) Weather Wire Service, using a national satellite-based information gathering system, collects and reports all types of weather data. Also, NOAA's Radio Network System offers routine weather information, including dense fog advisories, that reaches about 90 percent of the U.S. population.[3] It is interesting to note that for two days prior to the December 27, 1997 Skyway pileup, the U.S. Weather Service office in Ruskin, Florida had been predicted dense fog for Hillsborough and Pinellas counties. In the Tampa Bay area, hourly weather updates are provided on the Internet via the Florida Weather Center @ *http://www.weathercenter.com*, a free informational service provided by WFLA-TV News Channel 8 meteorologists. The National Climatic Data Center in Asheville, North Carolina collects detailed historical local climatological data from one collection point (Tampa International Airport) in the Tampa Bay area based on hourly averages for all days in the month and three-hour observation intervals for each day in the month.

Fog prediction can be very difficult because of the variability in density, location, development and dissipation rates, and area of coverage. According to the National Weather Service forecasters in Ruskin, "there is no particular favorite location for fog to form in the Tampa Bay area." Further, the National Transportation Safety Board (NTSB) has concluded that "although weather forecasts may alert authorities to the possibility of fog formation, they are not sufficiently accurate, comprehensive, or timely to predict that fog will form in a specific area."[4] Though meteorologists often can accurately forecast the initiation of conditions necessary for the formation of fog, the expected fog does not always appear, or it may appear under conditions that are not ideal for fog formation. WFLA-TV News Chief Meteorologist David Grant concurs with the National Weather Service and NTSB in their conclusions, but as previously stated, the ideal conditions for the formation of fog can be identified. Mr. Grant offers the following four-part "formula" for the most favorable conditions leading to the formation of fog:

(1) Air temperatures between 40-60 degrees F
(2) Sufficient moisture content (dew point close to air temperature, high relative humidity)

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3 "Reduced Visibility due to fog on Highway," NCHRP Synthesis 228.

4 "Special Public Hearing on Fog Accidents on Highways," National Transportation Safety Board.

(3)Calm to fairly light winds (less than 2 mph)
(4) Clear skies (since ground will radiate more readily)

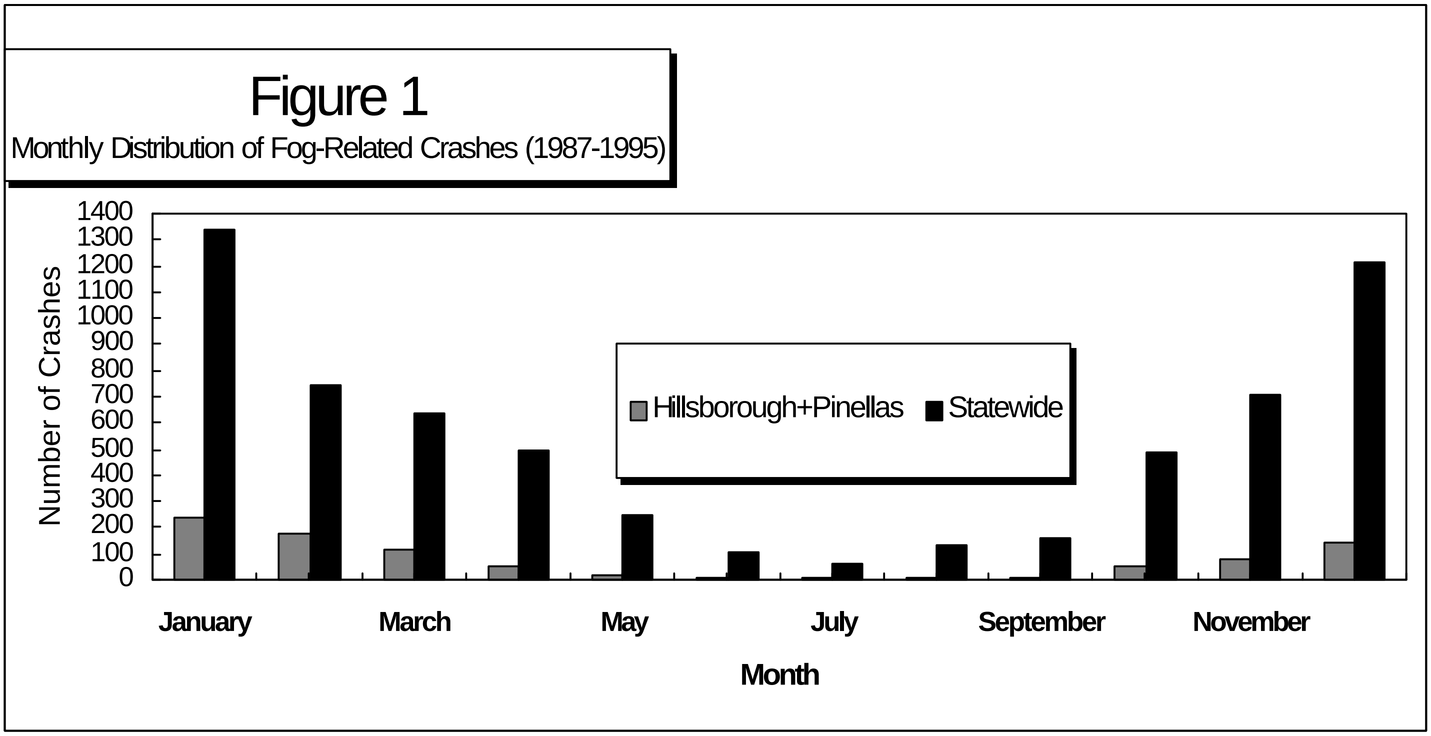
These conditions are generally known to simultaneously occur primarily during the months of December, January, and February. During these months, the Tampa Bay area generally has cool nights with little or no winds. This typical "fog season" for the Tampa Bay area can also be characterized by examining summary data from the National Climatic Data Center and Florida Department of Highway Safety and Motor Vehicles (DHSMV). Table 1 below summarizes average readings for climatological data (midnight - 7am) for eight selected days during the typical "fog season" when fog was recorded. The average of these values generally coincides with the previously mentioned ideal conditions for fog formation. Additionally, Figure 1 illustrates the monthly distribution of the fog-related crashes recorded by the Florida DHSMV for the period 1987-1995. Almost 60 percent (57.77 percent) of all reported fog-related crashes occurred during the months of December, January, and February. During the months of December and January alone, 43 percent of the crashes occurred.

Table 1
Selected Climatological Data
During "Fog Season"

DATE	AIR TEMP. (degrees F)	DEW POINT (degrees F)	RELATIVE HUMIDITY %	WIND SPEED (mph)	VISIBILITY* (miles)
Jan. 7, 1987	55.7	54.7	97	4.3	9.7
Feb. 15, 1987	58.3	58.0	99	3.7	10.7
Jan. 18, 1989	54.6	52.3	92	4.0	10
Dec. 20, 1990	67.3	67.3	100	4.3	7
Jan. 29, 1992	64.3	64.3	100	1.3	8
Feb. 13, 1992	49.0	49.0	100	1.3	7
Feb. 23, 1996	61.5	61.5	100	0	10
Dec. 27, 1996	61.0	60.0	96	3.7	10
AVERAGE	**58.9**	**58.4**	**98**	**2.8**	**9**

***** Visibility for the observation period prior to fog being recorded.
Source: National Climatic Data Center, Tampa International Airport, Asheville, North Carolina.

Figure 1
Monthly Distribution of Fog-Related Crashes
(1987-1995)



Source: Department of Highway Safety and Motor vehicles, Office of Planning Management Services, Traffic Crash Database

V. Crash Data Review

This section contains an overview of all motor vehicle crashes from 1987-1996 in Hillsborough and Pinellas counties in which fog was a primary contributing environmental cause of the crash. Data for the analysis were obtained from long-form crash reports contained in the Florida Traffic Crash Database and were provided by the Department of Highway Safety and Motor Vehicle (DHSMV), Office of Management and Planning Services. Crashes are recorded on a long-form and entered into the database only when they involve death, personal injury, driving while under influence of alcohol/or chemical/controlled substances, hit-and-run, or significant damage to the vehicle that requires removal from the crash scene. The inoperable vehicle requirement was dropped several years ago from long-form crash reports. For analysis purposes, 10 years of crash record data for Hillsborough and Pinellas counties were combined and frequency distributions were computed to identify crash, driver, vehicle, and roadway level characteristics. However, 1996 crash record data were incomplete due to the lag time between when the crash report originates at the local level and when that report is entered into the statewide Traffic Crash Database. As such, 1996 data were excluded from summary discussions. The following sections highlight the results of the data analysis.

Crash Data Analysis

This section contains information on the incidence of fog-related motor vehicle crashes, the number of fatalities and injuries, actions committed by drivers that contributed to the crash, the time of day that fog-related crashes are likely to occur, and the severity of crash and injury in fog-related crashes.

Fog-Related Crashes, Injuries and Fatalities:
Hillsborough and Pinellas Counties and Florida, 1987-1995

Statewide, 6,323 fog-related motor vehicle crashes occurred from 1987-1995. Of these crashes, 829 (13 percent) occurred in Hillsborough and Pinellas counties. Fog-related crashes peaked in 1989 when, statewide a total of 1,151 crashes were reported. That number dipped to 462 in 1991, the lowest number of fog-related crashes recorded during the nine-year period. Over that same period, 300 people were killed and 7,169 were injured on Florida's roadways in motor vehicle crashes in which reduced visibility (fog) was a contributing factor to the crash. Twenty-nine fatalities occurred in Hillsborough and Pinellas counties and another 812 people were injured. The overall percentage of fog-related crashes to all motor vehicle crashes in

Hillsborough and Pinellas counties is approximately equal to the statewide percentage over the nine-year period (0.30 percent compared to 0.32 percent). A summary of 1987-1995 fog-related crashes, injuries, and fatalities both statewide and in Hillsborough and Pinellas counties is shown in Table 2.

Table 2
Motor Vehicle Crashes, Fog-Related Crashes, and Crash Severity, Hillsborough and Pinellas Counties and Statewide, 1987-1995

	Hillsborough and Pinellas Counties					Florida				
Year	**Total number of all Crashes**	**Fog-Related Crashes**	**% Fog-Related Crashes**	**Fog-Related Crash Injuries**	**Fog-Related Crash Fatalities**	**Total Number of All Crashes**	**Fog-Related Crashes**	**% Fog-Related Crashes**	**Total Fog Related Injuries**	**Total Fog-Related Fatalities**
1987	**33,473**	**104**	**0.31**	**111**	**10**	**240,429**	**710**	**0.30**	**750**	**40**
1988	34,896	97	0.28	85	1	256,543	1,033	0.40	1,069	42
1989	33,990	150	0.44	149	2	252,439	1,151	0.46	1,282	43
1990	31,087	138	0.44	122	3	216,245	851	0.39	1,025	31
1991	28,680	41	0.14	39	5	195,312	462	0.24	573	31
1992	27,643	127	0.46	130	2	196,176	682	0.35	785	29
1993	27,639	69	0.24	63	1	199,039	463	0.23	549	33
1994	27,230	61	0.22	64	2	206,183	485	0.24	586	31
1995	32,990	42	0.13	49	3	228,589	486	0.21	550	20
Total	**277,628**	**829**	**0.30**	**812**	**29**	**1,990,955**	**6,323**	**0.32**	**7,169**	**300**

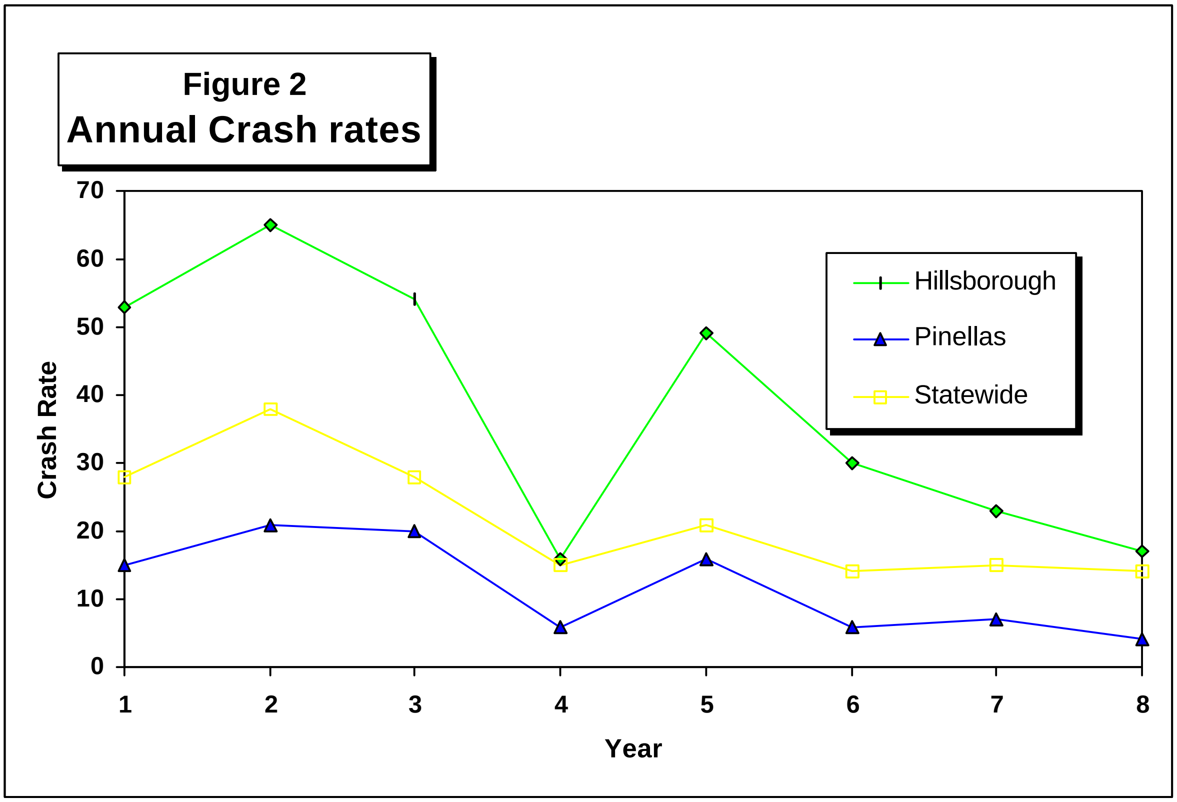
Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Two other key aspects of crash level data also have been summarized for purposes of this report: geographic location and rate. Hard copies of all fog-related crashes (1987-1996) were reviewed to depict each crash report site on a geographic base map. Only those crash reports with legible locations have been incorporated into Figure 2, Fog Related Crashes in the Tampa Bay Area. A total of 809 crash report sites were plotted on the map. Note that fog-related crashes over the last 10 years have occurred throughout the entire area and that there is no particular fog-crash-prone area. The scope of this evaluation did not include a comparison of the spatial distribution of fog-related crashes to all crashes. What appears to be clustering of crash sites (e.g., Plant City area, north along U.S. 41, Gandy Bridge) are crashes at different locations spread out over multiple years. These general areas can be utilized for future fog detection/ warning system evaluation.

Annual crash rates have been calculated per 10 million daily vehicle-miles traveled (VMT). Annual VMTs for all public roads, by county, were provided by FDOT's Transportation Statistics Office. Figure 2 illustrates the trend in this rate for the period 1987-1995 for Pinellas and Hillsborough counties compared to the statewide average. Hillsborough County has annually ranked above the statewide average, with its highest ranking reached in 1992 at 16th among Florida's 67 counties. The abrupt drop in the 1991 crash rate for Hillsborough County was due to a 71 percent drop in fog-related crashes with only a 10 percent drop in vehicle-miles traveled. On the other hand, Pinellas County has annually ranked below the statewide average, with its highest ranking also reached in 1992 at 47th among Florida's 67 counties.

Fog crash rate calculation sheets for all Florida counties, by year, are contained in the appendix of this report. One additional major finding can also be reached by review of these crash rate tables in the Appendix; with the exception of only two years, Hillsborough County has reported the greatest number of fog-related crashes in the state.

Figure 2
Annual Fog Crash Rates



Note: Crash Rate indicates the annual number of fog-related crashes per ten million daily vehicle miles traveled. Source: Florida Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database 1987-1995.

Driver Contributing Causes in Fog-Related Crashes

Although fog is the primary environmental contributing cause in these crashes, drivers often commit errors that also contribute to the crash. However, in 42 percent of the fog-related crashes, drivers were not issued citations for improper driving techniques (see Table 3). This is, in part, because law enforcement officers or other motorists must witness the infraction, which is extremely difficult under reduced visibility conditions. In crashes where drivers received citations, 19 percent contributed to the crash by driving carelessly, 9 percent failed to yield the right-of-way, and 5 percent exceeded safe speed.

Table 3
Most Common Driver/Pedestrian Contributing Cause* in Fog-Related Crashes, Hillsborough and Pinellas Counties, Florida, 1987-1995

Contributing Cause	Number of Times Cited	Percent Cause Cited
No improper driving/action	592	41.7
Careless driving	267	18.8
Failed to yield right-of-way	125	8.8
Exceeded safe speed limit	71	5.0
Other**	364	25.7
Total	1,419	100.0

*Drivers can be cited for more than one contributing cause.
**Other includes: improper backing, improper lane change, improper turn, alcohol - under influence, alcohol & drugs - under influence, followed too closely, disregarded traffic signal, disregarded stop sign, failed to maintain equipment/vehicle, improper passing, drove left of center, exceeded stated speed limit, obstructing traffic, disregarded other traffic control, driving wrong side/way and all other.

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Time

Table 4 shows all fog-related crashes that occurred in Hillsborough and Pinellas counties during 1987-1995 by the time of day when the crash occurred. Almost one half (48 percent) of the fog-related crashes occurred between 6 a.m. and 9 a.m., with the highest concentration of crashes occurring between 6 a.m. and 7 a.m. More than one-third (37 percent) of the fog-related crashes happened between midnight and 6 a.m. However, crashes during this time period tend to be more evenly distributed. Because the majority of fog-related crashes occur during the a.m. peak commute period, public service announcements (PSAs) promoting safe driving techniques in fog could be aired during this time.

Table 4
Fog-Related Crashes by Time of Day;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Time of Day	Number of fog-related crashes	Percent of fog-related crashes
Midnight to 2:59 am	146	17.6
3 am to 5:59 am	161	19.4
6 am to 8:59 am	399	48.1
9 am to 3:59 pm	25	3.0
4 pm to 7:59 pm	13	1.7
8 pm to 11:59 pm	61	7.4
Unknown	24	2.9
Total	829	100.0

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Crash Injury Severity in Fog-Related Crashes

Crash injury severity indicates the overall injury of the crash and is defined by the most severe injury to any person involved in the crash as perceived by the investigating officer. The crash injury severity for fog-related crashes in Hillsborough and Pinellas counties ranged from 37 percent of the crashes resulting in no injuries to 40 percent resulting in some type of non-incapacitating[5] or incapacitating injury[6]. Possible injuries[7] were noted in 20 percent of the fog-related crashes. A total of 24 (3 percent) of the crashes resulted in fatalities. Thus, some crashes resulted in more than one fatality. A summary of the crash injury severity in fog-related crashes is contained in Table 5.

5 Non-incapacitating injury is defined as any visible injuries such as bruises, abrasions, limping, etc.

6 Incapacitating injury is defined as any visible signs of injury from the crash and person(s) had to be carried from the crash scene.

7 Possible injury means no visible signs of injury, but complaint of pain or momentary unconsciousness.

Table 5
Crash Injury Severity in Fog-Related Crashes;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Injury Severity	Most Severe Injury	Percent of Total
No injury	304	36.7
Possible injury	166	20.0
Non-incapacitating	228	27.5
Incapacitating	107	12.9
Fatal	24	2.9
Total	829	100.0

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash database.

Driver Data Analysis

This section contains information on the age and place of residence of drivers involved in fog-related motor vehicle crashes.

Age

Table 6 shows the distribution of driver age groups involved in fog-related crashes in Hillsborough and Pinellas counties. Overall, younger and middle-aged drivers tend to be involved in fog-related crashes more often than older drivers. A total of 411 (33 percent) of the drivers involved in fog-related crashes were age 20 to 29 years, while 23 percent of the drivers were age 30 to 39 years. In part, over-representation among young and middle-aged drivers may be a function of the time of day fog-related accidents typically occur (e.g., peak a.m. school and work commute periods) and the general lack of driving experience in low visibility conditions. Thus, these results suggest that traffic safety education curriculum in high schools and universities might include instruction on safe driving techniques in reduced visibility conditions.

Table 6
Age Distribution of Drivers Involved in Fog-Related Crashes;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Driver Age Group	# of Drivers in Age Group	% Driver in Age Group
14 to 19 years	171	13.9
20 to 29 years	411	33.3
30-39 years	278	22.5
40-49 years	181	14.7
50-59 years	95	7.7
60+ years	84	6.8
Unknown	14	1.1
Total	1,234	100.0

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Residence Status

A total of 1,019 (83 percent) of the drivers involved in fog-related motor vehicle crashes were residents of the county in which the crash occurred (see Table 7.) These results indicate that most drivers were familiar with local roadways and conditions. It may be that drivers who are more familiar with roadway conditions drive less cautiously in adverse weather conditions. However, any correlation between roadway familiarity and driving habits under reduced visibility conditions cannot be assessed. These results do show that few drivers involved in fog-related crashes in Hillsborough and Pinellas counties are residents of other states or countries.

Table 7
Driver Residence Status in Fog-Related Crashes;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Place of Residence	Number of drivers	Percent of drivers
County of crash	1,019	82.6
Elsewhere in state	165	13.4
Non-resident of state	36	2.9
Foreign	6	0.5
Unknown	3	0.2
N/A	5	0.4
Total	1,234	100.0

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Vehicle Data Analysis

This section contains information on the type of vehicle involved in fog-related motor vehicle crashes and the movement of the vehicle when the crash occurred.

Vehicle Type

Table 8 contains a breakdown of the type of vehicles involved in fog-related crashes in Hillsborough and Pinellas counties over the past nine years. As expected, the largest percentage of vehicles (73 percent) in fog-related crashes were automobiles and passenger vans. These results reflect the higher percentage of registered automobile and passenger vans relative to other vehicle types. Approximately one quarter of all vehicles (22 percent) involved in fog-related crashes were trucks. Of the 267 trucks involved, 70 percent were pickup trucks and 30 percent were medium and large trucks.

Table 8
Type of Vehicle* Involved in Fog-Related Crashes;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Vehicle Type	Number of Vehicles	Percent of Vehicles
Automobile and passenger van	900	72.9
Light truck (pickup)	187	15.2
Other truck**	80	6.5
Motorcycle	21	1.7
Bicycle	14	1.1
Law enforcement vehicle	11	0.9
Bus	8	0.6
Motor home (RV)	5	0.4
Taxicab	4	0.3
Other	4	0.3
Total	1,234	100.0

*Modifications to vehicle category label were made in 1993: passenger car label changed to automobile; bus category collapsed to include public and private school buses, city transit, commercial, and other buses; recreational category to motor home (RV); truck categories added and defined as pickup/light truck (2 rear tires), medium truck (4 rear tires), heavy truck (2 or more rear axles) and truck-tractor (cab); and several extraneous categories were eliminated.
**Other truck total includes: medium truck, heavy truck, and truck tractor (cab).

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Vehicle Movement

The majority of vehicles involved in fog-related motor vehicle crashes were traveling straight ahead when crashes occur (see Table 9). Of the 1,234 vehicles involved in fog-related crashes, 68 percent of the vehicles were traveling straight ahead; 16 percent of the vehicles were slowing, stopping, or stalled, and 10 percent of the vehicles were turning left at the time of the crash.

Table 9
Movement of Vehicles Involved in Fog-Related Crashes;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Vehicle Movement	Number of Vehicles	Percent of Vehicles
Straight Ahead	834	67.6
Slowing/Stopped/Stalled	197	16.0
Making Left Turn	121	9.8
All Other	82	6.6
Total	1,234	100.0

*Other includes backing, making right turn, changing lanes, entering/leaving parking space, properly parked, improperly parked, making U-turn, passing, and driverless or runaway vehicle.

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Roadway Data Analysis

This section contains information on the type of roadway system where fog-related motor vehicle crashes occur as well as jurisdictional location where crashes tend to occur.

Type of Roadway System Where Fog-Related Crashes Occur

Table 10 contains a summary of the type of roadway systems where fog-related crashes are more likely to occur in Hillsborough and Pinellas counties. Most of these crashes tend to occur on county and local roads, the most frequently traveled roads within the counties. A total of 32 percent of the fog-related crashes occurred on local roads; 30 percent occurred on county roads. A total of 189 of the fog-related crashes (23 percent) took place on state roads.

Table 10
Roadway Type Where Fog-Related Crashes Occurred;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Roadway Type	Number of Crashes	Percent of Crashes
Local	267	32.2
County	246	29.7
State	189	22.8
Interstate	64	7.7
U.S.	41	4.9
Other	22	2.7
Total	829	100.0

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

Location of Fog-Related Crashes

Historically, crash location has been coded on the crash report as either rural or urban.[8] In 1993, an additional field was added to the crash report that defined the area as business, residential, or open country to more accurately reflect the environmental location of the crash. As Table 11 indicates that the majority of fog-related crashes (66 percent) in Hillsborough and Pinellas counties occurred in rural locations. An examination of the data from 1993-1995 shows that 43 percent of fog-related crashes occurred in areas considered to be primarily business locations and 32 percent occurred in residential locations. One-forth of the fog-related crashes during this period occurred in locations considered to be open country.

8 Rural indicates that the crash occurred outside the city limits or within the limits of a city with a population less than 2,500 population. Urban indicates that the crash occurred within the limits of cities and certain other police jurisdictions with populations greater than or equal to 2,500 population.

Table 11
Location of Fog-Related Crashes;
Hillsborough and Pinellas Counties, Florida, 1987-1995

Location of Crash	Number of Crashes	Percent of Crashes
	1987-1995	
Rural	549	66.2
Urban	280	33.8
Total	829	100.0
	1993-1995	
Primarily business	74	43.0
Primarily residential	55	32.0
Open country	43	25.0
Total	172	100.0

Source: Department of Highway Safety and Motor Vehicles, Office of Management and Planning Services, Traffic Crash Database.

In summary, the overall percentage of fog-related crashes to all motor vehicle crashes in Hillsborough and Pinellas counties from 1987-1995 was slightly less than the statewide percentage. In Florida, these crashes resulted in a total of 300 fatalities, 29 of which occurred in Hillsborough and Pinellas counties. In most crashes, drivers were not cited for any improper driving action that may have contributed to the crash. However, when driving actions contributed to the crash, the most-often-cited causes were careless driving, failure to yield the right-of-way, and excessive speeds. The majority of fog-related crashes in Hillsborough and Pinellas counties occurred between the hours of 6 a.m. and 9 a.m. with the greatest concentration of crashes occurring between 6 a.m. and 7 a.m. The crash injury severity for fog-related crashes in Hillsborough and Pinellas counties ranged from 37 percent of the crashes resulting in no injuries to 40 percent resulting in some type of non-incapacitating or incapacitating injury. Young and middle-age drivers are more likely to be involved in fog-related crashes; the largest percentage (33 percent) being 20 to 29 years old. The majority of drivers involved in fog-related crashes were residents of the county in which the crash occurred. More than 70 percent of the vehicles involved in fog-related crashes were passenger vehicles and vans, 22 percent of vehicles involved were trucks. Most fog-related crashes occur when the vehicle is traveling straight ahead on local and county roads in rural locations.

VI. Technologies

Visibility Detection

Tampa International Airport is the principal reporting station in the Tampa Bay for the National Climatic Data Center. The other general aviation airports and television stations in the area have minimal weather and visibility equipment. The Port of Tampa has one visibility sensor about five miles west of Egmont channel and seven meteorological sensors (temperature, atmospheric pressure, wind speed, and wind direction) positioned throughout Tampa Bay. There is also a rain detector on Clearwater Beach and wind monitoring equipment on the Sunshine Skyway Bridge. Therefore, the extent of visibility monitoring is conducted from only several point sources in the area, nothing within major travel corridor rights-of-way.

Real-time information on the presence and density of fog is important for carrying out countermeasures because any time gap between the onset of fog and the initiation of safety measures could be critical. Such information can be obtained by deploying fog and weather detection devices. Fog sensing devices have been in use at airports, waterways, and on some highways. There are three types of instruments available to measure visual range on a continual basis. These devices are readily available and have a wide price range. They are categorized as transmissometers, back scatter sensors and forward scatter sensors. Both forward and back scatter sensors can forecast the visibility conditions over a small volume of air, becoming "point detectors."

In a transmissometer, a projector transmits a known amount of light toward a detector usually set at a distance of about 1,000 feet away. Primarily used at airports, these instruments are costly, heavy, and require a long and accurate alignment. These instruments are not suitable for highway applications because of the problems involved in their installation. For example, source and receiver of a light source have to be placed in a clear line-of-sight (minimum of 1,000 feet apart) which cannot always be met on highways, and these devices are also very expensive, ranging from $10,000 to $15,000 each. The optics used in transmissometers also require frequent maintenance due to normal highway air quality environment.

In a back scatter sensor, the light source and receiver is pointed in the same direction and positioned in such a manner that light scattered back can be measured. A large amount of light scattered back indicates dense fog. Back scatter devices are one of the oldest technologies in this field and cannot differentiate among various poor visibility conditions like fog, snow, or rain drops.[9] Another disadvantage of this device is the variation in the amount and direction of back-scattered light.

The forward scatter visibility sensor is an active electro-optical instrument that determines visibility by measuring the optical extinction coefficient of a beam of light as it passes through a known volume of air. Particles in air such as fog, rain, or snow affect the extinction coefficient. This value is then transmitted to an external computer in its unaltered form or translated into an equivalent visibility in miles or kilometers. The sensor projects a beam of light into a receiver that measures fog and light scattered forward into a receiver is measured. Although new, this sensor is competitive in accuracy, reliability, and cost. Its lightweight, compact, easily mountable structure make it ideal for highway applications. The cost of these sensors range from $5,000 to $8,000.

The compact size and simple alignment requirements make the forward and back scatter sensors practical for highway applications. In these sensors, the source and the receivers of infrared light are placed at distances less than one meter apart thereby avoiding the line-of-sight problems. However, there are no established standards or precedents on the number of sensors required and ideal spacing configurations. This is primarily due to the limited information and evidence available on the formation of fog and its variability. It is known that fog is generally not "site specific" and varies from place to place. Thus, it is difficult to suggest specific guidelines on number and spacing requirements.

The information on fog can also be obtained by installing weather stations in fog-prone areas. Meteorology of fog shows that fog formation will be accompanied by some weather parameters like wind speed, temperature, humidity, and dew point. Weather stations equipped with day/night detectors, wind speed sensors, temperature/relative humidity sensors, rain gauges, and barometric pressure sensors provide information to monitor and forecast fog formation. These weather stations are also useful to correlate various weather parameters with the historical values, and, hence, it may be possible to arrive at ideal configurations for fog detectors. Closed circuit television (CCTV) cameras are also being utilized as a viable mechanism for monitoring and confirming adverse weather conditions.

Various facilities in United States have deployed or are deploying different types of fog detection devices, but, many areas are still relying on manual observation of fog. The Caltrans

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9 "Highway Fog: Visibility measures and Guidance Systems," William H. Heiss, NCHRP Report 171.

Meteorological System in the fog-prone Central San Joaquin Valley of California is equipped with high performance sensors and data acquisition equipment installed at nine separate locations. The device provides real-time weather and visual range data for a large monitoring area. They include remote sensor assemblies consisting of pavement sensors, forward scatter fog sensors, wind speed and direction detectors, barometric pressure recorders, rain gauges etc., and a central processing unit. A master computer uses the data to assess conditions and provide reports of special weather conditions to drivers within the monitored area.10 The cost of the entire project was more than $3.6 million ($1.32 million for California Department of Transportation CALTRANS and $2.35 million for California Highway Patrol CHP).11

Louisiana is relying on duty personnel to observe and monitor the highway facilities during fog and pass the information to control towers. However, a recent accident on a five-mile bridge on I-10 forced the LDOTD authorities to study the feasibility of fog detection and motorist warning technologies. Their study recommended not to install any detection technologies like fog sensors and cameras, estimated to cost about $330,000 and $500,000, respectively. Their recommendation was based on the maintenance, communication, and standardization problems they perceived. Their decision was also based on an FHWA evaluation study on sensor technologies indicating the discrepancies in their accuracy ranges. The LDOTD study also concluded that the best and most effective system would be to rely on law enforcement for fog detection.12

South Carolina installed weather monitoring equipment consisting of fog detectors and weather stations. The system resulted from a federal court action requiring the South Carolina Department of Transportation (SCDOT) to provide a plan for mitigating the effects of fog. The court action was a result of concern about the effects fog created by a paper mill near the Cooper River bridge in Charleston. (It could not be determined whether the paper mill was held liable for any mitigation costs.) The system is equipped with five forward scatter type fog detectors at 500-foot intervals. The system also has a weather station to detect wind direction, wind speed, temperature, and humidity. These devices provide information to a data recorder and a central computer to correlate the prevailing field conditions with a set of preselected parameters to determine the appropriate countermeasures of reduced visibility.

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10 User Manual on "Caltrans Meteorological System," Report 171, Qualimetrics, Inc., 1997.

11 "Strategies to Reduce Multi-vehicle Collisions During Limited Visibility Conditions," J.D. Walter, Caltrans, September, 1992.

12 Report on "Fog-Related Accidents," Louisiana DOT.

During 1960s, the New Jersey Turnpike Authority (NJTA) contracted with a private weather forecasting service to provide three daily forecasts and additional forecasts when foggy conditions are expected. For a short period of time during the mid 1970s, the turnpike opted for a laser system for fog detection. In the middle of the 1970s, the turnpike opted for a laser system. However, installation problems, coupled with components failure and difficulty in finding replacement parts, forced the turnpike to abandon the project. Instead, NJTA sought off-the-shelf detectors proven by other agencies and purchased two fog detectors and complete weather stations.13

In 1993, another fog detection and motorist warning system was installed on a river bridge on I-287 in New Jersey.14 The system developed for the 2,000-foot bridge was equipped with a forward scatter fog sensor known as Fog Sentinel™ FSA Series visibility sensor, designed specifically for highways. Built-in circuitry can activate warning instruments like signs and lighting systems. In the present case, it was designed to activate a light guidance system. The cost of the forward scatter sensor was about $5,600. However, the principal form of fog detection continues to be the personal observation by the State police.

The Idaho Transportation Department is continuing the development and testing of three types of sensors for measuring visibility and weather: Scanners, HANDAR, and LIDAR, provided by three individual companies. Scanner is provided by Surface Systems, Inc. The HANDAR system is provided by HANDAR Corporation and it includes one portable remote environmental monitoring system that measures weather condition, and one visibility sensor. Both Scanner and HANDAR are typical forward scatter detectors, and LIDAR is a laser-employed visibility detector provided by Santa Fe Technologies. The detector has a single visibility sensor and is incorporated with advanced laser technology recently developed at Los Alamos National Laboratories. The primary difference between LIDAR and Scanner or HANDAR is that the LIDAR system is capable of measuring visibility conditions over a large area. These sensors are used not only detecting fog but also other poor visibility conditions like snow, blowing dust etc., which are predominant in Idaho. HANDAR is considered the most cost-effective, and LIDAR uses the latest laser technology. The costs are expected to be around $15,800 for HANDAR and $75,000 and LIDAR.15

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13 NCHRP Synthesis 228.

14 Telephone conversation with Frank Dellarossa, FHWA Divisional Office, New Jersey.

15 Telephone conversation with Fred Kitchener, Project Manager, CH2M Hill, regarding Idaho study.

Following three severe chain reaction crashes (in 1978, 1979, and 1990) on I-75, Tennessee has developed a fog detection system. The I-75 system covers a 19-mile section of the highway identified as the fog-prone area. The system continually monitors the climatological and visibility conditions along the three-mile highway section with a history of severe fogging events. Eight forward scatter fog detectors integrated with two weather stations monitor visibility across the fog area. The weather stations measure temperature, wind speed, wind direction, and dew points. The information is processed by using the Management Information System for Traffic (MIST 2.0) developed by Farradyne Systems, Inc.

Climatological threshold criteria are being used to alert the operators in the central control center that a response is warranted.16 The system was set up to operate in four different pre-programmed visibility scenarios for operating variable message signs:

(1) clear--no visibility deterrent;
(2) moderate--moderate visual impairment;
(3) severe--severe visual impairment; and
(4) critical--critical visual impairment.

Depending upon the visibility scenario, various messages have been pre-programmed for displaying on variable message signs. The entire project cost about $4.5 million.

The Alabama Department of Transportation also is planning to install a fog detection system on a seven-mile flat sea bridge on I-10 near Mobile. This system will be equipped with seven forward scatter fog sensing devices and one weather station with several weather instruments that can detect wind speed, wind direction, temperature etc., These weather and fog detection devices will be integrated with other motorist warning technologies.17

The Georgia Department of Transportation and the Georgia Tech Research Institute are developing a fully-automated fog detection system along the heavily-traveled section of I-75 north of the Georgia/Florida border. The $3 million system is equipped with 19 forward scatter type fog sensors and several other types of weather monitoring devices including precipitation, wind, humidity, and temperature measuring instruments to monitor the visibility conditions over a 2-mile

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16 Telephone conversation with Dave Cox, FHWA Divisional Office, Tennessee, Florida.

17 Telephone conversation with Paul Watson, ALDOT Electrical Engineer.

section of the 13-mile long fog-prone section of the highway. The primary objective of these weather instruments is to detect the poor visibility conditions caused by conditions other than fog, such as smoke from agricultural burnings. These conditions are also used for study various weather parameters that contribute to fog formation. Information from these devices is sent via buried telephone lines and the system is also designed for transmission through fiber optics in the future.18 The fog sensors are expected to cost about $5,000 and the integrated weather stations under $6,000.

The problems of poor visibility conditions posed by fog are not limited to United States alone, and several European countries are also making efforts to counter the adverse impacts of foggy conditions. Project DRIVE in the Netherlands has proposed to install an integrated system of nephelometers to assess road visibility. The nephelometers measure the physical structure of the clouds, including their concentration, and the shape of cloud particles. PROMETHEUS' research program in Europe has developed a visibility monitoring system based on infrared laser beams (similar to the detector being tested in Idaho). The back scatter signals from the beam are processed to derive the visibility range. Motorway 25, which circles the city of London, is equipped with fog detection technologies to detect and forecast poor visibility conditions. The Automatic Fog Warning System (AFWS), equipped with backward scatter sensors, is designed to help drivers by providing real-time information on weather conditions.

Incident Detection and Motorist Warning

The National Transportation Safety Board believes that "the ITS program offers a unique opportunity to develop and carry out limited visibility traffic control measures. Traffic flow detectors, automatic message and vehicle speed control systems, and radar vehicle detectors to warn of preceding objects, such as other vehicles, are all appropriate candidates for ITS projects."19

Reports describing various accidents that have occurred due to poor visibility conditions in United States show that non-uniform driving speed is the most predominant cause of these accidents.20 They also show that drivers are observed to maintain different speeds and headways

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18 Telephone conversation with Dr. Gary Gimmestead, Georgia Tech Research Institute.

19 NCHRP Synthesis 228.

20 "Highway Accident Report on I-40 Crashes," Arkansas.

according to their individual perceptions about the conditions and risks, lacking any specific behavioral guidance or warning systems. Previous experiments also proved the fact that driver's reaction time improves significantly with the provision of warning signs.21 These warning systems could be either passive traffic control systems like fixed signs, raised reflectorized pavement markers, upgraded striping standards or active traffic control systems with variable message signs, surveillance systems, speed loops, closed circuit cameras. Currently within the Tampa Bay area, there are no incident detection systems. Changeable message signs are installed at three locations in each direction approaching the Sunshine Skyway Bridge. It is anticipated that a $2 million variable message sign system will soon be installed along I-275 approaches to Tropicana Field. Three surveillance cameras exist along State Road 60 east of I-75 and 13 cameras exist along the Sunshine Skyway Bridge. The City of Clearwater has one portable camera that is transported from site to site as needed. Plans exist in Hillsborough County for installation of surveillance cameras at nine north Tampa intersections in July 1997. Although not extensive at this time, the foundation for an area wide surveillance and motorist warning system is beginning.

Passive traffic control features like fixed signs are useful for less adverse conditions and also serve as a backup for active control features. Generally, fixed message signs are used to identify fog-prone areas. However, these signs may not be very effective, because the traveling public may consider them to be irrelevant since they represent the prevailing conditions only for a portion of the year. Another disadvantage of fixed signs is that they also may have to be flipped open manually during times of poor visibility.

An active motorist warning system is an integrated system of various technologies to perform different tasks. All these technologies can be operated, guided and controlled from a centralized traffic management center. Such technologies may include variable message signs (VMS), highway advisory radios, street lighting controllers, surveillance systems with CCTVs, lighted pavement markers (LPM), visual readout radars, barrier rail reflectors, and traffic flow measuring equipment.

These technologies can be integrated with visibility detection equipment and other systems like weather monitoring centers, integrated nephelometer, and knowledge-based expert systems, and can also be activated automatically from central traffic monitoring centers. It is also possible to classify the prevailing conditions into several classes, depending on the visibility conditions like

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21 "Highway Accident Report on I-40 Crashes," Arkansas.

potential fog, light fog, moderate fog, severe fog, critical fog, and, based upon the prevailing conditions, appropriate information can be flashed on VMSs. VMSs can also be used to inform drivers to tune to radios and other information sources to have an update on weather conditions, visibility standards, and road conditions.

Detailed information on road and prevailing visibility conditions can be provided through portable highway advisory radio (HAR) stations. The low-power A.M. band radios can be equipped with changeable and pre-recorded messages to describe the visibility conditions and guidance measures. Experiments have shown that variable message signs placed before HAR station alert motorists to tune to HAR. The HAR equipped with cellular capabilities (as being done in Tennessee) can be connected to a central management center so that appropriate messages can be transmitted according to the situation.

Real-time detection of traffic flow characteristics is important, not only for decreasing the delay on the freeway and city streets, but also in preventing secondary accidents.[22] It can be achieved by deploying flow interruption monitoring equipment like inductive loops, radar detectors, beacons, CCTV surveillance systems, video imaging, and magnetometer, etc.

Inductive loops are the most commonly used vehicle detector. However, the application of this detection method is not recommended for the facilities like bridges since it may cause some adverse effects on the bridge due to the installation of loops in the bridge deck.[23] Radar detectors are another type of device that can be used to measure traffic flow and speed. However, they need to be mounted over the lanes to get accurate information and this will require an extensive number of overhead structures. Video imaging is new technology developed for traffic detection. In this technology, computers are used to process the images produced by closed circuit cameras. This method can be used to monitor both vehicular flow and speed. However, these technologies are susceptible to failures during poor visibility conditions. Magnetometers are very useful for monitoring traffic flow on bridges by mounting them within and beneath the bridge decks.

Another device in the research and development stages that is useful to counter the problem of non-uniform driving speeds is visual readout radar. By using this system, the speeds

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22 "Highway Accident Report on I-40 Crashes," Arkansas.

23 "Fog Detection/Incident Management Feasibility Study," Parsons Brinckerhoff Quade & Douglas, Inc., Atlanta, Georgia.

being maintained by motorists can be flashed on the visual radar unit followed by a VMS showing the prevailing visibility conditions. It will also have a monitor to measure the speeds to figure out the effect of variable message signs.[24]

Surveillance systems like CCTV cameras can be installed on the roadways in the fog-prone areas to verify operation of the signs, weather conditions, and traffic incidents. Each site is equipped with cameras with zoom, pan, and tilt capabilities, along with encoding devices to convert an analog camera output into a digital signal for transmission over telephone lines. These systems are capable of providing the visual information necessary to select appropriate VMS and HAR messages, and early detection of visibility conditions and traffic flow characteristics may lead to reducing the number of accidents. The entire system, including camera manipulation, decoding equipment, and camera site transmissions, can be operated from a central traffic management center.

In the recent past, several other innovative operational measures such as the PACE Program, Trucks at Rest in Fog (TARIF), truck staging, truck metering, and truck convoying have been tested successfully.[25] The California Highway Patrol (CHP) conducted field tests with a special enforcement unit called the PACE team between November 1991 and February 1992. The CHP used six units for patrol during weekday commuting hours along a 44-mile freeway segment when the visibility was limited to less than 200 feet. Over the 4-month evaluation period, a total of 144 hours of CHP time was provided at a total cost of $235,000. In this measure, the patrol units entered the freeway at staggered on-ramps on the test section with flashing lights, not allowing the vehicles to pass. The officers selected the safest possible speed based on the prevailing visibility condition and paced the traffic at that speed before exiting the freeway and then re-entering in front of a different group of motorists to repeat the maneuver. The CHP authorities concluded that the presence of law enforcement vehicles resulted in a speed reduction and a decrease in the number of collisions. It was also noted that motorists began to call local media and traffic control centers to learn where the PACE team was working. Though the PACE has been tested successfully in California, it is difficult to conclude the efficiency of this measure from the limited information available, and it is also not clear how the officers were able to control the rush hour traffic on multi-lane highways.

Other operational measures like Trucks At Rest In Fog (TARIF) and truck staging involve

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24 NCHRP Synthesis 228.

25 "Highway Accident Report on I-40 Crashes," Arkansas.

encouraging truck drivers to delay or stop their trips during the fog periods voluntarily. For this purpose, staging areas were constructed at each end of the test station to “hold” trucks during periods of low visibility. Information on visibility, road conditions, and control measures was also provided through pamphlets and brochures at staging areas. Truck metering and truck convoying also were tested successfully as possible countermeasures for poor visibility conditions.

Various states in United States are engaged in analysis, design, and installation of several incident and motorist warning technologies. Leading advocate states are Alabama, Arkansas, Georgia, New Mexico, Oregon, Tennessee, Idaho, New Jersey, South Carolina, Louisiana, California, and Utah.

Alabama DOT is planning to install motorist system on a seven-mile sea bridge on I-10 in Mobile. This $3.4 million project will be equipped with an incident and motorist warning technology consisting of four new overhead variable message sign boards (two already exist), four CCTV cameras, 14 surveillance type cameras, 12 variable speed signs. All these components will be integrated with a control center that is already in place at the west end of bridge. VMSs are estimated to cost $941,000, speed signs about $24,000 each, CCTV cameras around $18,000 each, surveillance cameras are around $15,000 each. The operational costs are expected to be minimal, as most of the transmission equipment and control center with operators are already in place.

New Jersey has fog detection equipment connected to a light guidance system manufactured by 3M on I-287. This system includes a light guidance tube to illuminate a 2000-foot bridge on I-287. It is a delineation device that provides a visible line of light to guide drivers through road sections, especially at night or during poor visibility conditions. This system consists of ultraviolet stabilized polycarbonate tubes with an optical lighting film and follows the principle of “total internal reflection,” which allows a low voltage source to illuminate a 100-foot section of connected tubes. Multiple sections are linked together to give drivers a continuous illuminated delineation. The tube is activated automatically when the fog sensor detects that low visibility conditions are prevailing. The color of the tube can be changed easily by changing the filter contained in the system. The tubes also can be equipped to show different colors to drivers traveling in different directions. Typically, for a 2,000-foot section of a roadway, a light guidance systems cost about $25,000. These systems are being used in various states for a variety of purposes like steep curve negotiation, exit/entrance ramps, and construction work zones.

South Carolina has had an incident and motorist warning system in operation for about six years. This system was designed to monitor conditions on the Cooper River Bridge, advise the motoring public of adverse conditions, and direct corrective actions. The system has four primary components: passive traffic control features, active traffic control features, weather detection equipment, and a surveillance system. The main objective of the system is to provide enhanced guidance for traffic in the bridge area. This is accomplished by using passive traffic control features like fixed signs, upgraded striping standards, and raised reflectorized pavement markers. The active part of the traffic control includes lighted pavement markers, street lighting control, and a VMS system with eight VMSs. All these components are connected to a control center with fiber optics and are computer driven. Eight surveillance systems consisting of color, pan, zoom, and tilt CCTV cameras also have been installed. The conditions on the bridge fall into six classifications, and each condition has a programmed set of messages for the signs and directions to the different sections of the bridge.

The Idaho Department of Transportation is in the process of field testing a motorist warning technology that it gets activated automatically, once the visibility sensors detect poor visibility conditions. The addition of two more variable message signs to the existing (two) drum-type changeable message signs is being contemplated.

Tennessee also has a computerized incident and motorist warning system. This $4.5 million project encompasses a three-mile fog prone area of I-75 at the Hiwassee River crossing and eight-mile approaches on each side. Drivers are warned via one or more of the three HAR transmitters, 10 variable message signs, and 44 radar vehicle flow detectors. Thresholds in changes of speed and/or flow automatically activate control messages on the VMSs. On-site communication between system components is provided by buried optical fiber cables, and the data is transmitted by microwave through two repeater sites to the control center 40 miles away from the project site. No fatal or property damage accidents have been observed since the installation of the warning system in April 1995.

In Georgia, as previously mentioned, will be the one of the first fully-automated motorist warning systems in United States by the middle of 1997. This system is equipped with a network of 19 forward scatter fog sensors, 5 sets of highway-embedded speed monitoring loops to monitor traffic speed and volume, 4 changeable message signs, and several other weather instruments to measure precipitation, humidity, wind speed, and temperature. Two of the signs, which are 36 feet wide and 9 feet high, are installed over the traffic lanes. Two smaller signs, each measuring 16 feet wide by 9 feet high, are on the shoulder of the road. The latter could provide warnings to reduce speed or even provide detour instructions. These sensors, signs and speed-monitoring loops will be connected to the traffic control center in Atlanta through telephone cables and transmission can also be upgraded with fiber optic cables in the future. The signs can be turned on manually by the local Cook County Sheriff's office in Adel. The variable message signs are expected to cost about $110,000 each. The weather station with precipitation, humidity, wind, and temperature measuring instruments, may cost in the range of $5,000 to $6,000. The entire project is estimated to cost just under $3 million.

The Central San Joaquin Valley, which encompasses the Fresno area in California, is equipped with several incident and motorist warning features like portable changeable message signs, highway advisory radio, flow interruption technologies like CCTVs, weather stations, and fog detectors.[26] It has four remote processor assemblies consisting of pavement sensors, small weather stations with visibility sensors, and a processing unit in the Central Valley Traffic Operations Center (CVTOC). It also has incident loop detectors installed at 27 locations and four CCTV monitoring stations to verify the operation of variable message signs. The CCTV system provides the visual information necessary to select appropriate CMS and HAR messages without delay. Several operational measures such as truck staging, truck metering, and truck convoying have also been implemented. CALTRANS is also in the process of installing another fog and motorist warning system in the Stockton area. The proposed fog warning system will have field station/CMS (FS/CMS) sites, the substation (S/S) sites, and central computer with satellite terminal as its main components.[27] The nine FS/CMS sites will include CMS's, fog sensors, and communication devices. The communication system will consist of direct burial twisted pair communication cables. A personal-computer-based central computer center has also been planned for district headquarters in Stockton. This system detects reduced visibility conditions, and the vehicle detectors will detect the slowed/stopped traffic conditions without human input.

In a recent study done by Louisiana Department of Transportation and Development on the fog-related accidents occurring on elevated roadway sections of Louisiana, several incident and motorist warning technologies have been suggested to counter poor visibility conditions. This study recommended several countermeasures, covering more than 67 miles of elevated portions of roadways on I-10, I-55, I-310, and US-190. They included installation of variable message signs, use of advisory radios, installation of reflective raised pavement markers, and the installation of barrier rail reflectors on all bridge sections without shoulders under study. The total cost of the project is estimated to be more than $2 million. The study recommended installation of seven variable message sign, expected to cost $700,000. It also recommended the installation of raised reflective pavement markers at a cost of $21,120 per mile and the use of

26 Final Report on "Operation Fog" and NCHRP Report 228.

27 NCHRP Report 228.

barrier rail reflectors on the bridge sections at an estimated cost of $2,000 per mile at a spacing of 105 feet.28 The study also stressed the need to strengthen the public awareness campaign to improve the driving habits during poor visibility conditions.

An operational measure during heavy fog conditions is currently being applied along the 24-mile Lake Pontchartrain Bridge. The right lane only is used in each direction with police units escorting vehicle platoons from the front, rear, and middle.

Following an accident on Motorway 25 in conditions of patchy fog in 1984, the British Department of Transport installed an automated motorist and incident warning system to provide advanced information to drivers on the prevailing weather conditions. This system is equipped with several pre-programmed variable message signs. It is also noted that several other countries such as the Netherlands also have implemented a number of fog-related warning systems by using variable message signs, detection technologies, and surveillance technologies.

Summary

It can be concluded that several advanced technologies should be considered to mitigate the adverse visibility conditions posed by fog. However, the feasibility of advanced systems for automatic weather detection and motorist warning depends upon the characteristics of each location such as topographical features, roadway geometry, prevailing speeds, and extent and nature of recurring fog-related incidents. Benefits of investment versus effectiveness after installation have not been documented in the literature or from discussions with project participants. For purposes of this evaluation report, system components and associated costs have been summarized in Table 12, as compiled from other projects previously referenced in this report. This serves as guidance toward an "incremental approach" in technology application. In other words, if a particular area is found to be fog or fog crash prone in the future, then the effectiveness of a low-level technology application can be evaluated over time before significant investment is justified at a higher level (more elaborate combination of technologies). From bottom to top, this table can also be viewed as a hierarchy of technology deployment for areas of recurring fog-related incidents. For now, the Tampa Bay Area should carefully monitor the results of the I-75 fog detection and warning “prototype” system being deployed by the Georgia DOT before major investment in such systems is made.

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28 Louisiana DOT’s study on Fog-Related Accidents

Table 12
Fog Detection and Motorist Warning System Components

SYSTEM COMPONENT	ESTIMATED COST
Variable Message Signs	$75,000-$200,000 each
Variable Speed Signs	$15,000-$24,000 each
CCTV/Surveillance Cameras	$15,000-$18,000 each
Integrated Weather Stations[(a)]	$5,000-$6,000 each
Fog Sensors	$5,000-$8,000 each
Raised Pavement Markers	$21,120 per mile [(b)]

(a) includes precipitation, humidity, temperature, and wind measuring instruments.
(b) assumes 5 ft spacing along edge lines and 10 ft spacing along centerline for 2 lanes.
c) all costs have summarized from previously referenced reports, 1992-1996.

It is believed that technologies probably cannot provide effective solutions if problematic locations are dispersed and scattered. According to the Louisiana Department of Transportation and Development, "The state can provide detection, warning, and guidance technologies, but much of the responsibility must be placed on the motorists to adjust their driving habits to the environmental conditions. Without the motorists changing their driving habits during times of reduced visibility, these accidents will continue resulting in some catastrophic accidents at some time."29

VII. Driver Education and Awareness Techniques

Driver perceptions and responses are important during conditions of poor visibility because poor visibility conditions complicate driving tasks. Driver problems in fog include: restricted visibility; speed election beyond available visibility; over response to changes in vehicle speeds; sudden lane changing; and lack of knowledge on poor visibility crashes.

29 Louisiana DOTD's study on fog.

The National Transportation Safety Board (NTSB) has noted that, in many chain type fog-related crashes, various investigating agencies have attributed the cause to "Driver error." An example of one of the most-observed driver errors related to fog accidents have been "driving too fast for conditions." There are, of course, examples in which drivers travel at 60 mph under zero visibility conditions fully aware of the hazards and willing to assume risks. This is not driver error but rather a disregard of rights and safety of others in the use of a highway. An example of a driver error is simply stopping on the traveled portion of the highway, thus creating the first link in a chain-type accident. Another example would be passing another vehicle without assured clear distance ahead.

One of the most serious problems concerning the drivers in limited visibility is choosing a safe speed. The NTSB determined that the one main cause of poor visibility crashes is the non-uniform response of drivers and concluded that drivers tend to operate at significantly varying speeds. Several highway accident reports pointed out that, as the drivers approach and enter the fog area, they react in different ways. Some drivers may reduce their speed, some may turn on headlights and/or warning flashers, and others either may adopt a wait-and-see attitude before entering the fog area. Although the travelers could see the fog surrounding the highways, they may perceive risks differently and pursue their journey, lacking specific behavioral guidance.30

Very few studies have been done on driver behavior during poor visibility conditions. A 1967 study concluded that in poor visibility conditions mean and 85th percentile speeds would reduce by 5-8 mph, but it also observed that some drivers proceed at speeds higher than posted speeds. The posted speeds were observed to have significant impact on speed variations, however, posted speeds less than 35 to 40 mph had little impact on the speed reduction.31 Another study done in Oregon indicated that lower visibility conditions result in lower speeds, and this study also emphasized the importance of signing in advance of the fog and also in the fog area. A questionnaire survey concerned with driving habits performed as part of the survey indicated that, 46 percent of the drivers preferred to follow another vehicle in fog, 29 percent preferred to follow pavement markings, and 5 percent of the drivers indicated their preference to pull off the road and stop their trip.32

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30 "Highway Accident Report on I-40 Crashes," Arkansas.

31 NCHRP Synthesis 228.

32 "Speed Advisory Information for Reduced Visibility Condition," Report No. FHWA-RD-78-32, FHWA.

A vehicle speed analysis done in Idaho has been successful in answering two critical questions concerning driver-behavior in bad weather. The evaluation study done to test the Idaho storm warning system concluded that drivers indeed respond to poor visibility conditions by reducing their speeds, and the average drop in speed observed was about 10 mph. Another important observation from this study relates to non-uniform driving speeds. It concluded that the variability in individual vehicle speeds will be higher in poor visibility conditions when compared with normal conditions. These findings validate the observations made by NTSB on the aspect of non-uniform driving behavior.33

The problem of non-uniform driver behavior requires several measures to be taken to ensure that guidance for driving in limited visibility conditions be uniform and complete. The introduction of a warning system ahead of the initiation of a response serves to increase the time available for reaction. Previous studies revealed that drivers react 1.35 times faster to the anticipated stimulus than the unexpected stimulus (0.54 to 0.73 seconds).34 Another study showed that a warning signal with an optimal lead time of 200 milli-seconds could reduce reaction time by 50 milli-seconds.35 Though these studies signify the advantages of the presence of a warning system before a stimulus and response, there is no comprehensive evidence available to suggest that the provision of advance warning systems like speed signs, variable message signs, and highway advisory radios consistently lead to speed reductions. A 1979 study done in Oregon indicated that the installation of variable message signs may not result in speed reductions.36 Another Virginia study experimenting with pavement insert lights concluded that the improved delineation may indeed increase the potential for accidents with the increase in night time speeds.

The NTSB also found that most of the drivers involved in crashes due to fog lacked knowledge about whether they should leave or stay in their stopped vehicles. Unfortunately, none of the states outside of California associated with poor visibility crashes attempted to educate

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33 Phase 1 interim report on Idaho storm warning system ITS operational test, Idaho DOT.

34 "Drivers Brake Reaction Times," by G. Johansson and K. Rumar. Source: Highway Accident Report on I-40 Crashes, Arkansas.

35 "Facilitation and Inhibition in the Processing of Signals," by M.I. Posner and C.R.R Snyder. Source: Highway Accident Report on I-40 Crashes, Arkansas.

36 NCHRP Synthesis 228.

drivers in this area.37

In addition to electronically operated warning systems, extensive public awareness programs consisting of review and updating of remedial training material and driver license material are important in mitigating the poor visibility problems. Several highway accident reports previously referenced indicate the driver’s lack of caution as a reason for poor visibility accidents. However, the drivers involved in these crashes cited their lack of knowledge and lack of training in evasive procedures during fog conditions. Such low awareness problems can be solved largely with some well-coordinated public awareness campaigns. However, it is found that, among various states affected with poor visibility problems, California is the only state that is spending time and resources on public awareness campaigns. An example of one of California's public information brochures is noted in Figure 4.

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37 “Highway Accident Report on Corona Crashes, California.

Figure 4
California Public Brochure for Fog

-- Figure Not Available --

Public awareness strategies adopted by California include several elements like multi-lingual pamphlets, brochures, posters, and public service announcements (PSAs). A local Tampa Bay area example of a public awareness strategy is exemplified by the recent newspaper supplement entitled *1997 Hurricane Survival Guide,* sponsored by the Tampa Tribune, Radio Shack, and News Channel 8. This guide includes a storm tracking map, storm classifications, a survival checklist, and emergency management numbers. A similar guide could be developed for driving in fog and distributed during or just prior to the December-February fog season in Tampa Bay. Awareness programs in California have been designed to include information on general fog formation characteristics, fog and fog prone areas, and tips for driving in the conditions of poor visibility. These brochures and pamphlets were distributed through various agencies like highway patrols, trucking associations, truck stops, truck terminals, civic organizations, major employers, media outlets, automobile associations, insurance companies, local citizen groups, and special safety programs. Posters are designed for display at rest areas and truck stops to acquaint motorists with the measures to be taken in limited visibility conditions. Presentations have also been made to community groups and to trucking company officials and drivers.

The radio PSAs used sound effects like fog horns and police sirens to get the attention of listeners. News releases and press-conferences involving news papers, radio, and TV are the other media employed for carrying out public awareness programs. CALTRANS also made significant attempts to elicit the public perceptions and responses of the usefulness of the countermeasures implemented. By publishing a questionnaire in local newspapers, they obtained inputs from the traveling public on various countermeasures implemented such as fog pamphlets, VMSs, HARs, TARIF, and truck staging. The results from the survey indicated a favorable response rate of 80 to 92 percent, which is a clear indication of success of the countermeasures, however, fog pamphlets received only 53 percent favorable response rate.38 This has been attributed to the fact that the questionnaire published in newspapers was available to the residents of the entire valley, all of whom were not the targets of the fog pamphlet.

Drivers who do decide to venture out into heavy fog should be individually responsible for taking the necessary precautions to avoid collisions. As a start for public awareness, based on general information provided by the American Automobile Association and excerpts from a December 31, 1996, Tampa Tribune editorial, the following safe driving tips in fog are offered.

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38 NCHRP Synthesis 228.

Table 13
Safe Driving Tips in Fog

How to Drive in Fog

- *Consider delaying your trip, if at all possible, until the fog clears.*
- *Check weather forecasts before, and periodically during, trip making.*
- *Be patient; slow down.*
- *Use low beams, never just parking or fog lights and never emergency flashers when vehicle is in motion.*
- *Do not tailgate; leave safe braking space.*
- *Avoid slamming on brakes, except in an emergency.*
- *Minimize (or eliminate) lane changing, and signal turns if you must change lanes.*
- *Turn off music/radio and open windows to hear any trouble ahead.*
- *Avoid crossing traffic (i.e., try to avoid making left turns).*
- *Use wipers and defroster as necessary to maximize vision.*
- *If vehicle stalls or is disabled, move vehicle off travelway put emergency flashers on and move away from vehicle to avoid injury.*

VIII. Conclusions and Recommendations

Between 1987 and 1995, fog-related crashes represented 0.32 percent of total roadway crashes in the state of Florida. Within Hillsborough and Pinellas counties, fog-related crashes represented about the same proportion of total crashes (0.30) during the same period. Fog-related crashes for this period resulted in 300 fatalities statewide, 29 of which occurred in Hillsborough and Pinellas counties. Nationally, in 1994, the U.S. average for fog-related (weather condition only) fatal crashes only was 1.6 percent of total fatal crashes (2.2 percent for Florida in the same year). Based on this report, it has been determined that there are no particular fog-prone or fog-crash-prone areas in the Tampa Bay area. However, there is a fog season that occurs primarily between December and February. These are the months when heavy fog is typically reported for at least 3-4 days each month. The crash rate for fog-related crashes has been above the statewide average in Hillsborough County and below the statewide average in Pinellas County. Additionally, over the last 10 years, more fog-related crashes have been reported in Hillsborough County than any other county in Florida.

Leading advocate states in the installation of fog detection and motorist warning systems include Alabama, Arkansas, Georgia, New Mexico, Tennessee, Idaho, New Jersey, South Carolina, Louisiana, Oregon, Utah, and California. Several of these states have deployed $2-$3 million weather detection/motorist warning systems along specific travel corridors, but the benefits of these systems have yet to be documented. Common in all of the individual state reports examined was the recommendation to improve driver awareness for driving in fog (along with the technology applications to poor visibility mitigation). However, only California has actually invested time and funding toward a focused public awareness campaign, which has received positive public feedback. The National Transportation Safety Board has determined that the single greatest cause of poor visibility crashes is non-uniform response of the drivers. Further, a recently completed statewide fog crash evaluation study done in Louisiana concluded that “the state could provide warning and guidance technologies, but much of the responsibility for safety ultimately must still be placed on the motorists to adjust their driving habits during times of reduced visibility.”

In order to reduce fog-related crashes in an area with seasonal but scattered fog-prone and fog-crash-prone areas, a major investment in detection and warning technology would not be warranted at this time. Some minimal applications of low-level visibility enhancement and warning (raised pavement markers and/or variable speed signs) could be evaluated on an experimental basis for effectiveness in the most heavily-traveled corridors where fog crashes have occurred, only as uncommitted funding becomes available. A driver awareness program would be the most cost-effective countermeasure at the present time, given the aforementioned findings.

This report recommends that a very focused driver awareness campaign be initiated just prior to and during the fog season of December-February. Given the characteristics of fog-related crashes that have occurred over the last decade, it appears that this awareness campaign should be aimed at:

- Hillsborough more than Pinellas County residents,
- passenger car owners, between the ages of 20-29,
- driving during the morning commute hours,
- on local and county roads in rural locations.

Public service announcements, simple brochures describing driving tips in fog (see Table 13) and fog formation characteristics, and enhanced traffic reporting on radio and television highlighting current and historical fog information during the “fog season” would be most appropriate. Slowing down or delaying trip altogether would be of the more prominent messages to the public during heavy fog conditions. As they have for the “hurricane season,” the News Channel 8 weather team could be prominent in the PSAs. A monitoring aspect of the driver awareness campaign should also be included to determine effectiveness and trigger possible future detection/warning technology applications.

BIBLIOGRAPHY

Adverse Weather, Reduced Visibility Conditions, and Road Safety (a report on driving in reduced visibility conditions due to adverse weather), Organization for Economic Co-operation and Development, 1976.

Brisbane, G.J.B., "Driver Response to Fog Conditions: An Intelligent Approach," Pacific Rim TransTech Conference Proceedings, Volume 1, New York, NY, 1993.

Dahlinger, Don., "Fog Warning System Provides a Safety Net for Motorists," *Public Works*, Vol. 126, No. 13, 1995.

"Disaster on the Sunshine Skyway," *Tampa Tribune*, December 31, 1996.

"DOT considers Fog-Warning Systems," *St. Pete Times,* January 1, 1997.

"Driving in Bad Weather," video by American Automobile Foundation For Traffic Safety, 1994.

"Evaluation of M25 Automatic Fog Warning and Assessment Systems," Acer Consultants Ltd., Guilford, UK, 1993.

"Examination of Reduced Visibility Crashes and Potential IVHS Countermeasures," U.S. Dept. of Transportation, 1995.

"Fog Clouds Picture in Tampa Bay Area," *Tampa Tribune*, January 4, 1997.

"Fog shuts Skyway bridge during morning rush hour," *St. Pete Times*, December 31, 1996.

George, L.E., Hofstetter, D.K., and Wagner, D.R.. "Variable Message Fog Hazard Warning Signs to Control Vehicle Operating Characteristics," Report No. FHWA/OR-79/3, Oregon DOT, FHWA, Washington D.C., 1979.

Heiss, William H., "Highway Fog: Visibility Measures and Guidance Systems," NCHRP 171.

"Highway Accident Report on Multiple Vehicle Collision During Fog Near Milepost 118 on Interstate 40, Menifee, Arkansas, January 9, 1995," National Transportation Safety Board, Washington D.C., 1995.

"Highway Accident Report on Multiple-Vehicle Collisions During Limited Visibility (FOG) on Interstate 75 Near Calhoun, Tennessee, December 11, 1990," National Transportation Safety Board, Washington, D.C., 1992.

"Highway Accident Report on Multiple-Vehicle Collisions and Fire under Limited Visibility Conditions, Interstate Route 75 at Ocala, Florida February 28, 1983," National Transportation Safety Board, Washington, D.C., 1983.

"Highway Accident Report on Multiple Vehicle Collissions Under Fog Conditions and Fire, New Jersey Turnpike, November, 29,1969," NTSB, Washington, D.C., 1969.

Hinson, Joe, "Common Sense on Roadways," *Tampa Tribune,* January 5, 1997.

"How to Drive, A textbook for Busy Adults," American Automobile Association, 1993.

Idaho Storm Warning System IVHS Operational Test, Evaluation Plan, CH2M Hill, Boise, Idaho, 1993.

"Intelligent Transportation Systems: I-75 Fog Detection/Warning System," USDOT, FHWA.

"Interim Report on Reduced Visibility (fog) Study," California High Transportation Agency, 1965.

"I-526 Cooper River Bridge Surveillance and Response Plan," South Carolina Department of Highways and Public Transportation, June, 1992.

Moore, R.L. "Fog and Road Traffic," TRRL Report: LR 446, Transport and Road Research Laboratory, 1972.

McPhee, Ian J. et. al., "The Development of a Fog Potential Index for English Motorways," University of Birmingham, 1995.

"Pileups on Foggy Bridge Stall Bowl Trips," *St. Pete Times,* January 1, 1997.

Report on "Highway Visibility Conference," November 6-7, 1996, Huntsville, Alabama.

Sayed, Tarek, and Zein, Sany, "General Review of Advanced Technologies," G.D. Hamilton Associates Consulting Ltd., British Columbia, Canada, 1995.

Shannon, Patrick, et. al., "Idaho Storm Warning System ITS Operational Test Phase 1 Interim Report," Idaho Department of Transportation, 1997.

Shepard, Frank D., "Reduced Visibility Due to Fog on the Highway," *NCHRP Synthesis 228,* Transportation Research Board, 1996.

"Special Public Hearing: Fog Accidents on Limited Access Highways," National Transportation Safety Board. Washington, D.C, 1992.

"Special Study: Reduced Visibility (fog) Accidents on Limited-Access Highways," Report No. NTSB-HSS-72.4, National Transportation Safety Board, Washington D.C, 1972.

Strahler, Arthur N., *Physical Geography,* Third Edition, John Wiley and Sons, Inc, 1968.

"Touch Weather Wisdom," The Wisconsin Weather Team, News Channel 4, Jan. 7, 1997 and May 28, 1997.

"Troopers, Fog Shut Down Sunshine Skyway," *Tampa Tribune,* December 31, 1996.

User's Manual on "Caltrans Meteorological System," Report 171, Qualimetrics, Inc, 1997.

Wagner, D.R., and Hofstetter, D.K., "Speed Advisory Information for Reduced Visibility Conditions," Report No. FHWA/RD-78/32, Oregon DOT, FHWA, 1978.

Walter, J.D., "Strategies to Reduce Multi-vehicle Collisions During Limited Visibility Conditions," Caltrans, September, 1992.

White, M.E., "Some Aspects of Motorway Traffic Behavior in Fog," TRRL Laboratory Report 958 0305-1293, Highway Traffic Division, Traffic Engineering Dept., Transport and Road Research Laboratory, 1981.

APPENDIX
(Crash Rate Tables, by County, by year)

Fog-Related Crash Rates by County 1987

County	No. of Crashes	Daily VMT	Crash Rate	Rank
Okeechobee	10	682601	146	1
Hendry	8	651878	123	2
Hardee	6	494874	121	3
De Soto	6	555139	108	4
Lafayette	2	206321	97	5
Nassau	13	1525519	85	6
Franklin	2	258190	77	7
Gulf	2	291976	68	8
Putnam	9	1341373	67	9
Hamilton	6	983136	61	10
Polk	50	8385847	60	11
Calhoun	2	335690	60	12
Suwannee	6	1049347	57	13
Clay	9	1581595	57	14
Charlotte	10	1781472	56	15
Collier	13	2406491	54	16
Glades	2	374968	53	17
Hillsborough	**83**	**15600253**	**53**	**18**
Walton	6	1138312	53	19
Leon	19	3686637	52	20
Lee	33	6430265	51	21
Levy	4	800048	50	22
Marion	23	4635706	50	23
Bay	16	3326702	48	24
Wakulla	2	422593	47	25
Liberty	1	236322	42	26
Manatee	14	3357658	42	27
Hernando	7	1688787	41	28
Bradford	3	736055	41	29
Highlands	6	1582234	38	30
Union	1	273195	37	31
Alachua	17	4824145	35	32
Washington	2	568936	35	33
Martin	8	2331420	34	34
Seminole	13	3916420	33	35
Citrus	5	1513767	33	36
Indian River	6	1858022	32	37
Taylor	2	629963	32	38
Okaloosa	10	3185212	31	39
Lake	12	3889905	31	40
Orange	42	13668148	31	41
Columbia	6	1955262	31	42
Escambia	16	5324628	30	43
Baker	2	667572	30	44
Volusia	22	8247557	27	45
Sumter	4	1605073	25	46
Sarasota	14	5638916	25	47
St. Lucie	10	4100407	24	48
Gadsden	3	1245451	24	49
Madison	2	855333	23	50

Flagler	2	898633	22	51
Santa Rosa	4	1933942	21	52
Duval	33	16394810	20	53
Holmes	1	500118	20	54
Osceola	7	3515319	20	55
Palm Beach	28	14832587	19	56
Pinellas	**21**	**13800140**	***15***	***57***
St. Johns	4	2642941	15	58
Brevard	11	8242594	13	59
Pasco	4	3243893	12	60
Jackson	1	1686231	6	61
Dade	14	28101096	5	62
Broward	10	22826462	4	63
Dixie	0	363284	0	64
Gilchrist	0	182294	0	65
Jefferson	0	635506	0	66
Monroe	0	1867590	0	67
Statewide	***710***	***254424763***	***28***	

Fog-Related Crash Rates by County 1989

County	No. of Crashes	Daily VMT	Crash Rate	Rank
Glades	8	326795	245	1
Hendry	11	651169	169	2
Baker	12	718742	167	3
Calhoun	7	443225	158	4
De Soto	9	574436	157	5
Hardee	8	512535	156	6
Okeechobee	12	781532	154	7
Gilchrist	4	307757	130	8
Putnam	14	1472333	95	9
Levy	8	843770	95	10
Highlands	15	1637274	92	11
Collier	29	3237360	90	12
Lafayette	2	225804	89	13
Gulf	3	341968	88	14
Marion	47	5454837	86	15
Hernando	18	2188266	82	16
Taylor	6	736173	82	17
Clay	15	1884010	80	18
Charlotte	19	2389872	80	19
Lake	35	4467903	78	20
Bradford	6	770534	78	21
Polk	73	9930938	74	22
Union	2	293816	68	23
Leon	28	4228631	66	24
Manatee	28	4312109	65	25
Hillsborough	**118**	**18240154**	**65**	**26**
Holmes	4	618381	65	27
Citrus	11	1794073	61	28
Suwannee	9	1516866	59	29
Santa Rosa	12	2240260	54	30
Lee	31	6758543	46	31
Jefferson	3	669803	45	32
Duval	79	17806232	44	33
Wakulla	2	466605	43	34
Orange	68	16116021	42	35
St. Johns	13	3084291	42	36
Gadsden	6	1433521	42	37
St. Lucie	18	4459657	40	38
Walton	5	1372093	36	39
Pasco	17	4709485	36	40
Madison	3	835456	36	41
Bay	13	3803505	34	42
Liberty	1	306645	33	43
Seminole	18	5564142	32	44
Sarasota	25	7749347	32	45
Franklin	1	310489	32	46
Nassau	5	1612214	31	47
Columbia	7	2292346	31	48
Volusia	29	9858083	29	49
Washington	2	714714	28	50

Dixie	1	367362	27	51
Flagler	3	1140395	26	52
Palm Beach	44	16817134	26	53
Osceola	10	3911244	26	54
Alachua	13	5509249	24	55
Martin	9	3836676	23	56
Jackson	5	2153738	23	57
Indian River	5	2247661	22	58
Brevard	20	9558302	21	59
Pinellas	**32**	**15506420**	**21**	**60**
Hamilton	2	1019738	20	61
Escambia	13	6637017	20	62
Okaloosa	7	3619453	19	63
Sumter	3	1916866	16	64
Broward	36	24323526	15	65
Monroe	2	2447395	8	66
Dade	27	36580410	7	67
StateWide	***1151***	***300296907***	***38***	

Fog-Related Crash Rates by County 1990

County	No.of Crashes	Daily VMT	Crash Rate	Rank
Franklin	6	291562	206	1
Gilchrist	6	301535	199	2
Union	4	294209	136	3
Hardee	7	526497	133	4
De Soto	7	581286	120	5
Glades	4	336225	119	6
Dixie	4	359499	111	7
Gulf	3	316584	95	8
Gadsden	12	1485685	81	9
Okeechobee	6	765237	78	10
Calhoun	3	390859	77	11
Jackson	13	1879814	69	12
Holmes	4	606301	66	13
Walton	9	1407332	64	14
Wakulla	3	474087	63	15
Putnam	9	1489091	60	16
Polk	62	10533181	59	17
Clay	11	1871553	59	18
Jefferson	4	718809	56	19
Nassau	9	1643297	55	20
Hillsborough	**106**	**19461354**	**54**	**21**
Santa Rosa	12	2246782	53	22
Hendry	3	566269	53	23
Marion	29	5781833	50	24
St. Johns	15	3018008	50	25
Osceola	19	3933873	48	26
Citrus	9	1873858	48	27
Lake	20	4332491	46	28
Lafayette	1	226339	44	29
Taylor	3	721644	42	30
Suwannee	5	1224017	41	31
Leon	18	4514286	40	32
Sumter	7	1766290	40	33
Pasco	19	4811466	39	34
Manatee	16	4315522	37	35
Okaloosa	13	3635889	36	36
Columbia	8	2261342	35	37
Collier	12	3505960	34	38
Levy	3	877273	34	39
Lee	23	7447698	31	40
Highlands	5	1684994	30	41
Duval	53	17905725	30	42
Escambia	19	6518045	29	43
Alachua	16	5624521	28	44
Washington	2	710659	28	45
Hernando	6	2205603	27	46
Baker	2	739963	27	47
Flagler	3	1162810	26	48
Bradford	2	780952	26	49
Sarasota	16	6308932	25	50

Charlotte	6	2391213	25	51
Bay	8	3726430	21	52
Orange	35	16440085	21	53
Palm Beach	36	17353227	21	54
Pinellas	**32**	**15752525**	**20**	**55**
Hamilton	2	1021735	20	56
Volusia	18	9508494	19	57
Seminole	8	5510981	15	58
Madison	1	919051	11	59
St. Lucie	4	4390502	9	60
Broward	21	24831980	8	61
Indian River	2	2373019	8	62
Dade	21	35325747	6	63
Brevard	5	9447858	5	64
Martin	1	3234306	3	65
Liberty	0	296821	0	66
Monroe	0	2399598	0	67
Statewide	***851***	***301360612***	**28**	

Fog-Related Crash Rates by County 1991

County	No. of Crashes	Daily VMT	Crash Rate	Rank
Hendry	6	648774	92	1
Lafayette	2	225805	89	2
Gadsden	10	1541732	65	3
Glades	2	323916	62	4
Walton	8	1448518	55	5
Calhoun	2	378985	53	6
Hardee	3	602478	50	7
Santa Rosa	11	2435631	45	8
Flagler	5	1261301	40	9
Putnam	6	1522297	39	10
Marion	23	5928124	39	11
Clay	7	1868946	37	12
Escambia	24	6572564	37	13
Nassau	6	1673532	36	14
Jackson	7	1994192	35	15
Sumter	6	1725347	35	16
Gilchrist	1	325550	31	17
Duval	55	18249551	30	18
Gulf	1	333382	30	19
Lake	13	4395459	30	20
Washington	2	685103	29	21
Alachua	16	5715957	28	22
Bradford	2	742631	27	23
Okaloosa	10	3776347	26	24
Citrus	5	2075152	24	25
Suwannee	3	1248239	24	26
Osceola	9	3881489	23	27
Highlands	4	1758055	23	28
Madison	2	956898	21	29
Hamilton	2	1031558	19	30
St. Johns	6	3119708	19	31
Wakulla	1	540133	19	32
Polk	20	11063414	18	33
Seminole	10	5786962	17	34
Leon	8	4633070	17	35
Hillsborough	**31**	**19254192**	**16**	**36**
Taylor	1	634691	16	37
Collier	6	3848041	16	38
Bay	6	3924648	15	39
Charlotte	4	2631441	15	40
Jefferson	1	695542	14	41
Lee	11	7700618	14	42
Volusia	14	10295857	14	43
Pasco	7	5360426	13	44
Okeechobee	1	830960	12	45
Levy	1	865703	12	46
Orange	20	17632389	11	47
Columbia	2	2203788	9	48
Hernando	2	2256395	9	49
Indian River	2	2428417	8	50

Palm Beach	13	17227063	8	51
Pinellas	**10**	**16601716**	***6***	***52***
Brevard	5	10060598	5	53
Manatee	2	4744044	4	54
Dade	14	34742758	4	55
Sarasota	2	6329551	3	56
Broward	7	26217091	3	57
St. Lucie	1	4536705	2	58
Baker	0	729513	0	59
De Soto	0	588926	0	60
Dixie	0	361818	0	61
Franklin	0	294609	0	62
Holmes	0	625290	0	63
Liberty	0	298265	0	64
Martin	0	3334714	0	65
Monroe	0	2466222	0	66
Union	0	270150	0	67
Statewide	***462***	***310479341***	***15***	

Fog-Related Crash Rates by County 1992

County	No.of Crashes	Daily VMT	Crash Rate	Rank
Glades	9	410792	219	1
Union	3	230612	130	2
Hendry	7	719454	97	3
Nassau	15	1677810	89	4
Calhoun	3	361625	83	5
Jefferson	6	739795	81	6
Hardee	5	621076	81	7
Dixie	3	381218	79	8
Okeechobee	6	857366	70	9
Levy	6	905432	66	10
Highlands	12	1973713	61	11
Taylor	4	662826	60	12
Hernando	11	2020337	54	13
Suwannee	7	1286649	54	14
Polk	59	11336086	52	15
Hillsborough	**99**	**20047137**	**49**	**16**
Sumter	9	1896043	47	17
Clay	9	2044536	44	18
Washington	3	699151	43	19
Citrus	9	2193356	41	20
Baker	3	781403	38	21
Franklin	1	282293	35	22
Liberty	1	288751	35	23
Bradford	4	1159733	34	24
Gilchrist	1	295749	34	25
Holmes	2	642525	31	26
Alachua	18	6074230	30	27
Pasco	16	5609898	29	28
St. Johns	9	3252757	28	29
Marion	17	6186243	27	30
Putnam	4	1506063	27	31
Columbia	6	2313306	26	32
Duval	48	18879954	25	33
Charlotte	7	2812672	25	34
Lake	11	4424315	25	35
Leon	12	4899311	24	36
Lee	19	7884933	24	37
Santa Rosa	6	2516728	24	38
Jackson	4	1851219	22	39
Okaloosa	9	4165306	22	40
Manatee	10	4831785	21	41
Madison	2	966559	21	42
Gadsden	3	1552441	19	43
Wakulla	1	556355	18	44
Volusia	18	10225519	18	45
St. Lucie	8	4657839	17	46
Pinellas	**28**	**17105765**	**16**	**47**
De Soto	1	631416	16	48
Orange	28	18360611	15	49

Escambia	10	6871532	15	50
Sarasota	11	7632168	14	51
Walton	2	1508334	13	52
Palm Beach	25	18911103	13	53
Bay	5	3893764	13	54
Collier	5	4080262	12	55
Martin	4	3672318	11	56
Brevard	12	11314493	11	57
Osceola	4	3889617	10	58
Seminole	6	5839757	10	59
Indian River	2	2866438	7	60
Monroe	1	2455954	4	61
Dade	10	36395041	3	62
Broward	3	29502148	1	63
Flagler	0	1301684	0	64
Gulf	0	284665	0	65
Hamilton	0	1075510	0	66
Lafayette	0	228939	0	67
Statewide	***682***	***327504416***	***21***	

Fog-Related Crash Rates by County 1994

County	No. of Crashes	Daily VMT	Crash Rate	Rank
Hendry	7	700942	100	1
De Soto	5	633468	79	2
Gulf	2	318557	63	3
Glades	2	355557	56	4
Calhoun	2	391500	51	5
Bradford	4	795831	50	6
Wakulla	3	597884	50	7
Levy	5	1002806	50	8
Hardee	3	627115	48	9
Okeechobee	4	841576	48	10
Jefferson	3	717878	42	11
Union	1	245507	41	12
Walton	5	1514950	33	13
Holmes	2	647730	31	14
Highlands	6	1944986	31	15
Polk	35	11586205	30	16
Madison	3	1014015	30	17
Franklin	1	347450	29	18
Taylor	2	699700	29	19
Liberty	1	355367	28	20
Sumter	5	1832634	27	21
Jackson	5	1841448	27	22
Lake	12	4469406	27	23
Putnam	4	1593049	25	24
Charlotte	7	2821292	25	25
Marion	16	6458354	25	26
St. Johns	8	3415127	23	27
Hillsborough	**49**	**21088006**	**23**	**28**
Collier	8	3559098	22	29
Lee	17	8071495	21	30
Leon	10	4773808	21	31
Seminole	11	5346233	21	32
Osceola	9	4436319	20	33
Pasco	11	5434550	20	34
Duval	39	19277190	20	35
Volusia	21	10561983	20	36
Santa Rosa	5	2673204	19	37
Clay	4	2153132	19	38
Alachua	11	6069700	18	39
Orange	28	16207701	17	40
Flagler	2	1285099	16	41
Bay	6	3899492	15	42
Citrus	3	2198102	14	43
Gadsden	2	1524940	13	44
Nassau	2	1676988	12	45
Washington	1	838990	12	46
Baker	1	869176	12	47
Indian River	3	2762688	11	48
Manatee	5	5246388	10	49

Palm Beach	18	19534378	9	50
Hamilton	1	1120902	9	51
St. Lucie	4	4728665	8	52
Hernando	2	2473923	8	53
Martin	3	3752042	8	54
Suwannee	1	1357932	7	55
Pinellas	**12**	**16894401**	**7**	**56**
Okaloosa	3	4300163	7	57
Escambia	5	7202261	7	58
Brevard	6	10935375	5	59
Sarasota	4	7808506	5	60
Dade	14	36958924	4	61
Broward	11	30108847	4	62
Columbia	0	2545067	0	63
Dixie	0	393196	0	64
Gilchrist	0	323066	0	65
Lafayette	0	244101	0	66
Monroe	0	2830749	0	67
Statewide	***485***	***331237115***	***15***	

Fog-Related Crash Rates by County 1995

County	No. of Crashes	Daily VMT	Crash Rate	Rank
Glades	3	388187	77	1
Liberty	2	305116	66	2
Holmes	4	624780	64	3
Hendry	4	710088	56	4
Dixie	2	392614	51	5
Taylor	4	786278	51	6
Calhoun	2	393926	51	7
Leon	25	4993513	50	8
Madison	5	1053867	47	9
Putnam	8	1686740	47	10
Lafayette	1	243414	41	11
Highlands	8	2009257	40	12
Gadsden	6	1570543	38	13
Polk	44	11534111	38	14
Gulf	1	293114	34	15
Sumter	6	1902883	32	16
Gilchrist	1	328113	30	17
Marion	19	6676499	28	18
St. Johns	9	3378034	27	19
Jackson	5	1943340	26	20
Jefferson	2	778325	26	21
Lake	11	4583557	24	22
Columbia	6	2501862	24	23
Bradford	2	844608	24	24
Baker	2	874618	23	25
Alachua	14	6161361	23	26
Lee	20	9183722	22	27
Duval	41	20342563	20	28
Hamilton	2	1115324	18	29
Osceola	8	4512425	18	30
Citrus	4	2272181	18	31
Nassau	3	1768582	17	32
Hillsborough	**36**	**21552217**	**17**	**33**
Pasco	9	5741843	16	34
Hernando	4	2690880	15	35
Suwannee	2	1371751	15	36
Seminole	8	5976237	13	37
Flagler	2	1532526	13	38
Volusia	14	11214889	12	39
Walton	2	1718329	12	40
Orange	22	19349482	11	41
Washington	1	879605	11	42
Okeechobee	1	891036	11	43
St. Lucie	6	5617397	11	44
Okaloosa	5	4690926	11	45
Palm Beach	22	20736990	11	46
Charlotte	3	2975435	10	47
Clay	2	2328380	9	48
Bay	3	4031154	7	49
Santa Rosa	2	2714514	7	50

Sarasota	6	8365944	7	51
Dade	24	38732737	6	52
Manatee	3	5352045	6	53
Martin	2	3725531	5	54
Escambia	4	7461626	5	55
Brevard	6	11709809	5	56
Pinellas	**6**	**17021793**	**4**	**57**
Broward	11	31815456	3	58
Indian River	1	3289293	3	59
Collier	1	4157239	2	60
De Soto	0	609537	0	61
Franklin	0	367854	0	62
Hardee	0	593872	0	63
Levy	0	996606	0	64
Monroe	0	2942711	0	65
Union	0	259751	0	66
Wakulla	0	596037	0	67
Statewide	***486***	***350159975***	***14***	