MINIMIZING THE HAZARD OF RESTRICTED VISIBILITY IN FOG

Richard N. Schwab

The purpose of this paper is to briefly describe the nature of fog and its formation, effects of fog on driving and accidents, current fog abatement techniques, and possible guidance systems to aid drivers in minimizing the hazards encountered in fog.

THE NATURE OF FOG AND ITS FORMATION

Fog is a visible concentration of small water droplets that average between 10 and 20 microns in diameter (depending on fog type) and are in contact with the ground or close to it such that visibility is seriously affected. By meteorological definition, fog reduces the visual range to less than 3,300 ft (1 kilometer); however, even a dense fog by meteorological standards (visual range less than 1,300 ft) may not have any significant effect on driving performance.

Various mechanisms involving energy, heat, and moisture all contribute to fog formation (1). Specific mechanisms are associated with specific kinds of fogs. For example, a fog will occur if sufficient condensation nuclei are present in the atmosphere and the temperature and specific humidity conditions are above the values of the curve shown in Figure 1. This condition may arise from the cooling of air without altering the moisture content, by raising the relative humidity by evaporation of rain droplets, or by the mixture of 2 parcels of air having different temperatures and relative humidities. It is obvious that the formation of most fogs represents a complex and delicate balance of favorable meteorological conditions together with sufficient hygroscopic nuclei in the atmosphere to encourage condensation. This explains the relative rarity and unpredictability of fog and why it tends to be particularly troublesome in areas where industrial activities produce an abundance of nuclei in the effluents.

Figure 2 shows the average annual number of days having some period of dense fog (2), i.e., less than 1,300 ft visibility. Fog in this density range may or may not be significant for highway operations; however, the figure is included here simply to show the geographical distribution of fog. As can be seen, fog is rarely a problem in the Southwest and only an occasional problem in the Great Plains. On the other hand, fog occurs frequently along the west coast, in the Appalachian Mountains, and in much of New England. At times it is locally dense enough to affect traffic behavior. The local character of fog is itself a major part of the problem because driving into and out of small fog banks can be more dangerous than a more general reduction in visibility.

Many fogs are of short duration in local areas. For example, Figure 3 shows conditions at Newark Airport where approximately one-half of all dense fogs (¼ mile or less) endure for less than 1 hour (3). The median duration of denser fogs is about 1½ hours. This is contrary to the popular belief that most fogs last many hours, which is probably related more to the driver's lack of knowledge as to when fogs are of sufficient density to limit visibility than to the geometric design of the roadway on which he is traveling. This factor probably leads to an overstatement of the fog accident problem in the mind of the general public.

Figure 1. Atmospheric saturation curve (2).

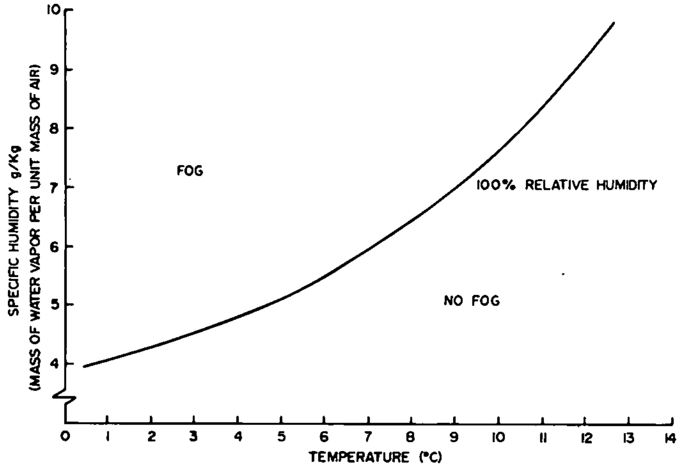


Figure 2. Average annual number of days having dense fog (2).

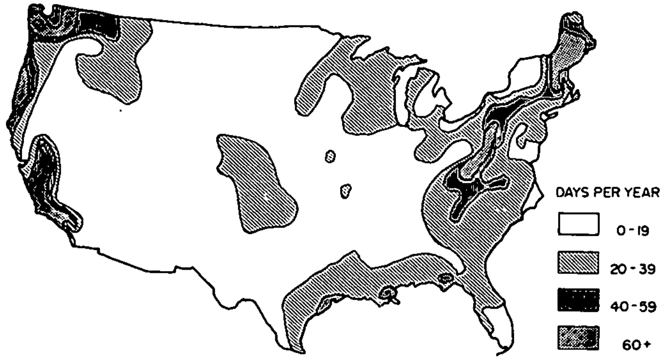
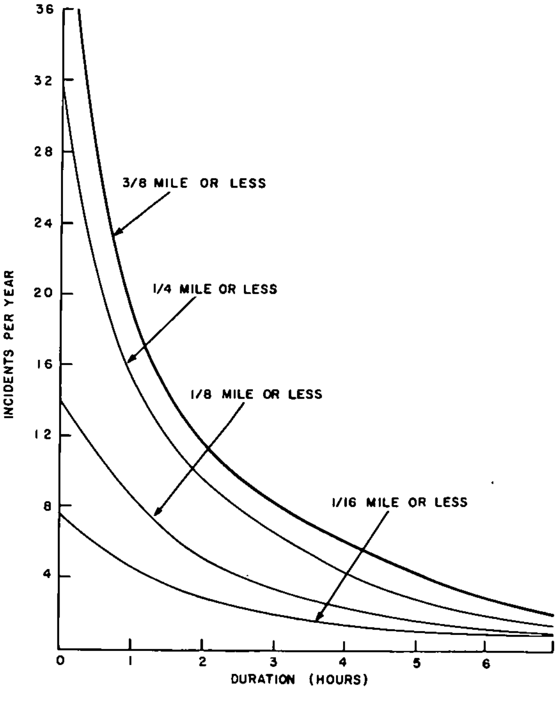


Figure 3. Incidents of reduced visibility at Newark Airport, 1956-1965 (3).



EFFECTS OF FOG ON DRIVING AND ACCIDENTS

An Australian study indicated that, for conventional roads, fog reduces the accident rate by 6 to 10 percent with the largest reduction in the more severe categories of accidents (4). Although comprehensive accident rate data are not available for fog accidents in this country, it does appear that fewer fatal accidents occur during fog than during clear weather conditions (5). This effect has been attributed to the driver's awareness of fog as a hazard, but the slight speed reduction observed on conventional highways in fog may also be a contributing factor, particularly with respect to reducing the severity of accidents.

For freeways, fog has proved to have the opposite effect. A California Transportation Agency study shows that the fatality rate for fog accidents on freeways was almost twice that of nonfog accidents (6). A study of California freeway accidents showed that the probability of a multiple-vehicle accident was greater in fog than in clear weather, particularly when 5 or more vehicles were involved (7). Fog did not have much effect on the mean number of vehicles per accident because there were also more single-vehicle accidents in fog. In fog, 98 percent of all accidents involved 4 vehicles or less. However, as indicated in Table 1, nearly two-thirds of all accidents involving 9 or more vehicles occurred in fog. These accidents accounted for less than 0.01 percent of all accidents and about 0.25 percent of fog accidents. The multiple-vehicle accident, because of its spectacular nature, is widely reported in the news media, giving the impression that accidents are widespread under fog conditions.

Measurements have shown that traffic behavior does not change significantly when visual range is reduced by fog, except for a slight reduction in average vehicle speed under some conditions (2, 8). Because of the reduction in visibility, however, there is an increased probability of overdriving. For free-flowing traffic operating on high-speed facilities with good geometric design, there appeared to be no consistent change in speed variability, lateral position, or collision course time (vehicle headway and speed differential with lead vehicle) that can be directly related to visibility restrictions caused by fog.

FOG ABATEMENT

Dry-ice seeding and other techniques have successfully dispersed cold fog, i.e., fog with liquid water droplets colder than 32 F (2). However, such fogs comprise only a small fraction of all fogs in the continental United States. For highways, dry-ice seeding might be useful at a few intersections with high traffic volumes in a limited area of the Northwest.

Most fogs in the United States occur at temperatures above 32 F and in the denser forms usually involve industrial pollution. Presence of pollution particles in the air will not in itself cause fog. However, when atmospheric conditions are right for the formation of fog, hygroscopic particles present in most industrial effluents will increase the density of the fog. Therefore, reductions in industrial pollution should decrease the occurrence of very dense fogs that are a safety problem for motorists. The clean air standards set forth by the Environmental Protection Agency are leading in that direction.

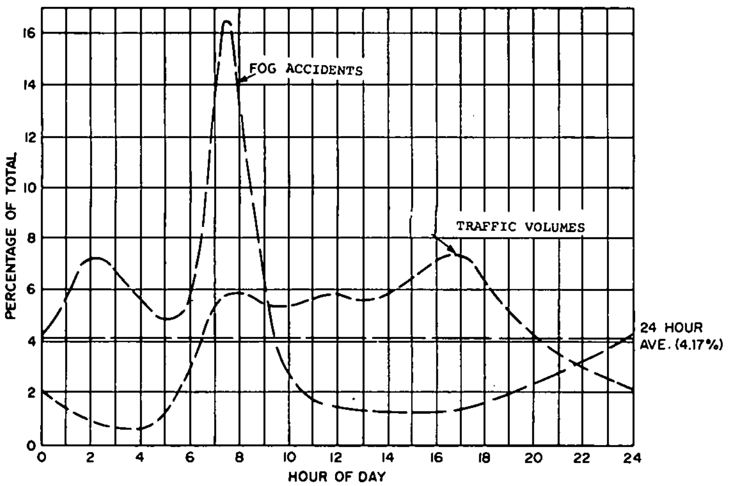
Efforts to achieve a reliable warm fog dispersal capability that might be economically feasible for highway use are far from encouraging. Four general fog dispersal techniques have been attempted: thermal (evaporation of droplets), chemical (evaporation and/or altering drop size), electrical (coalescence of charges droplets), and mechanical. A recent review of this research was contained in another report (2). Fog dispersal techniques require large installations, standby procedures, and maintenance expenses, and are often ineffective in dissipating the fog when it occurs. These techniques may be feasible at busy intersections or in other limited cases.

The relatively short persistence of most fogs limits the utility of portable dispersal equipment and installations that require long start-up times. Another limiting factor with portable dispersal equipment is the requirement for repeated application to the same roadway section. For example, with a 5-knot wind at 45 deg to the centerline and a device that initially clears a 100-ft wide path, fog would begin closing in again

Table 1. Accidents in fog on California highways, 1965-1968 (2).

Number of Vehicles per Accident	Total Number of Accidents	Accidents in Fog		
		Number	Percentage of All Accidents	Percentage of Involved Vehicles
1	149,798	3,631	2.4	20.3
2	262,346	4,911	1.9	54.9
3	38,344	786	2.0	13.2
4	7,623	223	2.9	5.0
5	1,708	81	4.7	2.3
6	471	43	9.1	1.4
7	160	23	14.4	0.9
8	47	15	31.9	0.6
9 or more	39	25	64.1	1.4

Figure 4. Hourly distribution of traffic volumes and fog accidents (11).



within approximately 10 sec. Therefore, if a 60-sec repeated-application cycle is required to keep the roadway above some minimum visibility level during periods of dense fog, a 2-mile section of freeway between interchanges might need as many as 8 vehicle-mounted dispersal devices (assuming 5 miles of travel per vehicle during each dispersal cycle at an average speed of 40 mph).

Natural vegetation (i.e., judicious landscaping with some forms of tree stands) has been applied in some specific locations to prevent shallow fogs from drifting over the road (2).

GUIDANCE SYSTEMS

A variety of methods designed to assist drivers during fog have been proposed, and some have been experimentally tried. These include both active and passive guidance systems. Because of the clear economic infeasibility of justifying active guidance systems, such as "automated highways," as possible solutions to the fog problem alone, they will not be discussed here. These types of systems might be justifiable for general purposes and, if so, would provide a solution to the fog problem by eliminating the driver from the control loop.

Under certain nighttime conditions, some highly directional types of fixed-lighting systems have proved to be effective in providing additional guidance information in fog (9). However, as is shown in Figure 4, the fog accident problem is particularly severe after dawn between the hours of 6 a. m. and 9 a. m., with the peak occurring about 7:30 a. m. (1). Approximately 50 percent of the fog accidents occur in daylight. Fixed-lighting systems can be designed (10) to be effective for the 50 percent of the fog accidents that occur at night. However, the additional expense of such equipment would probably not be recovered from the resulting reduction in accidents. Conventional types of street lighting may be useful in light and moderate fogs but are not of much help in a dense fog.

Present reflectorized pavement marking techniques result in only a slight increase in visibility during daytime fog and have virtually no effect on traffic behavior. The use of inset "pancake" marker lights has been suggested to provide guidance. They are relatively expensive and do not provide any information on stopped vehicles. Perhaps such a display technique, combined with the information on lane occupancy obtained from instrumentation similar to the passing-aid system, would work.

Results of research on vehicle rear lighting systems indicate that current vehicle rear lights are ineffective in fog, especially during daytime. Increased candlepower would be desirable, and the National Highway Traffic Safety Administration appears to be moving in that direction. The major problem concerns the control and possible misuse of a 2 or more level taillighting system.

The most successful of the proposed plans involves the use of variable message signs that warn drivers of fog conditions ahead and advise them as to desirable operating speed. Although these signs have little influence on mean operating speeds, they do reduce speed variance when the sign is set at approximately the mean speed of traffic (8). If the signs are set much below the prevailing speed, a bimodal speed distribution results, increasing the likelihood of rear-end collisions. Part of the reason for these results may be the lack of reliability of information provided by such signs in the past. Particularly, where manual changing of speed limits or folding advisory signing was required, the messages were often exposed long after the reduced visibility condition ended. Therefore, many drivers may have assumed that such lighting is meaningless.

A major installation of remotely controlled warning signs is being evaluated in Oregon at the Murder Creek Interchange on Interstate 5 (11). There are 3 large overhead signs in each direction with the final sign at the point of maximum accident occurrence. The variable speed message is controlled on the recommendation of a state police officer stationed in the signed area and is based on the distance he can see and traffic flow in the area. Research is currently investigating traffic and fog detection equipment for use in automating control of the signs.

Preliminary reports indicate that the Oregon installation is having a beneficial effect in terms of accidents and traffic flow. Traffic flow parameters, such as mean speed,

speed variance, and headway, may be more useful in determining required information to be displayed to drivers than in developing devices for detection of fog density. Use of optical and electronic devices for detection of fog appears to be too expensive for widespread use and too sensitive to small changes in local conditions within a few yards of the measurement station. Research (12) currently under way is attempting to relate the output of such a device to a meaningful fog index for drivers.

The Federal Highway Administration is currently planning research aimed at developing a speed advisory system that will inform drivers of the current status of other vehicles' speeds on the road ahead but beyond the limit of the drivers' available sight distances. Such a system might involve a simple fog-no-fog detector for system activation and a speed sensor with a simple roadside sign indicating an advisory speed. The speed would be set at approximately the mean speed of traffic ¼ to 1 mile ahead. The logic devices for controlling the system should probably be interconnected so that no sign calls for a speed that is more than 10 to 20 mph higher than the following sign, except under exceptionally critical conditions.

The installation of such a system should reduce speeds of traffic gradually and should aid in reducing multivehicle secondary accidents. Because the system will be designed to alert drivers to any slowing of traffic ahead regardless of cause, it is expected that the system will be useful for many situations in addition to those produced by fog.

In summary, there is no technology currently available that will solve the fog problem in a cost-effective manner. Current research in the area of warning-advisory signing for fog appears to hold significant potential. The only real safe advice at present is, If the situation gets bad enough, close the road.

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DISCUSSION

W. H. Heiss

Because there is no basic disagreement with the discussion paper, these remarks will be in the nature of a supplement to the paper.

It may be initially noted that fog works to reduce visibility by reducing the contrast ratio between the object to be seen and the background. This occurs because the fog reduces the amount of light (principally by fog scattering) reaching the observer's eyes from the objects and from the veiling produced by the scattering of light illuminating the intervening fog. Because of the veiling effect of illuminated fog, the practical visibility can, for a given fog density, be worse in daylight than at night. This is evident from the results of both the previous NCHRP study (2) and the current NCHRP highway fog study (Project 5-6A).

In studying and making measurements in natural fog, one fact soon becomes evident: Fogs have a wide degree of variability from area to area, and in many cases such variability exists within the fog itself. This variability can make the locating of fog measuring instrumentation critical because in many localities fog density can vary every ½ mile and in some cases can differ substantially over distances of less than 100 ft. Because of the variability among types of fogs, statistical data such as those shown in Figure 3 must be used with care. For example, incidences of fog of less than ⅛ mile in area and greater than 1 hour in duration are shown to be comparatively rare, averaging less than 10 per year. Also, the incidence rate drops rapidly for increasing durations. Although this is typical of many fogs and areas, in some areas the duration of the fog, when it occurs, may be greater on the average. Similarly, the hourly distribution of fog accidents (Fig. 4) shows the composite for all of the fog accidents of the study area; however, it does not necessarily follow that the fog accident experience of a particular location will exhibit the same hourly distribution. Also, it may well be that the hourly distribution of single-vehicle accidents differs from the distribution of the multivehicle accidents.

The NCHRP study (2) has included a study of visibility as perceived by a driver as a function of measurable fog parameters. Results of the analytical portion of the study have indicated that the prediction of driver visibility based on fog (and ambient light) measurements is feasible, and on-road tests to gather data for the validation and calibration of the analytic models developed are currently under way. Basic to any such instrument visibility determination is an instrument capable of measuring fog density. In the past 2 years there has been a considerable increase in interest by instrument manufacturers in the highway fog measurement problem, and there are several instruments now being sold for such usage although none is being produced in large quantities. The fog measuring instrument that has been used most frequently is the transmissometer; one or more of these has been installed at virtually every major airport in the world. Of the available fog measuring instruments, the transmissometer is probably the most accurate. It is not considered particularly useful for highway fog measurements, however, because of higher initial purchase and installation cost and the comparatively frequent periodic maintenance required to maintain its accuracy.

Most of the other available fog instrumentation measures some scattering property of the fog, e.g., back scatter, forward scatter, or an approximation of total scatter. All of the commercially available fog instruments are limited in that they sample only a comparatively small volume in the immediate vicinity of the instrument. Such measurements can be misleading in patchy and bank fogs. There are, however, some experimental devices being tested that are potentially capable of detecting fog at distances of 1 mile. Until such time that probing devices become available, a somewhat larger number of existing devices, carefully sited, will have to be used for instrumented systems.

Fog frequently tends to be stratified, being typically heaviest close to the ground at night and increasing in density with height during the day. The instrument should therefore be mounted such that the sampled volume is close to the height of a typical driver's sight line during restricted visibility.

In the area of fog countermeasures it is agreed that fog abatement techniques are not promising for widespread use, but they may have some application in selected areas where the fogs are typically associated with dead, still air. The California Division of Highways conducted a small study on an abatement technique last winter. The results, however, were inconclusive due in part to a lower-than-normal incidence of fog during the test period. The Division is considering the possibility of further testing.

Because of the variability in the nature of the different types of fogs that may be encountered at different locations, the efficacy of potential fog countermeasures is best considered in light of typical fog characteristics, driver behavior patterns, and accident experience at the particular location under consideration.

Although it is true that fully satisfactory cost-effective fog countermeasures are not currently available for generalized use, there are techniques that may be of use in specific trouble spots. The use of variable message warning and regulatory signs may be of considerable help, as evidenced by the encouraging preliminary results of the installation in Oregon on Interstate 5. Automatic control of warning signs may well be effective at specific spot locations where fog frequently occurs and drivers encounter the fog unexpectedly. The use of flashing or strobe lights or other improved delineators to mark the location of the roadway and to help prevent disorientation of the driver may be helpful, although care must be exercised in this latter case to avoid encouraging excessive overdriving, which could lead to increased multivehicle "chain-reaction" accidents. California has had sufficient success with Operation Fogbound (which includes an extensive educational campaign, public radio broadcasting announcements, and the use of pacer patrol cars) that it is planning to expand the program for the coming winter fog season.

Although the cost involved in implementing some of the more complex fog warning and guidance systems may deter their installation, the combination of such a system with a freeway or turnpike surveillance and control system may prove to be cost-effective.

Dwayne Hofstetter

With regard to Schwab's paper, we do not know yet whether the mean speed is the appropriate speed to use in signing. This is something that will be determined from the research being done in Oregon. Oregon's warning sign system was completed on November 15, 1968. The installation includes 6 remote-control variable message signs that are operated from the state police office.

Since the installation of the signs, research equipment, including detectors and a computer for vehicle speed and headway measures, has been installed. The system has been used by the Oregon State Police for a variety of reduced visibility driving conditions and for various emergency road conditions. The signs have been activated during periods of dense local fog, a hail storm, a severe snowstorm, periods of heavy smoke caused by field burning in the area, icy periods, a period of construction on the highway, and periods after vehicle accidents. The signs have also been activated during periods of generalized area fog when the entire Willamette Valley from Portland to Eugene was experiencing fog conditions.

The research project associated with the warning signs has not yet been completed, and the amount of information accumulated is not statistically significant; consequently, no quantitative conclusions may be made concerning the effectiveness of the signs in altering vehicle operating characteristics. However, early indications are that the vehicular stream does in fact very closely observe the indicated speeds shown on the variable message sign.

Accident experience since November 15, 1968, has been extremely favorable. No "chain-reaction" collisions or other serious types of motor vehicle accidents have occurred during the periods of limited visibility when the signs have been in use. The only accident that might at least partially be attributed to fog was one that occurred on December 18, 1970. Fog signs were on at the time, and visibility had dropped to 300 to 600 ft; however, the accident was primarily caused by skidding on ice (as stated in the accident reports).

The Oregon State Police, through mutual agreement with the highway division, are regulating the use of the signs on a very strict basis. They are used only when warranted by weather conditions or other abnormal conditions. As a result, state police reports indicate that driver observance of the signs is very good. During periods of generalized Willamette Valley fog, police reports indicate that the speeds shown on the signs in this section are still being observed by vehicle operators miles beyond the signed section. Verbal reports from the local patrol officers indicate a surprising amount of driver observance of the signs and also an increase in reliance on the part of the state police to use the signing system as an important supporting system for its reduced visibility patrol activities. During this past year, the signs have been used to control traffic more often during the aftermath of vehicular accidents than for reduced visibility in fog. The state police indicate that at least one less patrolman is generally needed in the sign section when the signs are in operation and that, for wreck situations, which formerly required 3 patrolmen, only one is needed when the signs are in use.

Based on the results of our studies so far, we are quite optimistic about the benefits that can be obtained from the use of variable message signs for reduced visibility conditions.

AUTHOR'S CLOSURE

I would like to express my appreciation to Heiss and Hofstetter for the time they spent in reviewing my paper.

I would like to stress again Heiss's point that, because of the variable nature of different types of fogs and the locations at which they occur, there is a great need to study the specific problem before exploring countermeasures. Currently, there is no technology available that will solve the highway fog problem in general. There is specific technology that may be helpful under limited sets of conditions. For example, certain types of fixed illumination might be useful. However, this is only true if the bulk of the fog accident problems occur at night in the specific situation for which the illumination system is installed. Stopping of vehicles and convoying them through the fog area with specially equipped lead vehicles will work if the fog is patchy and all vehicles can safely be stopped before they enter the affected area.

It is my belief that the warning-advisory signing approach is the most likely to produce effective results that can lead to a more general solution. Therefore, I would recommend that future research effort be concentrated on further development of advisory systems and especially in providing answers to the many driver behavior questions that influence the design and effectiveness of such systems. To achieve the desired improvements in traffic flow and safety, we must direct the next phase of research to these problems.