228

National Cooperative Highway Research Program

NCHRP Synthesis 228

Reduced Visibility Due to Fog on the Highway

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

National Cooperative Highway Research Program

Synthesis of Highway Practice 228

Reduced Visibility Due to Fog on the Highway

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Transportation Research Board
National Research Council

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to traffic and safety engineers; highway and bridge designers; police, fire, and emergency personnel; toll authorities and other officials concerned with roadway safety operations. It describes the forecasting and detection of fog, as well as countermeasures that are used by state and local transportation agencies to dissipate fog and to warn motorists during reduced visibility conditions.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

The presence of fog has often resulted in serious collisions due to reduced visibility. This publication of the Transportation Research Board presents a generalized background on the causes of fog, fog forecasting and detection methods, and how fog affects the roadway and the driver. The various countermeasures practiced by transportation agencies that are described herein range from techniques to dissipate fog to a variety of warning systems to alert drivers to adverse conditions. The National Transportation

Safety Board (NTSB) has held hearings and made recommendations for fog countermeasures, which are described in the synthesis. The synthesis is provided for information only; as with any function dealing with safety, practitioners are well advised to exercise appropriate judgment, carefully support the bases of decisions with factual findings, and document reasons for the decisions when implementing fog countermeasures.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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The Principal Investigators responsible for the conduct of this synthesis were Sally D. Liff, Manager, Synthesis Studies, and Stephen F. Maher, Senior Program Officer. This synthesis was edited by Linda S. Mason.

Scott A. Sabol, Senior Program Officer, National Cooperative Highway Research Program, assisted the NCHRP 20-05 staff and the Topic Panel.

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REDUCED VISIBILITY DUE TO FOG ON THE HIGHWAY

SUMMARY

In the United States during 1990 and 1991, four multiple-vehicle accidents caused by reduced visibility conditions resulted in 21 fatalities. Such catastrophic accidents dramatize the hazard of reduced visibility on the highway caused by fog, dust, or smoke. The extreme variability in density, predictability, and location of the hazard further complicates the task of improving highway safety conditions.

Much of the problem stems from inadequate traffic control techniques to provide specific behavior guidance for drivers in areas of reduced visibility, and from the unpredictability of when and where these techniques are needed. Also of great concern is erratic driver behaviors, including excessive or variable speeds, following too closely, or stopping on the roadway, which increase potential for accidents. Once an accident occurs, reduced visibility increases the likelihood of secondary accidents, where vehicles collide with those already involved.

Because of the ongoing problems associated with reduced visibility, emphasis on countermeasures has increased in the United States and Europe. This synthesis describes countermeasures implemented in California, Louisiana, New Jersey, New Mexico, South Carolina, and Utah, and in England and the Netherlands.

In California, significant initiatives have been taken to address the persistent problems of fog and dust in the Central San Joaquin Valley. Efforts in public awareness have been well received as witnessed by favorable public perceptions to fog countermeasures and an increase in the number of radio and TV stations seeking information. California Highway Patrol units used to pace traffic and to provide an enforcement presence were also believed to be effective in reducing speed and accidents. Similar projects are planned for Stockton and San Bernardino.

Louisiana has implemented countermeasures for fog on the Lake Pontchartrain Bridge for some time and recent improvements, including the use of changeable message signs (CMSs) and the restricting of vehicles to one lane have been successful. The system of speed limit and warning signs on the New Jersey Turnpike which alert motorists to driving conditions ahead is considered to significantly reduce secondary accidents. The variable speed limit system installed in New Mexico was found to respond quickly to changes in traffic conditions; however, driver behavior did not appear to change significantly after specific messages (WET AHEAD, SLOW AHEAD, WRECK AHEAD) were displayed.

South Carolina installed a traffic management system on the Cooper River Bridge that includes active and passive traffic control features, in addition to weather detection and surveillance capabilities. Tennessee has installed a fog detection/warning system consisting of CMSs with vehicle flow detectors for monitoring speed.

Utah has researched the use of aerial and ground seeding techniques for the dispersion of fog. These experiments have been successful in dispersing fog to improve safety; however, the success depends on logistical planning along with meteorological and physical conditions that are within the functional limits of the seeding concept.

European initiatives involved fog detection and monitoring on M25 circling London, where fog signs and CMSs are being used. The Dutch have implemented countermeasures that include traffic flow detectors, fog detection, automated traffic control, and enforcement. There is a substantial coordinated effort in the European community toward safety associated with reduced visibility situations.

In 1991, the National Transportation Safety Board convened a special hearing on fog accidents on limited-access highways. Numerous suggestions, conclusions, and recommendations for countermeasures resulted from the hearing and these are summarized in Chapters 6 and 7.

Research and development continued with initiatives being undertaken in various states along with those being supported by the Federal Highway Administration. There does seem to be an urgency to implement the Intelligent Vehicle Highway System capabilities because of the real potential for improvements in vehicle-driver communications.

This report cites a number of ongoing and planned studies; specifically, California, Georgia, Idaho, New Mexico, South Carolina, Tennessee, and Utah, in addition to those abroad. Because of the time factor in publishing this synthesis, additional information may now be available from those and other sources.

CHAPTER ONE

INTRODUCTION

Reduced visibility on the highway resulting from adverse weather conditions, smoke, or dust impairs motorists' ability to see pavement markings, signs, and other vehicles, and their ability to react appropriately to changing roadway and traffic conditions. One of the most serious meteorological restrictions on visibility is fog. The extreme variability in fog, especially its density and location, coupled with problems in driver perception and behavior, presents a threat to safe traffic operations. This hazard was recognized in the National Transportation Safety Board's (NTSB) special public hearing on fog accidents on limited-access highways, held in the spring of 1991 as a result of serious accidents in Tennessee and California. In the opening session, it was noted that "because of the complexity of fog related issues, the diversity and effectiveness of the measures with which states deal with fog conditions, the national implications of fog problems on limited access highways, and recent accidents involving fog, the NTSB believes it is time to revisit the issues."*(5)* [NTSB previously held a "fog symposium" in 1971.]

The NTSB noted that in 1990 and 1991, four accidents caused by fog on limited-access highways in the United States, involving more than 240 vehicles, had resulted in 21 fatalities and more than 90 injuries. Also, the NTSB noted that between 1981 and 1989, accidents where fog was present on all classes of highways in the United States had resulted in more than 6,000 deaths. Although this is a small percentage of the total accidents, they are catastrophic and generally attract national media attention.

Because of the ongoing problems associated with reduced motorist visibility caused by fog, and the need for research and safety countermeasures, a synthesis of information on the subject was undertaken.

PURPOSE AND SCOPE

The purpose of this project is to gather and publish information relevant to reduced visibility caused by fog on the highway. The synthesis focuses on the following:

- The meteorology of fog forecasting and detection;
- The state of knowledge regarding driver perception and behavior in fog; and
- The current state of fog countermeasures, including evaluations of those countermeasures for which such information is available, along with a review of practices that have proved unsuccessful.

This synthesis briefly describes forecasting and detection of fog and examines driver behavior during reduced visibility conditions. Details of countermeasures implemented in California, Louisiana, South Carolina, New Jersey, New Mexico, England, and the Netherlands are presented, with emphasis on recent endeavors. Suggestions and conclusions from NTSB hearings, along with comments on research and development activities in the United States and Europe are provided in the final chapter.

CHAPTER TWO

FOG FORECASTING AND DETECTION

Fog is simply a cloud on the ground composed of tiny droplets of water or, in rare cases, of ice crystals. The minute droplets of water are nearly spherical, varying in diameter between 2 and 100 microns. The transparency of a fog depends primarily on the concentration of droplets—the more droplets, the denser the fog. Table 1 shows the international classification of the various categories of visibility. Thick fog represents the most important visibility range for road users.

TABLE 1

INTERNATIONAL CLASSIFICATION OF VISIBILITY *(1)*

Visibility	Description
Less than 40 m	Dense fog
40 – 200 m	Thick fog
200 – 1000 m	Fog
1 – 2 km	Mist (if mainly due to water droplets) Haze (if mainly due to smoke or dust)
2 – 4 km	Poor visibility
4 – 10 km	Moderate visibility
10 – 40 km	Good visibility
Over 40 km	Excellent visibility

The average annual number of days with thick fog throughout the United States is shown in Figure 1. Thick fog is more prevalent in coastal areas than in the center of the continent. For example, the Pacific Coast states, the Appalachian Highland Region, and New England have the most days with heavy fog.

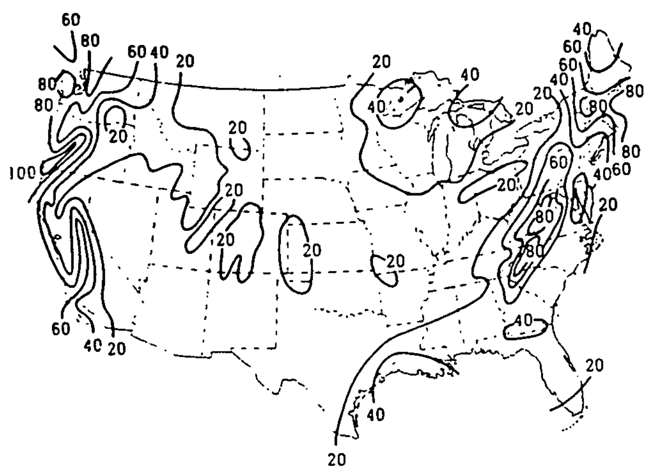

FIGURE 1 Average annual number of days with heavy fog throughout the United States *(2)*.

CLASSIFICATION OF FOG

Fog usually forms in one of two ways: (1) by air cooling to its saturation point (dew point); and (2) by mixing air parcels with different temperatures and humidities. Four prevalent types of fogs are discussed below.

Radiation Fog

Fog produced by the earth's radiational cooling is called radiation fog. It forms best on clear nights when a shallow layer of moist air near the ground is overlain by drier air. The moist lower layer, chilled rapidly by the cold ground, quickly becomes saturated and fog forms. The longer the night, the longer the time of cooling and the greater the likelihood of fog. Therefore, radiation fogs are most common over land in the late fall and winter and reach a maximum around dawn. The fog does not begin to dissipate until the sun is high enough to heat the atmosphere.

During the winter, when a high pressure system becomes stagnant over an area, radiation fog may form on many consecutive days. Radiation fog is frequently called "valley fog" because the cold, heavy air drains downhill and collects in low-lying areas. This is often the case in the Central Valley area of California where a fog layer settles between two mountain ranges.

Advection Fog

A different process produces what are called advection fogs. In this case, the fog arises from the movement of humid air over a surface that is already cold. An example of advection fog may be along the Pacific Coast during summer, when warm, moist air from the Pacific Ocean is advected by westerly winds over the cold, coastal waters. Another example is the moist air from the Gulf of Mexico that moves northward over progressively cold land and forms fogs in the southern and central United States. Similarly, air moving across the warm Gulf Stream encounters the colder land of the British Isles and produces the thick fogs of England.

Upslope Fog

Fog that forms as moist air flowing up along an elevated plain, hill, or mountain is called "upslope fog." Typically, upslope fog forms during the winter and spring on the eastern side of the Rockies, where the eastward sloping plains are nearly a kilometer higher than the land farther east. Upslope fogs that form over an extensive area may last for many days.

Evaporation Fog

A common form of evaporation fog is steam fog, which forms when cold air moves over warm water. This type of fog forms above a heated outside swimming pool in winter or on a hot roof or parking lot after a summer shower; the vapor rising from the warm water quickly condenses into steam in the cooler air above. In this way, the evaporation from a body of water on an unseasonably cold night may generate a shallow fog. Warm rain falling through cool air can give rise to a steam-like fog. When a warm raindrop falls into a cold layer of air, the saturation vapor pressure over the raindrop is greater than that of the air. This vapor pressure difference causes water to evaporate from the raindrop into the air and, when the cold surface air becomes sufficiently moist, fog forms. Fog of this type is often associated with warm air riding up and over a mass of colder surface air. The fog usually develops in the shallow layer of cold air just ahead of an approaching warm front or behind a cold front, which is why this type of evaporation fog is also known as "frontal fog."

METEOROLOGICAL FORECASTS

Predicting fog can be very difficult because it can vary in density and location, move from one location to another (horizontally or vertically), develop or dissipate quickly, and encompass small or large areas.

The presence of fog on the highway is observed and forecast primarily to (1) provide data for delineating problem locations and predicting the occurrence of fog; (2) to develop and relay information to the motoring public; and (3) to obtain data for use in conjunction with information advisories, reduced visibility systems, and countermeasures.

Summaries of climatological data, as well as current forecasts, are provided by the National Weather Service (NWS). The 1991 summary for Fresno, California, is shown in Appendix A. It is noted that along with the normals, means, and extremes, there is information on the number of days for "heavy fog visibility 0.4 km (1/4 mi) or less."

Forecasts for immediate use generally are in the form of advisories issued when fog restricting surface visibility to 0.4 km (1/4 mi) or less is expected. Information on location, visibility, and time of dissipation is disseminated in several ways. 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, its Radio Network System offers routine weather information, as well as dense fog advisories, that reaches about 90 percent of the U.S. population.

Meteorologists often can accurately forecast the initiation of conditions necessary for the formation of fog. However, the expected fog does not always materialize, or it may appear under conditions not normally conducive to fog formation. Because of these uncertainties, the NTSB recently 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."(*3*)

Real-Time Information

Real-time information on the presence and density of fog is of primary importance in countermeasures because any time lag between the onset of fog and the initiation of safety measures could be crucial. Such information is generally obtained with fog sensing devices, although estimates of visibility and a description of conditions may be provided from personal observations, usually by the police.

Fog Sensors

Fog sensing devices have been used for airports, waterways, and highways. They are categorized as transmissometers, and backscatter or forward scatter sensors. To be effective, visibility sensors must be placed in a manner to detect reduced visibility throughout the fog-prone area.

In a transmissometer, a projector transmits a known amount of light toward a detector usually set at a distance of 152 m (500 ft) ±. Primarily used at airports, these instruments are costly, heavy, and require a long and accurate alignment of projector and detector.

With the backscatter sensor, the light source and receiver are pointed in the same direction and positioned so that the amount of light scattered back is measured. A large amount of backscatter indicates dense fog. A disadvantage of this device is the variation in the amount and direction of back-scattered light (a function of the size of the scattering particles).

The forward scatter sensor has a projector that sends out a beam of light; the amount of light scattered forward into a receiver is measured. Although relatively new, this sensor is competitive in accuracy, reliability, and cost. Because it is compact and lightweight, making it relatively easy to mount, it is the predominant sensor used.

Both forward scatter and backscatter devices "see" only a small volume of air, becoming "point" detectors when an *area* is what is important. With any type of detector, maintenance is important and should be done on a regular basis, especially at the beginning of the fog season.

Additional information on sensors being used by various states and agencies is presented later in the summaries of countermeasures.

On-Site Weather Stations

Weather stations located in fog-prone areas can provide information on temperature, wind direction, wind speed, humidity, and other factors to monitor and forecast fog formation and dissipation. Also, this local weather information, along with information from other locations or from the NWS, can be used as a database to develop a forecasting model for adverse weather conditions if there is a complete coverage of weather stations in the area of interest.

Closed Circuit Television Cameras

Closed circuit television cameras (CCTV) can be used for monitoring adverse weather conditions and for verifying the operation of traffic control devices such as changeable message signs.

CHAPTER THREE

DRIVER BEHAVIOR UNDER REDUCED VISIBILITY CONDITIONS

The driving task involves performing a number of functions, some of the more important being guiding the vehicle within the highway geometrics and traffic control devices, while detecting other vehicles, and judging their speed and position, and possible behavior of their drivers. This task is complicated by conditions of reduced visibility, which may be accompanied by wet surfaces and darkness. The effects of these conditions on driver behavior has been a matter of concern for many years, and the subject of several studies.

UNITED STATES

A 1967 California study *(4)*, experimenting with variable speed signs, looked at driver speeds and headways for reduced visibility conditions and concluded the following:

- Mean and 85th percentile speeds were reduced as much as 8-13 km/h (5–8 mph). Exceptions were noted for high volume daytime and low volume nighttime freeway operations, where very small reductions were noted.
- Generally, variability in speed was not reduced.
- Posted speeds on expressways effected further reductions in mean and 85th percentile speeds, and also reduced speed variability. These reductions were not found for freeways.
- Posted speeds of less than 55 to 65 km/h (35 to 40 mph) had little additional effect in reducing speeds.
- Drivers tended to drive at speeds higher than the posted speed.
- Headways were not affected by fog or posted speeds.

Comments relative to studies conducted in California during the 1960s are interesting. At the 1991 NTSB special public hearings, it was noted that at low posted speeds in very dense fog on freeways, there was an increase in variance of speeds between vehicles. Some drivers believed the reduced speed limit was warranted and slowed down, while others did not. The probability of accidents increased because one group of drivers slowed relative to the others. The drivers who did slow down did not reduce speed to the posted limit. It was speculated that the drivers may discredit a warning sign that advises a speed significantly higher than that posted. *(5)*

Research in Oregon in 1978 used a test facility making fog conditions and derived the following findings: *(6)*

- When a single advisory sign was posted well in advance of the fog zone, there was a noticeable change in flow stability and vehicle speeds. In general, the speed sign appeared to smooth out the mean speed by making the deceleration start earlier and become more gradual.
- The lower visibility condition resulted in lower speeds.
- The addition of a posted speed generally resulted in higher coefficients of variation.
- There was an optimum posted speed for producing the smoothest traffic flow for each visibility condition.
- Signing was important both in advance of the fog and in the fog zone.
- After a number of exposures to false or unrealistic information given by a system, drivers would no longer respond to the system.
- Questionnaires revealed that:
  46 percent of the drivers preferred to follow another vehicle in fog;
  29 percent preferred to follow pavement stripes whenever possible; and
  5 percent said they would pull off the road and stop in dense fog.

A 1979 study in Oregon indicated that the use of a variable message warning sign on a fog prone interstate did not necessarily lead to a decrease in speeds when the posted speed was lowered. Accident data did, however, indicate that the system substantially increased safety during periods of reduced visibility by reducing the number and severity of fog related accidents. *(7)*

Research in Virginia (1977) investigating the use of pavement inset lights during fog for improved motorist guidance led to the following observations. *(8)*

- There was an increase in nighttime speeds and a decrease in daytime speeds after installation of the inset lights.
- The lights resulted in an increase in speed variability for cars.
- For all conditions (before and after), the actual sight distances were less than the safe stopping distances.
- Nighttime headways increased after the lights were installed.

It was noted that these changes in traffic flow could be construed as producing an increase in the potential for accidents, while safety might be enhanced by the improved delineation the lights provided.

In a recent presentation, Rockwell noted that driver problems in fog included the following: *(5)*

- restricted visibility;
- speed election beyond available visibility;

- gain lateral tracking control cues at the expense of close car following;
- over-response to velocity perturbations;
- indecision in lane placement, speed election, whether to
- leave the roadway and use of lights and hazard lights; and
- inability of driver to see far enough ahead to anticipate braking by lead car.

As a result of these situations, there are drivers with different elected speeds and very short headways in fog, and this flow instability is what Rockwell thought caused the problems.

Rockwell also noted that his research on signing showed that a driver spends anywhere from 0.8 to 2.0 seconds to read a sign, which in extreme cases does not allow a driver the desired response time. Therefore, he contended that signing must be placed prior to a foggy area, not in it.

In a 1990 accident in Tennessee, 99 vehicles were involved, 12 people were killed and 42 were injured. Investigators determined that the accident was probably caused by drivers operating their vehicles at significantly varying speeds following the sudden loss of visibility. A questionnaire survey of the drivers involved in the accident revealed that 18 estimated their speeds to have been between 24 and 81 km/h (15 and 50 mph) entering the fog, while 37 said theirs had been between 89 and 113 km/h (55 and 70 mph). The NTSB *(3)* noted that the multiple-vehicle, rear-end collisions involved slowed or stopped vehicles. They also noted that the presence of light fog and fog warning signs should have been distinct clues to dense fog and hazardous driving conditions ahead. In short, some drivers slowed for the light fog, some slowed for the dense fog, some slowed only when they encountered vehicles that had slowed or stopped, and others never slowed and consequently collided with vehicles that did slow or stop. These actions led to a questioning of the credibility of warning signs, and NTSB recommended that the warning given drivers should reflect actual conditions, which would produce more uniform driver behavior, and thus reduce variations in speed.

The NTSB also stated that in other areas where signs had been posted to instruct drivers to reduce speeds but did not cite a specific speed, variation in speeds had resulted in accidents.

It was also concerned that the disparity among implemented countermeasures around the country could cause driver confusion and result in nonuniform driver response. *(3)*

NETHERLANDS

Job Klijnhout, a Dutch researcher, reports that drivers will not slow down to a safe speed in fog because they are misled by the environment. In fog, the drivers' brains will translate the vagueness as "far away," thus, the drivers will have the feeling that they are driving slower than they are, and any advice to drive slowly will still lead to speeds that are too high. It was noted that measurements were made in the Netherlands comparing actual visibility range against perceived range and against traffic speeds. Visibility ranges as low as 150 m (490 ft) were hardly reflected in the traffic speeds. At ranges between 50 and 150 m (160-490 ft) speeds went down, but they were not low enough.

It was also noted that only with severe speed differences and traffic jams is there a real danger. Field tests have shown that when drivers are in fog and are shown an advisory speed equal to the average speed, the variance of the speed distribution was reduced to one-third. Similar tests under nearly saturated conditions gave similar results. Therefore, in specific situations, a speed advisory that does not differ from the average speed has a positive effect on the stability of traffic. The speed advisory was given every mile because (1) due to driver difficulty in estimating distance, a message "Accident 5 Miles Ahead" means little, and (2) drivers soon forget—a warning will have lost its effect after about a minute. Therefore, information should never be given more than a minute ahead and should be repeated in one-minute intervals.

It was noted that a problem with displaying messages for this purpose in fog is that the impact of the signals was reduced when used as a warning against traffic congestion.

Klijnhout concluded that the solution lies in stopping vehicles from running into standing or slow-moving vehicles when there is fog. The facility should be reserved for warning against slow traffic and only adequate monitoring and signaling systems can do something against fog accidents, a general warning is not enough. Also, experience showed that once police were on the site, warning traffic to slow down, the risk for the secondary accidents practically disappears. The solution, therefore, "is obvious—detect traffic jams and slow traffic down." In Europe, this is the focus: protection against secondary accidents using fully automatic surveillance and signaling equipment. *(9)*

SUMMARY

In summary, studies and opinions relative to driver behavior under reduced visibility conditions indicate that (1) motorists will not significantly alter their speeds until visibility in fog is below 150 m (490 ft); (2) reductions in speed can be effected through the use of signs, but drivers still travel at a speed in excess of what is considered safe under conditions of limited visibility; (3) signs should be credible and specify desired speeds; (4) motorists travel too close to other vehicles; (5) variability in speeds is the factor common to most accidents; and (6) there are questions concerning the use of signs in the fog zone.

CHAPTER FOUR

REDUCED VISIBILITY COUNTERMEASURES

Research on countermeasures for limited visibility has been going on for many years. Implementation of the results, however, has not been overly encouraging as evidenced by the number of multiple-vehicle accidents occurring since 1990 (see Table 2).

When current highway speeds and increasing traffic volumes are coupled with conditions of reduced visibility, the potential for more accidents is real and alarming. This concern has triggered a new call for countermeasures.

The results of a questionnaire that surveyed the states for countermeasures being used to reduce accidents in fog are summarized. A discussion follows of countermeasures that have been implemented and those in the planning stages, including comments and recommendations contained in a recent report by the NTSB.

TABLE 2

SUMMARY OF FOG RELATED ACCIDENTS *(10)*

State	Fatalities	Injuries	Vehicles
California			
January 9, 1991	2	8	18
February 7, 1991	4	31	75
November 29, 1991*	17		364
Tennessee			
December 11, 1990	12	42	99
Utah			
January 2, 1991	3	19	55
Virginia			
April 20, 1991	2	45	54

*Dust storm visibility impairment.

SURVEY OF FOG ACCIDENT COUNTERMEASURES

In preparation for the 1991 NTSB special hearings, the FHWA surveyed its field offices for information on state practices in development and use of countermeasures against accidents attributable to fog. The survey form consisted of 33 questions, divided into seven parts: (1) Problem Identification; (2) Detection; (3) Delineation; (4) Signing; (5) Incident Management; (6) Lighting; and (7) Fog Abatement.

The survey showed that 26 states had not identified a specific fog related accident problem. Ten states reported having identified at least one fog related, high-accident location. Three states (Wisconsin, Texas, and Wyoming) had identified two to three such sites, and nine states (Arkansas, California, Kentucky, Maine, Montana, New Jersey, North Dakota, Pennsylvania, and Utah) had identified several sites. Of the states that had identified one or more locations considered as fog-prone accident sites, most had erected passive signs (signs with fixed messages) to warn motorists of the possibility of fog. Nine states were using changeable message signs, and some others had mobile signs.

Regarding pavement markings used as countermeasures, two states were using pavement inset lights, similar to airport runway lights, along the edge of the highway. Five states were planning special installations of raised pavement markers, and to widen lane or edgelines. Four states said they used wider or closer spaced pavement markings.

Some states were using fog detectors; however problems were reported. Most states still depended on personal observations by police and highway agency employees to detect reduced visibility conditions.

Four agencies reported the use of speed limit reductions in fog areas. The most commonly used warning device was a passive sign, usually with a flashing beacon. Three agencies mentioned the use of convoys or restricted lanes of traffic.

The survey found that most of the countermeasures were used mainly on interstate highways. Comments indicated that the education of drivers was very important, and that little effort had been made to inform people of how to drive in fog.

DISCUSSION OF IMPLEMENTED COUNTERMEASURES

Countermeasures fall into two primary categories: (1) the dissipation of fog using artificial means to eliminate or lessen the reduced visibility condition, and (2) when fog occurs, taking action to provide a safer driving environment using passive and active traffic control methods.

Dissipation of Fog

Among the various possibilities for dealing with fog is its dissipation by artificial means. In the past decades, many schemes have been tried, however, no universally practical method has been found.

One method involved using fans to blow the fog away (a tactic used in areas of the Arctic); however, the method is applicable only on a small scale and in special situations. Another proposal involved using electricity, jet engine exhausts, or anthracite coal to provide heat, but the cost is prohibitive. Drying the air with chemicals rather than heat was effective in some cases; however, the expense and corrosive nature of the chemical limit the practice.

Dispersing warm fogs by droplet coalescence has been tried with some success in dissipating radiation fogs associated with calm air. Wind condition is crucial and a breeze can quickly refog a space that has been cleared.*(11)*

A promising method of fog dispersal being tested involves the injection of a catalyst that will cause the droplets to coalesce and grow large enough to fall to the ground. This procedure is effective in fogs consisting of super-cooled droplets. By seeding the fog with particles of a very cold substance such as dry ice, liquid propane, or liquid carbon dioxide, some of the fog droplets will freeze. Water vapor in the air then condenses into ice crystals and the resultant drying of the air turns additional fog droplets back into vapor. The vapor accelerates the growth of the ice crystals, which fall to the ground as they enlarge.

Two projects in Utah used liquid carbon dioxide for fog seeding. One used an aircraft for seeding, the other dispersed the liquid carbon dioxide from a vehicle on the ground. These similar procedures, described below, use dispersal techniques developed at the University of Utah by Dr. Norihiko Fukuta.

Airborne Seeding

A Cessna aircraft was used to disperse liquid carbon dioxide from a steel tank beneath the plane over the Great Salt Lake in Utah. Visibility was such that all airline traffic was grounded. A path was flown approximately 9 mi long and 20 ft deep inside the fog. It was noted that after about 15 minutes, sinkholes started to form at the fog's very top where it was seeded and eventually a hole in the fog 9 mi long, 2 mi wide, and 600 ft deep, was created using 9 pounds of liquid carbon dioxide. *(12)*

While still experimental, this technique is being revamped. For example, a system is being devised to allow seeding from above the fog which is safer for the pilot.

Ground Seeding

A 1993 research project *(13)* was conducted in Salt Lake City, Utah, where dense fog causing hazardous driving conditions has lead to multi-car accidents and fatalities. The emphasis of the research was on developing the logistics, procedures, and equipment involved with fog dispersal in specific highway trouble spots. Verification of the liquid carbon dioxide (LC) seeding concept had been accomplished in earlier projects, whereas, the equipment and operational procedure necessary to accomplish fog seeding with LC was developed. A mobile vehicle-mounted system was found to be the most effective method of dispersing LC for highway use.

The objective of the research was to improve safety and highway serviceability by:

- locating and identifying those areas where fog dispersal can effectively mitigate the hazard for the greatest impact on safety improvement,
- developing cross-street and parallel street routes for dispensing LC under different fog and meteorological conditions to delineate the most effective routes for a given set of conditions,
- developing operational procedures for maintenance crews to include target area treatment approaches, equipment requirements, and special safety considerations.

Two sites were chosen on Interstate 215, the criteria being frequency of dense fog occurrence, volume of traffic, posted speed, and fog related accident history. Equipment involved two "half-ton" trucks set up with double tank configurations capable of 6 hours of continuous dispensing.

Evaluations led to the following findings:

- All fog seeding attempts at the target locations were successful in dispersing fog when the limiting factors of temperature, fog density, wind drift, and dispensing routes were properly considered. A summary of the seeding attempts is shown in Table 3.
- Several attempts were made with one or more of the limiting factors outside or exceeding the proper conditions to establish operational limits. In virtually every case where an attempt was made to seed the fog without the proper conditions present, no appreciable improvement could be observed.
- Temperature and fog density proved to be the most significant factors relating to the success or failure of any attempt at fog dispersion. An example of the importance of these two parameters was emphasized during a fog occurrence at site No. 1 where the temperature was 1°C (33.8°F) and the fog density created a 61-m (200-ft) visibility limit. The seeding attempt yielded no appreciable increase in visibility after several LC dispensing passes and no evidence of ice crystal formation could be found anywhere in the vicinity of the target area. Attempts like this helped define the procedural limits of operation that are stated under the fog dispersion procedure below.
- It is important to note that changes in seeding procedures had to be implemented during treatment of the target areas when changes in the existing conditions such as wind direction, fog density, and localized atmospheric mixing occurred. The flexibility to respond to changes and an awareness of what changes were occurring during the operation had to be maintained to make any seeding attempt successful.
- A combination of the verification study results and experience gained during previous seeding trials aided in the development of a fog dispersion procedure.

Evaluation of the individual target area treatment procedures, comparison of the seeding attempts for both trouble spots, and the overall assessment of the process for all fog incidents have contributed to the formation of several conclusions: *(13)*

- When all meteorological and physical conditions are within the functional limits of the LC seeding concept, fog can be effectively dispersed or reduced to improve safety and serviceability.
- Successful dispersion of fog requires logistical planning and a systematic approach for each trouble spot on an individual basis.
- The fog dispersion process is an economically feasible program to implement in light of the potential reductions in property damage, loss of lives, and highway user delays.

TABLE 3
SUMMARY OF SEEDING ATTEMPTS *(13)*

Site No.	Date	Initial Visibility (m)	Start Temp. deg. C	Start Time	Final Visibility (m)	End Temp. deg. C	End Time	Road Condition
1	1-11-93	20	-7	06:05	500	-6	06:30	wet
1	1-12-93	50	-7	06:30	400	-7	07:00	wet
1	1-25-93	50	-7	06:00	300	-7	07:31	wet
1	1-26-93	50	-8	07:07	300	-7	07:24	wet
1	2-08-93	100	-7	06:50	300	-7	07:30	wet
2	1-11-93	20	-7	06:20	500	-6	07:15	wet
2	1-11-93	50	-6	07:35	800	-5	08:15	wet
2	1-12-93	60	-5	05:45	500	-4	06:50	wet
2	1-26-93	20	-7	06:15	1000	-4	07:15	wet
2	2-24-93	70	0	08:15	500	0	09:15	wet

* No internal seeding effect observed—cleared by sun.

Recommendations for implementation are as follows: *(13)*

- Application of the fog dispersal procedure should be tried on at least five fog trouble spots throughout the state of Utah. This program would fulfill requirements for an intermediate phase before attempting treatment of all qualifying trouble spots statewide.
- Maintenance groups should be the driving force to implement this intermediate phase where further improvements can be made in the procedure and equipment. This will set up a "train-the-trainer" situation to facilitate the transition into the final phase.
- Implementation Section staff will be available to maintain personnel to aid the implementation process and accept feedback on improvements to the program.
- All target areas should be selected by fog accident history, traffic volume, and frequency of fog occurrences. Other limiting factors may be found that influence selection criteria in specific cases.

CALIFORNIA

California has approximately 966 km (600 mi) of freeways that traverse fog-prone areas. The Central San Joaquin Valley, which encompasses the Fresno area, is especially plagued with dense radiation fog during late night and early morning hours. This type of fog is commonly referred to as "tule fog," because it forms most frequently in low-lying areas which typically have a variety of bulrushes known as the tule, growing in them. Tule fog can reduce visibility in some areas to only a few feet, while other areas nearby have much greater visibility. Each year, mostly during December and January, this area experiences an average of 39 days of fog in which visibility is reduced to 0.4 km (1/4 mi) or less. With visibility suddenly dropping to near zero and speeds at which the stopping distance is greater than the sight distance, hazardous driving conditions prevail.

Because of these dangerous areas, California has been heavily involved in research related to countermeasures for reduced visibility. The number of accidents stemming from reduced visibility in 1991 demonstrates the need to continue these efforts.

The California Department of Transportation (Caltrans) and the California Highway Patrol (CHP) formed a partnership with the objective of reducing the number of limited visibility multi-vehicle collisions. They were aided in this effort by the National Weather Service, the California Trucking Association, and REACT, a group of citizens' band radio enthusiasts. A demonstration program with a two-pronged approach was developed to address the problem.

The mitigation strategies were to promote public awareness of the problem and to examine operational measures. The immediate objective was to reduce fog related collisions in the Central Valley fog test area (Fresno County, SR 99) 10 percent below the number that had occurred in the same area during the period November 1, 1990, through February 1, 1991.

The mitigation strategies included the following:

1. Public Awareness
   - brochures and public service announcements
   - portable message signs
   - portable highway advisory radios
   - fog visibility test signs
   - Central Valley traffic operations center
2. Operational Measures
   - PACE operation
   - TARIF (Trucks At Rest In Fog) program and truck staging
   - Truck metering
   - Truck convoying

Public Awareness

The elements of the public awareness strategy are described below.

Fog Pamphlet and PSAs—A fog brochure (see Appendix B) was used to call public attention to the hazards of Valley tule fog. The brochure shows fog-prone areas and gives tips for driving through fog. These were distributed to or at the following agencies:

California Highway Patrol
California Trucking Association
Department of Motor Vehicles
California Automobile Association
Major truck stops
Major trucking terminals
Major trucking companies
Agriculture inspection stations
Safety roadside rests
All media outlets
Major insurance companies
Major employers
Civic organizations
Valley legislators.

Public Service Announcements (PSAs) issued included one video, three radio spots, and 3,000 copies of one poster. Information was distributed to 56 English and 14 Spanish radio stations, and to two Spanish and eight English television stations.

Posters were distributed for display at rest areas and truck stops to acquaint motorists with the project. Presentations were made to community groups and to trucking company officials and drivers. Caltrans displayed material in rest areas, local businesses, and truck stops, and distributed material to people using their services. Local REACT citizens' band groups broadcast fog information daily on band 17 to truck drivers traversing the Valley.

One PSA showed an officer standing in light fog and stating, "Now you see me," then, suddenly, in dense fog stating, "Now you don't. You probably wouldn't see this either," with a fade to an accident scene. The second PSA used the same dialogue, but with a patrol car with emergency lights appearing out of a dense fog. A third PSA used the same dialogue, with a car racing out of the dense fog. All three PSAs closed with safety tips for driving in the fog.

The radio PSAs used sound effects—specifically, fog horns and police sirens—to get the attention of listeners.

News releases and press conferences involving newspapers, radio, and TV were another important part of public awareness. Appendix C is an example of a news release.

Portable Changeable Message Signs—Changeable message signs, placed along the 72-km (45-mi) test section on Route 99 in Fresno County, were used to provide real-time road conditions and visibility information to motorists. The signs were remotely controlled from the Central Valley Traffic Operations Center (CVTOC). Being portable, the signs give the flexibility required to provide information at any location. Figure 2 shows a CMS, and Appendix D shows a typical menu used during fog.

Highway Advisory Radio—Portable Highway Advisory Radio (HAR) stations, as shown in Figure 3, were placed at each end of the test section. The message gave detailed road information, visibility, and weather conditions, and the control measures in effect. A sample menu of messages available is

FIGURE 2 Portable changeable message sign in fog location.

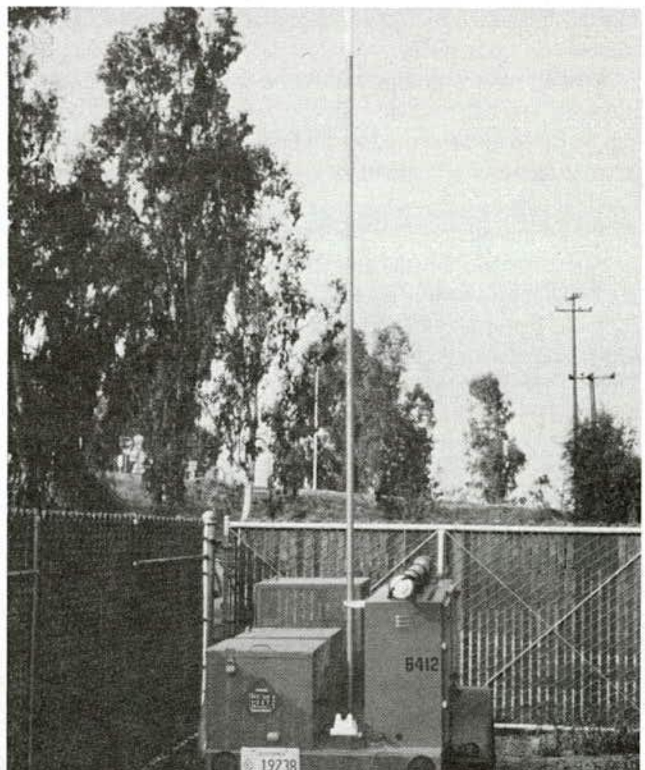

FIGURE 3 Portable highway advisory radio.

shown in Appendix E. The low-power A.M. broadcast, which could be received over a 8-km (5-mi) range, provided more detailed information than could be put on a CMS. It is noted that a CMS placed prior to the HAR alerted motorists to the HAR. The HAR has a cellular phone capability to allow the CVTOC to call and choose an appropriate message and frequency. A generator on the HAR can supply electricity.

Fog Visibility Test Signs—Signs were placed along the shoulders at 0 m, 30 m, 61 m, and 91 m (0 ft, 100 ft, 200 ft, and 300 ft), respectively as shown in Figure 4. The primary purpose of these signs, placed northbound and southbound, was to demonstrate to the public how far they could actually see in the fog. Figure 5 shows one of the test signs.

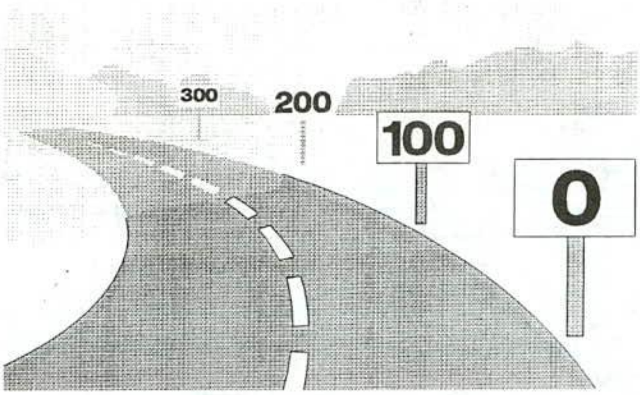

FIGURE 4 Schematic of fog visibility test signs *(14)*.

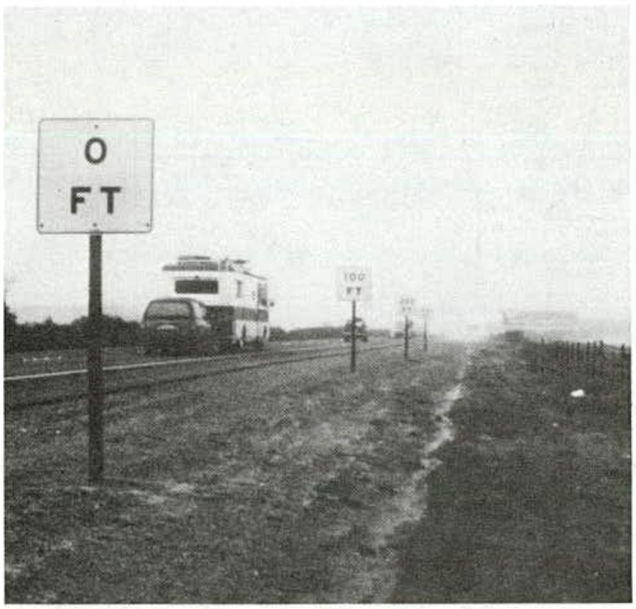

FIGURE 5 Fog visibility test sign.

Central Valley Traffic Operations Center—The Central Valley Traffic Operations Center (CVTOC) served as the central point for coordinating activities during the fog season. Real-time information on roadway and weather conditions, and control measures in effect was conveyed through the operations center.

Press releases and press conferences were used to increase public awareness of the program, and the media were supplied updated information as it became available. This activity involved 56 media outlets and 82 broadcasts per day.

The public could obtain hourly updates on fog conditions by calling the CHP "fog phone." Also, the public could provide the CVTOC with information by using an 800 number or by a cellular phone number. The CVTOC is assigned CHP and Caltrans personnel for cooperation and coordination. HAR sites and CMS locations, as shown in Figure 6, are controlled from the center.

Operational Measures

The operational measures included the pacing of vehicles by the CHP, along with various measures to combat any detrimental effects of trucks.

PACE Program—The CHP established a special enforcement unit called the "PACE" team that operated from November 1, 1991, through February 29, 1992. The CHP used six units for in-view patrol during commute hours on days when visibility was limited to less than 61 m (200 ft). The patrol units entered the freeway at staggered on-ramps on the 71-km (44-mi) test section with lights flashing and did not allow vehicles to pass. The officer selected the safest speed for the conditions, and paced all traffic at that speed before exiting the freeway and then re-entering in front of a different group of motorists to repeat the maneuver. PACE operations were normally in effect during commute periods from 6 a.m. to 10 a.m. on weekdays.

Trucks at Rest in Fog and Truck Staging—Trucks at Rest in Fog (TARIF) involves encouraging truck drivers to voluntarily wait out fog periods, either at staging areas or at some other location. To help in this cause, truck staging areas were constructed at each end of the test section to hold trucks during periods of low visibility. The staging areas were made large enough to accommodate 30 to 40 trucks and portable toilets. Free cellular phone use and coffee were available for those choosing to stay.

Fog information pamphlets and road condition updates were provided at the staging areas. Truck drivers who chose to travel were told of visibility conditions and what control measures were in effect before being allowed to proceed. Truck stops and local businesses were encouraged to offer TARIF specials on foggy days.

Truck Metering—Truck metering was used on certain days by requiring all trucks to exit to staging areas. There they were advised by a uniformed CHP officer of the prevailing conditions and control measures in effect. Trucks were then metered back onto the freeway.

Truck Convoying—To form convoys, trucks were required to meet at the staging areas and wait to be led out in groups of 10 to 20 by a CHP patrol car. The convoys were protected by a traffic break on the mainline and followed by a Caltrans dump truck outfitted with a CMS and attenuator to notify other motorists that a convoy was ahead.

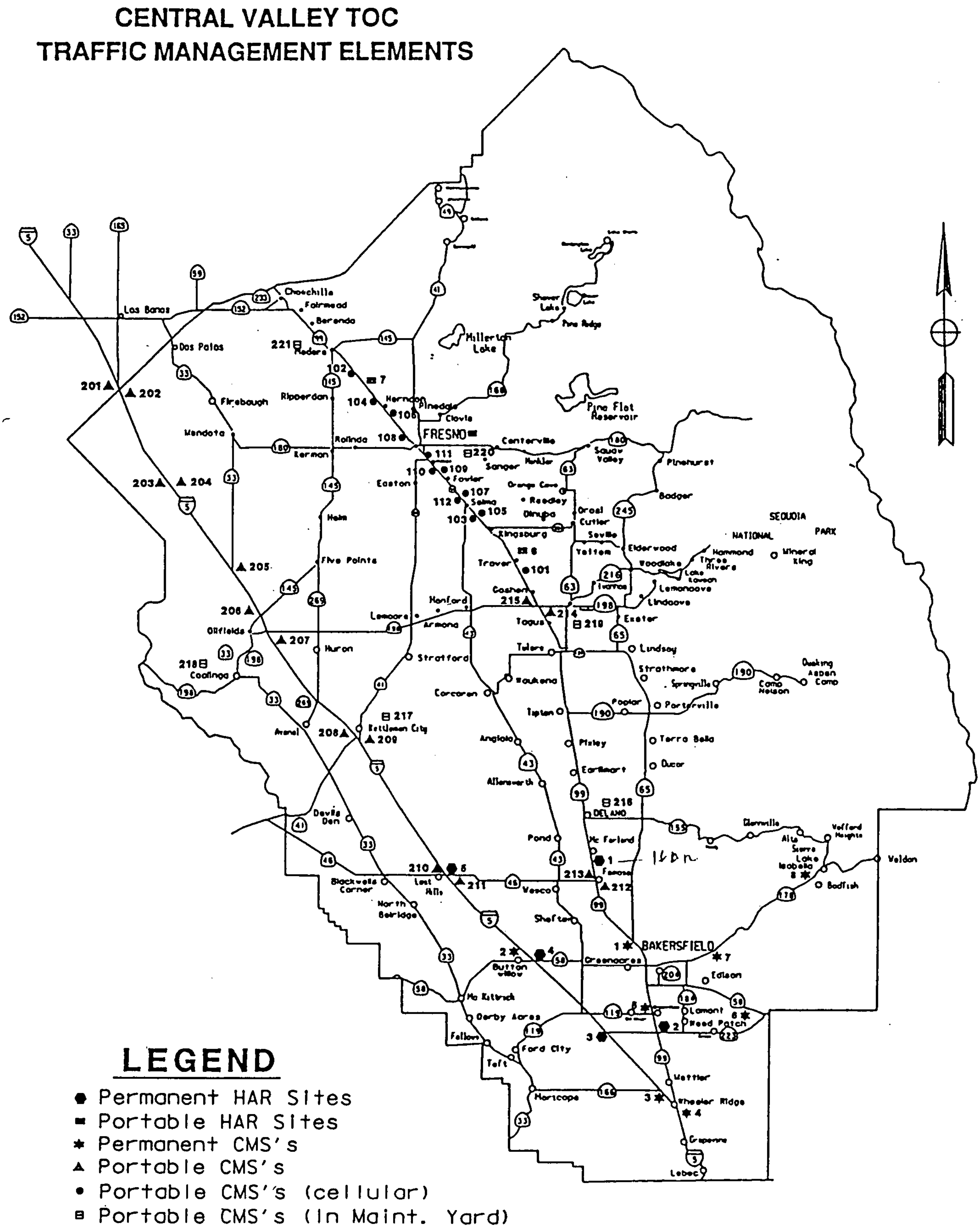

FIGURE 6 HAR and CMS sites *(14)*.

Procedure for Operational Measures

The operational measures involved setting up a criterion for call-out and response for the CHP and Caltrans. The CHP field units on the graveyard shift estimated the visibility distances based on viewing known distances (centerline skips, etc.) and reported visibility conditions to the dispatch center hourly. Fog visibility was categorized as follows:

Critical Fog:	visibility < 61 m (200 ft)
Dangerous Fog:	visibility 61 m–152 m (200 ft–500 ft)
Light Fog:	visibility > 152 m (500 ft).

For critical fog visibilities, the CHP PACE units were activated and Caltrans personnel were called to implement the other measures. A call-out was initiated by the CHP, since their field units provided the information on visibility conditions.

A typical call was made around 4 a.m., at which time the PACE units were dispatched and traffic operations personnel turned on the CMSs and HARs. The CVTOC staff arrived to provide information to the media and public and to monitor road and weather conditions. All activity would end when this fog lifted.

Periods of Operation—The operational measures were implemented on the number of days shown in Table 4. Each staging area was used once during the test period to provide truck drivers with information on conditions and to then meter them back onto the freeway.

TABLE 4

NUMBER OF DAYS OPERATIONAL MEASURES IMPLEMENTED *(10)*

Days	Operational Measures Implemented	PACE Program Implemented	Visibility less than 0.40 km
1991			
November	2	1	2
December	7	9	9
1992			
January	15	7	22
February	4	9	6
March	1	10	2

Evaluation

Accident Analysis—Collision data from the Caltrans Traffic Accident Surveillance and Analysis System (TASAS), along with the number of days that visibility was reduced by fog to less than 0.4 km (1/4 mile), are shown in Table 5.

It is noted that the ratio of fog related collisions to the number of reduced visibility days ranged from 1.2 to 1.5 during the 3 years prior to the demonstration project; however, based on the limited data available after the mitigation strategies were implemented, this ratio was much lower. A breakdown of fog related collisions into a Primary Collision Factor (PCF) for a 4-year period is shown in Table 6.

TABLE 5

COLLISION DATA *(10)*

Year	Fog-Related Data	Days Visibility < 1/4 mile	Ratio Collisions/Reduced Visibility Days
Before			
1988–1989	28	22	1.3
1989–1990	52	35	1.5
1990–1991	23	20	1.2
After			
1991–1992	9	41	0.2

The data in Table 6 report the results of the demonstration project; however, they are not conclusive since subsequent results may depend on a variety of other factors such as local climatological or traffic conditions or even on the quality and consistency of accident data reporting. Applications in other areas would similarly require more research and testing of data.

TABLE 6

FOG RELATED COLLISIONS *(10)*

Year	Primary Collision Factor	Percentage
Before		
1988–1989	speeding	79 (22 of 28)
1989–1990	speeding	73 (38 of 52)
1990–1991	speeding	74 (17 of 23)
After		
1991–1992	speeding	33 (3 of 9)

Driving too fast for conditions was the primary collision factor in approximately three-fourths of the fog related collisions during the 3 years prior to the demonstration project. However, as can be seen, this figure dropped to only one-third for the demonstration period.

Public Awareness—Since one of the primary objectives was to increase public awareness, an attempt was made to determine the public's perception of the usefulness of the countermeasures implemented. Although letters to newspaper editors and comments at media interviews were received, a more useful avenue for public input was a questionnaire published in a local newspaper.

The results of the 128 questionnaires returned are shown in Figure 7. To arrive at the percentage of positive responses, the number of "very helpfuls" and "somewhat helpfuls" were divided by the total questionnaires returned minus the number for "no answer." With one exception, the favorable responses ranged from 80 to 92 percent, which California officials took as an indication that the measures were successful and useful. The fog pamphlet, which received only a 53 percent favorable response,

> . . . was initiated to provide an ongoing means to alert motorists of the characteristics and visibility problems of the Central San Joaquin Valley tule fog. The severity of multiple-vehicle collisions dramatically increases with the involvement of large

Technique Used	Very Helpful	Somewhat Helpful	Not Helpful	Undecided	No Answer	Percentage Favorable
Fog Pamphlet	21	36	28	21	22	55.8
Changeable Message Signs	92	21	6	4	5	91.9
Visibility Test Signs	57	42	13	9	7	81.8
Highway Advisory Radios	77	24	8	9	10	85.6
Truck Staging Areas	64	25	9	13	17	80.2
CHP Pace Patrol	97	18	7	2	4	92.7
Right Lane Only Truck Restriction	89	19	6	3	11	92.3
TARIF— Trucks at Rest in the Fog	73	16	10	16	13	77.4
Overall Fog Operation	74	34	3	2	15	95.6
TOTALS	644	235	90	79	104	83.9

FIGURE 7 Operation Fog public perceptions.

trucks, and many drivers on Interstate 5 and State Route 99 are operating out-of-state long-haul rigs. These drivers were believed to be not as familiar with the characteristics of tule fog and so they made up a large part of the target audience for the pamphlet.

Considering also that the questionnaire was distributed to Valley residents via the newspapers and that they were not the target of the pamphlet, it was not surprising that a number of respondents indicated they had never seen a fog pamphlet. This suggests that we should enlarge our distribution network to cover a larger audience in future years.(*10*)

Another indication that the public awareness program was well-received was that the CVTOC saw a steady increase in the number of radio and TV stations that wanted morning broadcasts for their listeners. Because of the volume of calls received and radio broadcasts made, coupled with the tasks of operating CMSs, and HARs, and coordinating field personnel during the morning commute, "the CVTOC staff was pushed to their limit."

It was reported (*10*) that the bulb matrix display of the portable CMSs was very visible, even during dense fog.

The portable HARs were used extensively and added to the information that could be made available to motorists. By using a CMS to alert motorists to tune in to the desired station, information already seen could be supplemented. The radio station was audible for almost 16.1 km (10 mi), ensuring motorists would hear a complete broadcast several times.

Evaluation of Operational Measures

PACE Program—California (*10*) concluded that the CHP PACE units were the most visible part of the demonstration project. The presence of law enforcement vehicles resulted in a speed reduction and a decrease in the number of collisions with "speeds unsafe for conditions" as the primary factor. It was noted that motorists began to call local media stations and the CVTOC to find out where the PACE team was working.

Truck Staging and Metering—Staging operations (used twice) presented a variety of problems: local motorists were unfamiliar with what was happening and with the traffic control measures; there was insufficient lighting in the staging areas; trucks were forced to merge again with traffic, and approaching motorists had to deal with an additional merge of large trucks under reduced visibility conditions; and a large number of personnel was required, with increased exposure to traffic.

Because of these problems, it was decided to use the staging/metering measure only for emergency situations.

Truck Convoys—California reported (*10*) that early trials of this concept proved to be unsuccessful. Communication with the truck drivers was difficult, as was forming and maintaining the convoy formation after leaving the staging area. Most truck drivers were not expecting to encounter a convoy and the volume of trucks did not allow time for a lengthy explanation of the concept to each driver, leading to some confusion. For example, once the trucks were lined up, some drivers left their vehicles and didn't return in time as the convoy started to leave, causing a backup. Different makes and models of trucks and varying loads caused problems in keeping the convoy together. All of these factors plus the large number of personnel required to run the operation and their increased exposure to traffic during periods of reduced visibility eliminated the convoy concept from being used during the fog season.

Project Costs

Project costs for Caltrans were $1,321,900 and the CHP spent $235,300. See Appendix F for a cost summary. The CHP commented (*10*) that personnel costs were high for the project, but that the reduction in accidents was well worth the expenditure and that, overall, the project was cost-effective.

Conclusions

California reported (*10*) that the demonstration project achieved the main objective: the number of fog-related collisions in the test section was sharply reduced during the winter of 1991–1992. They believed that the success of the project was based on the combination of public awareness, press conferences, and operational measures to assist motorists traveling on State Route 99. Specific conclusions are listed below.

1. The efforts in public awareness were well-received, as the CVTOC saw a steady increase in the number of radio and TV stations that wanted morning broadcasts.
2. The bulb matrix displays of the portable CMSs were very visible, even during dense fog.
3. The portable HARs were used extensively and added to the information made available to motorists.
4. The fog pamphlet was well-received by those who got it.
5. The CHP believed (*10*) the project to be very effective in reducing accidents and reducing the speed of motorists during periods of limited visibility. The CHP PACE units were the most visible part of the project, and the increased law enforcement presence was thought to be a major factor in the success of the project.
6. Considering the large number of personnel required to make truck staging/metering work and their increased exposure to traffic, it was decided to use it only if some emergency situation arose.
7. Early trials of truck convoying proved unsuccessful because of difficulty in communicating with the truck drivers, getting them lined up, and keeping them together in a convoy. This measure was eliminated during the fog season.

Recommendations

Based on the results of this project, California recommended that the project activities be continued and expanded to other locations in the state experiencing reduced visibility conditions on a regular basis. The specific recommendations were as follows:

1. Central Valley Traffic Operations Center
   Provide personnel, equipment, and cash overtime resources for continuing the CVTOC role each fiscal year.
   Expand the CVTOC operation with dispatch capabilities to 16 hours a day from November 1 to April 1 (4:00 a.m. to 8:00 p.m.).
   Expand the demonstration project measures to other routes that experience reduced visibility conditions on a regular basis, consistent with a regional TOC function.
   Provide an 800 number exclusively for road condition information.
2. PACE
   Support the CHP decision to establish a permanent PACE team and provide TOC support for other locations at which it is used in the state.
3. Fog Pamphlet
   Revise the fog pamphlet to include a section on PACE activities. Eliminate the list of CHIN/CHIBN numbers, replacing it with a single 800 number.
   Distribute the pamphlet by mass mailing or other method to the Fresno/Clovis metropolitan area and to Bakersfield to ensure more familiarity with the program.
4. Changeable Message Signs/Highway Advisory Radio
   Develop a regional Traffic Operations System plan, with emphasis on permanent CMS and HAR locations. Begin to program individual projects to complete system within five years.
5. Maintenance Support
   Provide additional resources for maintenance, if continued participation is anticipated.

Dust Storms

In addition to reduced visibility caused by fog, the southern San Joaquin Valley is plagued by dust storms. Dry soil conditions, compounded by light rainfall and drought cycles form the basis for dust storms that can arrive suddenly, be miles long, and reduce visibility to near zero.

The worst dust storm traffic accident in California history occurred in 1991 when dust blew from barren, nonagricultural land across a major freeway.

Many of the countermeasures discussed above for the San Joaquin Valley are used for reduced visibility conditions caused by dust. Current strategies being used for dust are listed below.

- A dust pamphlet is distributed to over 300,000 individuals and businesses in the San Joaquin Valley. (See Appendix G.)
- Thirteen permanent CMSs have been installed along Interstate 5 at strategic locations for motorist information. Appendix D shows a CMS menu for dust conditions. These

CMSs are controlled from the Central Valley Transportation Management Center and can be activated much more quickly than the portable CMSs they replaced. Portable CMSs are available to supplement the permanent CMSs.

- Permanent and portable HARs are used to provide additional information that a CMS cannot. They are placed along Interstate 5 at major interchanges and in the rest areas.
- The Central Valley Transportation Management Center operates seven days a week during the dust prone season (November through March) and remains on call in the event of an emergency. The operators have control of CMSs, HARs, Traffic Management Teams, and a wide range of media contacts to spread information from Los Angeles to San Francisco to Sacramento. In mid 1994, a command center van was activated that can be dispatched to the scene of major incidents. It is equipped with cellular phones, radios, computers, and other devices to allow it to become the Scene Command Post.
- Four remote weather stations to provide weather data along the Interstate 5 corridor. Factors such as wind speed, relative humidity, precipitation, etc., are monitored from the TMC to predict adverse conditions that may lead to blowing dust. The district planned to install CCTVs to allow visual verification of conditions along Interstate 5 and then activate the nearby CMSs if needed.
- The California Department of Forestry and Fire Protection is assisting Caltrans with a Coordinated Resource Management Plan (CRMP) for the areas along Interstate 5 that are considered susceptible to blowing dust. A steering committee has been formed consisting of government agencies and private owners to create and implement land use practices that will minimize the potential for blowing dust.
- The CHP successfully demonstrated that pacing traffic at a speed safe for conditions reduced accidents in poor visibility conditions. The program was expanded from Route 99 in Fresno County to be used on any route when circumstances required it. The CHP has a PACE Team on call during the dust season to pace traffic on Interstate 5.
- Detection loops were added along Interstate 5 to feed back information to the TMC about traffic volumes and speeds. This will be another tool to verify slow traffic conditions and to help detect incidents. The loops will be included during major rehabilitation projects on Interstate 5 over the next several years.

Future Considerations

Fresno

Efforts to combat problems associated with reduced visibility are ongoing in California, and various projects are being planned for the Fresno area.

Weather Monitoring Station—The CVTOC objective and responsibility is to monitor the flow of traffic and provide motorists with real-time driving and traffic conditions. There are no road and atmospheric data-gathering stations; driving and traffic information are obtained from field reports by the CHP and Caltrans maintenance.

A weather monitoring system would provide advanced warning and increased ability in monitoring fog and other types of inclement weather. This would increase safety with reduced accidents and result in greater efficiency through reduced labor and data communication costs. The information could be interfaced with the CMSs and HARs. Also, the real-time information would improve response to adverse weather conditions and aid in the commencement of the PACE operation.

It has been proposed that four remote processor assemblies consisting of pavement sensors, small weather stations with visibility sensors, and a processing unit be established. A control processor would be installed in the CVTOC and, once information was obtained, it would be accessed by maintenance personnel and the CVTOC. Also, this information would be monitored along with data from other Caltrans installations and the NWS. It would be possible to use historical data to develop a computer model for forecasting adverse atmospheric and weather conditions.

Flow Interruption Monitoring—Real-time detection of traffic speeds and accidents is important, not only for decreasing motorists' delay on the freeway and city streets, but in preventing secondary accidents. Caltrans estimated that the current response time of 30 to 45 minutes of the Traffic Management Team to incidents in the urbanized area can be reduced by 30 percent if incident detectors were in place to give CVTOC real-time information. Objectives of these projects are (1) to detect that an incident has occurred; (2) to identify the nature of the incident and initiate the appropriate response; and (3) to monitor traffic flow and volume.

Projects incorporating incident detectors and/or CCTV monitoring stations (on Fresno Freeways 41 and 99) were completed by December 1994. It has been proposed that loop incident detectors be installed at 27 locations (12 northbound and 15 southbound) and two CCTVs be installed on State Route SR-41; 44 incident loop detectors (22 northbound and 22 southbound) have been planned for SR-99. Loop detectors would be approximately 0.8 km (1/2 mi) apart.

CCTV Monitoring—This project proposes to use four CCTV monitoring stations on Route 99 to verify changeable message sign operations, adverse weather conditions, and traffic incidents. Each site would have a camera equipped with zoom, pan, and tilt capabilities, along with encoding devices to convert the analog camera output into a digital signal for transmission over telephone lines. A monitoring station at the CVTOC, including decoding equipment, camera manipulation facilities, and monitors to display the camera site transmissions, has been proposed.

The CCTV system would provide the visual information necessary to select appropriate CMS and HAR messages without the delay in confirming the sites' weather or traffic problems. Early warnings provided by this system should result in a reduction of accidents.

Stockton

Because of safety problems associated with the frequent occurrences of dense fog in the Stockton area, a project has been initiated by Caltrans to install countermeasures. The fog in this area is prevalent throughout the winter months, can move in rapidly, and can be dense (less than 60 m (200 ft)) only in patches. This area is a major corridor for commuters into the San Francisco bay area and there is heavy truck traffic.

The main objective is to install a real-time warning system that will automatically detect fog and alert motorists to hazardous conditions.

The purposes of the fog warning system are (1) to provide early warning to drivers when conditions of reduced visibility due to fog and/or slow traffic conditions exist downstream of the present location, and (2) to recommend counteractive driving actions in the interest of safety.

The system will be designed to perform the following functions:

- Detect the presence of fog in the vicinity of the I-5 crossing of the San Joaquin River.
- Detect the presence of slow-moving or stopped traffic in the southbound lanes of I-5 and westbound lanes of Route 120 within the project limits.
- Based on the detection of fog and slow-moving or stopped traffic, select one of a number of prescribed alternative messages to transmit to drivers through fixed CMSs.
- Provide a means through which other customized messages can be transmitted to drivers through the CMSs.
- Provide a location where the system status can be monitored in real time and where historical records of system operation will be maintained.

The proposed fog warning system consists of three major elements: (1) field station/CMS (FS/CMS) sites; (2) substation (S/S) sites; and (3) central computer with satellite terminal. All FS/CMS sites will include a CMS, a fog sensor, an open architecture transportation controller (OATC), communication devices and a collocated substation site. There will be a total of nine FS/CMS sites, five on I-5 and four on Route 120. The FS/CMS sites will be located 0.4 km to 0.8 km (1/4 to 1/2 mi) downstream of an on-ramp.

All substation sites will include a vehicle detector station composed of loop detectors in each lane, a controller, and communication devices. Substation sites will be located at approximately 0.8-km (1/2-mi) intervals, beginning at the first (i.e., the farthest upstream) FS/CMS site. Every other substation site, beginning with FS/CMS #1 on I-5 and with FS/CMS #6 on Route 120, will have a fog sensor. Consequently, the fog sensors will be spaced at approximately 1-mile intervals.

The communication system will consist of 50-pair, direct-burial, twisted-pair communication cables and communication devices located at the FS/CMS and substation sites. A communication cable will extend continuously along the length of each leg of the project, connecting the first FS/CMS site with all FS/CMS and substation sites downstream in a "multi-drop" configuration.

A central computer (PC-based) will be located at District 10 headquarters in Stockton. The computer will monitor the system continuously, providing information on messages and alarm conditions. In addition, it will have the capability of manually inputting messages to each CMS individually. A satellite computer station will be located at the CHP office in Stockton for monitoring purposes only.

The District 10 fog warning system will be highly automated. The fog sensors will automatically detect reduced visibility conditions and the vehicle detectors will detect slow/stopped traffic conditions without human input. Then, using data from its own and downstream fog sensors and vehicle detectors, the OATC at each FS/CMS site will automatically determine and display the appropriate message to advise motorists of fog and traffic conditions ahead. If necessary, any desired message to any CMS can be input by an operator using the central computer. Messages can also be input manually at each CMS.

Visual Readout Radar—A possible future fog countermeasure being considered is use of a visual readout radar. A schematic of this equipment is shown in Figure 8. The speed being traveled by a motorist would be shown to the motorist on the visual readout radar unit followed by a CMS indicating the visibility distance. A monitor would then measure the speed to determine what effect the signs would have. This

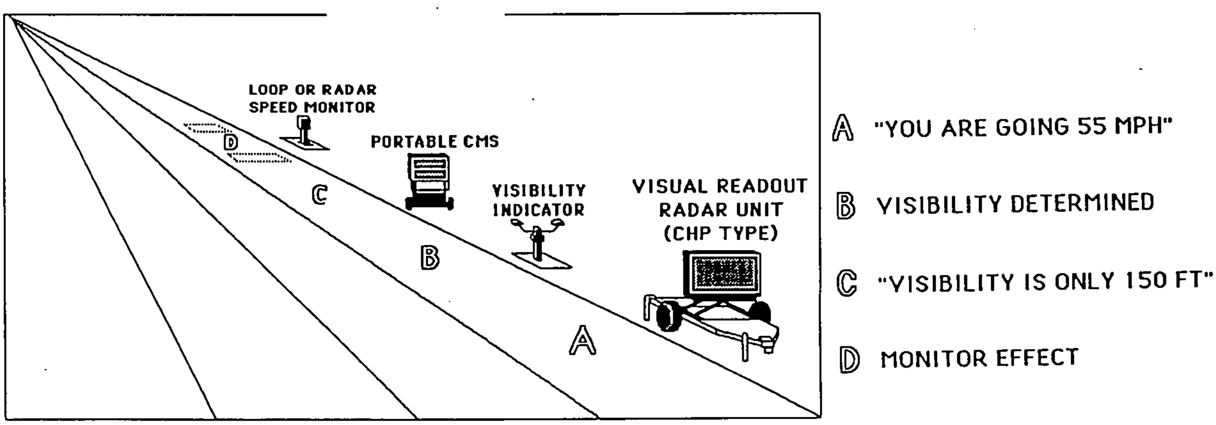

FIGURE 8 Visual readout radar unit from Caltrans.

setup would promote education/association of speed with visibility, make motorists think, and produce speed alteration.

General Comments

California's effort to develop countermeasures to the problem of reduced visibility focused on the Fresno area, has served as a proving ground for various countermeasures. Those measures, and others that have been proposed, are now being considered for other parts of the state.

Discussions with personnel in the CHP and Caltrans indicate that the overall effort in the Fresno area, including public awareness materials, press conferences, PACE program, etc., has had a positive impact, especially in educating the public about fog and the hazards it presents for motorists. During periods of fog, motorists are now calling in to find out if the PACE program is in effect. The education process continues, with the fog brochure now included in the driver education program and relevant questions being included on the drivers test. Also, there are foggy day schedules for school buses, under which buses run two hours late and classes start at noon.

Cooperation and teamwork between the CHP and Caltrans was a significant factor in both the field and the CVTOC operations. Because of the significant truck traffic in the Fresno area, it has been the locale for a special effort by the two agencies to demonstrate and get feedback on various countermeasures.

There are many programs proposed to further improve overall efforts in the Fresno area, to continue public awareness and education endeavors, and to upgrade the techniques used to provide the public with real-time and accurate information about visibility conditions.

LOUISIANA

Fog related accidents occurring on the 39-km (24-mi) causeway spanning Lake Pontchartrain in southern Louisiana have led to use of the facility for evaluating fog countermeasures. The causeway consists of twin bridges carrying two northbound and two southbound lanes connected by seven crossovers.

Proximity to the Gulf of Mexico gives the area a tropical climate conducive to the formation of patches of dense fog. On approximately 20 days each year the fog reduces visibility. On 5 to 10 days the fog is dense. Countermeasures were started in 1977, with 102 call boxes being located approximately 0.6 km (0.4 mi) apart. In 1984 a motorist information system was installed, with the main elements consisting of sixteen 2.4 m x 7.3 m (8 ft x 24 ft) changeable message signs (CMS).

Fog Detection

Under the present system, fog detection generally starts with a commercial radio and television weather station report on the possibility of fog in the area. Highway officials consider this to be a first stage alert, and it leads to a close monitoring of radio, television, and National Weather Service (NWS) reports and an assessment of personnel and equipment on hand. Also, it initiates a review of scheduled special events and marine operations.

A second stage of alert is triggered by a different NWS report on the high probability of fog. This requires that management and supervisors at all levels be notified and that all personnel remain on duty throughout the alert. At this time, the causeway is visually monitored by duty personnel and continuous contact is maintained with the NWS and radio and television stations. Transmissions on citizens band radios of tractor-trailer trucks and passenger cars are monitored along with those of marine traffic on Lake Pontchartrain to gain an idea of the direction from which the fog might be coming. All police agencies, including the state police, sheriff's office, New Orleans police, and any others available, are monitored.

At this time, a review is made of planned scenarios and assignments, and all equipment is evaluated and put in a state of readiness.

The final stage is a confirmation that fog has become visible in the area, and it signals the implementation of operational countermeasures.

Countermeasure Strategies

One of the initial strategies developed to provide safe travel across the causeway during fog was a convoy system using police units as lead and rear cars. This system worked well, however, because of the limited number of police available, many motorists were kept waiting for a convoy. This delay, along with other problems with vehicles in the convoy being separated because of an accident or a slow-moving vehicle, led to the system being revised. It was decided to put vehicles in a single file with police units as the lead and rear vehicles. Also, an additional unit "rode herd" to prevent vehicles from passing or gapping. Although the revisions worked quite well, there were problems, primarily because traffic was directed into the left lane and thus created situations in which vehicles could not safely or conveniently stop or maneuver.

The system currently in use has traffic moving in the right lane only, with police again riding herd to prevent passing and look for possible breakdowns. CMSs are located prior to the entrance and at each of the seven crossovers. Of the 99 CMS messages available, the following are the most used during fog.

- FOG AHEAD, REDUCE SPEED
- BRIDGE CLOSED, CONVOY IN PROGRESS, DIAL 1610 ON AM RADIO FOR TRAFFIC, WEATHER & ROADWAY INFO
- 55 MPH, BOTH LANES NOW OPEN
- 45 MPH, BOTH LANES NOW OPEN
- FOG ON BRIDGE, REDUCE SPEED, LOW BEAM ONLY, STAY IN RIGHT LANE ONLY
- FOG ON BRIDGE, LIGHTS ON LOW BEAM, DEFROSTER ON PLEASE

FOG PROCEDURE
CAUTION

◆

FOG ON BRIDGE
RIGHT LANE ONLY
NO PASSING
strictly enforced
offenders will be cited

◆

I. FORM A SINGLE LINE IN THE RIGHT LANE.
II. PUT ON HEAD LIGHTS.
(do not use brights or emergency lights)
III. STAY CLOSE ENOUGH TO THE VEHICLE IN FRONT OF YOU TO KEEP SIGHT OF ITS TAIL LIGHTS; HOWEVER, BE SURE TO ALLOW ENOUGH DISTANCE TO STOP YOUR VEHICLE.
IV. IN CASE OF VEHICLE FAILURE (motor or tire failure, etc.) DO NOT STOP IN THE RIGHT LANE.
1. TURN ON EMERGENCY FLASHERS.
2. PULL IN THE NEAREST CROSSOVER (there are 7 crossovers that connect the north and south spans located approximately 3 miles apart). IF PULLING IN A CROSSOVER IS NOT POSSIBLE, PLEASE PULL INTO THE LEFT LANE CLOSE TO BRIDGE RAILING. ALL PERSONS SHOULD GET OUT OF THE VEHICLE AND MOVE A SAFE DISTANCE TO THE REAR OF THE STALLED VEHICLE. PLEASE STAND ON **WALKWAY** OF THE LEFT LANE AND FLAG APPROACHING VEHICLES UNTIL CAUSEWAY POLICE ARRIVE.
V. TUNE TO 1610 AM RADIO FOR UP TO THE MINUTE INFORMATION.
VI. BE SURE YOUR HEATER/DEFROSTER, WINDSHIELD WIPERS, AND ALL HEADLIGHTS/TAIL LIGHTS ARE WORKING BEFORE ENTERING THE BRIDGE.

FIGURE 9 Fog procedural pamphlet. Greater New Orleans Expressway Commission, 1993.

- FOG ON BRIDGE, REDUCE SPEED, LOW BEAMS ONLY
- 25 MPH, RIGHT LANE ONLY
- 35 MPH, RIGHT LANE ONLY
- 45 MPH, RIGHT LANE ONLY
- FOG ON BRIDGE, REDUCE SPEED, LOW BEAMS ONLY, ALL VEHICLES STOP AT TOLL BOOTH

It is noted that one of the first CMSs tells the motorists to tune to an HAR that gives the following message:

> While the causeway bridge is open to traffic, motorists are instructed to drive in the right lane only. Be on the lookout for information signs placed on the centerline of the roadway. These signs will be located every few miles throughout the entire length of the causeway. Also, refer to the variable message signs in the crossovers and obey the speed limit displayed on these signs.

A procedural pamphlet, see Figure 9, is given to each motorist prior to entering the causeway.

When visibility is below 91 m (300 ft) traffic control requires the closing of the left lane with signs or cones being placed 0.6 m (2 ft) to the left of the centerline at 0.4 km (1/4 mi) intervals. Signs have messages informing motorists of restrictions: "KEEP RIGHT," "NO PASSING," or "35/45 MPH." Signs are also placed prior to each crossover to indicate the crossover is ahead, and CMSs are placed at each crossover to give the posted speed (35 or 45 MPH). The following is a list of actions required under the system.

- The drawbridge is kept closed, particularly if fog has started to move in, because of the stopping and backing up of traffic that increases the potential for rear-end collisions.
- Speed is changed depending on visibility, something that "motorists appreciate."
- Auxiliary policemen from the sheriff's office are used to supplement the existing force.
- A backup plan is implemented if needed. Such a plan might include shutting down the facility and U-turning vehicles to get them off the facility.
- Practice runs are made when there is little traffic on the bridge.
- Arrangements are made with the fire department and medical support. For example, they may be required to go northbound on the southbound bridge, which does not present a problem.
- Once the system is in effect, there is a visibility roll call that allows monitoring visibility for the entire bridge. All units on the bridge, one at a time, give their location and visibility.
- The system is installed in about 30 minutes, without stopping traffic.
- Disabled vehicles are instructed to pull into the left lane, which "is one of the keys to the success of the program."
- Trucks are provided a place to go (left lane) should there be a problem with stopping.
- Redundant signs are used in the first 3 miles, a practice that is believed to be very effective.
- Ten safety vehicles are spread along the bridge to circulate and help motorists.

It is believed that this system has been very effective, and it was noted that no traffic fatalities have occurred on the bridge since 1987. Other opinions and conclusions included the following: *(5)*

- The safety lane or area that a motorist can pull into is very critical. Also, the single lane prevents passing.
- It is important that traffic is kept moving and generally at the same speed, although slowly in most cases (as opposed to being stopped, which motorists dislike).
- Strong media and public confidence in the system has been engendered.
- There is less liability, which might prevent the development of innovative measures for reduced visibility situations.

SOUTH CAROLINA

Fog investigative efforts in South Carolina are focused on a system installed on the Cooper River Bridge in Charleston.

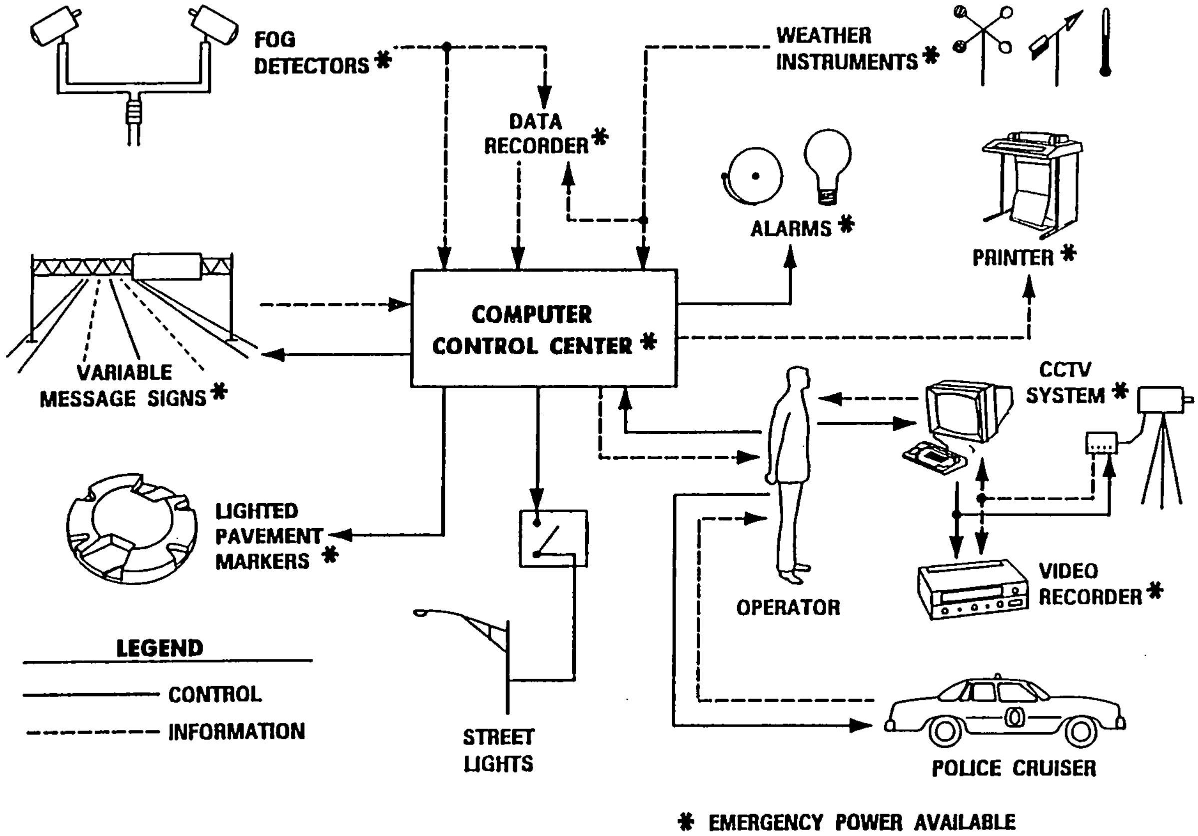

FIGURE 10 Traffic management system components *(14)*.

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 on the traffic. The court action stemmed from a concern about the possible effects of plume-induced fog created by a paper mill near the bridge.

The subject bridge is an elevated structure carrying Interstate 526 over the Cooper River. The paper mill is located upstream, approximately 610 m (2000 ft) from the bridge. Approximately a 3.2-km (2-mi) strip has been designated a fog-prone area. The potential for fog in the overall area is great during the winter months. Normally, fog forms in the early morning hours and dissipates by about 8 or 9 a.m.

The paper mill pumps about 6 million gallons (22 million liters) of water vapor into the atmosphere daily. Also nearby, there is a spoil disposal area at which dredge spoil operations are conducted daily, with a lot of free water on the ground.

Given the court mandate, the SCDOT hired a consulting firm to evaluate the situation and propose measures to mitigate the potential hazards from fog on the Cooper River Bridge. Based on the consultant's recommendations, a traffic management system was installed on the bridge.

Traffic Management System Overview

The system was designed to monitor conditions on the bridge, advise the motoring public of adverse conditions, and direct corrective actions. The system, as shown in the schematics in Figures 10 and 11, consists of four components: passive traffic control features; active traffic control features; weather detection components; and surveillance system.

Passive Traffic Control Features—The first objective was to provide enhanced guidance for traffic in the bridge area. This was accomplished by using fixed signs, upgraded striping standards, and raised reflectorized pavement markers. The fixed message signs identify the area as being prone to fog and serve as a backup for the active control features.

Lane and edgelines were upgraded using a 150-mm (6-in.) retroreflective cold plastic line, and raised reflective pavement markings were placed along the entire length of the bridge, spaced at 3 m (10 ft) on center for the edgelines and 12 m (40 ft) on the lane lines.

Active Traffic Control Features—The active part of the traffic control includes lighted pavement markers (LPM), street lighting control, and a CMS system. All of these components are controlled from the control center and are computer driven.

Additional delineation is provided by a system of pavement inset lights right and left along the edgelines spaced at 152-m (110-ft) intervals through the area on both lanes.

The primary components of the system are the fiber optic CMSs used to advise the motorist of real-time adverse conditions on the bridge and of the proper response actions. More detailed information is presented under System Operations.

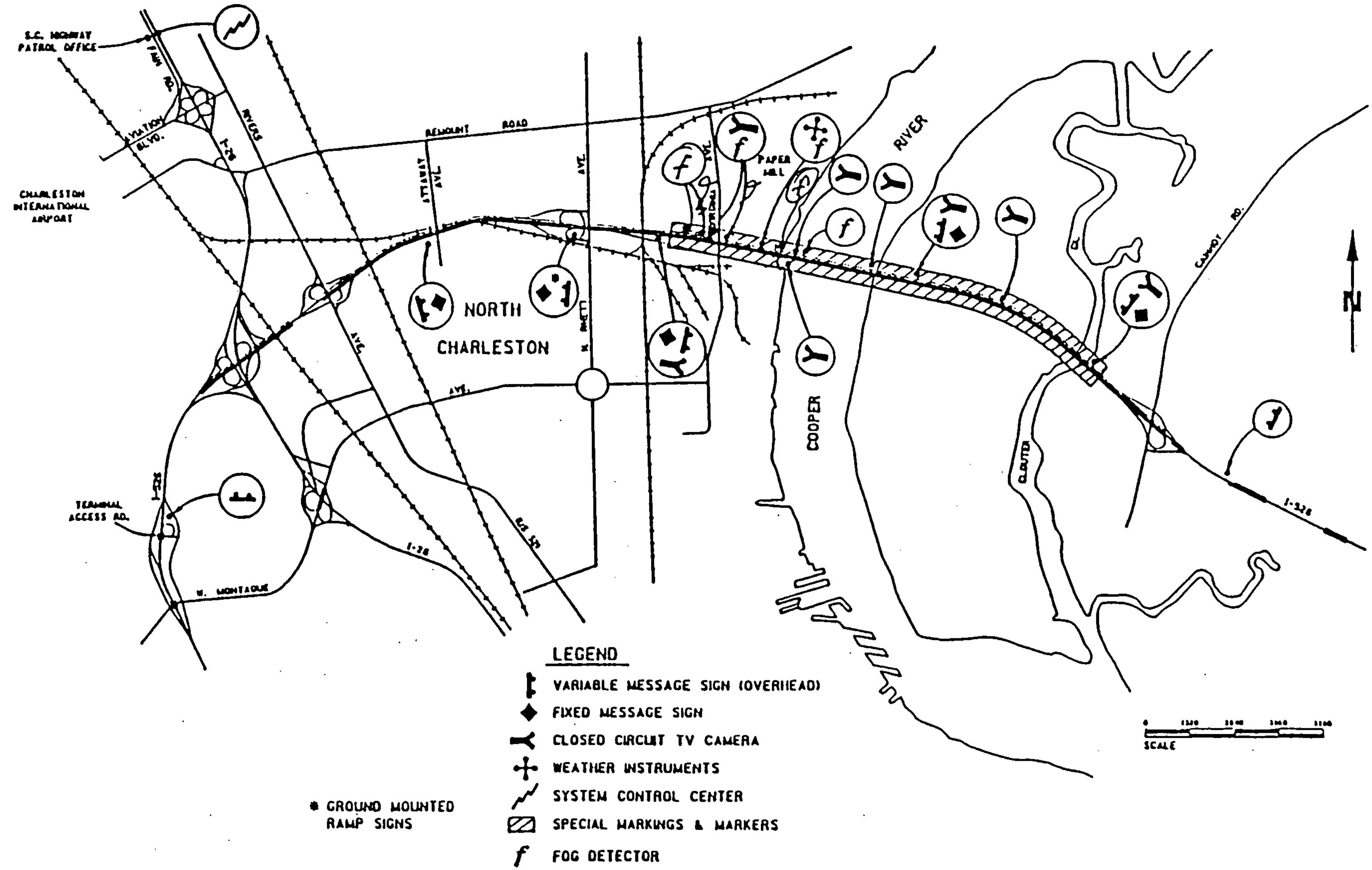

FIGURE 11 Location of system elements *(14)*.

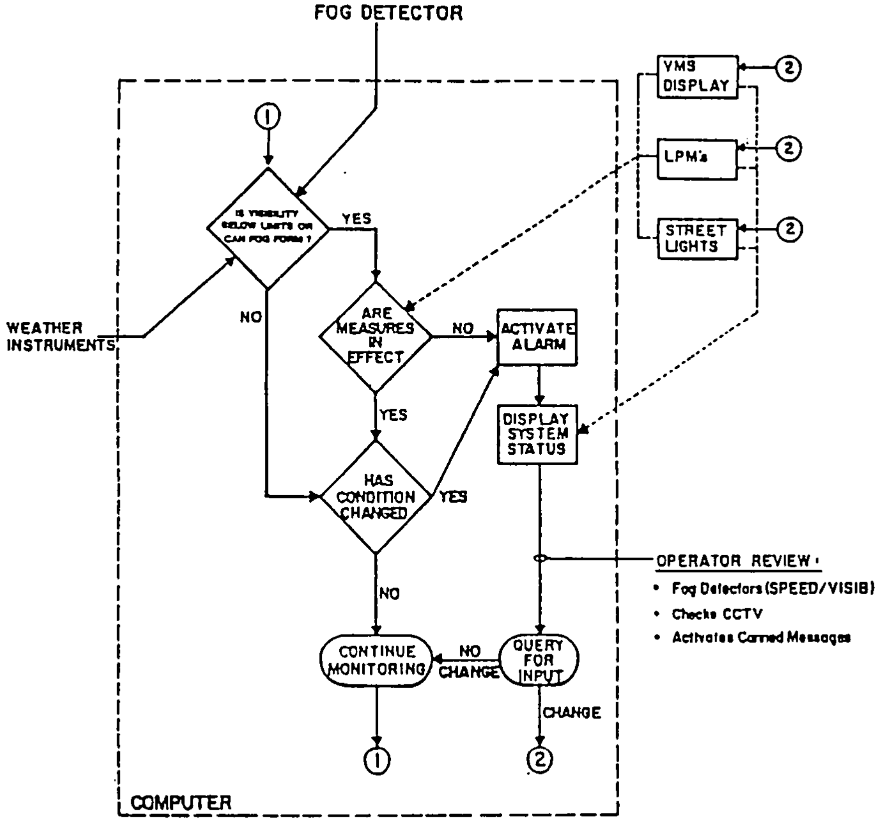

FIGURE 12 Schematic diagram of system operation *(14)*.

Weather Detection—Five fog detectors are located at approximately 152 m (500-ft) intervals on the bridge structure. The detectors are forward scatter type devices. Temperature, wind direction, wind speed, and humidity are also measured. This information is recorded and sent back to the control center, where it is compared with a set of preselected parameters to determine the mitigation measures to be implemented. A data logging system with hard copy capability is available so that permanent records can be maintained.

Surveillance System—Eight CCTV cameras are located along the length of the bridge in the fog-prone area. These color cameras, which have tilt, swing, and zoom capabilities, are monitored and controlled from the control center. Camera viewing can be manually controlled or automatically sequenced on an adjustable cycle. Standard and time-lapse video recording capabilities are available as needed or to record incidents. Backup surveillance is available from the highway patrol, and other police agencies and citizens may provide input.

System Operation—The system operates through a central computer located at the Highway Patrol Office, which operates it 24 hours a day, seven days a week. Figure 12 is a schematic of the system.

The computer receives information from the fog detectors, weather instruments, and operations, and under a predetermined protocol alerts the operator when reduced visibility is detected or when the weather instruments determine that fog is likely to occur. At that time, the operator, through the CCTV, can verify the conditions on the bridge and make a decision as to whether any mitigation measures should be put in place. The conditions on the bridge have been classified under six headings and each condition has a programmed set of messages for the signs and directions to the different sections of the bridge.

For the ROUTINE condition, visibility is greater than 366 m (1200 ft), the CMSs are blank, pavement markers are off, and the speed limit is 89 km/h (55 mph). As the visibility drops to between 366 m and 274 m (1200 and 900 ft), the operator is alerted to pay close attention to the system.

During the WATCH condition, the signs are still blank, the streetlights are on, the inset pavement lights are off, and the speed limit remains at 89 km/h (55 mph).

When visibility drops to between 274 m and 213 m (900 and 700 ft), a CAUTION system is suggested by the computer and it may be activated by the operator. Figure 13 shows the CMS messages generally used to warn of the "potential for fog" and to give the instruction "TRUCKS KEEP RIGHT, 45 MILES PER HOUR." The inset pavement lights are off and the speed limit for cars is 89 km/h (55 mph).

The next stage is a MODERATE fog condition, where visibility is from 229 m to 137 m (750 to 450 ft). As shown in Figure 13, the speed limit is reduced to 72 km/h (45 mph) and there are "REDUCED SPEED" and "TRUCKS KEEP RIGHT" messages. The pavement inset lights are illuminated at a 67 m (220 ft) spacing and streetlights can be operated.

The next stage in the mitigation plan is for SEVERE fog with visibility between 137 m and 91 m (450 and 300 ft).

<table>
<tr><th></th><th>Caution</th><th>Moderate Fog</th><th>Severe Fog</th><th>Critical Fog</th><th>Bridge Closure</th></tr>
<tr><td>Sign #1 EB</td><td>Potential
For Fog</td><td>Fog
Reduce
Speed</td><td>Fog
Reduce Speed
45 mph</td><td>Fog
Reduce Speed
45 mph</td><td>I-526 Bridge
Closed Ahead
Use I-26</td></tr>
<tr><td rowspan="2">Sign #2 EB</td><td>Potential
For Fog</td><td rowspan="2">Fog
Reduce Speed
45 mph</td><td>Fog
Reduce Speed
35 mph*</td><td>Fog
Reduce Speed
35 mph*</td><td>Bridge
Closed
Ahead</td></tr>
<tr><td>Trucks
Keep Right</td><td>Trucks
Keep Right*</td><td>Trucks
Keep Right*</td><td>All Traffic
Must Exit
N. Rhett Ave.</td></tr>
<tr><td rowspan="2">Sign #3 EB
Ramp</td><td rowspan="2">Light Fog
Caution</td><td rowspan="2">Fog
45 mph</td><td rowspan="2">Fog
35 mph</td><td rowspan="2">Fog
25 mph</td><td>I-526 Bridge
Closed Ahead</td></tr>
<tr><td>Exit
Virginia Ave.</td></tr>
<tr><td rowspan="3">Sign #4 EB</td><td rowspan="3">Light Fog
Trucks
45 mph</td><td>Fog
Reduce Speed
45 mph*</td><td>Fog
Caution
35 mph</td><td>Dense Fog
Reduce Speed
25 mph*</td><td>Bridge
Closed
Ahead</td></tr>
<tr><td rowspan="2">Trucks
Keep Right*</td><td rowspan="2">Plant Fog
0.3 Mile</td><td>Trucks
Keep Right*</td><td rowspan="2">Prepare
to
Stop</td></tr>
<tr><td>Dense
Plant Fog
0.4 Mile*</td></tr>
<tr><td rowspan="3">Sign #5 WB</td><td rowspan="3">Light Fog
Trucks
45 mph</td><td>Fog
Reduce Speed
45 mph*</td><td>Fog
Caution
35 mph</td><td>Dense Fog
Reduce Speed
25 mph*</td><td>Bridge
Closed
Ahead</td></tr>
<tr><td rowspan="2">Trucks
Keep Right*</td><td rowspan="2">Plant Fog
0.4 Mile</td><td>Trucks
Keep Right*</td><td rowspan="2">Prepare
to
Stop</td></tr>
<tr><td>Dense
Plant Fog
0.4 Mile*</td></tr>
<tr><td rowspan="2">Sign #6 WB</td><td>Potential
For Fog*</td><td rowspan="2">Fog
Reduce Speed
45 mph</td><td>Fog
Reduce Speed
45 mph*</td><td>Fog
Reduce Speed
35 mph*</td><td>Bridge
Closed
Ahead</td></tr>
<tr><td>Trucks
Keep Right*</td><td>Trucks
Keep Right*</td><td>Trucks
Keep Right*</td><td>Prepare
to
Stop</td></tr>
<tr><td rowspan="2">Sign #7 WB</td><td rowspan="2">Potential
For
Fog</td><td rowspan="2">Fog
Reduce Speed</td><td rowspan="2">Fog
Reduce Speed
45 mph</td><td rowspan="2">Fog
Reduce Speed
45 mph</td><td>I-526 Bridge
Closed
Ahead</td></tr>
<tr><td>All Traffic
Must Exit
Cainhoy Rd.</td></tr>
</table>

FIGURE 13 System messages for CAUTION, MODERATE FOG, SEVERE FOG and CRITICAL FOG. Caltrans, 1992.

```
                              VIEW LOG FILE
0880 12-08-92 03:33    FOG DETECT 3 - Visibility 33941 feet
0881 12-08-92 03:33    FOG DETECT 5 - End comm failure
0882 12-08-92 03:33    FOG DETECT 4 - Visibility 46871 feet
0883 12-08-92 03:33    FOG DETECT 5 - Visibility 6695 feet
0884 12-08-92 03:34    TROY W       - has logged on
0885 12-08-92 03:37    FOG DETECT 5 - Visibility 1832 feet
0886 12-08-92 03:38    FOG DETECT 5 - Visibility 10471 feet
0887 12-08-92 03:40    3: CAUTION   - Sequence activated manually
0888 12-08-92 03:40    VMS4-VIRGINA - SENDING A DISPLAY
                                       by Central Computer
                                      Command correctly received
                                      Display name: FOG TR 45
                                      Attribute name: STEADY
0889 12-08-92 03:40    VMS4-VIRGINA - Sign is Lit
0890 12-08-92 03:40    VMS4-VIRGINA - Current display
PGUP PGDN HOME END : Scroll ¦ <ESC> : Return
```

(1 ft = 0.3048 m)

FIGURE 14 Example of log file. South Carolina Department of Highways and Public Transportation, 1992.

The primary change is to reduce the speed to 56 km/h (35 mph). Streetlights are turned off and pavement inset lights are on at 34 m (110 ft).

When visibility is less than 91 m (300 ft), the CRITICAL phase of the plan is followed. Speed limit is 40 km/h (25 mph) and the inset lights are illuminated at 34 m (110 ft) spacing. It was noted that the safe stopping distance for a heavy truck going downgrade was used for setting the speeds, which was thought to be a conservative approach. (*5*)

The final stage of the plan is a complete closure of the bridge. The CMSs direct traffic to exit the area and signs beyond the exit areas show "BRIDGE CLOSED AHEAD, PREPARE TO STOP."

As noted earlier, the control center has a data logging system with hard copy capabilities. Records from fog detectors, the time at which the mitigation measures were put into effect, and the messages displayed on the CMS are some of the data logged. Figure 14 shows examples of the log file for a particular time.

Appendix H shows an inventory of routines for different fog visibilities, component failure, bridge closure, and sign operational test.

Responsibilities—The system is under the jurisdiction of the South Carolina Department of Highways and Public Transportation. A management committee responsible for interdepartmental coordination and tracking is made up of representatives from the District Highway Patrol Office, maintenance, traffic engineering, and a chairman.

As noted, the Highway Patrol Office is responsible for the day-to-day operations of the system control center, where operators monitor the CCTV and weather instruments, activate and deactivate the CMSs and maintain a log of all system problems.

CCTV records of relevant events on the bridge can be maintained. Also, accident records for the fog-prone area are compiled; accident records for a control site are maintained to facilitate study of the system benefits and its impact on traffic safety.

The district traffic engineer is responsible for system oversight, which includes the following:

- Establish and maintain a program to assess the safety of the fog-prone area on the I-526 Cooper River Bridge,
- Access accident information,
- Monitor traffic information,
- Review system operations,
- Recommend system improvements to the management committee,
- Implement system changes,
- Maintain weather records,
- Perform system improvement activities, and
- Participate as a member of the management committee.

Continuing Program—The management committee reviews the accident records for the fog-prone area and provides direction for study needs and support. Questions relative to potential improvements include the following:

- Can the system serve public needs other than those identified?
- Can the system be more extensively automated?
- Are modifications in operation interaction required?
- Are the limits of the fog-prone area properly delineated?
- Are threshold limits in need of adjustment?
- Is the light intensity of the lighted pavement markers appropriate?
- Can variations in sign messages be implemented for different directions?
- Can wind direction and wind speed be better employed to predict adverse fog conditions?
- Are adjustments in advisory speeds appropriate?
- Are the fog detectors properly located?
- Is the number of fog detectors appropriate?
- Are system improvements required?

Evaluation

The evaluation addresses the question of system effectiveness; i.e., does it provide the public with information needed to operate vehicles under the reduced visibility conditions. Although data that may be used for evaluation purposes is being logged, no specific information is yet available.

Summary

The system was designed to give a real-time advisory for motorists crossing the bridge. It provides information on conditions, guidance, and speeds, using the flexibility of the system of CMSs, coupled with enhanced delineation by inset pavement lights and improved striping.

NEW JERSEY TURNPIKE

The New Jersey Turnpike Authority (NJTA) operates a 196 km (122 mi) limited access toll road that follows the Interstate 95 corridor. The alignment along the eastern coast lends itself to fog formation throughout the year. The NJTA, being very concerned about the effects of fog on traffic, conducted the following studies.

- In the early 1950s, propellers 6.1 m (20 ft) in diameter and raised about 12 m (40 ft) off the ground were placed at four locations where fog was known to accumulate. They proved effective in circulating the fog but not dispersing it.
- In 1957, low-level fluorescent lights were used for lane delineation without success.
- In 1964, roadway lights inset into the pavement at 30 km (100 ft) intervals were tested on a 0.81 km (1/2 mi) test section and then removed.

As a result of all the investigations, it was concluded that the fog could not be dissipated and attention was turned to detecting fog early and then notifying the drivers. Warning signs were installed as follows:

1953 – 8 speed warning signs in fog-prone areas
1954 – 18 speed warning signs installed
1958 – total of 40 signs
1962 – 67 speed limit signs changed from manual to remote control
1963 – 75 additional speed limit signs installed
1973 – Total of 95 speed warning signs and 101 speed limit signs installed.

Today, the NJTA employs CMSs, including 63 changeable message drum sign pairs along with 135 speed limit/speed warning signs that are remotely controlled. The speed limit signs are placed at approximately 3.2-km (2-mi) intervals throughout the length of the turnpike and can post variable distances of 0.8, 1.6, 2.4, 3.2, or 4.0 km (1/2, 1, 1–1/2, 2, or 2–1/2 mi), respectively.

An automatic traffic surveillance and control system operates in the 44 northernmost miles of the roadway. This system samples traffic flow at 950 locations on the turnpike with loop detectors, magnetometers, video imaging detection systems, and microwave detectors. Although the system is not designed to provide guidance with respect to fog, it can determine reduced speed, whether caused by congestion or fog.

The traffic operations center in New Brunswick houses the automatic traffic surveillance and control system, a 4-channel radio system, a computer dispatch system, and graphics to integrate these systems. The center can also provide traffic services, which are in contact with more than 80 radio stations in the New York-Philadelphia region.

Fog Detection

Since 1963, the turnpike has contracted with a private weather forecasting service for three forecasts every day. More frequent forecasts are provided when fog or other inclement weather conditions are expected.

Methods for detecting fog were considered as early as 1952, and further efforts, including the testing of five fog detectors in 1975 and 1976, led to the selection of a laser system. However, after installation, problems with component failure (communications and foundation), and difficulty in finding replacement parts, resulted in this effort being curtailed. At present the NJTA is seeking off-the-shelf detectors that have been proven by other agencies and have purchased two fog detectors and complete weather stations. It is noted that the M25 system surrounding London (discussed later) provided them with various leads. The principal form of fog detection at present is the State Police's personal observations.

Other Considerations

The NJTA has a fog manual that dovetails with the State Police manual to outline notifications and actions to be taken in the event of fog-limited visibility conditions. The director of operations for NJTA noted that "there seems to be little driver education about driving in fog" and "appears to be few advances in fog detection for the highway environment, as opposed to airports." Early warning of fog occurrences with greater accuracy and with more confidence was felt to be an improvement in considering future countermeasures.

Recent countermeasures with which the NJTA has been involved include:

- Design and operation of 14 CMSs that will span the mainline where a variety of information for motorists can be posted.
- Twelve miles of rumble strips were installed using grooves into the right shoulder approximately six inches beyond the right shoulder edge line. While their primary purpose is to arouse fatigued drivers, they may also provide an added delineation of the roadway during fog.
- An HAR system was activated in July 1992 at three fixed sites with one portable unit. The HAR system allows communication with motorists on congestion, speed limit reductions due to fog and other conditions, and route diversion. Through expansion, the system is expected to cover nine sites.
- Initiation of a Highway Advisory Telephone providing motorists with an 800 telephone number that gives traffic

updates by turnpike region. This system complements information given to the media by traffic services.

• An alpha-numeric variable message sign will be purchased and installed in the vicinity of Interchange 7A to alert motorists to travel conditions on the turnpike, other regional facilities, and to advise motorists on route diversion. The CMSs will employ LED technology.

Although no formal evaluations have been conducted on the effectiveness of speed limit and speed warning signs, NJTA believes the speed limit and speed warning signs significantly contribute to the reduction in secondary accidents because they alert motorists to driving conditions ahead, thereby increasing their attentiveness to their driving environment.

NEW MEXICO

In an attempt to provide motorists with timely and credible information based on roadway, traffic, and environmental conditions, a study was conducted in Albuquerque, New Mexico, for the design, implementation, and evaluation of a variable speed and warning system to automatically change its messages based on measured, real-time conditions. The objective of the system is to reduce the variance in traffic speeds, respond to changing traffic and environmental conditions, and improve safety.

System Description

A prototype of the variable speed limit system was installed on I-40 in Albuquerque, New Mexico. Stations were provided downstream of three interchanges for eastbound traffic, and they were connected by radio to a central control station.

Evaluation

The initial evaluation in Albuquerque tested the operation of the hardware and software. The signs were first tested with the signs turned away from the road. When the signs were turned toward traffic, the effects of the signs on speeds and gaps were monitored.

It was found that the system responds very quickly to changes in traffic conditions. The posted limits shadowed the traffic speeds very reasonably when road work was present at one of the stations.

Traffic behavior, defined by average speed and standard deviation in speed, did not appear to change significantly after the signs were turned to face the road. For specific sign changes, such as WET AHEAD, SLOW AHEAD, WRECK AHEAD, driver reactions (measured by changes in their speed) were mixed and therefore inconclusive.

The ultimate objective of the system is to reduce accidents. In the second phase of the system evaluation, the equipment has been turned over to the New Mexico State Highway Department for an accident study. The state had been collecting data for approximately three years prior to system installation and expects to continue collecting accident data for three more. The results of this accident study will provide information on the effectiveness of the system in reducing accidents.

ENGLAND

Following an accident in 1984 in which 11 people were killed on the M25 in conditions of patchy fog, the Department of Transport decided to upgrade its motorway signalling system to give drivers automatic advance warning of fog ahead. The M25 motorway is a 188-km (117-mile), 6-lane (3 lanes in each direction) facility encircling London and carrying 150,000 vehicles a day.

The first step in expanding the system was to determine which areas of the motorway were most prone to fog. Also, commercially available fog detectors suited to roadside operations were evaluated. A detailed study was then made to pinpoint locations where fog detectors should be placed.

A summary of the background and progress is presented for the automatic fog warning system which became operational in October 1990.

Identification of Potentially Fog-Prone Areas

Studies to identify areas prone to fog concentrated on radiation fog, the formation of which is highly dependent on a specific topography in which cold, foggy air may collect. The studies identified 54 sites, as shown in Figure 15, that are prone to localized or patchy fog. These included valley bottoms, steep valley sides, small dips or undulations, and flat and low-lying areas such as floodplains and large bodies of water. The following techniques were used to identify locations for the detectors:

• Topographical studies, using maps and on-site inspections;

• Analyses of visibility and cloud base data held in computer archives;

• Acquisition and review of information from local traffic police, motorway organizations, and weather observers;

• Thermal mapping by aircraft and satellite; and

• Derivations of the localized fog climatology by use of a fog potential index.

Automatic Fog Warning System

The new fog warning system is designed to help drivers by giving advance warning of unexpected pockets of fog that can suddenly reduce visibility.

The automatic fog warning system was integrated into the National Communications System (NMCS2), which supports a comprehensive range of functions such as motorway signalling,

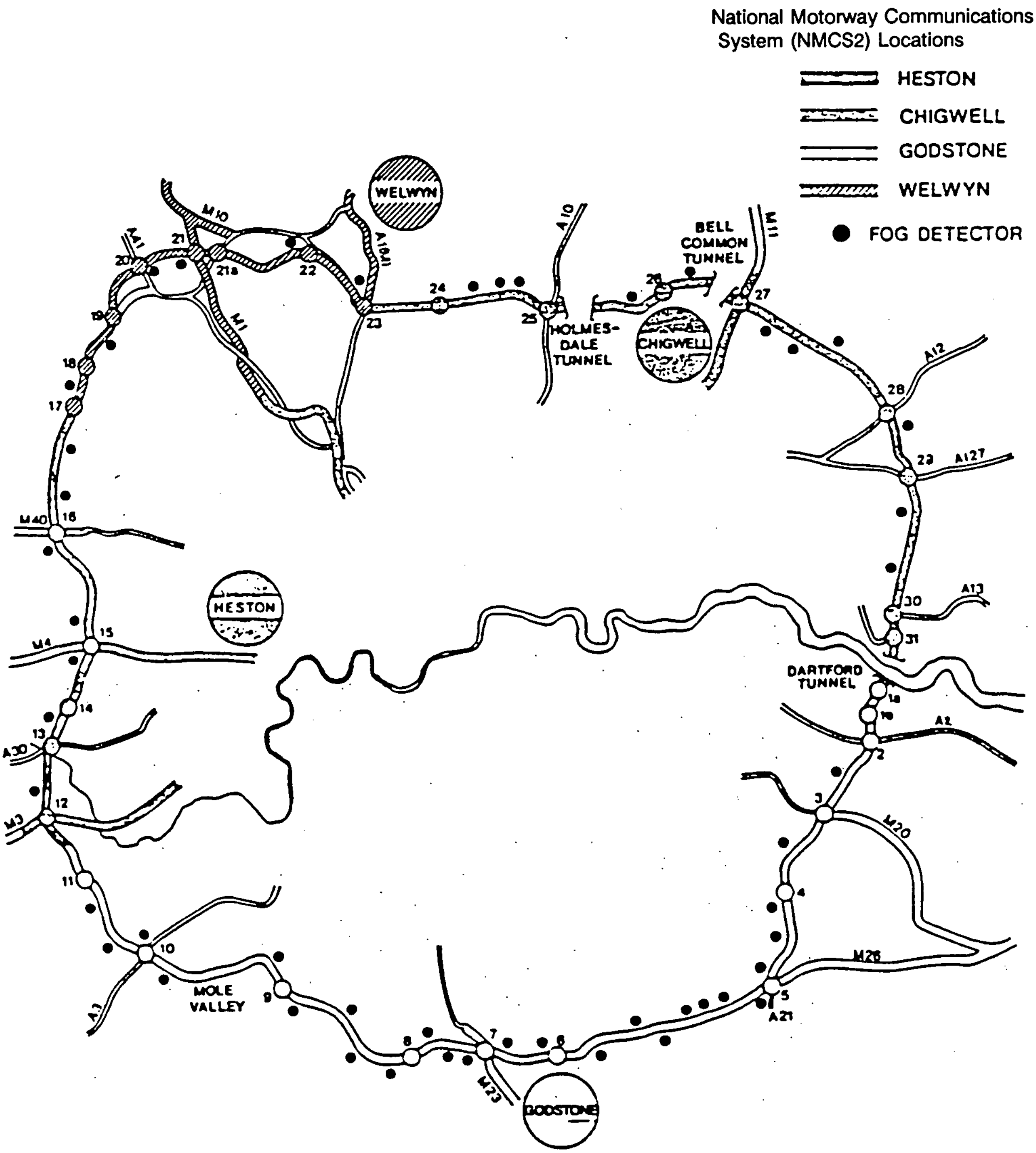

FIGURE 15 Schematic of M25 motorway *(15)*.

emergency telephones, and automatic incident detection. Four NMCS2 systems cover the M25 motorway, as shown in Figure 15.

When visibility lies between 500 m (1640 ft) and 300 m (984 ft), a general warning is given to the operators in the appropriate motorway control center. The fog alarm indicator flashes and the system reports the latest visibility distance on a visual display unit.

When the fog detector reports that visibility is less than 300 m (984 ft), the system automatically displays the legend "Fog" on the signs up to 2 km (1.24 mi) upstream on both sides of the road to give advance warning to oncoming drivers. When the fog detector reports that visibility is less than 100 m (328 ft), more upstream fog signs automatically cover a wider area. The exact location of the fog warning depends on the existing warning sign locations, which never exceed a spacing of 2 km (1.24 mi). As visibility improves, the system automatically removes the sign displays. It is noted that the process is fully automatic; however, operators may remove unnecessary displays.

Evaluation

To measure the effectiveness of the system, the Department of Transport has chosen, in addition to the principal fog detector sites, six other areas in which to place evaluation facilities. These facilities monitor traffic movement using inductive loops installed under the surface of each lane.

The evaluation systems are used in pairs to allow detection of any changes in the vehicle parameters that result when motorists have passed an illuminated "FOG" sign. The evaluation system is designed to work unattended, and most of the operation is performed either via the motorway communication network or via site visits with a portable data terminal.

When the visibility is less than 300 m (984 ft) and the signs are activated, the relevant traffic data collection equipment is triggered to record data until its memory is full. The data are then stored until downloaded from the evaluation system and transferred to a personal computer for analysis. This procedure allows the speed, headway, and classification of vehicle (by length) data to be recorded against arrival time at each monitoring site.

Three years of recorded data are required to show statistical significance. Data will then be analyzed by the Transport and Road Research Laboratory to determine the effect of the control system on driver behavior and speed when a fog sign is activated.

NETHERLANDS

It was reported "that the Dutch have achieved uniform driver behavior and a reduction in speed variation through limited visibility areas by implementing comprehensive countermeasures that include detection, automated traffic control, and enforcement. Variable message signs (VMS) display appropriate speeds and provide behavioral guidance for drivers; double loop detectors and microprocessors sense the traffic flow and detect disruptions; automatic equipment is used to adjust and maintain speed limits in advance of and through the strictly controlled section of road; and police aggressively enforce the posted speed limit. Thus, drivers traveling about the same speed uniformly enter and safely proceed through the hazardous area." It was also noted that "such strict control is not common on U.S. highways and requires carefully designed highway engineering practices, enforcement, and public education programs to make it a viable countermeasure."*(9)*

CHAPTER FIVE

RESEARCH AND DEVELOPMENT

UNITED STATES

In addition to the initiatives that are being undertaken in California and South Carolina's reduced visibility projects, others are being considered here and in Europe and many are related to IVHS concepts.

IVHS holds promise as one of the best solutions for problems associated with driving during reduced visibility conditions. For example, a Dutch Department of Transport researcher during the 1991 NTSB hearings endorsed IVHS technology as a solution, noting that the vehicle and the driver are the best sources of information, but that the driver does not, at present, have a means of communication. But communication protocols are already being made, and vehicles are communicating with each other and with beacons. This innovation makes it possible to collect relevant information and possibly to pass the information back to the source. These facilities are being demonstrated as part of the PROMETHEUS program.

The NTSB believes that "the IVHS program offers a unique opportunity to develop and implement limited-visibility traffic control countermeasures. Traffic flow detectors, automatic message and vehicle speed control systems, and radar vehicle detection to warn of preceding objects, such as other vehicles, are all appropriate candidates for IVHS projects." The NTSB has recommended that the DOT include limited-visibility countermeasures in demonstration projects funded through the IVHS program.

Some specific efforts both in the United States and abroad are summarized below.

Idaho

Because of accidents on Interstate 84 resulting from restricted visibility caused by wind-blown snow or dust, the Idaho Transportation Department is continuing development of a storm warning system to detect hazardous visibility conditions.

The proposed storm warning system would incorporate two existing VMSs while adding three more.

It is proposed that the storm warning capabilities be automated by installing sensors at appropriate locations.

Two sensors for measuring visibility and weather will be used on this project; HANDAR because it is more cost-effective and LIDAR because it uses the latest laser technology. The HANDAR costs about $15,800 each, whereas the LIDAR costs $75,000 to install.

Proposed evaluations will include a before-and-after comparison of number of accidents, accident severity, and economic loss. Weather data from the Raft River Weather Station will be used for comparisons. Loop detectors will be installed to measure the effectiveness of the speed advisory messages.

The project started in 1993, and is being funded through the FHWA, IVHS Operational Program.

Tennessee

Following the accident on I-75 near Calhoun in December 1990, the Tennessee Department of Transportation (TDOT) initiated a plan to aid drivers traveling through the fog-prone 8-mile stretch of I-75. A fog detection and warning system is presently being installed to warn motorists of hazardous driving conditions through a series of warning and reduced speed limit signs with changeable messages, weather stations, fog detectors, and highway advisory radio.

The system, which is shown in Figure 16, will continually monitor the climatological and visibility conditions in and near the fog-prone area using two meteorological stations and four or more visiometers (backscatter). Climatological threshold criteria will be used to alert the operators in the Central Control Center (CCC) that a given response is warranted. The operator's response will be to activate pre-determined messages on some or all of the 10 CMS included in the project. The internally illuminated fiber optic or light-emitting diode CMS will have three rows of 18- x 18-inch-high characters. These scenarios will also include changing of speed limits on 10 changeable speed limit signs, activation of HAR messages from one or more of the three HAR transmitters and when the interstate is closed, the closing of six swing gates located on interstate on-ramps. There will also be four fixed overhead signs and several fixed warning signs with activated flashing lights. The CMS will also be accessible remotely from the CCC computer or from a compatible computer (NIC) over dial-up phone lines to initiate messages not relevant to the fog warning scenarios.

A sub-component to the system will be a series of 44 radar vehicle flow detectors on the approaches to and within the fog-prone area. These detectors will be attached to breakaway poles mounted on the roadway shoulder and will monitor the speed and numbers of vehicles. Thresholds in changes of speed and/or flow monitored by the site computer will automatically activate messages on the CMS and change speeds on the changeable speed limit signs.

The primary communications between the site and CCC will be by microwave through at least two repeater sites. A climatically controlled pre-engineered shelter and a mono-pole tower are required at the site control center to accommodate communications and control equipment. Backup communications will be provided by dial-up telephone service between

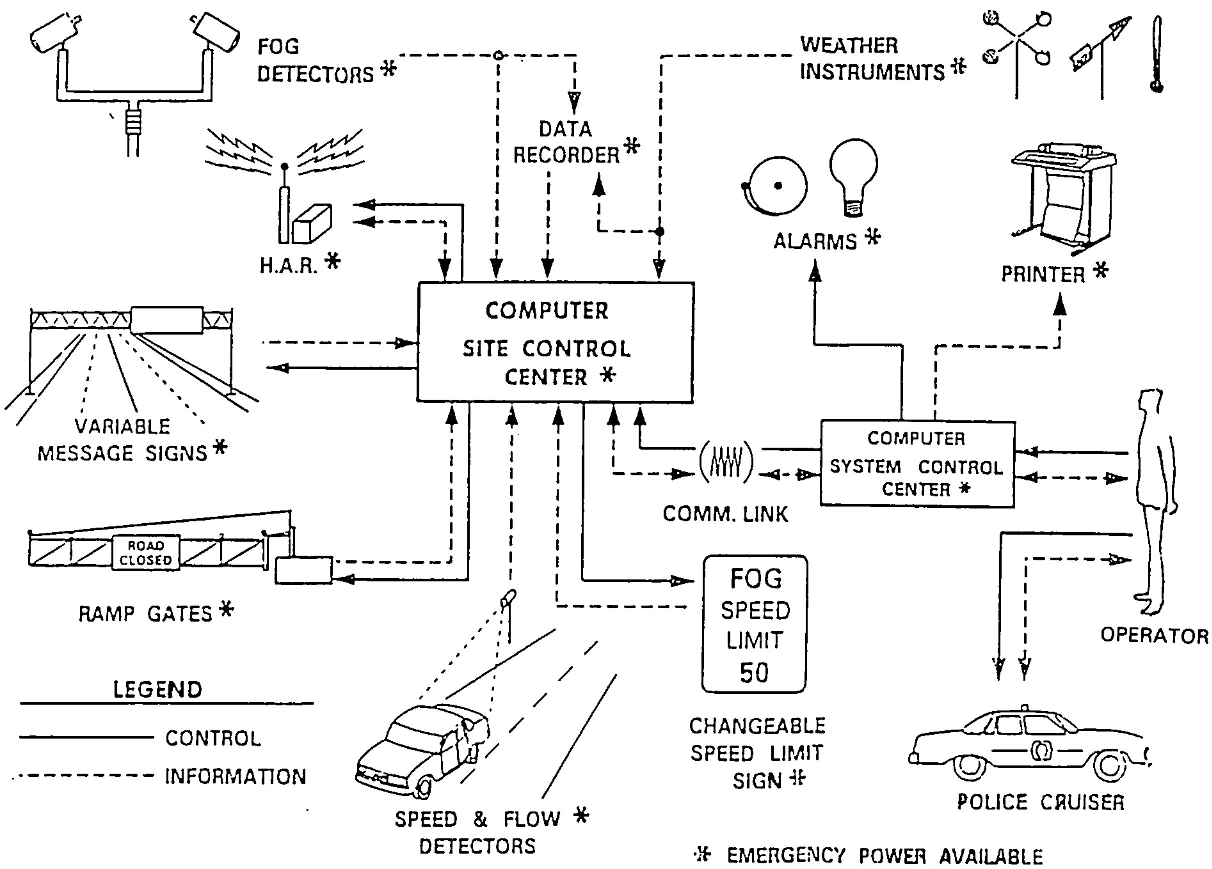

FIGURE 16 Fog detection and warning system components. Tennessee Department of Transportation, 1993.

the CCC and the site. Communications between the site control center and the system components will be by direct buried fiber optic cable in the I-75 right of way. The site power requirements will be met by three service points and emergency power will be provided by a propane powered emergency generator at each.

The system will be under an operational test for one year following installation.

FHWA Supported Research

Because of fog related accidents, especially the four winter 1990-1991 accidents with their 21 fatalities, the FHWA decided there was a need to develop, install, and evaluate a condition-responsive adverse visibility warning and control system for real-time application.

A research study entitled "Development of Prototype Adverse Visibility Warning and Control Systems for Operational Evaluations" was funded for Georgia and Utah.

Georgia will install forward scatter visibility sensors, variable message signs, and real-time control. Communication will be by radio from a processor to the signs and a police station. The signs are automatically activated by a manual override. Evaluation will include a determination of driver responses to the warnings by using vehicle detectors to measure speed, speed variability, and headways. Also, an analysis of costs of the systems, along with reliability and maintenance operations, will be made. The study started in 1993 and lasts three years.

Utah proposes to use CMSs and a radio to provide warning messages to motorists. Fog sensors, mounted 1.1 m (3.5 ft) above the surface, will measure visibility with hard wire connected to a VMS. Fixed systems in areas known for recurring fog conditions will be automated with limited human involvement. The CMS bulb matrix sign with two lines of 22 characters per line will be mounted overhead.

An evaluation will include accidents, speed and travel times, delays, headways, and queue lengths and capacities, which will be correlated with different reduced visibility conditions. An attempt will be made to determine appropriate speed reductions for different visibility levels. A human factors study will determine what driver warning messages are most effective for the CMSs and HARs. This study takes three years and began in 1993.

Another study sponsored by the FHWA entitled "Environmental Sensor Systems for Safe Traffic Operations" provides an assessment of the functional requirements for environmental sensors in highway applications, as well as examining state-of-the-art sensing systems.

ABROAD

In Europe there are several research programs that include studies of environment sensor systems. These are generally multi-national initiatives, in contrast to individual state iniatives in the United States. These are the PROMETHEUS program, COST (European Cooperation in the Field of Scientific and Technical Research), and DRIVE (Dedicated Road Infrastructure to Vehicle Safety in Europe).

PROMETHEUS

PROMETHEUS is a $700 million research program undertaken to define and develop the future of road traffic based on advanced technologies. The objective of this collaborative effort between European automobile manufacturers and their respective governments is to create concepts and solutions that will make vehicles safer and more economical. Initiated in 1986, the program aims to produce a totally integrated highway transportation system throughout Europe. PROMETHEUS combines basic research conducted by universities and research institutes with applied research conducted by industry. Three primary topics are being considered: (1) safe driving, (2) traffic flow harmonization, and (3) travel and transport management.

Under safe driving there are several projects relating to environmental sensor systems. These involve the use of sensors to enhance vision and to detect loss of control during adverse weather conditions.

A vision enhancement system is being demonstrated to provide improved driver vision during adverse weather conditions. Image sensors can improve a driver's vision by supplying higher quality information than available through human vision, providing a depth map of all obstacles, and producing data for the formation of an image with reduced visual noise. Four approaches are being investigated: (1) ultraviolet illumination, (2) thermal image using infrared cameras, (3) infrared illumination and CCTV cameras, and (4) gated, intensified cameras with pulsed illumination.

Other parts of the PROMETHEUS research program (under Volkswagen) have developed a visibility monitoring system based on an infrared laser beam (similar to the detector being experimented with in Idaho). Backscatter signals from the beam are processed to derive the visibility range. A speed appropriate to the prevailing conditions is then recommended to the driver.

COST

The COST program was started more than 20 years ago. One of its projects, COST 30, aimed to improve traffic safety and flow conditions through the use of electronic traffic aids for detecting traffic conditions and communicating with the driver. This project was split into nine research areas, one of which examined the relationship between traffic and weather. One new project emanating from this effort was COST 309, which investigates highway weather detection, forecasting, statistics, and service strategies. COST 309 involved eleven countries, and research was divided into different areas. Sweden looked at sensors and measuring systems, France the detection and prediction of fog, and other countries examined aspects such as weather radar and satellite information.

DRIVE

DRIVE is an initiative through which the Netherlands is developing and demonstrating IVHS. One of the projects in the DRIVE program is CROW, which investigated systems that can reduce traffic accidents due to bad weather. It has looked at means for improving data acquisition techniques and has developed a system to provide an integrated road and weather monitoring system. The main elements of CROW relative to reduced visibility are as follows.

- A knowledge-based expert system to provide fog warnings (prototype microwave, infrared and laser-based sensing systems for monitoring the conditions of road surfaces),
- An integrated nephelometer to assess road visibility,
- A road/weather control center, and
- An algorithm to define safe travel levels in bad weather conditions, based on road, weather, and traffic data.

The results of the CROW project will be implemented in the GERDIEN demonstration project in the near future as part of DRIVE-2. The GERDIEN project is evaluating the operation of a number of monitoring systems within an integrated communications framework in the Rotterdam area. Monitoring systems to be appraised include weather sensors, weigh-in-motion systems, variable message signs, and image analysis.

CHAPTER SIX

CONCLUSIONS

The synthesis examines the reduced visibility countermeasures that have been developed in the areas of fog dissipation, traffic control, and public awareness. Some experimental results indicate that improvement in road conditions can be demonstrated to disperse or reduce fog and to improve safety and serviceability through aerial or ground seeding. However, more investigation is needed to demonstrate effective and reliable tools to dissipate fog under a variety of climatological, geographic, and road conditions.

Programs to reduce fog related collisions in California have demonstrated that morning broadcasts on radio and TV stations during periods of heavy fog and the distribution of fog safety brochures were successful in increasing public awareness. Other means of informing the public about real conditions are the use of bulb matrix displays of the portable CMSs, which are visible even during dense fog; the use of portable HARs, which make additional information available to motorists; and the use of CHP PACE units. Increased law enforcement presence is thought to be a major factor in improving driver vigilance in a heavy-fog situation.

When causeway driving is a factor in a fog environment (as it is in Louisiana), CMSs, HARs, and pamphlets are used along with traffic control measures that allow traffic to move in the right lane only (2 lanes in each direction), with police riding herd to prevent passing and to look for possible breakdowns. Closure of the left lane is a key to maintaining smooth traffic flow as it allows a place for motorists to pull into in the event of a problem.

Secondary accidents are a major problem under driving conditions of reduced visibility. A system of speed limit and warning signs was used in New Jersey and New Mexico and was thought to significantly contribute to the reduction of secondary accidents by alerting motorists to driving conditions ahead. However, traffic behavior, as defined by average speed and standard deviation in speed, does not appear to change significantly after signs are displayed.

The states have also been guided in their efforts by recommendations of the National Transportation Safety Board. An NTSB special public hearing (*3*) on fog accidents on limited-access highways provided the following suggestions and conclusions:

- Countermeasures are needed that ensure drivers proceed through limited-visibility conditions at uniform reduced speeds [to prevent multiple-vehicle collisions during limited visibility].
- A 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.
- Reliance on police patrols to detect limited-visibility conditions will not ensure their timely detection.
- 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.
- If visibility sensors are to be effective in highway applications, they must be strategically placed throughout an area prone to limited visibility as one component in a comprehensive fog countermeasure system.
- The credibility of highway and weather condition warning and behavioral guidance signs is essential to reducing speed variation.
- Countermeasures vary, and the disparity among states could cause driver confusion and result in nonuniform driver response. . . Countermeasures should be similar nationwide to minimize driver confusion.
- Uniform, specific guidance for driving during fog and limited-visibility conditions should be developed and incorporated in driver license manuals and tests.
- Development of effective fog and other limited-visibility countermeasures should continue and relative information about them be made available to the states on a timely basis.
- The Intelligent Vehicle Highway System (IVHS) program offers a unique opportunity to develop and implement limited-visibility traffic control countermeasures. Traffic flow detectors, automatic message and vehicle speed control systems, and radar vehicle detection to warn of preceding objects (such as other vehicles) are appropriate candidates for IVHS projects. Therefore, limited-visibility countermeasures in demonstration projects should be included in and funded through the IVHS program.

There is a major focus on further developing reduced-visibility countermeasures, as witnessed by ongoing and planned projects in at least eight states (in addition to efforts abroad). It is very important that this new information be used to advance the knowledge surrounding the effectiveness of reduced-visibility countermeasures. It is recommended that the following areas be considered.

Motorist Information Systems—It is important that the results of ongoing and planned projects involving motorist information systems be analyzed, in combination with those already available, to better understand how information on reduced-visibility conditions influences the driver. This would help establish guidelines for installing systems that are effective and that offer uniform and credible information to the driver. Special consideration should be given to the following:

- Effectiveness of different messages (word and speed limit);
- Number and location of messages,
- HAR messages and location, and
- Providing real-time information.

Consideration should be given to studies involving driver behavior relative to the psychophysics of driving under conditions of reduced visibility to help understand how drivers react and what the psychological elements of depth perception are. How the brain interprets the eye's visual cues in the distance-judgment process and whether faulty judgments are made as a result of misinterpretation are matters of concern. A better understanding of this would help in determining what visual information is best to give motorists.

Other Traffic Control Techniques—Traffic control techniques that have been effective in specific locations or situations may be useful in other areas or for corroborating the technique's effectiveness. A good example is the PACE program in California and the single-lane concept on the Lake Pontchartrain Bridge in Louisiana.

Fog Detection—There continues to be a need for reliable, economical methods of detecting conditions of reduced visibility; information from ongoing and planned projects on detection will be useful.

Education and Public Awareness—Educating the public concerning the hazards of reduced visibility and the problems associated with driving is an important step in increasing driver safety in these conditions. California's success is a good example of the benefits that result from better public awareness.

Fog Dissipation—Considering the success of fog dissipation experiments using seeding techniques, these may be investigated further so that guidelines for their use on the ground and in the air can be established.

IVHS—Solutions to the hazards of driving during reduced-visibility conditions using IVHS technology hold promise for effective mitigation.

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APPENDIX A

Summary of Climatological Data for Fresno, California

NORMALS, MEANS, AND EXTREMES

FRESNO, CALIFORNIA

LATITUDE: 36°46'N LONGITUDE: 119°43' W ELEVATION: FT. GRND 328 BARO 330 TIME ZONE: PACIFIC WBAN: 93193

	(a)	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	YEAR
TEMPERATURE °F:														
Normals														
-Daily Maximum		54.2	61.2	66.5	73.7	82.7	91.1	97.9	95.5	90.3	79.9	65.2	54.4	76.1
-Daily Minimum		36.8	39.7	42.0	46.5	52.7	58.9	64.1	62.2	57.8	49.7	41.1	36.3	49.0
-Monthly		45.5	50.5	54.3	60.1	67.7	75.0	81.0	78.9	74.1	64.8	53.2	45.3	62.5
Extremes														
-Record Highest	42	78	80	90	100	107	110	112	111	111	102	89	76	112
-Year		1986	1991	1972	1981	1984	1964	1991	1990	1955	1980	1949	1958	JUL 1991
-Record Lowest	42	19	24	26	32	36	44	50	49	37	27	26	18	18
-Year		1963	1990	1966	1982	1975	1955	1955	1966	1950	1972	1975	1990	DEC 1990
NORMAL DEGREE DAYS:														
Heating (base 65°F)		605	406	336	187	52	8	0	0	0	88	354	611	2647
Cooling (base 65°F)		0	0	0	40	135	308	496	431	277	82	0	0	1769
% OF POSSIBLE SUNSHINE	42	48	66	77	85	90	95	96	96	94	88	66	46	79
MEAN SKY COVER (tenths)														
Sunrise - Sunset	42	7.2	6.0	5.3	4.3	3.1	1.9	1.2	1.4	1.7	2.8	5.2	6.9	3.9
MEAN NUMBER OF DAYS:														
Sunrise to Sunset														
-Clear	42	5.5	7.9	11.2	14.2	18.9	23.2	26.8	26.1	23.7	20.4	11.5	7.0	196.4
-Partly Cloudy	42	7.0	7.9	8.1	8.0	7.4	4.5	2.9	3.5	4.0	6.0	7.2	6.0	72.4
-Cloudy	42	18.5	12.5	11.7	7.8	4.7	2.3	1.3	1.4	2.3	4.7	11.2	18.0	96.5
Precipitation														
.01 inches or more	42	7.5	6.9	7.1	4.2	1.9	0.7	0.2	0.3	1.0	2.1	5.4	6.7	44.1
Snow, Ice pellets, hail														
1.0 inches or more	42	0.*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.*	*
Thunderstorms	42	0.3	0.4	0.9	0.6	0.5	0.5	0.3	0.3	0.7	0.5	0.2	0.3	5.4
Heavy Fog Visibility														
1/4 mile or less	42	11.5	6.1	1.7	0.4	0.1	0.0	0.0	0.*	0.1	0.9	6.0	12.1	38.9
Temperature °F														
-Maximum														
90° and above	28	0.0	0.0	0.*	2.1	9.9	19.6	28.7	26.3	17.2	4.6	0.0	0.0	108.4
32° and below	28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
-Minimum														
32° and below	28	7.6	3.2	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.1	1.9	9.1	22.8
0° and below	28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
AVG. STATION PRESS. (mb)	19	1009.1	1007.7	1005.3	1004.3	1001.7	1000.5	1000.4	1000.5	1000.8	1004.1	1007.5	1009.2	1004.3
RELATIVE HUMIDITY (%)														
Hour 04	28	91	90	86	80	71	64	61	67	72	77	87	92	78
Hour 10 (Local Time)	28	84	76	65	51	42	39	37	42	45	52	71	84	57
Hour 16	28	67	55	47	35	26	23	22	25	28	34	54	68	40
Hour 22	28	88	83	75	62	49	43	40	46	52	64	81	89	64
PRECIPITATION (inches):														
Water Equivalent														
-Normal		2.05	1.85	1.61	1.15	0.31	0.08	0.01	0.02	0.16	0.43	1.24	1.61	10.52
-Maximum Monthly	42	8.56	5.97	7.24	4.41	1.65	0.60	0.08	0.25	1.19	1.58	3.50	6.73	8.56
-Year		1969	1962	1991	1967	1990	1972	1979	1964	1976	1982	1972	1955	JAN 1969
-Minimum Monthly	42	0.04	T	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-Year		1976	1964	1972	1991	1982	1983	1983	1981	1981	1978	1959	1989	DEC 1989
-Maximum in 24 hrs	42	2.59	1.99	1.63	1.39	1.42	0.60	0.08	0.25	0.97	1.55	1.35	1.76	2.59
-Year		1969	1969	1958	1983	1990	1972	1979	1964	1978	1976	1953	1955	JAN 1969
Snow, Ice pellets, hail														
-Maximum Monthly	42	2.2	T	T	0.0	0.0	0.0	0.0	0.0	0.0	T	0.0	1.2	2.2
-Year		1962	1990	1991							1974		1968	JAN 1962
-Maximum in 24 hrs	42	1.5	T	T	0.0	0.0	0.0	0.0	0.0	0.0	T	0.0	1.2	1.5
-Year		1962	1990	1991							1974		1968	JAN 1962
WIND:														
Mean Speed (mph)	42	5.2	5.7	6.7	7.3	8.1	8.3	7.3	6.8	6.0	5.2	4.7	4.8	6.3
Prevailing Direction through 1963		SE	NW	NW	NW	NW	NW	NW	NW	NW	NW	NW	SE	NW
Fastest Obs. 1 Min.														
-Direction (!!!)	13	27	31	32	30	32	30	31	31	31	32	32	22	30
-Speed (MPH)	13	31	29	29	32	30	28	23	28	29	23	28	28	32
-Year		1983	1977	1982	1984	1991	1983	1983	1984	1978	1982	1991	1991	APR 1984
Peak Gust														
-Direction (!!!)	8	SE	S	SE	NW	NW	NW	NW	NW	NW	N	N	S	SE
-Speed (mph)	8	55	46	43	41	41	33	28	36	33	46	44	48	55
-Date		1987	1986	1987	1984	1991	1984	1991	1984	1991	1991	1991	1991	JAN 1987

(!!!) See Reference Notes on Page 6B.

METEOROLOGICAL DATA FOR 1991

FRESNO, CALIFORNIA

LATITUDE: 36°46' N LONGITUDE: 119°43' W ELEVATION: FT. GRND 328 BARO 330 TIME ZONE: PACIFIC WBAN: 93193

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	YEAR
TEMPERATURE °F:													
Averages													
-Daily Maximum	57.5	68.9	60.3	72.3	79.9	89.9	99.1	93.2	95.6	85.1	68.0	57.2	77.3
-Daily Minimum	36.4	42.7	42.7	46.7	52.2	59.5	68.4	64.0	64.1	55.9	43.5	36.7	51.1
-Monthly	47.0	55.8	51.5	59.5	66.1	74.7	83.8	78.6	79.9	70.5	55.8	47.0	64.2
-Monthly Dewpt.	37.7	43.2	41.9	40.9	42.6	45.8	57.2	54.2	53.4	49.7	43.4	36.7	45.6
Extremes													
-Highest	68	80	78	87	96	105	112	105	103	99	84	72	112
-Date	18	26	30	30	24	11	5	24	3	10	7	27	JUL 5
-Lowest	27	31	35	39	44	53	62	57	52	41	31	28	27
-Date	1	1	16	11	2	22	16	28	10	31	30	21	JAN 1
DEGREE DAYS BASE 65 °F:													
Heating	549	253	412	163	65	0	0	0	0	81	276	551	2350
Cooling	0	0	0	6	107	298	588	428	454	259	5	0	2145
% OF POSSIBLE SUNSHINE	54	68	56	93	88	94	99	96	97	89	79	62	83
AVG. SKY COVER (tenths)													
Sunrise - Sunset	5.5	5.6	6.3	2.8	3.4	2.7	0.7	1.5	1.4	1.8	3.1	6.1	3.4
Midnight - Midnight	5.1	5.1	6.0	2.4	2.9	2.3	0.8	1.5	1.2	1.7	2.9	5.7	3.1
NUMBER OF DAYS:													
Sunrise to Sunset													
-Clear	13	8	9	20	17	19	28	28	24	25	20	11	222
-Partly Cloudy	5	9	7	7	11	8	3	2	5	3	5	4	69
-Cloudy	13	11	15	3	3	3	0	1	1	3	5	16	74
Precipitation .01 inches or more	3	4	16	1	1	0	0	0	0	2	1	6	34
Snow, Ice pellets, hail 1.0 inches or more	0	0	0	0	0	0	0	0	0	0	0	0	0
Thunderstorms	0	0	2	0	0	0	0	0	1	0	0	0	3
Heavy Fog, visibility 1/4 mile or less	6	7	0	0	0	0	0	0	0	2	2	9	26
Temperature °F													
-Maximum													
90° and above	0	0	0	0	3	19	31	24	27	18	0	0	122
32° and below	0	0	0	0	0	0	0	0	0	0	0	0	0
-Minimum													
32° and below	11	1	0	0	0	0	0	0	0	0	2	7	21
0° and below	0	0	0	0	0	0	0	0	0	0	0	0	0
AVG. STATION PRESS. (mb)	1010.2	1007.1	1003.7	1005.8	1002.4	1000.0	1000.0	1002.4	1000.3	1002.4	1007.8	1007.1	1004.1
RELATIVE HUMIDITY (%)													
Hour 04 (Local Time)	90	86	86	77	70	61	64	67	66	74	86	84	76
Hour 10	75	67	69	50	43	35	40	42	39	47	64	70	53
Hour 16	54	45	55	33	26	21	24	28	22	31	45	55	37
Hour 22	81	76	78	58	49	42	44	49	43	56	77	82	61
PRECIPITATION (inches):													
Water Equivalent													
-Total	0.13	1.01	7.24	0.02	0.03	T	0.00	T	T	0.80	0.04	1.22	10.49
-Greatest (24 hrs)	0.11	0.62	1.52	0.02	0.03	T	0.00	T	T	0.77	0.04	0.74	1.52
-Date	3- 4	27-28	17-18	20	13	28		12	25	26	17	29	MAR 17-18
Snow, Ice pellets, hail													
-Total	0.0	0.0	T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	T
-Greatest (24 hrs)	0.0	0.0	T	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	T
-Date			25										MAR 25
WIND:													
Resultant													
-Direction (!!!)	085	346	124	317	311	306	302	304	301	313	353	092	312
-Speed (mph)	0.4	1.2	1.5	6.0	8.1	7.1	7.0	7.2	3.0	1.2	1.2	1.8	3.2
Average Speed (mph)	2.7	5.1	7.0	8.5	10.0	9.0	8.7	8.4	5.6	5.6	4.8	4.9	6.7
Fastest Obs. 1 Min.													
-Direction (!!!)	34	31	32	32	32	29	31	30	31	32	32	22	32
-Speed (mph)	12	20	23	29	30	23	20	22	22	21	28	28	30
-Date	19	17	1	30	16	18	16	14	9	27	14	27	MAY 16
Peak Gust													
-Direction (!!!)	NW	S	NW	N	NW	NW	NW	NW	NW	N	N	S	S
-Speed (mph)	15	32	30	39	41	28	28	29	33	46	44	48	48
-Date	19	28	14	10	16	18	12	14	9	26	29	27	DEC 27

(!!!) See Reference Notes on Page 68

APPENDIX B

Example of Fog Brochure

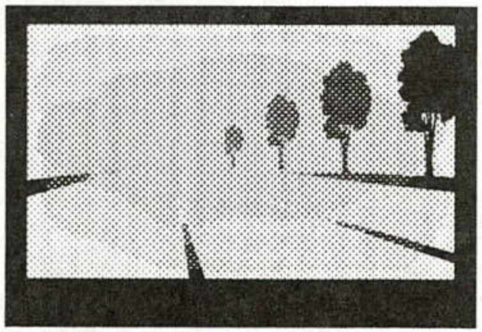
CALIFORNIA HIGHWAY INFORMATION NETWORK (CHIN)

City/Location	Phone No.
Bakersfield (N)	805/393-1582
Bakersfield (S)	805/393-7350
Chico	916/895-8111
Fresno	209/227-7264
Marysville	916/743-4681
Merced	209/383-4291
Modesto	209/521-2240
Sacramento *	916/445-7623
Stockton	209/948-7365

* Cities with Touch Tone Feature

Caltrans Highway Information Broadcast Network (CHIBN)

KFBK/KAER - 1530 AM / 92.5 FM - Sacramento
KRAK - 1140 AM / 105.1 FM - Sacramento
KGNR/KCTC - 1320 AM / 96.1 FM - Sacramento
KOVR TV - Channel 13 - Sacramento
KPAY - 1060 AM / 95.1 FM - Chico
KBLF/KALF - 1490 AM / 95.7 FM - Chico
KHOP - 104.1 FM - Modesto
KAAT - 107.1 FM - Oakhurst



Pete Wilson
Governor

Carl D. Covitz
Secretary California Business, Transportation and Housing Agency

James W. van Loben Sels, Director
California Department of Transportation

Caltrans

Produced in cooperation with:
Caltrans Districts 3, 6, and 10
California Highway Patrol
California Trucking Association.
National Weather Service
National Oceanic and Atmospheric Administration

Graphics by Kris Binger

A KILLER!

CENTRAL VALLEY TULE FOG

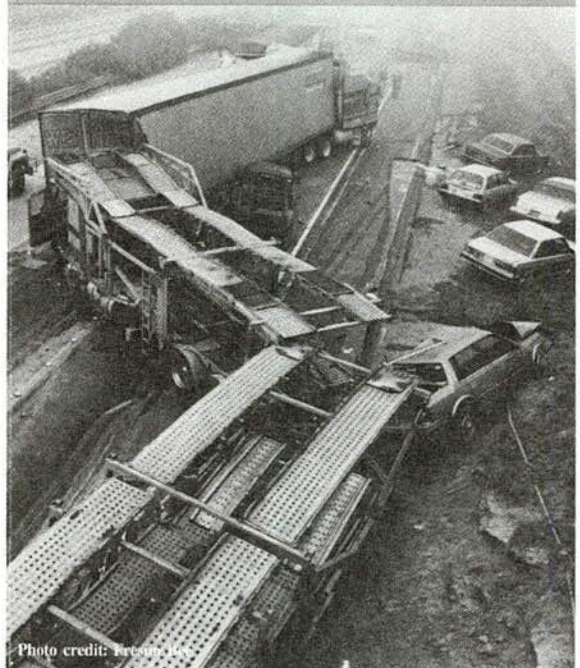


Photo credit:

FACTS AND TIPS

CALTRANS * CHP * CTA * NOAA

CALIFORNIA TULE FOG

As the storm track moves further south during the winter months, rain begins to spread over the San Joaquin Valley. Radiation fog (called tule fog) forms during the night and morning hours during the winter months across the Central Valley.

On clear nights (when the ground is moist and winds are calm) the ground cools rapidly. This in turn causes the air adjacent to the ground to cool and condense into fog. As successive layers of air cool, the deeper the fog layer becomes. During the day, the sun heats the airmass and ground. The fog then begins to evaporate and "lift" which is responsible for improved visibilities.

The visibility in "tule fog" can often be less than 1/8 mile (660 feet) and can be as little as 10 feet! Valley bottoms are prime areas for tule fog formation. The coldest air always settles and these areas will experience the densest fog. Please keep this in mind as you travel in rolling terrain or through a basin area.

Exercise extreme caution if you must travel in a tule fog situation. Visibilities can deteriorate rapidly at any time. Multi-car accidents could occur if you do not keep your distance and reduce your speed.

FOG SEASON

Months that tule fog is most likely:
November through February

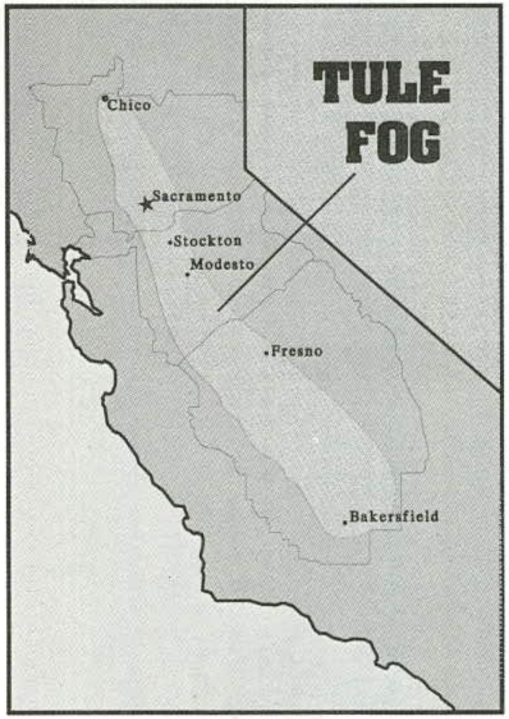
Typical number of Fatal Fog days:

November...6 days / December...12 days
January...12 days / February...6 days

FOG DRIVING TIPS

1. Drive with lights on low beam. Never drive with just your parking or fog lights.
2. Reduce your speed.
3. Avoid crossing traffic unless absolutely necessary.
4. Listen for traffic you cannot see.
5. Use wipers and defroster as necessary for maximum vision.
6. Be patient! Don't pass lines of traffic.
7. Unless absolutely necessary don't stop on any freeway, or other heavy travelled road.
8. If your car stalls or is disabled, move away from the vehicle to avoid personal injury.
9. Consider postponing your trip until the fog clears.

CENTRAL VALLEY FOG PRONE AREAS



EXPECT
CHP led truck convoys through dense fog in urban commute areas.

APPENDIX C

Example of A News Release

news release

Caltrans

California
Department of
Transportation

District 6
P.O. Box 12616
Fresno 93778
91-125

October 25, 1991

CONTACT: DAVE BALDRIDGE
SHARON SCOTT
PUBLIC AFFAIRS
(209) 488-4044

FOR IMMEDIATE RELEASE

HELP FOR MOTORISTS TRAVELING THROUGH THE FOG IN THE CENTRAL VALLEY

FRESNO--The California Department of Transportation (Caltrans) and the California Highway Patrol (CHP) today announced the start of winter fog operations designed to reduce weather-related accidents along Highway 99 in the Central Valley.

"As winter settles in over the valley, tule fog can drastically reduce visibility for motorists. In the past, that condition has contributed to serious multi-vehicle traffic accidents on Highway 99," said Bob Coleman, Caltrans District 6 Director. "In an effort to reduce the carnage along this vital thoroughfare, we are instituting a number of steps designed to improve traffic safety."

Some of the steps are an expanded public educational program about driving in the fog, the use of changeable message signs providing traffic information and temporary staging areas where motorists can pull over safely until conditions improve.

"With the help of the motoring public and our commitment to public safety, we're confident that we can reduce the number of fog-related, multi-vehicle accidents on Highway 99," Coleman said.

Coleman urged all motorists to slow down or make alternate plans and stay off the highways during thick, blinding fog.

###

APPENDIX D

Typical Menu Used During Fog

CMS MASTER MENU

PHRASE 1001	FOG/INFO // TUNE/AM 530
PHRASE 1002	ALL/TRUCK/EXIT // AVE/7
PHRASE 1003	TRUCKS/RT LANE/ONLY // NEXT/30 MILES
PHRASE 1004	TRUCKS/RT LANE/ONLY // NEXT/24 MILES
PHRASE 1005	TRUCKS/RT LANE/ONLY // NEXT/18 MILES
PHRASE 1006	TRUCKS/RT LANE/ONLY // NEXT/9 MILES
PHRASE 1007	FOG/ALERT// DRIVE/WITH /CARE
PHRASE 1008	ALL/TRUCKS/EXIT // AVE/384
PHRASE 1009	TRUCKS/RT LANE/ONLY // NEXT/28 MILES
PHRASE 1010	TRUCKS/RT LANE/ONLY // NEXT/23 MILES
PHRASE 1011	TRUCKS/RT LANE/ONLY // NEXT/20 MILES
PHRASE 1012	TRUCKS/RT LANE/ONLY // NEXT/12 MILES
PHRASE 1013	DENSE/FOG // DRIVE/WITH/CAUTION
PHRASE 1014	ROAD/INFO // TUNE/AM 530
PHRASE 1015	FOLLOW/PACE CAR // DENSE/FOG
PHRASE 1016	FOG/ADVISORY //DRIVE/WITH/CAUTION
PHRASE 1018	ROAD/ADVISORY // I-5 OVER/GRAPEVINE/CLOSED
PHRASE 1019	ROAD/ADVISORY // GRAPEVINE/CLOSED
PHRASE 1020	HIGH/WINDS/DUST // PROCEED/WITH/CAUTION
PHRASE 1021	HIGH/WINDS/AHEAD // PROCEED/WITH/CAUTION
PHRASE 1030	SLOW // PREPARE/TO/STOP
PHRASE 1031	ACCIDENT/AHEAD // PREPARE/TO STOP
PHRASE 1050	TEST

CMS MASTER MENU

Fog Conditions

Phrase #	Phrase
# 20	DENSE FOG
	NEXT XX MILES
# 21	DENSE FOG
	FREEWAY CLOSED XX MILES
# 22	DENSE FOG AHEAD
	FREEWAY CLOSED
# 23	DENSE FOG
	FOLLOW CHP PACE CAR
# 24	DENSE FOG
	PROCEED WITH CAUTION
# 25	DENSE FOG AHEAD
	EXPECT SLOW TRAFFIC

Accident

Phrase #	Phrase
# 30	ACCIDENT AHEAD
	FREEWAY CLOSED AHEAD
# 31	ACCIDENT AHEAD
	FREEWAY CLOSED
	EXIT AT XXX
# 32	ACCIDENT AHEAD
	PREPARE TO STOP

CMS MASTER MENU

Wind Conditions

Phrase #	Phrase
#1	GUSTY WINDS
	NEXT XX MILES
# 2	GUSTY WINDS AHEAD
	TRUCKS TRAILERS CAMPERS
	NOT ADVISED

Dust Conditions

Phrase #	Phrase
#10	WIND DUST
	NEXT XX MILES
#11	DUST STORM AHEAD
	FREEWAY CLOSED
	EXIT AT XXXXX
# 12	DUST STORM AHEAD
	EXPECT SLOW TRAFFIC
# 13	DUST STORM
	NEXT XX MILES
# 14	DUST STORM
	FOLLOW CHP PACE CAR
# 15	DUST STORM AHEAD
	PROCEED WITH CAUTION
# 16	DUST STORM AHEAD
	FREEWAY CLOSED XX MILES

APPENDIX E

Master Menu of HAR Messages

S.R. 99—HAR
Master Menu

Message A: This is Caltrans Highway Advisory Radio. There is a **Fog Advisory** in effect on Route 99 in Fresno, Madera, and Tulare Counties. The CHP **Pace Program** will be operating in Fresno County. Please follow CHP Pace Car.

Message B: This is Caltrans Highway Advisory Radio. The CHP Caltrans **truck staging** operation is in effect. All southbound trucks must exit at **Ave. 7**. Watch for slow-moving trucks at Ave. 7. KNEC 996.

Message C: This is Caltrans Highway Advisory Radio. The CHP Caltrans Operation **Fog staging** is in effect. Watch for slow-moving traffic in the right lane at Ave. 7. KNEC 996.

Message D: This is Caltrans Highway Advisory Radio. The CHP Caltrans **truck staging** operation is in effect. All northbound trucks must exit at **Ave. 384**. Watch for slow-moving trucks at Ave. 384. KNEC 996.

Message E: This is Caltrans Highway Advisory Radio. The CHP Caltrans Operation **Fog staging** is in effect. Watch for slow-moving traffic in the right lane at Ave. 384. KNEC 996.

Message F: This is Caltrans Highway Advisory Radio. There is a **Fog Advisory** in effect on Route 99 in Fresno, Madera, and Tulare Counties. **Low visibility** is reported throughout the valley. If you must drive, please proceed with caution. KNEC 996.

Message G: This is Caltrans Highway Advisory Radio. There is a **HIGH WIND ADVISORY** in effect on Route 99 in Fresno, Madera, and Tulare Counties. **Low visibility** is reported throughout the valley. Please proceed with caution. KNEC 996.

APPENDIX F

Cost Summary for California

OPERATION FOG
FINANCIAL SUMMARY

CALTRANS

EQUIPMENT	$757,936.36
CONSTRUCTION	522,418.79
LABOR	31,412.99
PRINTING	10,099.45
PER DIEM	75.33
SUBTOTAL	$1,321,942.92

CHP

LABOR	$119,346.00
OVERTIME	33,548.00
EQUIPMENT	36,936.00
INDIRECT COSTS	33,858.00
CONTRACT SERVICES	11,225.00
PRINTING	450.00
SUBTOTAL	$235,363.00

TOTAL..........$1,557,305.92

APPENDIX G

Dust Brochure

CALTRANS HIGHWAY INFO NETWORK (CHIN)

1-800-427-ROAD

CALTRANS HIGHWAY INFO BROADCAST NETWORK (CHIBN)

KFBK/KAER -
1530 AM / 92.5 FM
Sacramento

KRAK/KEWT
1140 AM / 105.1 FM
Sacramento

KKRV -
102.3 FM / 95.1 FM
Lake Isabella

KWAK -
1490 AM
Bakersfield

KHOP -
104.1 FM
Modesto

KAAT -
107.1 FM
Oakhurst

NOAA WEATHER RADIO

The National Weather Service will issue a Blowing Dust Advisory whenever winds reach 30 mph and sand or dust is blowing. Motorists should be alert for the issuance of these advisories, which are broadcast widely on local radio stations and on NOAA Weather Radio. In addition, motorists should read and heed electronic message signs along the highway.

A Dust Storm (or Sand Storm) Warning means: wind speeds of 40 miles an hour or more when sand or dust is blowing. Visibility will be announced at that time.

Weather Radio consists of high frequency (VHF) radio stations serving the San-Joaquin Valley.

Sacramento	162.55 MHz
Fresno	162.40 MHz
Bakersfield (daytime only)	162.55 MHz

Pete Wilson
Governor

Thomas S. Sayles, Secretary
Business, Transportation
and Housing Agency

James W. van Loben Sels, Director
California Department of Transportation

Caltrans

CALIFORNIA HIGHWAY PATROL

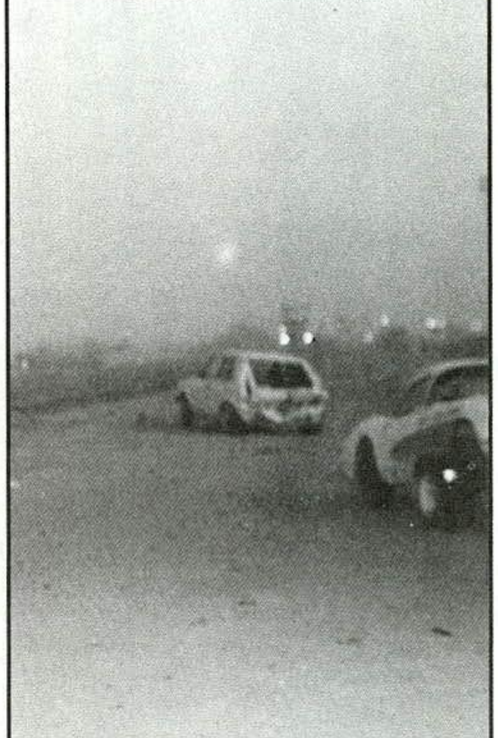
Produced in cooperation with:
Caltrans, District 6 and 3
California Farm Bureau Federation
California Highway Patrol
California Trucking Association
National Oceanic and
Atmospheric Administration
National Weather Service
U.S. Department of Commerce

Design: K. L. Binger
Photo credit: Coalinga Record

93 23627

ZERO VISIBILITY

CENTRAL VALLEY DUST STORMS



FACTS AND TIPS

CALIFORNIA DUST STORMS

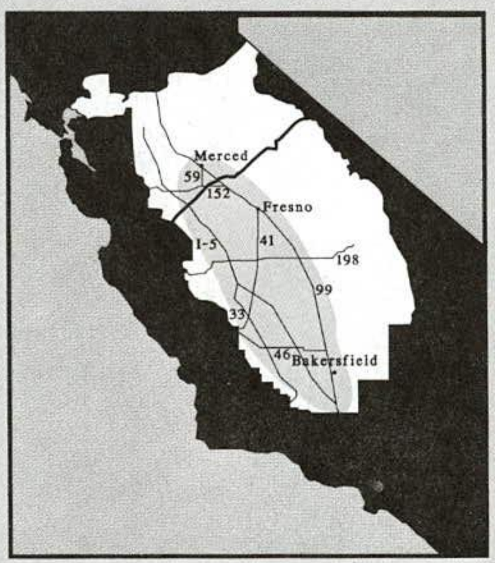
A dust storm usually arrives suddenly. Dust storms take the form of an advancing wall of dust and debris. At its worst, a dust storm may be miles long, several thousand feet high, and have little or no visibility. Blowing dust is a common phenomenon, particularly in desert or agricultural areas. Two factors are needed for blowing dust. First, there must be a layer of dry soil or sand at the surface. Second, winds must blow across this dry surface at speeds sufficient to lift the sand or soil into the air.

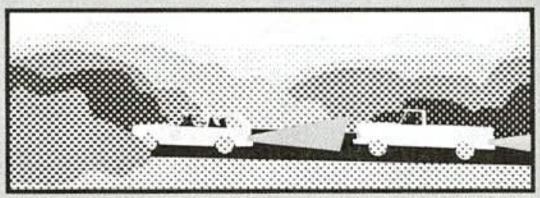
Even a relatively light wind can pick up some dust and begin to reduce visibility. Stronger winds will pick up an increasing amount of soil or sand and may reduce visibility to near zero in a matter of seconds...giving birth to a "dust storm."

Dry soil is a naturally occurring condition in California, particularly in the southern San Joaquin Valley. Normal rainfall is very light in this area, and the problem can be compounded in drought years. Many areas lie fallow because of lack of water. The worst dust storm traffic accident in history occurred when dust blew from barren, non-agricultural land across a major freeway. Agricultural land also can be susceptible to blowing dust, particularly between tilling and planting. In any event, a layer of loose earth provides the fuel for a strong wind to create a dust storm.

As with dense fog, extreme caution must be used when driving in a dust storm. Multi-car accidents can occur if drivers do not keep their distance and reduce their speed.

CENTRAL VALLEY DUST STORM AREAS





LIGHTS OUT!

In the past, motorists driving in dust storms have pulled off the roadway, leaving lights on. Vehicles approaching from the rear and using the advance car's lights as a guide have inadvertently left the roadway and in some instances collided with the parked vehicle. Make sure all of your lights are off when you park off the roadway.

DUST STORM DRIVING TIPS

Dust storms strike with little warning, making driving conditions hazardous. Blinding, choking dust can quickly reduce visibility, causing accidents that may involve chain collisions, creating massive pileups.

Dust storms usually last only a few minutes, but the actions a motorist takes during the storm may be the most important of his or her life.

1. If dense dust is observed blowing across or approaching a roadway, pull your vehicle off the pavement as far as possible, stop, turn off lights, set the emergency brake, take your foot off of the brake pedal to be sure the tail lights are not illuminated.

2. Don't enter the dust storm area if you can avoid it.

3. If you can't pull off the roadway, proceed at a speed suitable for visibility.

4. Turn on your lights, and sound your horn occasionally.

5. Use the painted center line to help guide you.

6. Avoid crossing traffic unless absolutely necessary.

7. Listen for traffic you cannot see.

8. Be patient. Do not pass!

9. Never stop on the traveled portion of the roadway.

10. Consider postponing your trip if dust storms have been reported in your area.

APPENDIX H

Inventory of Routines

FOG VISIBILITY RANGES

I. **Condition Mode VARIABLE:** Visibility Range Variable

II. **System Functions**

- CPU reads weather instruments and fog detectors every 5 minutes
- CPU reads status of traffic control devices
- Readouts, messages and status displayed on computer monitor and recorded on strip chart
- CCTV system operating

III. **Operator Checklist**

Checklist of Activities	Operator Response
• Verify location and type of incidence.	• Notify shift supervisor to: • Initiate appropriate messages
• Verify System operation: VMS, LPM and lighting systems are properly set.	• If Not: • Initiate proper changes
• Monitor CCTV system and status of the System to verify responses are appropriate.	• If change appears necessary: • Notify shift supervisor • Verify visibility range • Select and implement appropriate change

ROUTINE VISIBILITY

I. **Condition Mode CLEAR:** Visibility Range Exceeds 1200 Feet

II. **System Functions**

- CPU reads weather instruments and fog detectors every 5 minutes
- CPU reads status of traffic control devices
- Readouts, messages and status displayed on computer monitor and recorded on strip chart
- CCTV system operating

III. **Operator Checklist**

Checklist Activity	Operator Response
• Verify system is properly operating at start of shift and generate printout	• Describe any failures on log and notify shift supervisor
• Confirm that VMS, LPM and fixed lighting are properly set.	• Note status change on log and follow checklist on appropriate Tab
• Regularly check computer monitor and CCTV monitor and immediately when alarms activate	• If change appears necessary: • Verify roadway conditions • Verify visibility range • Implement change • Notify shift supervisor if condition warrants

CAUTION CONDITION

I. **Condition Mode YELLOW:** Visibility 700 ft to 900 ft or Conditions Suitable for fog to form

II. **System Functions**

- CPU reads weather instruments and fog detectors at 1 minute intervals
- CPU reads status of traffic control devices
- Readouts, messages and status displayed on computer monitor and recorded on strip chart
- CCTV system operating

III. **Operator Checklist**

Checklist Activity	Operator Response
• Compare visibility ranges: CCTV versus fog detectors at shift change or when alarms activated	• If results are dissimilar: • Determine actual conditions. • Notify shift suppervisor • Got to Tab C-1
• Check computer monitor for suggested computer-generated status change at 5 minutes intervals, and immediately when alarms activate	• Approve or override (refer to tab corresponding to the correct mode) and note on log. If override: • Notify shift supervisor • Select and input desired message • Refer to Tab relating to the proper mode
• Check CCTV monitors at least every ten minutes	• Verify that messages and lighting are appropriate for visibility conditions. If not: • Check fog detector readouts for confirmation of CCTV • If CCTV condition not confirmed, verify actual conditions • Notify shift supervisor • Go to Tab C-1

WATCH CONDITION

I. **Condition Mode GREEN:** Visibility 900 ft to 1200 ft or Conditions Suitable for fog to form

II. **System Functions**

- CPU reads weather instruments and fog detectors at 2 minute intervals
- CPU reads status of traffic control devices
- Readouts, messages and status displayed on computer monitor and recorded on strip chart
- CCTV system operating

III. **Operator Checklist**

Checklist Activity	Operator Response
• Compare visibility ranges: CCTV versus fog detectors at shift change or when alarms activated	• If results are dissimilar: • Determine actual conditions. • Notify duty officer • Got to Tab C-1
• Check computer monitor for suggested computer-generated status change at 5 minute intervals, and immediately when alarms activate	• Approve or override (refer to tab corresponding to the correct mode) and note on log. If override: • Notify duty officer • Select and input desired message • Refer to Tab relating to the proper mode
• Check CCTV monitors at least twice per hour	• Verify that messages and lighting are appropriate for visibility conditions. If not: • Check fog detector readouts for confirmation of CCTV • If CCTV condition not confirmed, verify actual conditions • Notify duty officer • Go to Tab C-1

MODERATE VISIBILITY

I. **Condition Mode ORANGE:** Visibility 450 ft to 700 ft

II. **System Functions**

- CPU reads weather instruments and fog detectors at 1 minute intervals
- CPU reads status of traffic control devices
- Readouts, messages and status displayed on computer monitor and recorded
- CCTV system operating

III. **Operator Checklist**

Checklist Activity	Operator Response
• Compare visibility ranges: CCTV versus fog detectors at shift change or when alarms activate.	• If results are dissimilar: • Determine actual conditions • Notify shift supervisor • Go to Tab C-1
• Check for computer-suggested changes in messages at 5 minute intervals, or immediately when alarm sounds.	• Approve or override messages corresponding to the correct mode (refer to Tab 11). • If override: • Notify shift supervisor • Select and input disired message • Refer to Tab relating to the proper mode
• Check for proper LPM and fixed lighting at shift change or when alarm sounds (LPMs ON at 220', Street Lights FREE).	• If settings are improper: • Activate LPMs at 220'. • Free street lighting. • Notify shift supervisor
• Monitor CCTV for Visibility and Icidence.	• Verify that messages and lighting are appropriate for the visibility conditions. If not: • Check fog detector readouts for confirmation of CCTV • If CCTV condition not confirmed, verify actual conditions • Notify shift supervisor • Go to Tab C-1.

SEVERE VISIBILITY

I. **Condition Mode RED:** Visibility 300 ft to 450 ft)

II. **System Functions**

- CPU reads weather instruments and fog detectors 1 minute intervals
- CPU reads status of traffic control devices
- Readouts, messages and status displayed on computer monitor and recorded on strip chart
- CCTV system activated

III. **Operator Checklist**

Checklist Activity	Operator Response
• Compare visibility ranges: CCTV versus fog detectors at shift change or when alarms activate.	• If results are dissimilar: • Determine actual conditions • Notify shift supervisor • Go to Tab C-1
• Check for proper LPM and fixed lighting at shift change or when alarms sound (LPMs ON at 220', Street Lights OFF).	• If settings improper: • Activate LPMs at 220' spacing • Street lighting OFF • Notify shift supervisor
• Check for computer-suggested changes in messages at shift change or when alarm sounds.	• Approve computer-suggested message when appropriate; remain in current response if inappropriate.
• Verify at 5 minute intervals that messages and traffic control settings are appropriate.	• If inappropriate note in log and: • Activate appropriate mode • Notify shift supervisor • Select proper message • Select proper lighting settings • Verify actual conditions if appropriate action can't be determined
• Monitor CCTV for Visibility and Incidence.	• Verify that messages and lighting are appropriate for the visibility conditions. If not: • Check fog detector readouts for confirmation of CCTV • If CCTV condition not confirmed, verify actual conditions • Notify shift supervisor • Go to Tab C-1.

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