Fog Detection for Interstate and State Highways

Prepared by

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16. Abstract

Fog is a common and recurrent phenomenon in West Virginia which is the cause of nearly 1.3% of all fatal crashes occurring all over the state. All three types of fog are common in the state which results in lack visibility, limited contrast, distorted perception, judgment errors, and reduction in headway and speed of the vehicle traveling in foggy conditions. State of West Virginia is suffering from lack of suitable fog detection and warning system along many of its arterials where fog is a major issue. The purpose of this project is to first determine favorable fog condition in terms of different meteorological components and introducing various forecasting tools which are utilized by different agencies in fog forecasting process. In addition, it has been tried to identify the critical fog prone areas across the state. These places might serve as the potential location for implementation of fog detection and warning systems. Also, a complete description of the available detection and warning system which are currently active across the country has been presented in this report to provide useful insight regarding these system's capabilities and effectiveness. Finally, through a simple benefit cost analysis justification efficiency of fog detection and warning system is demonstrated.

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1.0: Background

Sudden reduction in visibility conditions in highways caused due to fog, smoke and rain often lead to increase in crash levels (Abdel Aty et al, 2010). Effect of fog on drivers' safety and crashes has been heavily studied in the United Kingdom. Moore and Cooper, 1972 found that even though traffic reduced by 20% under foggy conditions, total number of crashes leading to injuries increased by 16%. Crashes occurring under foggy conditions frequently involve multiple vehicles (summer et al, 1997). A class example of this is the multi vehicle accident that occurred on I-68 near Big Savage Mountain in May 2003 (SWA, 2003). In West Virginia 1.3% of all crashes is due to fog. Table (1) shows the share of fog in total number of crashes in year 2003 for West Virginia.

Table 1 Share of fog in weather related crashes in WV for year 2003

Weather	Number	% Total
Clear	22,962	44.69%
Cloudy	15,323	29.83%
Raining	7,145	13.91%
Fog, Smog	678	1.32%
Snowing	4,166	8.11%
Sleeting	278	0.54%
Hailing	5	0.01%
Crosswinds	6	0.01%
Unknown	813	1.56%
Total	**53,376**	**100%**

Driving condition and visibility can deteriorate extremely rapidly under fog instances Inability to navigate the vehicle, limited contrast, distorted perception, judgment errors and reduction in headway and speed are the direct effects of driving in fog dominant conditions which compromise the safety of roadway commuters. Fog detection systems help identify conditions of limited visibility and forewarn the drivers before they encounter the fog. The warning system may be simple signs warning motorists that the freeway section is susceptible of to heavy fog or advanced ITS system such as Variable Message Signs (VMS) which provide warning messages or advisory information on recommended speeds. Active systems such as fog detection systems comprised of sensors to collect about weather, visibility, and traffic conditions in combination with motorist warning systems. In addition, there are several passive which help warn and delineate traffic such as delineators, reflectors, striping etc.

Study Objectives

This study will also summarize the components and factors that are crucial in fog development and formation. Furthermore, the results will be extended to identify the most critical fog prone areas across the states. In addition, in this report a detailed literature review is conducted to identify active and passive systems or products used for fog detection and motorist warning. The report will also provide detail information on current practice and methodology used by other state DOT's in dealing with the fog problem. The study performs a benefit cost analysis to provide insight on the economic efficiency of fog detection and warning system. Finally, the best recommendation is made for West Virginia in order to deal with the recurrent fog issue along the roadway.

Data Gathering Process

The information provided in this report has been collected through making several contacts with US DOT, State DOT's, FHWA, National Weather Service, Army Corps of Engineer, and several companies working in the traffic control and warning system area.

2.0: Fog

The international definition of fog is a collection of water particles that reduces visibility to below 1 km (National Oceanic and Atmospheric Administration, 1995). It is essentially a cloud that is near the earth's surface. Fog forms when the air temperature and dew point approach each other. This can happen by increasing the amount of moisture in the boundary layer or when warm air gets cooled to its dew point. The dew point is the temperature when gas becomes 100% saturated a state when gas condenses into water. Fog in West Virginia is very prevalent and can lead to reduced visibility on the roads and highways. Not only is reduced visibility the problem, but the lack of contrast with other cars and the environment makes people drive at higher speeds than they think they are (Vanderbilt 2008). Heavy fog conditions have resulted in multiple vehicle accidents. A serious multi vehicle accident occurred on I-68 near Big Savage Mountain in 2003. It was a chain reaction of vehicles crashing into one other, and a total of 90 vehicles were involved in the pileup.

2.1: Favorable Fog Conditions

If the air temperature and dew point are identical, this does not necessarily mean fog is going to form. For fog to develop there needs to be an inversion in the boundary layer. A temperature inversion is a layer in the earth's atmosphere where as the altitude increases, the temperature increases. This occurs when a warm front passes over a cold front because cold air is denser than warm air. An inversion is critical for fog to develop because it traps moisture (University Corporation for Atmospheric Research, 2004). If you don't have that inversion to trap the moisture, then the layers of the atmosphere just above that moist layer will mix with drier air and cause the fog to dissipate. There also needs to be a presence of condensation nuclei in the air. Condensation nuclei (also called aerosols) are tiny particles in the air such as dust, sea salt, volcanic ash, sand, etc. that are required for fog to form. Otherwise the air stays a gas even after reaching the dew point. A higher relative humidity is also conducive to fog formation because this increases the dew point and it's easier for air to cool to its saturation point. Moist soil not only aids in forming fog, but can prolong it because as the moisture in the soil evaporates, it allows for the temperature and dew point to converge more rapidly.

2.2: Types of Fog

There are three types of fog that can occur in West Virginia: upslope, radiation, and advection. Upslope fog occurs in higher elevations near hills and mountains when warm moist air is adiabatically lifted by light winds up the slope of a hill or mountain and gets cooled to its dew point (National Weather Service, 2007). Upslope fog can intensify a fog event that is dominated by an advection process. Radiation fog usually occurs during nighttime into early morning when during the day heat absorbed by earth's surface gets radiated back into the atmosphere. The air cools as night approaches and it condenses and forms fog. For radiation fog to form, there usually needs to be calm winds and clear skies (National Weather Service 2007). If there is too much cloud cover, it doesn't allow for solar radiation to escape and keeps the air warm. Clear skies allow for maximum cooling of the surface after sunset. If there is high wind speeds then this leads to mixing of air in the surface and higher in the atmosphere. Usually air higher in the atmosphere is drier and this mixing prevents fog from forming. Advection fog can form two ways. It can form when a cold air mass moves over a warm water surface which causes the water to evaporate into the air mass and increase the moisture. The other process forms when a warm air mass usually moves over a cold surface and the air mass gets cooled to its dew point. The surface can be a cool body of water or a snow pack. The latter is what is usually occurring in West Virginia. Advection fog is usually associated with light winds (4-7 m/s).

2.3: Fog Characteristics

Radiation fog occurs in lower elevations like the valleys and usually remains stationary. It tends to be localized and patchy and usually doesn't last very long. It usually forms late at night or early mornings. Advection fog often looks like radiation fog, but advection fog moves horizontally over a surface. Advection fog can form very thick layers in low pressure warm sector areas and is more susceptible to cover a larger area than radiation fog. It can form almost any time of day and can last for days. It is common during winter warm ups and early spring thaws when there is snow cover.

2.4: Fog Prone Areas in West Virginia

Most of West Virginia is affected by fog because of the changes in altitude where temperature inversions are common. In West Virginia some areas are of more concern due to fog. If the seriousness due to fog is just being based on the amount of fog days per year, areas west of the Allegheny Mountains called the Appalachian Plateau get about 30 fog days per year and areas from central West Virginia to southern Pennsylvania get about 50 dense fog days per year. In the Appalachian Valleys of West Virginia especially in the Monongahela National forest, cool overnight temperatures create inversions and deep condensation in the valley bottom causing fog to form 50 to 60 days a year (Burt 2007; Stroud 2007).

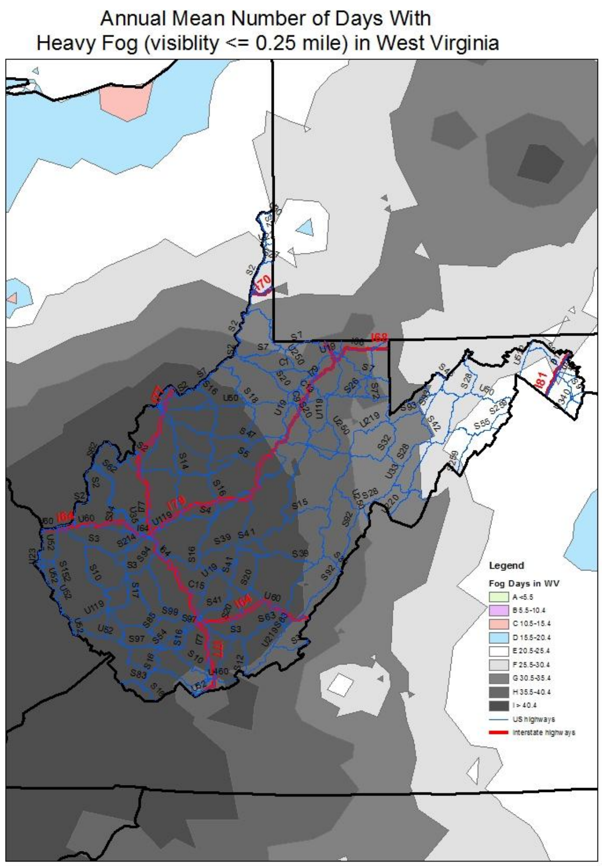


Figure 1 Map of fog areas by amount of days in United States (National Climatic Data Center, 2010)

Figure (1) illustrates annual days of fog in West Virginia and the major interstates and highways that could be affected by adverse driving conditions due to fog. In West Virginia, heavy fog occurs most frequently from June to October. Radiation fog is most likely occurring during these late summer months due to longer nights and relatively humid air masses. It must be noted that this data was collected from 1961-1990. There are five weather observation stations in West Virginia that report fog days. The stations are located at airports in Charleston, Beckley, Parkersburg, Huntington, and Elkins. They are mainly used in forecasting for aviation purposes. This data can be accessed at the state NWS website. Figure (2) shows the fog and heavy fog days (visibility < ¼ mile) for the five stations. The data is from Nov. 2010 to Oct. 2011. In addition we conducted a survey of DOH engineers in the various districts to collect information on fog prone areas in the state. The responses of the DOH personnel are summarized in the next section.

2.5: Local Fog Areas as Reported by DOH Personnel throughout State

"From what I have seen, the major fog areas in District Six (Hancock to Tyler County) encompass the roads that run in the Ohio River Valley. These major roads include all of WV 2 in the six counties, sections of I-470 & I-70 (in Ohio County), sections of US 22 (in Brooke County) and US 30 (in Hancock County)" (Wallace, District 6).

"We have several roads which can be considered fog problem areas. Cabell County, WV 2, from Huntington to the Cabell/Mason County Line. You can center in on the Green Bottom area of WV 2. US 52, WV 527, and WV 106 Bridges which cross the Ohio River in the City of Huntington. Mingo County, the whole length of the King Coal Highway. Wayne County, US 52. Nearly the whole length of the road runs parallel to the Big Sandy/Tug River " (Mantzel, District 2).

"Hello. I am Traffic Engineer for the WVDOH in District Eight. District Eight is comprised of four counties, namely Tucker, Randolph, Pocahontas and Pendleton. US Route 219 on Backbone Mountain in Tucker County is our worst area for driving in fog. Of particular concern is the 10 mile section of US 219 south of Thomas" (Morgan, District 8).

"I 79, Exit 91 – Major fog problem from Stonewall Jackson Lake, in early winter/spring, we have a lot of wrecks at this location due to freezing fog" (Hunt, District 7).

"The New River Gorge Bridge is the worst area that we have in Fayette County on US19" (Hypes, District 9).

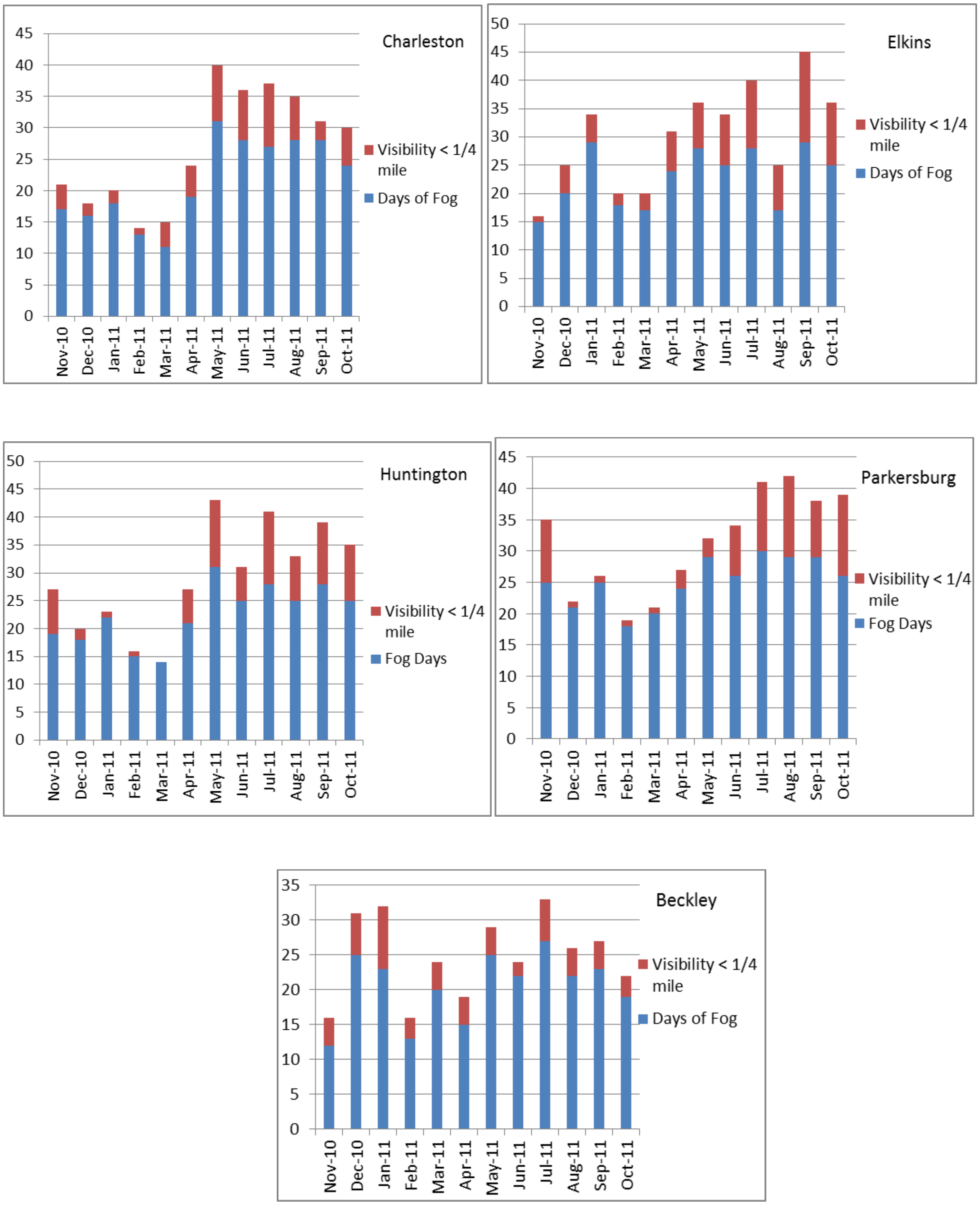


Figure 2 Fog days for West Virginia from 5 weather observation stations (National Weather Service 2011)

"I am the supervisor on Corridor L Section Two on US 19 we cover 208 lane miles of Expressway in Nicholas Co, part of Fayette Co, and part of Braxton Co we have an area known as Powell Mt on US 19 that has a lot of fog problems at times we also have a visibility problem during the winter with snow, I don't know if this will help you but it is a problem at times we use flexible delineators to mark the edge of the roadway, this helps some but they are constantly getting torn out and it is expensive to keep replacing them. Hope this is of some help to you; the mile post for this location is from 22 to 29" (Reel, District 7 and 9).

"One segment of roadway that comes to mind is WV Route 99 that runs from the junction of WV Route 3 at Glen Daniel in Raleigh County and terminates at the junction of WV Route 85 in Boone County, near the Wyoming County line. This is an approximately 10 mile stretch of road that crosses Bolt Mountain, which has an elevation of around 3700 feet where extremely dense fog conditions are very common, especially during nighttime hours and times of rain. The ADT is somewhere around 3000 vehicles per day which may be less than what you are looking for. Let me know if you have any questions or if I can be of further assistance" (Brown, District 10)

"I know of three areas that I'm aware of on US and WV highways in our Monongalia County road system. The areas are US 119 from the Taylor County line to Pine ridge road, The area of Kingwood Pike at the Preston County line to Upper Arrons Creek road, and the last one is WV 857 from Snake Hill to the Pennsylvania State Line. During cold wet weather the fog is pretty dense in these areas" (Weaver, District 4). Table (2) provides a list of possible potential fog prone areas across the state.

Table 2 Fog Prone Areas across WV by county

County	Highway or Interstate
Monongalia	WV 857
Tucker	US 219
Raleigh	New River Gorge Bridge
Wayne	US 52
Cabell	US 52, US 527, WV 106
Mason	WV 2
Lewis	I-79
Taylor	US 119
Grant	US 50
Hardy	Co. Rt. 220, Co. Rt. 55

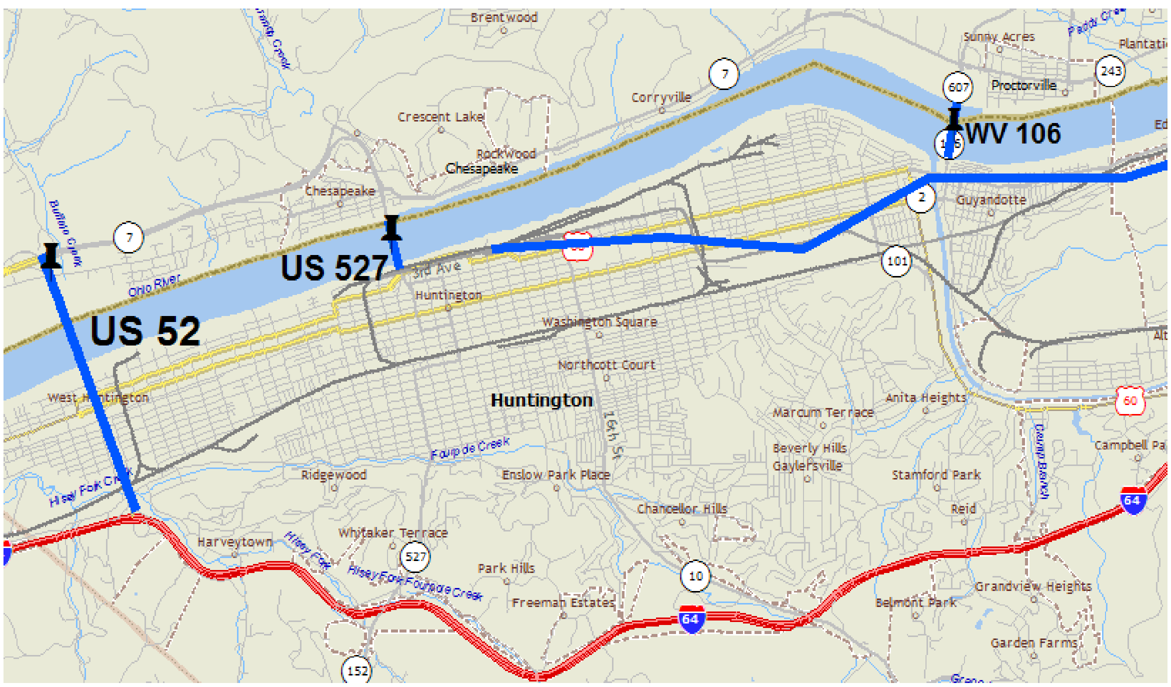


Figure 3 Cabell County US 52, US 527, WV 106

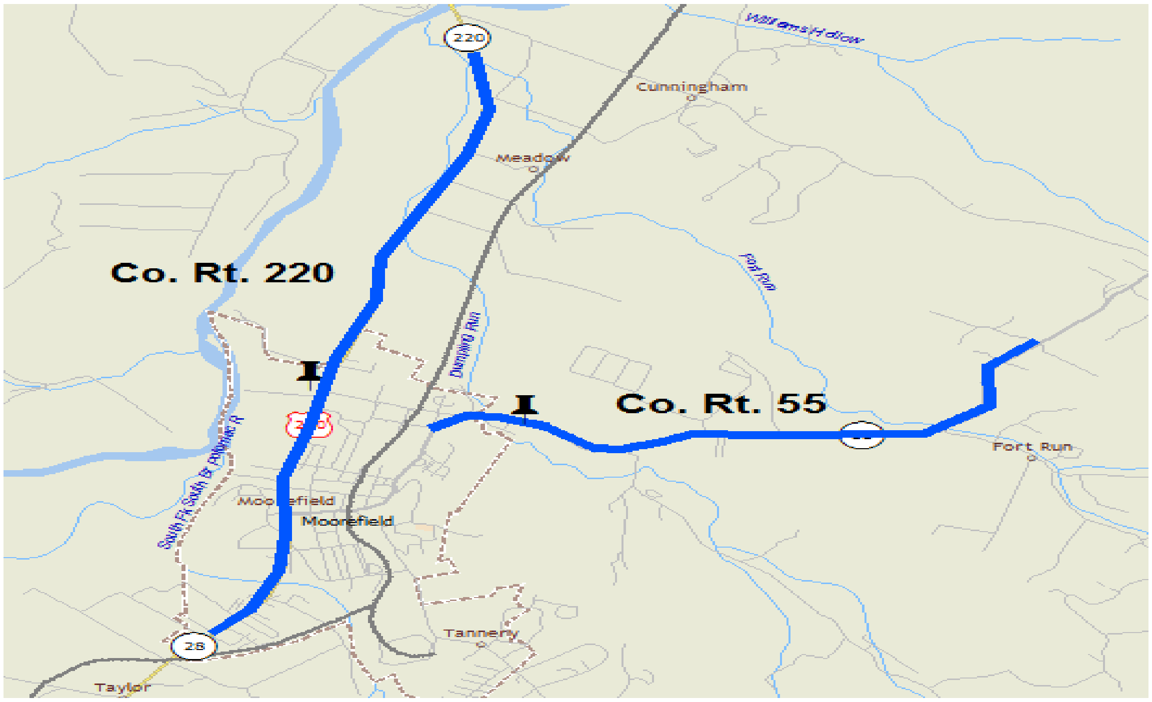


Figure 4 Hardy County, Co. Rt. 220, Co. Rt. 55

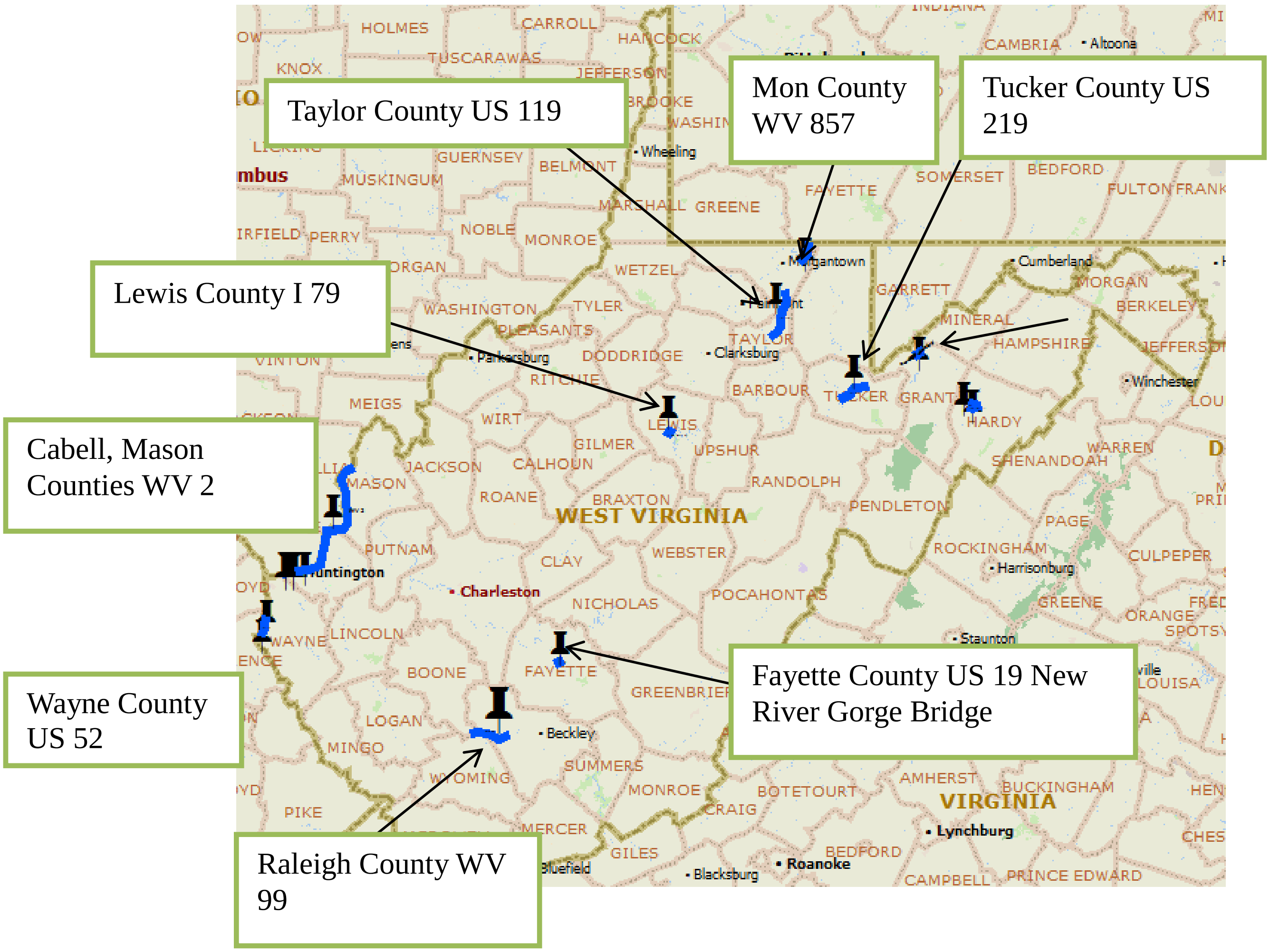
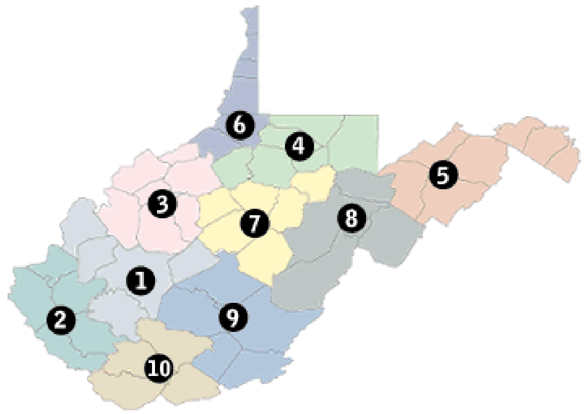


Figure 5 Fog prone areas by county across the West Virginia



DISTRICT 1 Boone, Clay, Kanawha, Mason and Putnam counties	**DISTRICT 6** Brooke, Hancock, Marshall, Ohio, Tyler and Wetzel counties
DISTRICT 2 Cabell, Lincoln, Logan, Mingo and Wayne counties	**DISTRICT 7** Barbour, Braxton, Gilmer, Lewis, Upshur and Webster counties
DISTRICT 3 Calhoun, Jackson, Pleasants, Ritchie, Roane, Wirt and Wood counties	**DISTRICT 8** Pendleton, Pocahontas, Randolph and Tucker counties
DISTRICT 4 Doddridge, Harrison, Marion, Monongalia, Preston and Taylor counties	**DISTRICT 9** Fayette, Greenbrier, Monroe, Nicholas and Summers counties
DISTRICT 5 Berkeley, Grant, Hampshire, Hardy, Jefferson, Mineral and Morgan counties	**DISTRICT 10** McDowell, Mercer, Raleigh and Wyoming counties

Figure 6 Different Districts in West Virginia

The only way to classify fog areas in West Virginia is using the amount of fog days per year. This is not a good indicator how dangerous road conditions are due to fog because it is not measuring the amount of visibility or how long the fog lasts which are crucial factors in measuring how dangerous road conditions are due to fog. Visibility is officially defined as the greatest distance at which a black object of suitable dimensions may be seen and recognized against the horizon, sky, or in the case of night observations, could be seen and recognized if the general illumination were raised to the normal day light level (Meteorological Office 1969). Table (3) classifies different visibility conditions.

Table 3 Visibility Conditions and Description (Cho 2005; Kim 2005)

Visibility	**Description**	**Visibility**	**Description**
Less than 40 meters	Dense Fog	2-4 km	Haze
40-200 meter	Thick Fog	4-10 km	Poor Visibility
200-1000 meter	Fog	10-40 km	Good Visibility
1-2 Km	Mist	More than $0 Km	Excellent Visibility

There was a study done in Korea where the goal was to develop an index where it quantified how dangerous the road conditions were due to fog (Cho 2005; Kim 2005). For the study, 72 manual observation stations across Korea gathered detailed weather information from 1998-2000. Not only did it measure amount of fog days, but the visibility conditions, and how long the fog lasted from starting time to ending time. Knowing when the fog started and when it ended is important in knowing when fog is likely to occur (fog occurring during high peak periods are more dangerous than fog occurring during low volume periods).The hazardous fog index considers parameters such as days of fog, duration, and visibility. The weights are found by the highest distributed values. Equation 1 shows how to get the HFIp for a specific area.

$$HFIp = (2 + On/2) * Wt * Ws \quad (1)$$

Where

On: expresses the normalized annual days of fog occurrence

Wt: weights of fog duration

Ws: weights of reduced visibility due to fog

The Hazardous Fog Index (HFIp) expresses the degree of danger of fog due to reduced visibility at a given location p. It is a function of average annual days of fog, fog duration, and visibility. The Hazardous Fog Index was found to be a good indicator of hazardous road conditions due to fog. For the study, cities in Korea were compared by the ranks of fog prone areas with just amount of fog days and using the hazardous fog index and there were differences in some areas. It's especially good to rank areas where the amount of fog days was only separated by a small difference. By comparing just fog days it might seem that two areas have the same level of concern due to fog, but when you measure it using the HFI, the two areas were found to have a difference in severity of road conditions due to fog. This study has shown that number of days is not a good index to classify a location as a fog prone area, but additional parameters such as duration and visibility in combination with number of fog days are better indicators. A similar study should be conducted in West Virginia in order to rank fog areas in West Virginia by better assessing how dangerous road conditions are due to fog.

2.6: Fog Forecasting

Fog forecasting is not an easy task. The probability of detection for 200 ft. ceilings and visibility less than < ½ mile is about 0.30. Most fog forecasting done by the National Weather Service is used for aviation purposes using sensors located at airports (Tom Green, National Weather Service). For aviation purposes, impacts are seen for anything less than 6 mile visibility. Public advisories for fog are only issued when visibility is less than a ¼ mile. Levels of warning the public range from mentioning fog in the forecast, then Special Weather Statements (outlining potential for a few hours), and finally a Dense Fog Advisory. The sensors used at airports are called automated surface observing stations (ASOS). ASOS constantly collects and streams data and helps the NWS increase the accuracy and timelines of its forecasts and warnings. ASOS reports basic weather elements such as surface visibility up to 10 miles, obstructions to vision such as fog, haze, and/or dust, air and dew point temperatures, wind direction/speed, etc. The limitation of ASOS is its inability to see weather that has not encountered the sensors.

2.7: Forecasting Tools

2.7.1: Sounding

Sounding profiles provides a snapshot of the vertical structure of the atmosphere and can be a valuable tool for diagnosing and forecasting fog. The types of data that can be gathered from a local sounding include:

- Location and strength of stable and unstable layers
- Temperature and dew point structure
- Inversion layers and strength
- Moist and dry layers

- Wind structure
- Potential for lifting or sinking motions
- Level at which clouds will form
- Indication of whether clouds will be stratiform or convective in nature

There are some limitations when using observed soundings. They are unreliable predictors for local events because the observations are widely scattered. Also the observations are only taken once every twelve hours which makes it difficult to identify important changes in the atmosphere. Lastly the resolution is insufficient to locate changes that can affect fog formation or dissipation.

2.7.2: Fog Detection Using Satellite Imagery

Detecting fog using satellite imagery can be a difficult task. For remote sensors it is hard to differentiate between a low lying stratus cloud and fog (Thomas 1997; Turk 1997; Richardson 1997).At nighttime it can be even harder to detect fog due to the poor thermal contrast between the backgrounds using infrared imaging. If there is snowfall it can be difficult to differentiate between fog and snow cover. Geostationary Operational Environmental Satellites (GOES) is used to monitor storm developments and track their movements, and is often used to track fog. Satellite imagery is useful in showing if a fog event is spreading or eroding at a synoptic scale. It is also used to monitor mid and high level clouds in order to predict their effects on underlying stratus or fog. For example, the presence of high clouds during the daytime can impede dissipation of low lying fog or stratus cloud.

2.8: Models

Models have been proven to not be an accurate tool to forecast fog at a local scale or mesoscale, but are good to provide a big picture. Model plan views and cross sectional data can be used to look at pattern development that may aid or hinder fog or stratus development. For more reliable predictions, computer models need to do a better job handling moisture. Moisture is typically the variable that computer models handle the most poorly. Other limitations include an incomplete boundary layer physics, and insufficient resolution of surface characteristics such as vegetation, soil type/moisture, terrain, etc. Statistical methods are also trying to be used to improve fog forecasting.

2.8.1: UPS Technique

This popular forecasting technique was created by UPS airlines to predict fog (Baker 2002). The technique uses a conceptual model that measures vertical profile of humidity or hydrolapse rates in the near-surface layer. This entails using the crossover temperature which is the minimum dew point temperature during warmest daytime hours. This is because during the warmest daytime hours, the planetary boundary layer is well-mixed and established and the upward transfer of water vapor is maximized. Fog is likely to occur if the shelter temperature is expected to cool to a few degrees below the crossover temperature instead of the dew point. Essentially, this method forecasts whether air will be saturated about 100-200 feet above the ground, where fog condensation usually begins. Determining whether the boundary layer will be saturated is not enough to definitively say fog will develop. The forecaster must also assess whether boundary layer turbulence will support fog formation. It is known that sufficient wind speed can create turbulent mixing and therefore will ventilate humidity upward through the boundary layer which is more prone to stratus cloud formation rather than fog. The real requirement for radiation fog forming is not lack of wind, but lack of turbulence, which is a combination of stability and boundary layer wind speeds. The UPS established an index that quantifies the boundary layer turbulent mixing called the "modified Richardson number" and is calculated as follows:

$$MRi = (T_b - T_{sfc})/u^2 \tag{2}$$

Where T_b = boundary layer temperature forecast (T1 or T3, whichever is warmer (°C)

T_{sfc} = shelter temperature forecast (°C)

If MRi $\leq$ 0.025, turbulent mixed boundary layer is suppresses cooling in the lowest 200 ft. and favors stratus rather than fog if saturation occurs

MRi between 0.025 and 0.040 is "marginal"

MRi $\geq$ 0.040, low level winds separated from high level winds and the unmixed boundary layer supports strong cooling in the lowest 200 ft. and favors fog rather than stratus, if saturation occurs.

2.9: Fog Forecasting Process

The various steps in the fog forecasting process are summarized below.

1. Preconditions/Analysis
    a. First step is to assess preconditions and try to predict if these conditions are conducive to a fog event occurring. You want to look at the big picture (synoptic scale) and also local influences (mesoscale).
        i. Surface observations – look at dew point, wind speed, relative humidity to see if these conditions are favorable for fog forming

ii. Satellite imagery – check to see if low level clouds/ stratus are present in the area

iii. Upper air and sounding analysis – assess whether there are low level moist areas, surface based inversion present

2. Climatology
   a. Look at preconditions and try to determine if a fog event is likely to occur based on local and regional climate patterns.
3. Use forecasting techniques/tools such as UPS/Bufkit, Modeling Output Statistics (MOS), statistically driven models, etc.
4. If it is determined that a fog event is likely, try and assess whether radiation or advection processes are involved and which is dominating. Once that is known, determine the onset, duration, and intensity of the event and make appropriate advisories/warnings.

2.9.1: Clarus Initiative

The Clarus Initiative was established in 2004 with the collaboration of the U.S. DOT, FHWA, and ITS to reduce the impact of adverse weather conditions on surface transportation users. The goal of the initiative was to create a data collection system using statewide sensors (Environmental Sensing Systems (ESS) or Road Weather Information Systems (RWIS)) to provide real time atmospheric and pavement conditions to traffic agencies and also to the public. The system allows better collaboration with different agencies for better forecasting and prediction. This system can be used to better predict fog. Measurements that can be accessed include temperature, dew point, pressure, visibility, wind speed, pavement conditions, etc. Currently in West Virginia, there are multiple sensors on the major interstates, but none of the sensors in West Virginia report fog conditions, but they do provide visibility conditions.

2.9.2: Data Acquisition

The NOAA provides a dataset called the MADIS Meteorological Dataset that provides data from observed station reports. This feature is free but an application must be submitted in order to receive the data. The types of data available include temperature, relative humidity, wind, precipitation, etc. It also reports various types of weather occurrences such as hail, fog, and thunder. It is uncertain how many stations are in West Virginia, but this could be a resource in order to locate fog problem areas in West Virginia. The National Climatic Data Center also has a dataset available, but it is not free. The monthly summaries include maximum, minimum, and average temperature, temperature departure from normal, dew point temperature, average station pressure, ceiling, visibility, weather type, wet bulb temperature, relative humidity, degree days (heating and cooling), daily precipitation, average wind speed, fastest wind speed/direction, sky cover, and occurrences of sunshine, snowfall and snow depth.

3.0: Fog Detection and Warning System across the United States

3.1: Lessons from Fog Detection and Warning Systems by Other States

In this section information and details on different methodology and states of practice used by other DOT's across the country in dealing with the fog problem has been provided and discussed. Ten different fog warning and detection systems in California, Florida, Alabama, West Virginia, Virginia, Tennessee, Georgia, Utah, South Carolina and Maryland has been selected which cover almost all major fog detection and warning systems installed by state DOT's across the country. Some of the systems have been recently deployed like the system installed by Florida DOT and Caltrans whereas the system in Tennessee was installed in 1992. The systems which are now operating in various states are also different in terms of sophistication, deployment, cost, and the coverage area. For example the installed system by Caltrans in Fresno, CA cost more than $12 million which covers 13 miles stretch of the major arterials in the area whereas the system deployed in St. Albans, WV cost less than $100,000 covering a hazardous intersection. Information and description of the deployed system has been collected through various contacts by state DOT's, US DOT and several companies working on the area of fog detection and warning systems.

3.2: Caltrans Fog Detection and Warning System

One of the advanced fog detection and warning system known as Caltrans Automated Warning System (CAWS) was design and implemented in Stockton, CA in 1996. The system was developed based on the available multi-sensor warning system which was originally built for the purpose of traffic reduction in this highly congested area. The system was comprised of 9 stations for measuring the environmental parameters, 36 speed detectors, and 9 variable message signs for communication with the drivers. A network of Closed-Circuit Television (CCTV) cameras provided the Transportation Management Center (TMC) with real time visual data on time and location of the incidents. The whole system operation was controlled through three computer devices in the in the District 10 TMC. This system is believed to be the first fully automated warning system in the United States (MacCarley,1998 and 1999).

The total cost of the establishment was approximately $2.5 million. The overall assessment of the first three years of operation showed significant reduction in numbers of fog related multi vehicle accidents, as the drivers tend to change in behavior in response to VMS messages. However on December 1997 a multi vehicle fog related accident happened outside the system coverage area.

Figure 7-Visibility Sensors Installed by Caltrans

A very recent type of fog detection and warning system is installed by Caltrans along highway 99 and Interstate 5 near Fresno area. Highway 99 and interstate 5 are major arterials in the central part of the state which are handling more than 100,000 vehicles per day. Historical data reveals that several piles up of multi vehicle crashes have been occurring in the area over the years as a result of reduced visibility caused by a very dense and frequent fog named "Tule". "Tule fog" reduces the driver's visibility and sight distance of the travelers to a very low extent and in some cases the visibility of zero was reported. In year 2007 a multi vehicle crash in which 101 vehicles were involved happened in that area which ended in two casualties and more than 40 injuries and lots of property damages. Following the severe multi vehicle crash Caltrans installed an integrated fog detection and warning system along thirteen miles of CA-99 to reduce the possibility of future multivehicle crashes. The project was started in October 2008 and completed in two phases in February and November 2009. The installed system broadcasted messages through VMS to the vehicles approaching the fog area after analyzing the road weather and traffic condition by visibility sensors. The system was comprised of three main different components: i) Weather station, ii) Speed detectors iii) Motorist warning system.

The detection unit system is monitors the weather and traffic condition with data provided through various weather, visibility, speed sensors, and cameras. Normally the messages are provided by processing the data at Caltrans Traffic Management Center (TMC) and a proper message according to the prevailing condition on the road way is sent to the output units like VMS and HAR. Messages appearing on the VMS are generated based upon the level of measured visibility distanced and speed differential of the traffic platoons on the highway. If the visibility distance falls below a certain threshold a predefined message will be broadcasted to the drivers as the precaution. Data is transmitted to the TMC through wireless communication;

furthermore the system has the ability to continue operating during the disrupted connection with TMS. At the time of the disrupted connection with the TMC on-site processing of the data is performed and the message will be sent to the VMS accordingly. The installed visibility sensors are PWD10 forward scatter sensors which are deployed every half miles on driver eye level. Traffic congestion level and speed is monitored through HD radar spot speed which is installed every quarter mile along the highway. The radars provide the speed, traffic flow volume, lane occupancy and vehicle presence in both direction of the highway. According to the preliminary assessment of the system a significant reduction in number of fog related crashes was achieved after the system deployment (Berman et al 2009).

Figure 8- Sensor Arrays Deployed by Caltrans

Motorist warning system has the role of communicating with the vehicles through CMS and highway advisory radio (HAR). VMS are installed every half mile along the highway on both sides. The system is taking advantage of dissemination method to convey the road condition information to the farthest possible audience. The speed and travelers information is also provided for 511 travelers' information system which is able to notify the commuters of any incident in the area through phone and internet before leaving their home or office. The performance of the system can also be improved through addition of different features such as colored Matrix VMS, close circuit television cameras, pavement lightings, incident detectors, and installing more RWIS station to cover the whole area and provide more reliable weather related data. The total cost of the implemented system was about $12 million (Berman et al 2009).

3.3: I-68 Fog Detection System-Installed in Big savage area

Big Savage, Keysers Ridge and Friendsville are considered as the most hazardous place for fog formation and consequently the most appropriate places for fog detection and driver warnings systems in Maryland. The purpose of this system is to detect fog and warn motorist traveling along Interstate 68 to reduce their speed and turn on their lights before entering the area. The location for deploying the system was selected according to fog type and density, available infrastructure, highway profile, and line of sight.

The incentive for this project was a serious multi-vehicle accident experienced on I-68 in year 2003 where nearly 90 vehicles involved in that accident, two persons died and so many injured. In this regard, in order to reduce the possibilities of the future accidents State Highway Administration (SHA) decided to install a system to alert the motorist driving in foggy conditions. The installed system is the first fog detection and warning system implemented in Maryland. The system has the ability to identify different levels of visibility and notifies the approaching drivers before entering the foggy area; furthermore it is designed in a way to take advantage of current available infrastructure along the roadway.

Figure 9-Typical Warning Sign Installed in I-68 Maryland

Weather detection system along the road is carried out by the available Road Weather Information unit System (RWIS) which is equipped with different sensors gathering both weather and pavement related data. Every RWIS station is comprised of precipitation sensor gathering type and rate of participation, wind sensor measuring wind speed and direction, air temperature, humidity and visibility sensors. Therefore, RWIS stations are installed along the highway to collect the weather data. A preliminary processing of the data is performed through the provided Remote Processing Unit (RPU) placed in the field. The RPU is capable of controlling the warning signs directly via speed spectrum radio connection. A version of the collected data is backhauled to a server located at SHA District 6 operation center for extra processing and data backup. The communications between field and the SHA server is provided via dial-up telephone. Warning signs, radio warning messages, reduced speed limits, and complete closure of the Interstate are adopted as the traffic control strategy to reduce the vulnerability of the driver to the risk associated with driving in fog condition.

Providing the system with a proper source of energy was a huge problem since the radio and warning signs where in a place that providing the AC power was infeasible. Therefore a solar power system was implemented as the major source of the AC power serving the flashing beacons, radio spectrum, and solar control panel. The final cost of the system set up for three locations was $375,000 (Sabra et. al, 2003).

Figure 10 Reduced visibility sign installed in I-68

3.4: West Virginia

The only fog detection and warning system in West Virginia is installed on I-64 Kanawha River Bridge. The area is considered as one of the fog prone areas in the state. The original system has been upgraded recently to a more organized arrangement to apprise the drivers entering the foggy conditions. The original detection system utilized forward scatter infrared technology placed in two locations in the proximity to the I-64 St Alban's intersection. The problem with the original system was that all the data processing and weather forecast was performing in the local processing unit, but in the new configuration each of the two sites has been equipped with a distinct RPU unit making independent decisions. The forward scatter infrared technology has been replaced by backward scatter infrared technology in the upgraded system. Sensors are located one mile east and one mile west of the I-64 Kanawha River Bridge near the St. Albans interchange. The system activates flashers while the visibility of less than 1200 feet is reported and will start warning the motorist to slow down and drive cautiously. The system operation is monitored through communication with Vaisal network and the highway operators are notified through the web when the system is triggered. The system is also equipped with video cameras to provide visual confirmation of the fog condition to traffic engineers in Highways' headquarters. The total cost of the installed system was approximately $89,000.

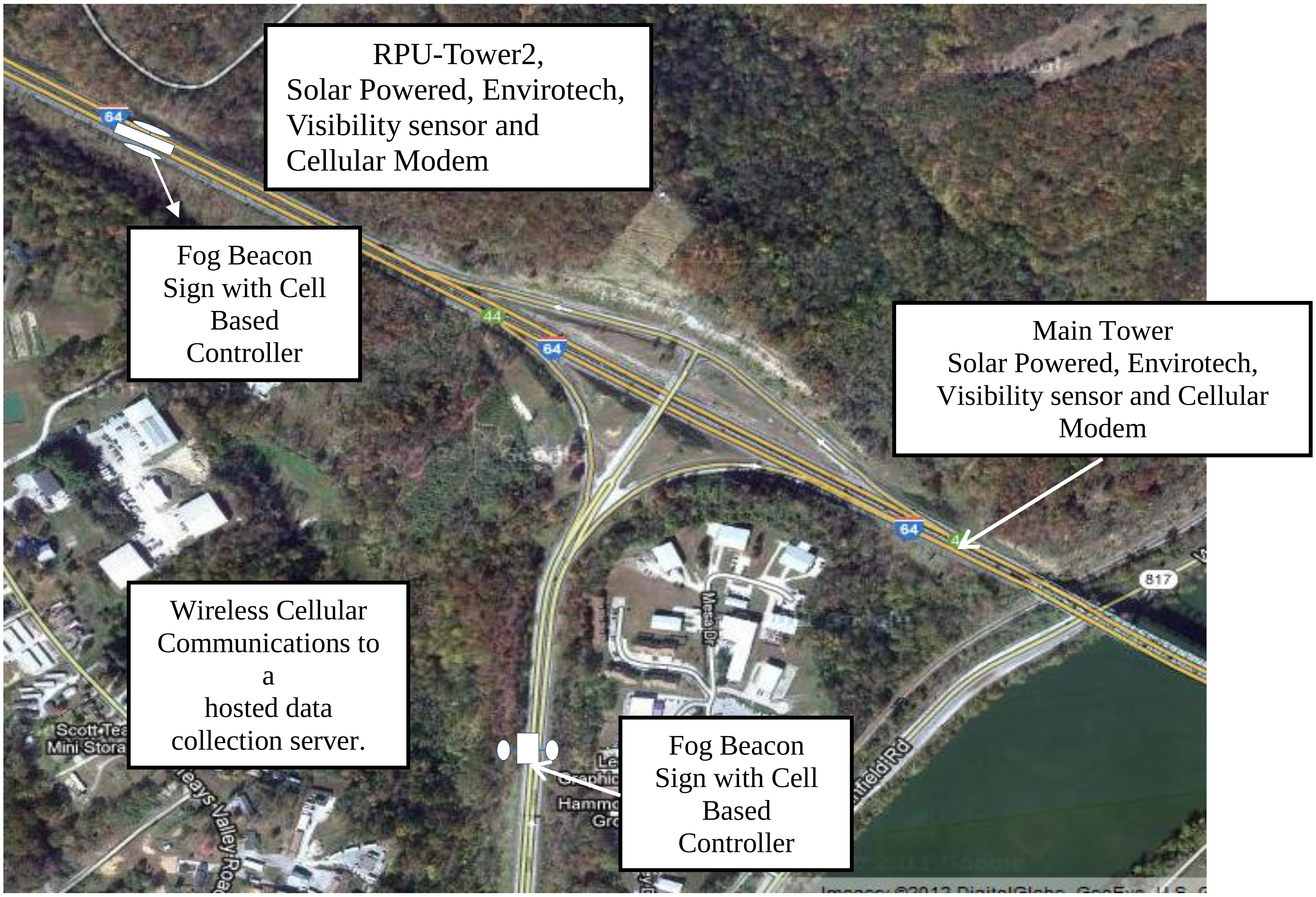


Figure 11 Detection and warning system in WV

3.5: I-75 Fog Detection/Warning System

The pileup of 99 vehicles on a foggy section of I-75 in year 1990 near the Tennessee-Georgia border grab the attention of the state officials to install a system to warn and alert the motorist in this area, where weather conditions can change almost instantly. In that time the visibility distance at that section of the I-75 was decreased significantly to less than 10 feet. The installed

Figure 12 Installed Visibility Sensor and CCTV camera along I-75

system in I-75 covers almost 19 miles of the highway which is supposed to be a fog prone area. Two weather forecasting station and eight fog detection sensors were installed along the highway to check for the driver's sight distance visibility in the fog area (Dahlinger, D. 2001. and Dahlinger, D. and McCombs, B. 1995). The weather stations measure temperature, wind speed, wind direction, and dew points. Four different visibility scenarios were defined for the system conveying the road condition to the drivers by 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 on the fog density and sight distance visibility one of these four messages would appear as the message to alert the drivers encountering the fog. The system is also able to decrease the speed limit as the fog density starts to increase. For example, it is capable of adjusting the speed limit from 55 mph to 35 mph as the fog start to get denser. The total system cost was $4.5 million at the time (Tennessee ITS State Status Report 2000).

3.6: Virginia

I-77 in Fancy Gap Mountain and I-64 in Fancy Gap are two major highways in Virginia experiencing persistent dense fog during the hostile weather conditions. Multi vehicle crashes due to the impaired visibility sight distance of drivers started to happen shortly after the highway was opened in 1972. In 1977 the state DOT implemented pavement lighting system along 5.8 miles stretch of highway I-64 to guide the vehicle in adverse weather conditions. Short term study of the system demonstrates improvement in reducing the fog related crashes; however increase in number of crashes in clear weather were observed after placing the pavement lightings. Although the pavement lighting systems improved travelers' visibility, it increased traveler speed which ended up in more number of crashes. While the fog related multi vehicle crashes still existed in the area, the system was upgraded by approximately $5.3 million investment in 1997. In 2002 several recommendations were made by a team of expert to help to improve the roadways safety in various aspects. Placing variable message signs (VMSs), installing different video cameras, supplementing the current variable message signs with strobes and lasers, increasing police visibility in foggy condition, and seeking authorization for placing the variable speed limits were the recommendation made to improve the visibility of drivers and increase the safety along the state highways (Casanova L. 2002).

3.7: Georgia

An augmented fog and smoke detection and warning system in Adel, Georgia was initiated in 2001 along 19 miles segment of the highway to reduce the likelihood of crashes due to impaired visibility distance caused by fog and smoke. The total cost of the system set up was approximately $2.4 million at the time. Various sensors implemented along the 19 mile stretch of the highway provide reliable visibility and weather data resources for assessing the roadway condition. Fiber optic network facilities the transmission of the collected fog and weather data to a computer on the site. The received data is fully analyzed, processed and the proper message appears on the variable message sign accordingly. The collected data is eventually transmitted to the GDOT officials for the purpose of monitoring and remote control of the system. Different messages were generated based on the four predefined threshold levels of visibility distance of the system. There is even the option of interstate closure in the most extreme weather condition for the operator's officials (Gimmestad et al 2004).

3.8: Utah

In response to recurrent fog problem on the I-215 corridor in Salt Lake City, Utah Depart of Transportation (UDOT) implemented a low visibly detection and warning system along two miles of the roadway. Likewise many other detection system visibilities were measured by forward scatter visibility sensors installed along the roadways and the communication to the drivers were achieved by DMS. There were only two DMS to send the proper message to the drivers based on the measured traffic and visibility conditions. The goal of the system was to achieve a uniform stream of vehicles and reduce speed differentials among the vehicles in foggy conditions (FHWA Road Weather Management Program).

In order to study the effectiveness of the system Utah Traffic Lab (UTL) and UDOT installed a system known as Adverse Visibility Information System Evaluation (ADVISE) along the roadway to check for the visibility condition and efficiency of the posted messages for the approaching drivers of the upcoming fog ahead. The evaluation of the system was performed through continuous measurement of visibility condition and sending the advisory speed to the drivers based on the predefined thresholds of visibility levels. The study revealed that reduction in speed variability among the vehicles driving in foggy condition was the major outcome of the system as the gap between the high speed and the low speed of the drivers were decreased by almost 22% after the system deployment. However, the mean speed was reduced by 15%. Table (4) shows the posted messages on the VMS used by UDOT in low visibility conditions (Rockwell Transportation Systems, 1997, Perrin, et. al, 2002 and Jones et. al, 2011).

Table 4 Messages communicated to the drivers by DMS in Utah

Highway Advisory Rang (Meter)	**Message**
>250	No message
200-250	"Fog Ahead"
200-150	"Dense Fog" Altering with "Advice 50 mph"
150-100	"Dense Fog" Altering with "Advice 40 mph"
60-100	"Dense Fog" Altering with "Advice 30 mph"
<60	"Dense Fog" Altering with "Advice 25 mph"

3.9: South Carolina

A fog detection and warning system was installed on approximately 7 miles of the Interstate 526 near Cooper River Bridge, SC in 1992. The primary aim of the system was to notify and guide the drivers through advisory speed limits and warning messages was broadcasted to the drivers. The system used five forward scatter visibility sensors and eight CCTV cameras for detecting visibility and monitoring road traffic condition. In addition to surveillance and visibility measurements the system was capable of warning the drivers through eight installed VMS. All the system commands were generated by the help of an onsite RPU and off sight central computer unit. Initially microwave communication was used as the means of linkage between different system component which failed to operate properly because of the humid and hot weather condition of the area. Therefore the microwave system was replaced by fiber optics to provide a reliable means of communication between various systems unit which secures the system operation during the hostile weather conditions. According to further studies, no major accidents and fatalities due to the fog were reported after the system deployment and major improvement in traveler's safety driving in foggy conditions were observed. The preliminary cost of the system was approximately $5 million (FHWA Road Weather Management Program).

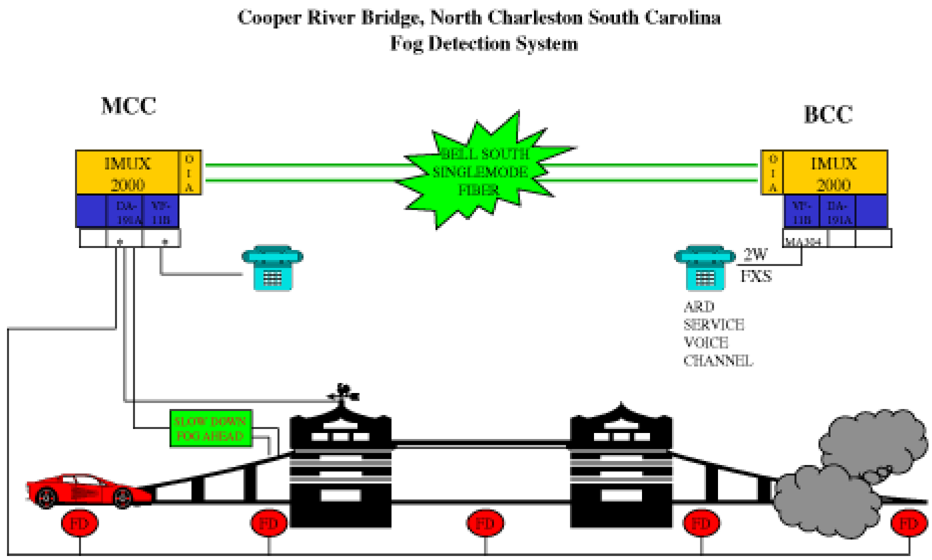


Figure 13 Fog detection system installed on Cooper river Bridge South Carolina

3.10: Florida

State of Florida has long history of fog related crashes and is among the top states across the country in dealing with fog problem. Although several systems are now in place but the state is still suffering from fog related crashes happening on its roadways. A very recent and fatal multi vehicle fog related crash happened in January 2012 on I-75 near Gainesville where 10 people were killed and 18 were severely injured. Limited visibility due to the fog and lack of suitable traffic control devices were reported as the primary cause of the accident.

The first study of fog prone areas in Florida started with Tampa bay area which has an average of 22 heavy fog days per day. In this area visibility sight distance of less than 1/4 mile was reported. According to the historical data between years 1987 to 1995 about 829 fog-related crashes took place in Tampa Bay area which was 0.30 percent of the total number of crashes in Tampa Bay. The study exhibits that there is not a specific fog prone site in Tampa Bay area and accordingly no further attempt was made in order to install a fog detection system in the area. Instead the study recommended focusing on driver awareness campaign as an economical and effective method of reducing fog related crashes (Center for Urban Transportation Research, 1997).

In 2010 a system called Early Detection System for Reduced Visibility was installed by University of Central Florida (UCF). The system was a break through as it was comprised of inexpensive and available components and could be installed as either fix or portable system. Another big difference of this system with the conventional systems is the source of power as the system can be supplied through DC power source like cars battery whereas other system requires AC sources of power (Abdel-Aty et al 2013).

The system was comprised of four different stations that were connected to visibility sensors along with a unit which control the system operations. Figure (16) expand the idea behind the system architecture. Also, the system was taking advantage of two types of communication links, internal communication link which provide communication between sensors stations and cellular communication link that transmit the data to the main control unit. The deployed visibility sensors in the stations are continuously monitoring the visibility condition along the roadway and sending the measured visibility distance to the base station every 15 minutes. This is mainly to make sure that all the system components and communication units are working properly all the time. When the visibility falls below the certain predefined threshold the base station will generate the proper message and send it to the output units like DMS or will send an email to the TMC (Abdel-Aty et al 2013).

Table 5 Strategy Used by Visibility System in Florida

	E-Mail Title	Highway Visibility Range
1	Emergency: No visibility	<20ft
2	URGENT: Extremely Low Visibility	<200ft
3	Warning: Moderate Visibility	If visibility is between 200-500 ft
4	Warning: Fog and Smoke Conditions Affecting Visibility	If visibility is between 200-500 ft
5	Normal Condition	Visibility greater than 800 ft
Frequency of Reporting to TMC		
Every Hour	Normal Condition	
Every 1 Minutes	In Emergency	
Every 5 Minutes	Otherwise	

The initial analysis of the system proves the system ability in measuring the visibility condition however the efficiency of the model in reducing fog related crashes requires further investigation and study.

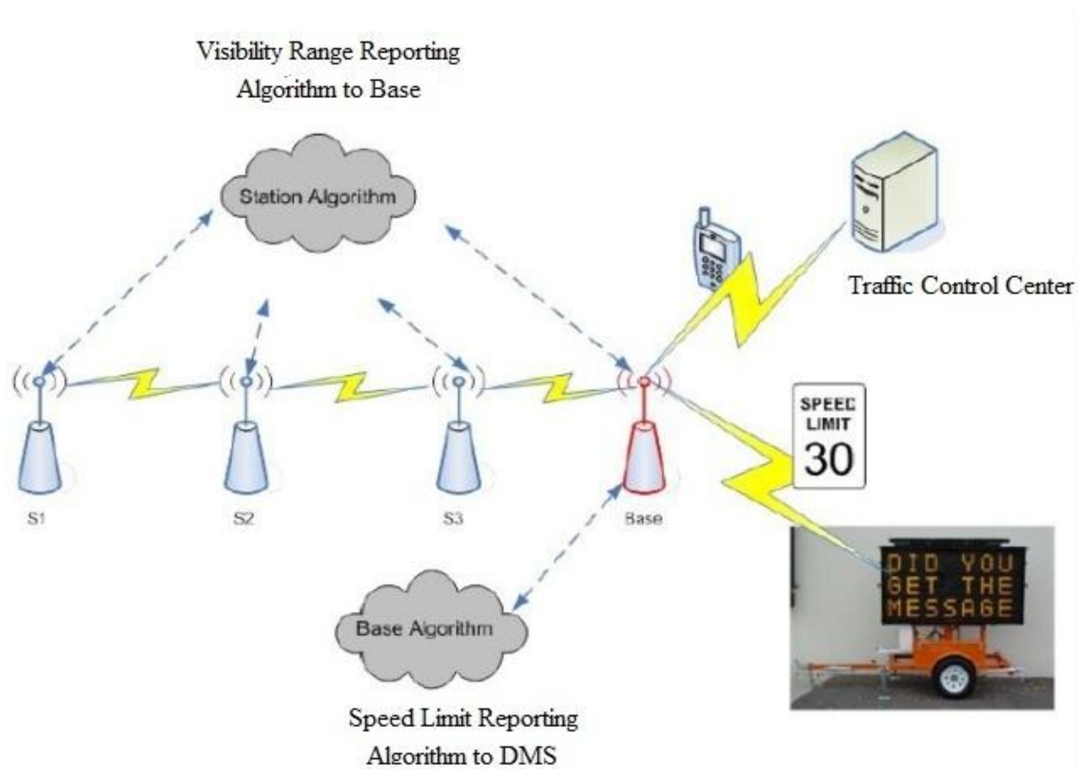


Figure 14 Configuration of the visibility System Used by FDOT (Abdel-Aty et al 2010)

3.11: Alabama

A low visibility detection and warning system has been deployed on interstate 10, after series of multi vehicle pileup crashes took place in the area. The system was integrated with a tunnel management system in Mobile Alabama covering six miles stretch of the highway. The initial configuration was comprised of six forward-scatter visibility sensors installed every one mile monitoring the visibility of the roadway along with 25 CCTV cameras reporting the ongoing traffic on the highway. With the help of fiber optic communication, the collected data was transmitted to the main control unit and then based on the system predefined standards advisory speed and messages would appear on 24 variable speed limit signs and five changeable message signs. The

VMS provides the drivers with real time information regarding the current condition of the roadway ahead of the foggy area.

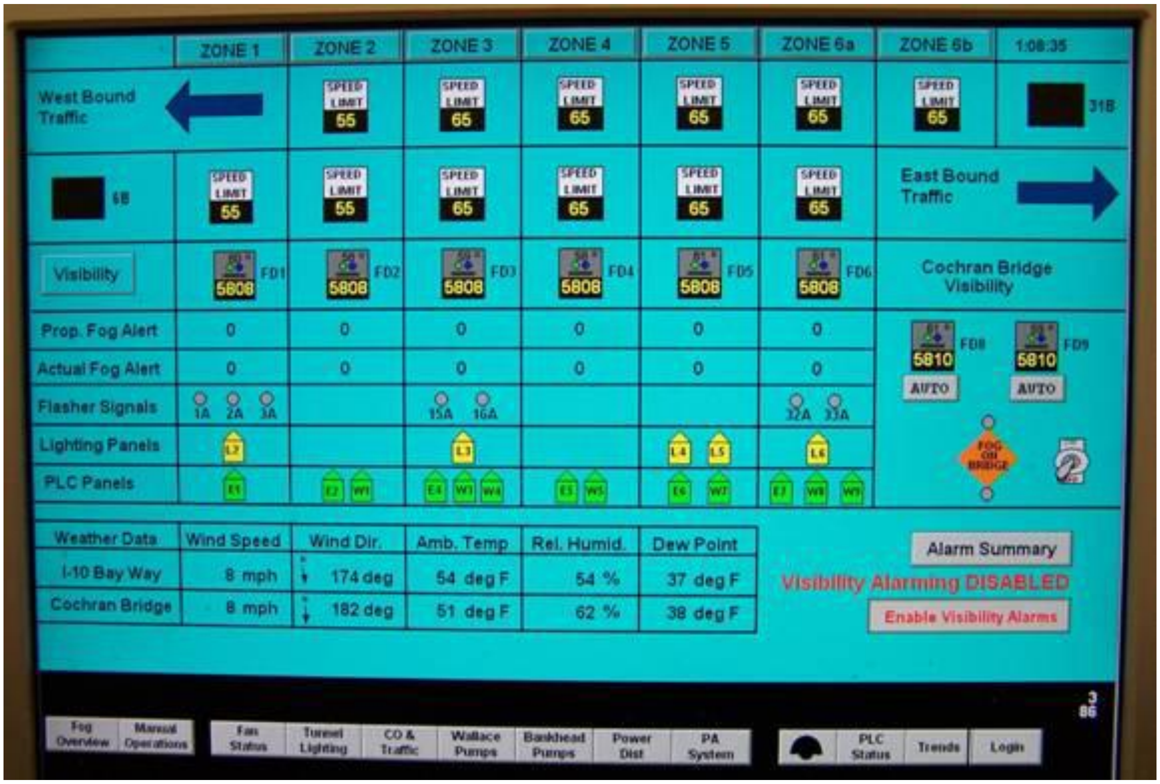


Figure 15-Alabama DOT low Visibility Warning System Screen Shot

There was a major upgrade to the system in 2008 where the communication method changed to a point to point system of Ethernets and also Radar Vehicle Detection was installed every third mile of the road way. The installed warning system was believed to improve the safety measurements as the average speed of the vehicles and potential for crashes during the low visibility conditions were reduced.

Table 6-Defined Thresholds and the associated Strategy for Alabama Visibility System

Visibility Distance	Advisories on DMS	Other Strategies
Less Than 900 ft	“FOG WARNING”	Speed Limit at 65 mph
Less Than 660 ft	“FOG” alternating with “SLOW, USE LOW BEAM”	Speed Limit at 55 mph “TRUCKS KEEP RIGHT” on DMS
Less Than 450 ft	“FOG” alternating with “SLOW, USE LOW BEAM”	Speed Limit at 45 mph “TRUCKS KEEP RIGHT” on DMS
Less Than 280 ft	“DENSE FOG” alternating with “SLOW, USE LOW BEAM”	Speed Limit at 35 mph
Less Than 175 ft	I-10 Closed, KEEP RIGHT, EXIT	½ Mile Road Closure by Highway Patrol

4.0: Fog Detection and Warning Systems

In this section different approaches in dealing with the fog problem in terms of installed system has been discussed and explained. In general there are two different strategies for traffic control and motorists warning on the roadways: i) passive traffic control devices, and ii) active warning systems. Passive traffic warning and control devices including static signs, pavement marking etc. placed along the road ways which help the drivers to have a better knowledge of current road condition. Active traffic control and warning system are more complex systems comprised of number of changeable or static signs controlled from a central decision center. The communication to the drivers in such systems is based on the received messages achieved based on the real time assessment of the road way condition.

4.1: Passive Fog Warning Systems

Passive fog warning systems are low-cost treatments that could be widely implemented along the roadways to warn the motorist of upcoming hazard thus improving safety. Static signs are among the most common and frequent passive traffic control devices and are mainly useful when installed in the area with less adverse fog conditions. Selecting the most relevant and appropriate place for installing the fog warning sign is the big challenge for traffic engineers. According to MUTCD general guideline for static sign placement, the location of the static sign must be in a way to give the driver adequate time to perceive, identify, decide, and perform the necessary maneuver. It should be noted that in general passive control devices and specifically static signs may lose their applicability and influence on the drivers due to conveying the irrelevant message for the most days of the year. Thus, the efficiency of static sign should be reviewed over the period the sign is in place both during day and at night. The passive signs can also operate as the backup for the active warning systems at the time the active warning system fails to operate and give service to the road users. Figure (16) shows the only fog warning sign according to the MUTCD. In various experiences companies attempted to augment the static sign by the help of flash beacon to draw the attention of the motorist during low visibility condition. An example of the static signs with flash beacon located along I-68 has been shown in figure (9).

Figure 16 Left Sign: MUTCD Sign in Fog Prone Area

Raised reflectorized pavement markers (RRPM) and upgraded striping standards are the other types of passive warning systems which are installed along the road way to keep the drivers within the road limit by making the roadway edge conspicuous to the motorists driving during the fog and adverse weather conditions. A harsh sound as the result of the vehicle vibration will be created if a vehicle runs over the line of markers. The sound and vibration give alarm to the drivers that he or she has crossed the roadway centerline or edge. In a broader scope RRPM's can be an effective tool for alerting inattentive, fatigued drivers as well as those who are driving under the influence of alcohol.

Raised reflective pavement markers are made up highly hard and durable devices. RRPM can also be used as a supplement to the painted stripes on pavements. In some cases they can also be used as an alternative to the painted strips. The primary role of RRPM's is to reflect the lights coming from the vehicle headlights to the driver's eye and to provide a distinct and clear outline of the pavement marking and roadway edge. On the other hand RRPM's helps the drivers in locating the exit ramp and to make the proper decision well in advance in order to exit the roadway. However, in many cases it has been observed that during the night and adverse weather conditions construction joints that are not correspondent to the highway marking convey false information to the drivers (NCHRP SYNTHESIS 380).

In recent years the apparent successful implementation of new technologies such as ITS foster the interest in implementation of such systems in many safety related project in order to better allocate the public fund and manage safety in roadways. In the next section active fog and warning system as a part of ITS application has been discussed.

4.2: Active Fog Detection Systems

An active motorist warning system is a comprehensive system comprised of various components each performing a separate pre-defined task. The linkage between all the system components and devices is provided through a centralized control center. The main role of the fog detection and warning systems is the online surveillance of weather, visibility distance and traffic condition presents in the highway and subsequent alert to the motorists of the possible hazard on the way. In general active fog detection and warning system is made up of three different components: data gathering system, output unit, and main control center. Variable message signs (VMS) and highway advisory radios normally serve as the output unit and means of communication with the drivers. There are also some other features like highway lighting controllers which might be used on special occasions. Similar to all output units the highway lighting activity is controlled by the control center. The system is operated through online gathering of the existing weather and traffic data along the highway. Essential data is provided through different visibility and traffic sensors deployed along the roadway. Upon the accomplishment of data processing task, the fog severity level is determined to have an accurate understanding of the current weather and traffic condition of the roadway. Finally, the proper message is generated based on the collected and processed data is generated and communicated to the drivers through the available output unit (Sisiopiku, V., and Elliott JR 2005). Formerly, the communication between different units were performed through wire lines deployed or available on the site, but today with increase in communication technology wireless communication is used in many existing fog warning system as the mode of data communication. Providing a reliable source of electrical power for the whole system is a crucial factor that the designer must take into account. Normally, the active fog warning systems are set up along the roadways where accessibility to electricity is limited and economically infeasible. Fortunately, with recent improvement in green energy many companies are now offering solar energy as the major power source for providing the AC electricity current in order to establishing active fog detection and warning system(Goodwin, L., 2003). A complete description of different units within an active fog warning system is presented in the next section.

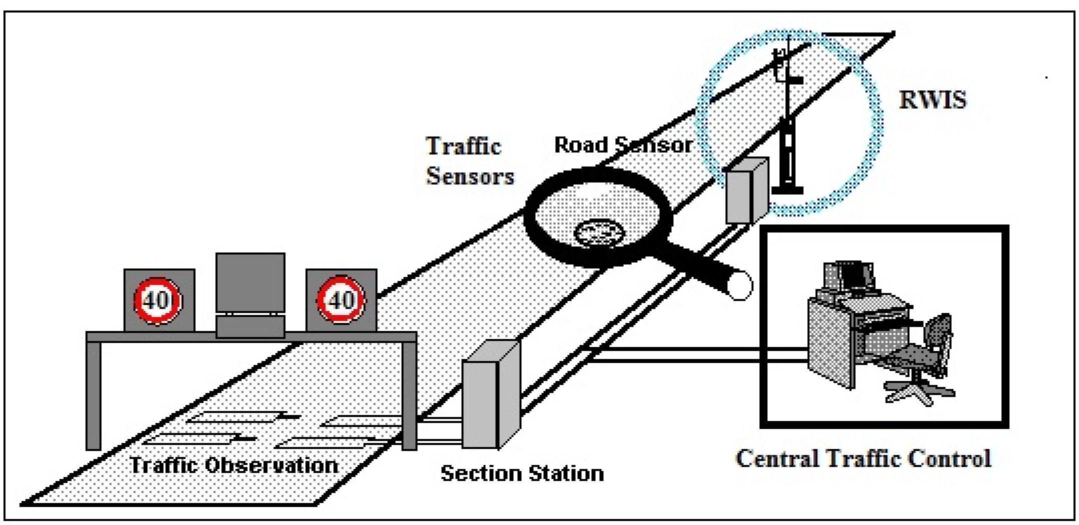


Figure 17 Configuration of an active fog detection system

4.3: Data Gathering Components

The operation of the fog detection and warning system is highly dependent on the traffic data and weather related information. In this part, different data gathering units for providing reliable source of weather and traffic data has been explained and discussed.

4.3.1: Weather Monitoring Systems

Road Weather Information Systems (RWIS) monitor the weather and pavement conditions in different sections of the roadways. Each RWIS is supported by different types of meteorological and pavement sensors which predict the weather condition according to the real time and available historical data. RWIS is comprised of Environmental Sensor Stations (ESS), remote processing unit (RPU) and communication links for gathering and displaying the data and communicating the data. Environmental sensor unit (ESS) is the source for the environmental data collection by which different types of data such as air, temperature, amount and type of precipitation, visibility, dew point, relative humidity, wind speed and direction, surface pavement temperature, subsurface temperature, surface condition (dry, wet, frozen), amount of deicing chemical on the roadway, and freezing point of the road are collected. Visibility sensors are extremely useful in fog warning systems as they provide an accurate estimate of visibility sight distance of the drivers in fog condition. Visibility sensors measure meteorological optical range by utilizing different techniques (Ozbay et. al 2003).

In general, there are two major techniques of sensors for measuring the visibility sight distance. This classification is based on how the systems emits and received the scattered light. The two most frequent categories of visibility sensors are forward scatter and back scatter technology.

Back Scatter: The technology was mostly popular in 1970s before the development of forward scatter sensors. In backscatter sensors the collected light is projected in the backward direction collides with fog elements in the air. The backward scatter works according to the weakest energy scattered and received backward to the sensor. Although the back scatter sensor is a small and compact type of sensor but its poor function during the snow blowing lead to the development of forward scatter sensors.

Forward Scatter: Forward scatter sensors collect light scattered in a forward direction. The sensor releases light in the forward direction that hits the suspended particles in the air. These existing particles in the air spread out the light in all directions and this sensor utilizes the stronger energy scattered forwards toward a receiver that collects the light. The results of the visibility measurements are dependent on scattering angle, on the other hand there are also sensors available in the market with adjustable scattering angles. Based on the Federal Aviation Administration (FAA) standards an angle of 42 degrees is considered to give the best response in all weather conditions. Forward scatter is known by the National Weather service (NWS), Federal Aviation Administration (FAA), and World Meteorological Organization (WMO) as preferred technique in visibility measurement (Matilla T, Douthwaite W and Hurst M 1995).

Due to better performance and availability of forward scatters sensors in the market RWIS typically adopted infrared forward-scatter technology as measurement tool. About ninety percent of the sensors used in RWIS stations are forward scatter visibility sensors. One limitation of these sensors is that anything in the optical path that scatters the infrared light beam may result in erroneous readings which lead in imprecise evaluation of roadway condition. Figure (18) shows an example of visibility sensor.

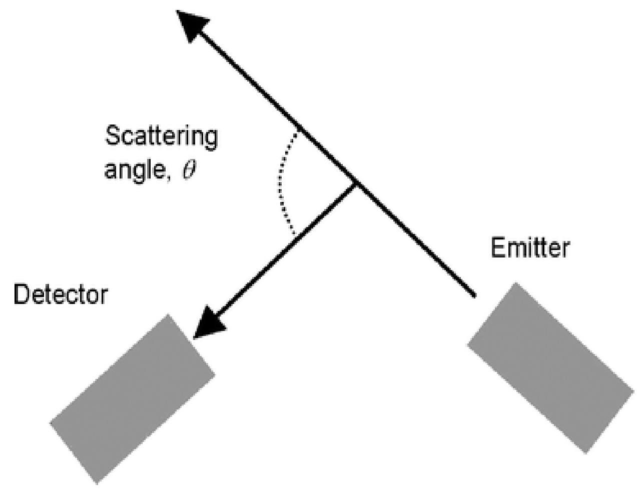


Figure 18 Visibility Sensors and Scattering Angle

In recent years companies offered the four -head design of visibility sensors which tend to be more reliable than the conventional sensors. It has been claimed that if one of the sensor heads fail in a conventional two-head sensor, the system would be inoperative while in the four-head sensor, if one head fails the other three will continue to operate with no degradation in accuracy.

In order to perform an accurate fog detection purpose weather forecasts data must be tailored to an applicable format to the need of the system operators. A forecast tailored would indicate the visibility sight distance of the traveler in road condition. An initial processing will be carried out on the stored data in the field cabinet by Remote Processing Unit (RPU). The primary role of the remote processing unit placed along the roadway is to connect the road and weather sensors to a central location. Therefore, a version of accumulated tailored data will be transmitted to the Server of the SHA for the purpose of communications, collection, archiving, and distribution. There are several paths for backhauling the data to the main control center. Landline telephone link to a Computer/Server and RF link to a telephone line using an RF Telephone Relay Unit are the two most frequent techniques for transferring data. In the latter method the communication between the land phone and RPU unit is wireless. These two aforementioned communications paths compose the majority of the RWIS communications links, other method of communication can be used based on the available infrastructure or technology in the area. For instance use of a cellular modem is recommended in the areas where the use of phone service neither economical nor feasible due to the area topography (Sabra et. al 2003, FHWA *Road Weather Management Program)*

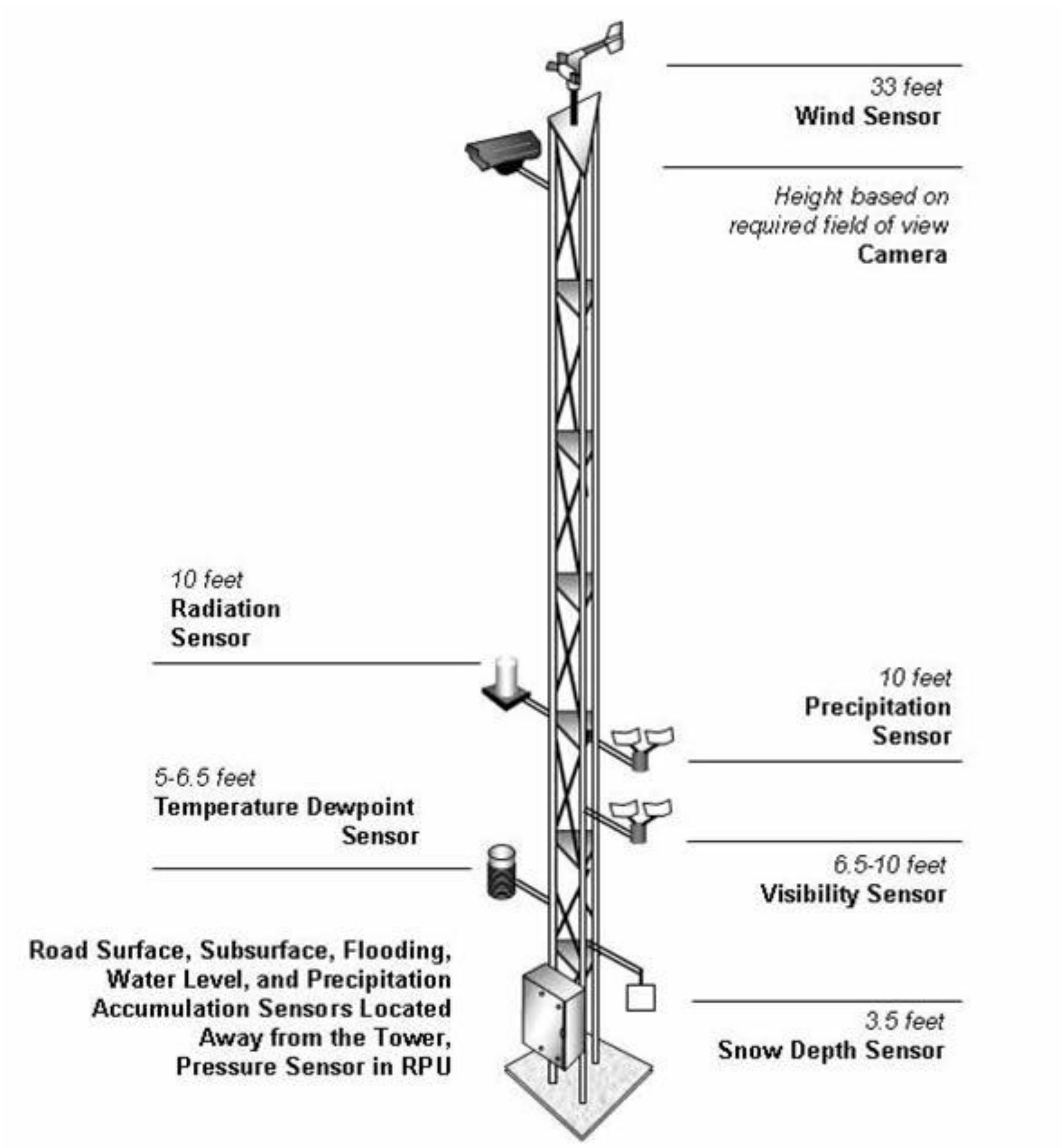


Figure 19 Different Component of a weather monitoring tower

4.3.2: Traffic Monitoring System

According to the National Transportation Safety Board recommendation for improving the safety of the roadway vehicle traveling in fog areas, every comprehensive limited-visibility countermeasure system should include both traffic flow detectors and visibility sensors that automatically activate traffic control devices either when hazardous conditions occur or when traffic slows. Therefore, real-time detection of traffic flow characteristics is a crucial element in fog warning and detection system. During the adverse weather condition speed is the most important feature of the traffic flow characteristic that must be attained through the traffic sensors. Reduction in speed profile of the platoon of the vehicle traveling in the hostile weather condition can be a sign of low visibility condition. This requires the system to respond and generate the proper message to the drivers inside or approaching the fog area promptly.

Traffic flow data can be attained by deploying flow interruption monitoring devices such as inductive loops, radar detectors, beacons, CCTV surveillance systems, video imaging, and magnetometer, etc. Inductive loops are the most commonly used vehicle detector. Radar detectors are another type of device that can be used to measure traffic flow and speed. However the efficiency of the traffic detector system will reduce during the adverse weather. 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. The counted traffic and the speed of the vehicles then will be sent to the main control center.

CCTV cameras are another type of technology for monitoring the traffic condition in fog prone areas. These surveillance systems due to providing the close visual information of the system through the videos are able to confirm operation of the signs, weather conditions, and traffic incidents. Cameras in CCTV sites are equipped with zoom, pan, and tilt capabilities. The system also takes advantage of 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 early detection of visibility conditions and traffic flow characteristics that 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.

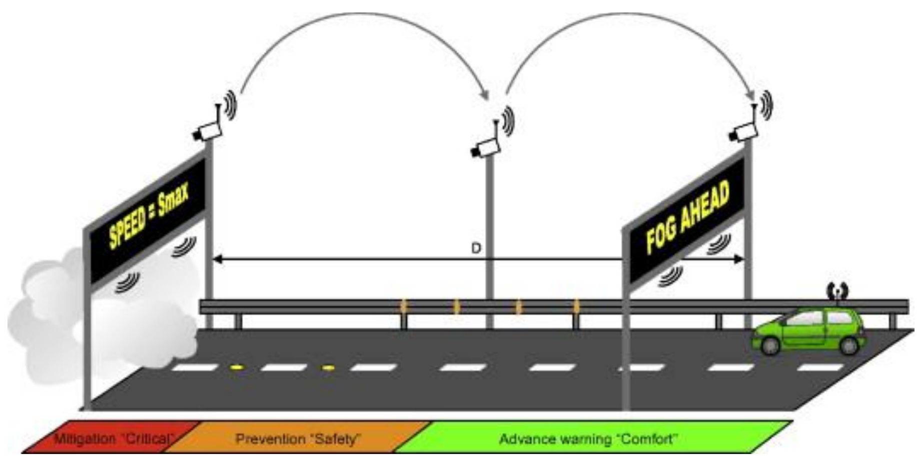


Figure 20 Early Detection of Fog by Sensors

4.4: Output Unit

The system communicates with the motorists traveling along the highway through the output unit. One of the advanced ITS technology that has been widely adopted is Variable Message Sign (VMS) also known as Dynamic message signs (DMS) and changeable message sign (CMS). VMS provides traffic related information to help drivers in making informed choices about their travel routes and inform them of any possible incident and issue ahead. VMS may also give alternative routes at the time of congestion, set the speed limit, or just merely provide alerts or warnings. There are different types of variable message signs varying in size and display capabilities based on the application. They can be mounted on a post, build up on structures, tunnels, or other, special devices. The character size at the posted messages and display size must correspond to MUTCD guideline. VMS size varies from very large, typically capable of three lines of 18 characters each, to small signs which may display only two lines and 7 characters. Some of different VMS are as below:

- Full-Matrix Message Signs
- Three-Line Message Signs
- Color Message Signs
- Truck-Mount Signs
- Fixed-Mount Message Signs

In fog detection systems drivers will receive information through VMS based on the visibility sight distance, fog density, or sudden changes in speed profile. If any of the mentioned criteria passed a predefined threshold a proper message will be broadcasting to the driver to help them to take subsequent proper action in a safe and timely manner. Table (7) shows a typical type of messages for low visibility system installed in Tennessee which notifies the driver based on different levels of fog severity.

Table 7 Tennessee Low Visibility Warning System Messages

Conditions	Displayed Messages
Reduced Speed Detected	“CAUTION” alternating with “SLOW TRAFFIC AHEAD”
Fog Detected	CAUTION” alternating with “FOG AHEAD TURN ON LOW BEAMS”
Speed Limit Reduced	“FOG AHEAD” alternating with “ADVISORY RADIO TUNE TO XXXX AM”
	“FOG AHEAD” alternating with “REDUCE SPEED TURN ON LOW BEAMS”
	“FOG” alternating with “SPEED LIMIT XX MPH”
Roadway Closed	“DETOUR AHEAD” alternating with “REDUCE SPEED MERGE RIGHT”
	“I-75 CLOSED” alternating with “DETOUR"
	“FOG AHEAD” alternating with “ADVISORY RADIO TUNE TO XXXX AM”

Highway Advisory Radio

Highway Advisory Radio (HAR) systems, also known as Travelers’ Information Stations (TIS), broadcasts real-time roadway condition to travelers and residents through the use of AM Radio. Advance signing for HAR is critical to add to the efficiency of the system as the motorists may not tune in if they are unaware of the available system. In some cases advance VMS placement has been recommended to provide motorists with directions for tuning in and specific reasons to do so. However, there are some restriction associated with the HARS as there are certain limits on frequency assignments and power transition of the system according to Federal Communication Commission. Long distance broadcasting through HARS is both ineffective and economically expensive.

There are several more ways to communicate the drivers; some of them are as follows:

- Closed Circuit Television Cameras to provide real time detailed information to the TMC and to the public over the internet.
- Pulsing in-pavement lighting to be triggered by the system to slow traffic down when an accident is spotted

The integration of the discussed parts will result in an active fog detection and warning system which is able to detect traffic and lack of visibility sight distance due to fog and alarm the drivers in advance of potential impaired visibility by VMS and HAR. The integration of different components in synthesis of a fog detection system is provided in figure (21).

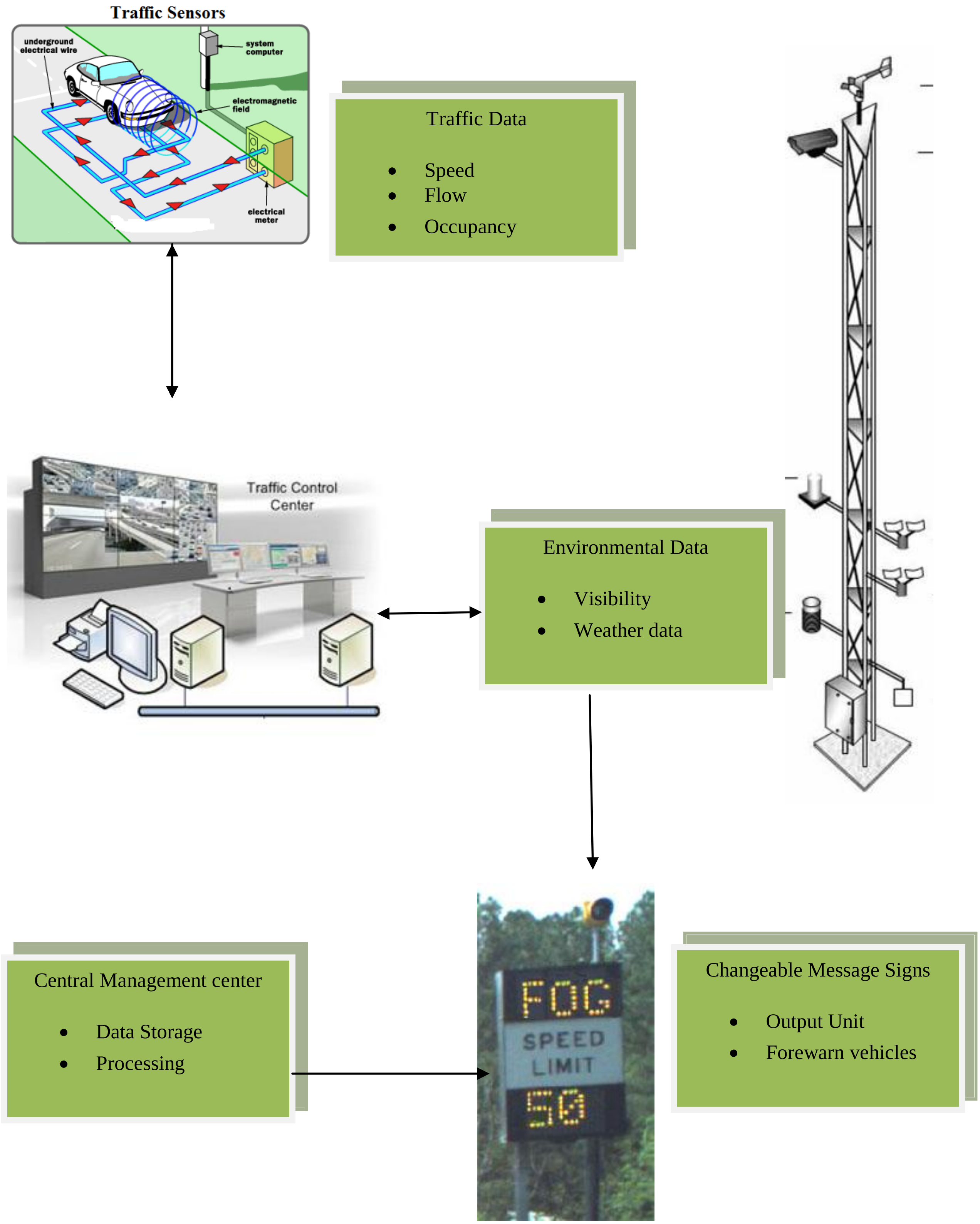


Figure 21 Different Components of an Active Detection and Warning System

5.0: Benefit Cost Analysis of Fog Detection and Warning Systems

In this section feasibility of active fog detection and warning strategy in dealing with low visibility condition has been analyzed by benefit cost analysis framework. A correct assessment of the fog warning system requires a strong understanding of benefits to have a proper evaluation about the system efficiency. In many cases determining the exact nature of benefits and converting them to money is not an easy task and even with the best evaluation methods the precision of final outcome is not guaranteed. Improves in safety in form of reduction in number of accidents comprised the major part of benefits in fog detection and warning systems. Although there are other types of benefits like increase in mobility of the vehicles associated with a fog detection and warning system but in this report savings in number of accidents has been considered as the only benefit coming from the system as the empirical data on other types of benefits is rare. There are different reduction percentages in number of fog related accidents reported by different states. For example Caltrans reported 80 % reduction in number of fog related accidents while Pennsylvania claimed elimination of 60% of iced related accidents in its roadway during winter time. Following the same approach, at first it is assumed that an active fog warning and detection system is capable of reducing 40% of fog related crashes, then, it has been tried to show the effect of various crash reduction factors on final outcome of the benefit cost analysis. Furthermore, we assume that the total cost of motor vehicle occupants crashes as $88 million per year for West Virginia. It is worth to be mentioned that the cost of crashes in dollar has been adopted from Center for Disease Control and Prevention (CDC) website (www.cdc.gov/motorvehiclesafety/statecosts/). Considering the fact that fog account for 1% of crashes we make this assumption that approximately the total cost of fog related crashes happening in the state is $0.88 million per year. Moreover, project service life is considered to be

10 years and assuming the present value factor for 4% rate is equal to 8.11. Therefore the net present value of benefits is calculated as below:

BNPV: 0.88*0. 4*8.11=2.85 Million dollars

In this report project cost is calculated based on the total cost to design and install a system. Here it is assumed that the system includes RWIS, traffic sensors, CCTV, main processing unit, VMS, highway advisory radio, and connection to power and communications, and design and construction engineering. Also in this report is assumed the system is deployed along five miles segment of a highway. The detail for project cost is provided as table (8). It should be noted that all the unit price cost has been derived from Intelligent Transportation Systems Benefits, Costs, Deployment, and Lessons Learned version 2008.

Table 8- Cost estimation table for an active fog warning and detection project

Cost Estimation			
Item	**Number**	**Unit Price**	**Cost**
Roadway Weather Information System	4	11,000	44,000
Variable Message Signs	4	50,000	200,000
Fiber Optic Cable Installation	-	40,000 (per Mile)	200,000
Closed Circuit Television (CCTV)	4	20,000	80,000
Inductive Loop Surveillance	6	12,000	72,000
Environmental Sensor Station	4	40,000	160,000
Highway Advisory Radio	3	25,000	75,000
Conduit Design and Installation	-	40,000 (per Mile)	200,000
		Total Cost	1,031,000

The yearly operational and maintenance including the labor cost is assumed to be 10 percent of the capital cost which is equal to $103,100 annually (Leviäkangas et al 2010 and Stowe, R. 2001).

Therefore the net present value for cost is equal to:

CNPV=Initial Cost+8.11*Operating cost=1,031,000+8.11*103,100=1,816,711

Subsequently, the benefit cost ratio is calculated as below:

$$B/C=\frac{2,850,000}{1,816,711}=1.57$$

Following the same approach, the sensitivity analysis of the cost benefit study has been performed based on different values of crash reduction factor on project life spans as demonstrated in table (9):

Table 9 Summary of Benefit Cost Analysis (*i*=4%)

Crash Reduction Rate is equal to %40			
Life Span	**NPV of Cost ($)**	**NPV of Benefits ($)**	**Benefit Cost Ratio**
10	1816614	2854720	1.571451
15	2117544	3910720	1.846819
20	2366313	4783680	2.021575
25	2569942	5498240	2.139441
Crash Reduction Rate is equal to %30			
Life Span	**NPV of Cost ($)**	**NPV of Benefits ($)**	**Benefit Cost Ratio**
10	1816614	2141040	1.178588
15	2117544	2933040	1.385114
20	2366313	3587760	1.516182
25	2569942	4123680	1.604581
Crash Reduction Rate is equal to %20			
Life Span	**NPV of Cost ($)**	**NPV of Benefits ($)**	**Benefit Cost Ratio**
10	1816614	1427360	0.785725
15	2117544	1955360	0.923409
20	2366313	2391840	1.010788
25	2569942	2749120	1.069721

The results of the benefit cost analysis show that the project is economically efficient as the achieved benefit cost ratio is greater than one. Moreover, with increase in life span of the project the benefit cost ratio tends to grow as shown in table (9). However for a low crash reduction factor of %20 the benefit cost ratio is less than one for the first 15 years but the system will yield benefit for life span of 20 and 25 years.

6.0: Conclusions and Recommendations

Limited and distorted visibility sight distance due to fog is a serious problem in West Virginia's interstate and state highways and is the cause of nearly 1.3% of all fatal crashes all in the state. Most of West Virginia is affected by fog because of the changes in altitude where temperature inversions are common. According to the collected data in this report all three types of fog that can occur in West Virginia: upslope, radiation, and advection which results in lack visibility, limited contrast, distorted perception, judgment errors and reduction in headway and speed of the vehicle traveling in foggy conditions. It is also discussed that the current fog measurement criteria which is number of foggy days per year is not a robust measurement and fog classification should be based on parameters like fog density, duration and visibility.

For the drivers who are traveling in adverse weather condition it is very crucial to receive proper information regarding the road condition well ahead of the fog conditions in order to make subsequent proper action. In this report two different active and passive warning systems which are used to forewarn the travelers has been explained and discussed. Passive traffic warning control devices are low cost treatment and are mostly useful in the areas where fog is not a serious issue whereas active systems are a part of ITS technology and developed by integrating various technologies.

Currently, there is only one active fog detection and warning system in West Virginia which is installed on I-64 Kanawha River Bridge which is covering I-64 St. Alban's intersection. However, there are still more highway locations which are suffering from the limited visibility due to fog. In this report it has been tried to identify the most critical fog prone areas which are vulnerable to low visibility related crashes. Identification of these locations may serve as the potential place for deploying active fog detection and warning systems.

In addition, a detailed literature review of the implemented fog detection and warning systems in U.S in terms of system configuration, components, and the approximate set up cost has been presented in this report. The information regarding the discussed systems, their methodology in sensing the fog and alerting the drivers has been collected through making several contacts by State DOT's, US DOT and some of the companies who are involved in the area of traffic control. The systems used by other states are different in terms of sophistication, cost, coverage are and deployment. For example it is claimed that the system installed by Florida DOT is inexpensive where as the system installed by Caltrans cost approximately $12 million. Moreover, the systems operation might vary from fully autonomous systems like the FDOT system or the configurations which can be triggered from the TMS. Topological properties of the area, traffic volume, fog density, history of the weather related crashes, available source of power and infrastructure and allocated budget are all prominent parameters which may come into play in preferring one system on the other.

Finally, the economic efficiency of the fog detection system has been highlighted by performing traditional cost benefit analysis as many of the state reported significant amount of reduction in number of fog related accidents after the system was put in place. The results of the cost benefit analysis prove the efficiency of the fog detection system and provide justification for implementation of such systems.

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