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DRIVER VISIBILITY UNDER VARYING ADVERSE WEATHER CONDITIONS

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FOREWORD

Continuing its long standing interest in the ability of drivers to see, the Committee on Visibility decided in early 1977 that the subject of driving under adverse visibility conditions deserved attention. The committee planned and held a symposium August 16-18, 1977 and this circular contains abridged versions of several of the presentations. Portland, Oregon was chosen as the site in order to afford attendees the opportunity to see the nearby Oregon DOT Fog Research Facility, and the contributions by Oregon and its employees is gratefully acknowledged.

SAFE DRIVING IN FOG

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Although highway engineers probably think of the word fog with reference mostly to a ground-level suspension of fine water particles (1), in more general usage the word refers to any thick or murky condition of the atmosphere wherein there is reduced visibility due to a variety of particulates (2). These include not only condensed water vapor, but also rain, snow, dust and smoke. The word fog is believed to have its origins in related Scandanavian words descriptive of all these physical causes of diminished visibility.

Fog of various kinds has often made traveling hazardous for many centuries. Nomads went astray in the dust storms on steppes and deserts (3), and in northern latitudes fog has terrified mariners until very recently. Even with radar, ship handling in close quarters can be dangerous when fog is thick. During the past several decades fog has become much less treacherous for many travelers because our railroads are protected by improved automatic control systems, the larger airports have electronic landing systems, and at sea, Loran and radar are safeguarding ships when visibility is restricted.

But it is another matter with the menace of fog on the highway. Limited-access roads have brought about faster speeds by more and more vehicles, and fog-prone areas are only rarely serviced by automatic signing, vehicle guidance systems, or convoying operations (4, 5, 6). As a consequence, it is likely that a greater number of people experience the terrors of fog today than ever before, and possibly with more injuries and deaths than in years gone by. We don't know for sure, because recent and reliable data on the overall frequency of fog accidents in the United States are unavailable (5, 6, 7, 8).

In the absence of countermeasures for reduced visibility on the highway, how should you or I drive in fog so as to best protect our own lives and those around us? Unfortunately, I have discovered no unequivocal answers. Most of my driving years have been spent along the foggy New England coast line, and today my home is close to the Atlantic Ocean. With this background, I am of the opinion that safe driving in fog seems to be a matter of common sense, alertness and good guesswork. The guesswork is necessary because driver behavior in highway fog is largely unpredictable (8, 9, 10). Unless fog is very dense, drivers slow down very little on the open highway (7, 11), and even under the worst conditions only to about 60 km/h (37 mph). Studies have shown that most drivers overrun their sight distance in fog, and thus become unable to stop their vehicles within the distance on the highway ahead wherein stationary hazards can be identified (5, 12). Because of personality differences and diversity in locale, highway configuration and fog severity, the speeds which drivers choose in fog are substantially different (7). In my own experience, one cannot afford to assume that other operators will drive in fog at predictable speeds. In the absence of guiding data and protocol, therefore, it is my own technique in fog driving to rely on hunches based on long experience as to what other drivers may be doing, on the practices which I am now about to describe, and upon what might be termed, "a little bit of luck".

When I come to a patch of fog the first things I do are to slow down and turn on my headlights, and I try to do this before I get into the fog. At first I don't slow down too rapidly or too much, for fear someone will rear-end me. If I find myself driving for more than fifteen or twenty seconds in severely reduced visibility, I get over to the right and slow down to about 55 km/h (34 mph). In a genuine "pea soup fog" a much lower speed may be necessary (4, 13). In a line of cars, I sometimes tap my brake pedal lightly, so that the brake lights will warn cars immediately behind (11).

My own preference is for low headlight beams in fog, so as to minimize the illumination which is scattered back from the droplets of fog in the air (11, 12). This back-scattering seems to occur mostly in the mid-distance, where I am striving to see a slow moving or stopped vehicle. Some experienced drivers in fog periodically flick their headlights on high beam momentarily, which sometimes seems to aid in guiding the vehicle and avoiding collision. The farther away one is from a directional beam of light (such as a searchlight or vehicle headlights) the better one can see in fog, because there is less light backscattered from the beams (14, 15). Hence, truck drivers use low-placed fog lights. Because they sit high off the road, and hence farther away from both fog lights and headlights, truck drivers can see farther in fog than you or I can in our automobiles. Some truckers, and car drivers as well, believe that they are aided by yellow fog lights. While it is true that they may provide less discomfort glare, there is no credible evidence of any actual increase in sight distance (6, 16).

On a divided highway, when fog is not too thick, my favorite driving lane is the high-speed, outboard one. Here I can drive moderately fast because inexperienced or timid drivers tend to drive in the right-hand lane when fog is persistent. In whatever lane you are driving, it is especially important in fog to watch for slower vehicles in front and faster vehicles coming up from behind. As often as attention can be momentarily diverted with safety, scan for escape routes into adjacent lanes or off the road altogether, just in case a collision situation develops.

There is sometimes apparent safety in driving in a line of cars, especially if it is a low speed chain, and you are in the middle. However, in heavy fog the security of platoon driving is frequently illusory. There is a tendency to bunch up, follow too closely, and a chain collision awaits only a sudden slowdown up ahead. Sometimes the vehicle in front cannot follow the road, furthermore. I remember once following a tractor-trailer truck in a snow storm on an eastern interstate. I felt that I was safe in following a truck because I could surely stop faster than he could. At a bend in the road, however, I pulled away only just in the nick of time as he drove straight ahead off the road in a curve, and crashed into the woods.

The fact that fog on a highway sometimes occurs only in patches, interspersed with clear areas, offers deceptively dangerous confidence to drivers in a hurry. They frequently seem to assume that beyond each patch of fog there will be an area of good visibility. Such conditions frequently are a prelude to disaster, as was the case in the 29-vehicle catastrophe on the New Jersey Turnpike in November 1969 (8). Accordingly, patches of fog should be treated as warnings, rather than as opportunities for seemingly minor risk-taking.

Highway fog is often clammy, and tends to condense on cold glass. Under such circumstances one should be careful to use windshield wipers, and occasionally wipe off the inside of the windshield. If there is a great deal of moisture in the air inside the car, it may be helpful to use defrosters or air conditioner, and heating wires in the rear window. If the windshield should fog up suddenly, before the defrosters can take hold, opening side windows can sometimes help reduce fogging. With several people perspiring in a warm car, open windows may be a necessity for an extended period.

If a road is blocked by an accident, or for any reason you can drive no farther, pull off the highway as far as you can, preferably onto the shoulder of the road and off the paved surface altogether. Get everyone out of the car immediately ... don't wait for an instant. Scramble over the guardrail, if there is one, and stay there until the situation clears up. All illumination should be turned off in a vehicle parked and abandoned in fog. Studies have shown that there is a "moth-to-a-flame" tendency to drive towards an illuminated vehicle parked completely off the roadway under reduced visibility conditions, and collisions result (13). Another thing: Forget about walking back with flares or other devices to warn other drivers of an accident which has occurred in fog. Very likely there would not be enough time to do the job properly, and experience has shown that many pedestrians have been struck while trying to do this very thing (9, 13).

The best way to avoid a fog accident, of course, is to avoid fog altogether by selecting an alternate route. Make it a habit to listen to the radio for local weather reports and traffic advisories for commuters (6). A CB radio can be a great boon for fog warnings, because fog is often quite local and transitory. If the fog is not too bad, and I have to continue on when improvement is uncertain, I get off a main highway at the first available exit. Usually I can find a place to park off the pavement on a secondary road, and plan an alternate route on slower-speed roads, using the map from my glove compartment. The connecting roads through towns and cities generally are safer in fog than limited-access highways because the traffic moves much slower and more carefully (6, 17). Furthermore, there are traffic signals, road lighting, edge striping and other driving aids. Nevertheless, one must stop and look carefully at intersections, which are treacherous in thick fog. Alert other drivers with turn indicators, horn, and low-high-low headlight signalling. Once into an intersection, drive decisively.

In summary, the trick in safe driving through fog is to slow down, turn on your low headlight beams, scan vigilantly in all directions for danger, watch constantly for escape routes out of any threatened conflict, and remember that the best way not to get hurt in fog on a highway is to either get off onto the grass alongside or on an exit to a slow-speed road.

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LIMITED VISIBILITY DRIVING CONDITIONS—WHAT DO WE DO?

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INTRODUCTION

Highway safety and human factors experts have long been aware of the problems created when drivers are surprised by unexpected events. One of the most frightening and memorable of these events is to run into a dense bank of fog, smoke, dust, or other reduced visibility conditions that suddenly make it impossible to see the car in front that was so clear to them just an instant ago. The state of panic some drivers experience and the wide range of reactions that occur while in this frightening situation often cause drivers to do unexpected things which often trigger minor rear-end accidents that suddenly grow into multiple vehicle crashes with high probability of multiple injuries and fatalities. Such traffic tragedies almost always receive widespread attention in the news media. People hearing or reading of these events seldom have difficulty remembering the time they were involved in a similar reduced visibility state of panic and they become emotionally involved and concerned with the fact that little has been done to prevent such catastrophies. The limited visibility accident is one of the several types of "innocent victim" accidents that traffic engineers have recognized a need to cope with, regardless of whether the direct accident costs are sufficient to justify the cost of countermeasures.

SCOPE OF THE PROBLEM

It is widely recognized that there is little dependable data upon which to make a determination of just how widespread are the involvement of limited-visibility accidents. The National Safety Council has suggested that two percent of the annual fatalities could be a result of limited visibility accidents. In 1973 these figures were set forth as:

Fatalities	1,000
Injuries	60,000
Loss from personal injury	$267 million
Loss of Property	$141 million

The National Transportation Safety Board has investigated and published reports of six major highway accidents that have involved limited visibility as a cause or probable cause. Over the past ten years, the Safety Board has conducted field investigations with no published reports on an additional twelve accidents with similar causal factors. The majority involved fog but others occurred under dust, snow, rain, and smoke conditions. In each of these accidents there were multiple vehicles involved; drivers had little or no advanced warning; suddenly found themselves enveloped in an adverse weather condition which prevented them from being able to see normally - often less than 50 feet ahead of their car; and NOT KNOWING JUST WHAT TO DO NEXT and very little time to contemplate the unknown.

In August 1971, the Safety Board conducted a symposium on the subject of fog and possible countermeasures to either disperse the fog or notify drivers in advance of the presence of the fog or through education and training; what to do when they find themselves in such circumstances.

On November 15, 1972, the Safety Board adopted a special study titled "Reduced Visibility (FOG) Accidents on Limited-Access Highways. The findings and conclusions of that study are as valid today as the day they were published. The recommendations are still being struggled with, with no definite results that have resulted in significant national benefits.

SUMMARY

Examination of probable cause statements included in reports of five major fog-related accidents produced this list of safety factors:

a. Limited visibility
b. Excessive speeds
c. Variable speeds
d. Strange environment
e. Illusionary effects
f. Illusive fog locations
g. Deceptive warning signs
h. No advanced warning
i. Inability to judge distances and speeds
j. Not knowing what to do next

CONCLUSIONS

After an analysis of the accidents investigated and observed, the data presented during the FOG Symposium and its special study, the Safety Board arrived at a number of specific conclusions. Listed below are the most pertinent to the overall subject:

1. In heavy fog the severity of accidents occurring on high-speed highways - which under normal conditions permit driving at high rates of speed - exceeds substantially the severity of highway accidents that take place on conventional roads where vehicle operators exercise greater caution in their driving and by law are required to proceed at lower rates of speed.
2. Highway accidents that take place under conditions of fog generally involve a greater number of vehicles and hence a greater number of passengers than other types of highway accidents and correspondingly result in a higher rate of fatalities.
3. The most significant driver-related problem is overdriving one's visual range; this results from the inability and failure of the driver to assess his visual range in fog and to relate that distance to the stopping capability of the vehicle. One of the methods found to be helpful in meeting this problem is the employment of standardized delineator spacing or lane markings which provide drivers with more accurate determinations of visual range.
4. The traffic of heavy trucks is greater on freeways or high-speed highways than on conventional roads, and such traffic, while proceeding under conditions of limited driving visibility, creates substantial additional hazards when intermixed with passenger car traffic. Available experience suggests that fog chain reaction accidents involving trucks often produce many fatalities whereas similar accidents can involve many passenger cars and may result in very few fatalities.
5. The intermixing of passenger cars and trucks during limited-visibility conditions invalidate occupant characteristics of passenger cars. Cars and trucks do not operate as a compatible system to reduce occupant fatalities.
6. Limited visibility accidents often involve the incompatibility in stopping distance between trucks and automobiles, the inherently dangerous nature of a large volume of truck shipments that include flammable or explosive materials, and passenger vehicles underriding the rear or side of a higher vehicle, or being overridden by the higher and heavier vehicle.
7. There is no national agreement among educators and experts as to specific steps to be taken when drivers enter and operate in a dense fog zone. A need exists to resolve the present controversy over the conflicting advice currently being disseminated concerning driving procedures in fog.
8. At present, there are no criteria in driver education or research literature that will aid drivers in determining safe driving speeds under various conditions of fog.
9. Some progress has been made in the design and manufacture of equipment for fog detection, for measuring the density of fog, and for operational guidance systems, but most of these facilities and programs are still in the experimental stage, and therefore, cost-effectiveness determinations cannot be made.

   The automatic electronic fog sensing and hazard-warning and speed-limit warning system now active on the north end of the New Jersey Turnpike show great promise of relief from this condition and providing timely, accurate hazard-warning and safe speed-limit advice to motorists traveling on such highways.

   Fog abatement techniques have not proved to be economically feasible for wide application to clearing of highways. However, it appears that some concepts might be useful on a limited basis at high-risk locations such as intersections.
10. With a few exceptions, there are no standard emergency operational procedures employed by State highway departments and police agencies for dealing with the problems related to driving on Interstate highways and freeway systems under heavy fog. However, one procedure in limited operation concerns the escort system as exemplified in "Operation Fogbound" by the California Highway Patrol.
11. A need exists for areawide organizational control and training relating to the specific problems of preventing and controlling large-scale fog-related accidents in those areas susceptible to highway fog which may cover several jurisdictions.

12. To reduce the number and severity of multiple-vehicle fog collisions, dense fog should be treated as an emergency situation so that adequate manpower and vehicles can be available.
13. A need exists for an automatic hazard warning system in fog-susceptible areas to provide more information to drivers about the hazard to be encountered.
14. Hazard-warning and speed-limit signing systems that rely on human observers to locate and classify limited visibility conditions do not provide a method which is fully responsive to the problems associated with highway operations under limited-visibility conditions.
15. Under conditions of deteriorating visibility in areas of recurring fog experience, frequency of patrols should be initiated to alert responsible authorities to take preventive action.
16. Highway speed advisory and hazard-warning signs that exhibit incorrect advice tend to inhibit response from motorists.
17. Current rear lighting systems of the vehicles involved in the accidents do not give enough warning to overtaking motorists. There is a need for rear lighting systems that are more visible to overtaking motorists.
18. After the collisions, many drivers do not know what they should do to protect themselves and their passengers from injury.
19. The actions of drivers involved in these collisions demonstrate the need for improved criteria in driver education to aid drivers in determining safe driving speeds, safe driving methods, and safe postaccident actions under fog conditions.
20. Smoke from adjacent field or dump fires can combine with patchy fog and temperature inversions to cause limited visibility conditions. Temperature inversions are predictable, the burning of fields and dump is controllable. This is a jurisdictional responsibility.
21. Because of reduced visibility, drivers can not judge vehicle separation, vehicle speeds, and vehicle deceleration. As a result they do not have sufficient time to react to stopped or slowing vehicles ahead.
22. Occupant restraints where used, served their intended function in preventing or minimizing personal injury.
23. Highway design features -- median strips, median barriers, wide paved shoulders, highly visible lane and road-edge markers and reflective delineators -- serve to reduce crash results by providing guidance and areas of refuge and preventing crossover into opposing lanes of traffic.
24. The general public is but little aware of the hazard in remaining in a car on a paved portion of highway in a dense fog.

RECOMMENDED COUNTERMEASURES

Over the past 10 years, the Safety Board has issued some 39 safety recommendations calling for corrective actions that would contribute to a reduction of limited visibility induced accidents. Some of the more pertinent recommendations are summarized below:

Special Study - Reduced-Visibility (Fog) Accidents on Limited-Access Highways, 1971

1. The Federal Highway Administration and the American Association of State Highway Officials, in cooperation with various state highway departments, particularly in those states subject to heavy fog, develop standards and procedures for controlling highway traffic on the interstate and high-speed highways during heavy fog or other visibility-limiting conditions, which would: (a) close down temporarily to all vehicular traffic that segment of the highway experiencing heavy fog; or (b) to close down temporarily to all heavy-duty trucks access to those segments of the highway under adverse visibility conditions.
(Recommendation H-72-49)
2. The Federal Highway Administration expedite its short- and long-range program to develop highway guidance systems that provide drivers with information about the status (i.e., speed) of vehicle operation ahead.
(Recommendation No. H-72-50)
3. The National Highway Traffic Safety Administration assume a leadership role with driver educators to resolve the conflicting information which is being taught relative to driving tactics in fog.
(Recommendation No. H-72-51)
4. The National Highway Traffic Safety Administration recommend to driver education instructors the need to stress in the teaching of drivers that there is no single solution to the highway fog problem, and point out the need to avoid or discontinue highway use until conditions warrant safe travel.
(Recommendation No. H-72-53)
5. The National Highway Traffic Safety Administration reemphasize the necessity for the states to fully implement Highway Safety Program Standards: Emergency Medical Services (Standard No. 11), Police Traffic Services (Standard No. 15), and Debris Hazard Control and Cleanup (Standard No. 16).
(Recommendation No. H-72-54)
6. The Federal Highway Administration, the American Association of State Highway Officials, and the International Association of Chiefs of Police urge the State Highway Departments and State Law Enforcement Agencies to cooperate in the development of written guidelines and procedures that provide for mutual assistance when limited visibility or any natural disaster warrants highway closings.
(Recommendation No. H-72-55)
7. The International Association of Chiefs of Police recommend to its members that the escort service as exemplified by "Operation Fogbound" utilized by the CHP be instituted where highway conditions warrant its use.

8. The States encourage their political subdivisions to develop and implement programs that provide for area wide organization, planning, training, and operational control, in the event of all types of accidents that involve the emergency rescue services of several jurisdictions. Such programs provide for the overall control and coordination of an accident situation by one authority.
9. The American Bar Association, the IACP, and the National Committee on Uniform Traffic Laws and Ordinances review the existing basic speed rule as it applies to the operation of vehicles under fog conditions and existing practices relating to the enforcement of the rule under these conditions. There is presently an absence of criteria that can be used by drivers in determining a common and appropriate speed for given conditions. Likewise there is an absence of enforcement except where an accident occurs.

REDUCED VISIBILITY ON THE HIGHWAY: A PERVASIVE PROBLEM RECEIVING INTERNATIONAL ATTENTION

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About two years ago, this writer conducted a survey of highway reduced visibility hazards. The survey was part of a study sponsored by the Organization for Economic Cooperation and Development (OECD), entitled "Adverse Weather, Reduced Visibility and Road Safety." The purpose of the survey was to learn about the highway-related reduced visibility problems experienced by OECD member-nations, and their planned or practiced means to deal with them. Thirty-eight of the fifty United States, and all but two OECD members reported significant reduced visibility problems on their highways, where "significant" was defined operationally as a condition sufficiently serious to require some form of remedial aid.

As expected, the majority of the problems were attributed to fog, but several others were mentioned in large numbers as well. Dust and sand storms plague the southwestern (and some northwestern) regions of the United States. The Phoenix, Arizona area is particularly affected by severe summer dust storms known as haboobs. Major snowstorms called whiteouts affect several of our northern and high altitude states as well as portions of Canada and several European nations. And locally heavy rainstorms can significantly degrade visibility in nearly all reporting jurisdictions.

In addition, unique, localized problems were mentioned by nearly every respondent. These were often man-made rather than natural; although the two tend to interact. For example, Sweden reported a locally severe fog condition caused by hot wastewater piped from a dairy plant into a cold stream adjacent to the highway. Effluents from industrial plants, especially pulp and paper mills, have caused locally hazardous conditions, as has smoke from roadside agricultural fires in many areas. One of the more unusual problems reported was a smoke hazard caused by the burning of sugar cane in Hawaii.

Obviously, the more localized and predictable the problem is, the easier it may be to identify a remedy - although there is no guarantee that it will be successful. Sweden and Hawaii have been fairly successful in coping with their specific problems by emplacement of one or two flashing warning signs, activated by police or company personnel when the hazard is present.

The magnitude of the reduced visibility problem as measured by accidents is difficult to determine due to widely varying measurement and reporting techniques. A common estimate is that fog accounts for only two or three percent of all highway accidents. But, to the extent that the problem area can be identified, the figures are considerably more dramatic. After a particularly bad fog-related accident in 1968, the Oregon State Highway Division examined the five-year accident history in the area. They found that that particular six and one-half mile section of Interstate 5 had experienced more fog-related rear-end accidents than had the entire remaining 300 miles of the freeway in the State. And, within that section, fog was associated with 19% of all accidents and over 40% of all injuries and fatalities. Unfortunately, it is not often that we can localize a reduced visibility hazard to such an extent that we can deal with it effectively, as Oregon seems to have done with its system on I5. Far more common is the situation in which the hazard is, to a great extent, unpredictable - in time of onset, duration, location, and severity.

There have been many diverse approaches to dealing with the reduced visibility problem, and this paper can do little more than summarize them.

The survey mentioned above indicated that remedial aids in use or under consideration around the world could be classified into four general categories by the method employed in an attempt to improve the driving situation. First were systems that approached the weather condition itself, and attempted to disperse, abate or broadly improve the cause of the visibility reduction. The second group included those techniques designed specifically to improve those portions of the visual field that provide the critical cues for driving. The third category encompassed attempts at modification to the vehicle itself so as to reduce the impact of adverse weather on its operation. And the fourth group included approaches aimed at modifying driver behavior to optimize performance within the environmental constraints.

Let us briefly examine these four areas. In the first category, fog dissipation and dispersal have been much talked about weather control techniques, and although they have been rather successful in aviation use (where a specific runway must be cleared for a discrete time period), they have proven to be generally ineffective for highway use. Tree plantings have been successfully employed to reduce the severity of certain coastal fogs in Japan, and Arizona has experimented with trees to trap blowing dust. Several other programs of this type have been tried, but their results were not reported to us. Snow fences appear to be reasonably successful in the prevention of blowing or drifting snow from crossing the highway. And an American manufacturer has developed a "fog fence" which precipitates liquid droplets out of the air, thus reducing fog on the side of the fence away from the source. Obviously, such a device has relatively limited application. Fixed lighting to reveal the general highway contour may be included in this category, but in most cases the installation is for a purpose other than reduced visibility guidance, and evaluations of effectiveness have therefore not generally been undertaken. Other attempts to deal with the general hazard include legal controls on man-made pollutants; highway alignment and geometric design; and pavement and drainage design.

In the second category, that of selective guidance enhancement, are included roadway delineation treatments; fixed lighting of specific hazards, such as fog-prone bridges or dangerous curves; and a combination of lighting and delineation, such as a system recently installed on Afton Mountain in Virginia in which variable voltage lights are inset into the pavement where they serve as close range delineation and mid-range guidance. This category is benefiting from increased research efforts, several of which will be discussed in other papers presented at this symposium.

The third category deals with vehicular factors. In the past, the greatest emphasis has been given to front and rear lighting - both general and special purpose. Other vehicle-based countermeasures that have received some attention are the systems that wash, wipe, defrost and demist the windows; and those that attempt to control splash and spray. Interesting interactions exist within some of these factors. Some are beneficial, such as the Swedish-pioneered systems that wash and wipe headlights. Other interactions, however, are detrimental. For example, those tire tread designs and rubber compounds which improve wet weather traction also tend to direct the greatest amount of spray to following vehicles. The trucking industry has placed great importance on research aimed at minimizing splash and spray through vehicle and equipment redesign.

Driver behavior modification constitutes the fourth category. This is the most diverse area, with approaches that include: (a) specialized driver education programs (which are in their infancy); (b) radio advisory systems (both general and dedicated) to warn motorists of hazardous conditions; (c) speed restrictions (which are generally used only for specific areas under extreme conditions); (d) vehicular convoys or platoons; (e) road closure, which appears to be an increasingly employed countermeasure; and (f) motorist advisory and guidance systems, which may include a complex network of weather or vehicle detectors, combined with variable message signs. More and more jurisdictions are employing advisory systems in some form, unfortunately, without a firm understanding of the need for such a system. The Federal Highway Administration presently has underway a research study dealing with the effectiveness of guidance systems. A progress report on this effort will be given during this symposium.

In summary, reduced visibility due to adverse weather is a highway problem that plagues the nations throughout the world. Attempts to minimize the impact of these conditions have been quite diverse. This paper has briefly discussed such efforts in the three major categories of driver, vehicle, and environment.

THE WYOMING EXPERIENCE

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Adverse weather conditions can best be defined as those conditions which affect normal driving behavior and roadway level of service. Usually this condition can be detected by slower and erratic driving speeds, vehicle stoppage, minor run off the road accidents, and major accidents. The seriousness of the problem is almost always in direct relationship to the extent to which visibility has been reduced. The road surface condition can also be quite critical during periods of reduced visibility.

It is apparent that it is necessary to detect adverse driving conditions and provide this information to the traveling public before, if possible, and during the reduced visibility activity. The discussion of the detection techniques will not be presented at this point. Later in the symposium R. A. Schmidt will discuss "Measuring Visibility in Blowing Snow" and Ron Tabler will discuss "Visibility in Blowing Snow and Applications in Traffic Operations". They will quite adequately cover the techniques of measuring visibility in blowing snow. After limited visibility due to blowing snow has been detected, it can be relayed to the public by a multitude of sources. In Wyoming, the highway department uses variable message signs, highway advisory radio, ports-of-entry, and special telephone numbers. Other sources not directly involved with the highway department are CB radios, commercial AM radio and television stations, truck stops, and motels.

Vehicle operators react differently to reduced visibility based upon their driving experience in blowing snow and the type of vehicle they are driving. In Wyoming, drivers can be divided into three classes for this purpose: local, foreign, and trucks. The local driver can be described as a driver from Wyoming or an adjacent state and as having the most experience in driving in blowing snow. The foreign driver is one who is not from the Rocky Mountain area and is usually the least experienced with driving in blowing snow. The truck drivers can not be classified as local or foreign. They are probably the most experienced with their vehicles of any driver and have the advantage very often of being above the blowing snow and therefore not having as severe a problem as drivers of lower vehicles. This fact can cause a safety problem since the trucks due to their experience and better visibility often travel at a higher speed which has resulted in rear-end or passing accidents.

Visibility is most often affected by the amount of snow available for being blown, size of snow particles, and the wind velocity. If the visibility is limited during daylight hours it is much worse at night - often vehicle headlights make the situation even more hazardous. Again road surface conditions must be mentioned because packed snow or ice added to blowing snow makes the driving task even more difficult. Random icy patches or spots prove to be even more difficult when driving in blowing snow.

Safe vehicle operation in adverse weather conditions is based upon average minimum visibility and the road surface conditions as previously described. All of these variables are presently being evaluated and a value for safe stopping sight distance is determined. This value is set equal to an average minimum visibility and determines the "safe" operating speed for the roadway.

FOG RESEARCH IN OREGON

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In the past several years, Oregon has been involved in conducting three federally funded fog research projects which are related to the problems encountered on the highway when dense fog occurs. We have been involved in this research since 1969, in cooperation with the U.S. Department of Transportation. The contents of this paper do not necessarily reflect the official views or policy of the Department of Transportation.

One of the studys entitled, "Demonstration of Visibility Measuring Device to Detect Highway Fog Conditions" was completed in 1975. In this study a videograph, which is a back scatter type visibility measuring device, was tested to determine its applicability in the field of traffic control during reduced visibility. Originally, it was thought that it may be feasible to use the videograph as a sign control to control the speed settings on signs. There were several factors which prevented us from using the videograph for this. Visibility measurements in the less than 200 foot range were not reliable enough and rapid changes in fog density caused the videograph output to fluctuate accordingly which would in turn cause speed advisory information to fluctuate. Although the videograph was not acceptable as an off the shelf piece of equipment for automatic sign control at the time we tested it, improvements which have been made since 1969 and equipment modifications or additions may make the videograph acceptable as a control device if it is feasible to use a visibility detector. The videograph tested was found to be relatively maintenance free and is currently being used to give us a record of visibility along I-5 north of Albany.

Another project which is currently being conducted is the "Variable Message Fog Hazard Warning Signs to Control Vehicle Operating Characteristics". In this project 6 variable message signs are being used to advise drivers along I-5 north of Albany. There are three signs in each direction of a 6 1/2 mile section of highway. Red neon tubing is used to form the legends which are displayed on a black background with 2 alternating yellow flashers. The word "SLOW" is displayed with either the word "FOG" or "WRECK" with speeds of 10 to 50 MPH in 10 MPH increments. The signs are operated by the State Police from a central control panel with the speeds set based on their judgment.

Prior to the variable message sign installation, this section of highway was experiencing almost as many fog related chain reaction accidents as the remaining 300 mile section of I-5. The problem was brought to a head with chain reaction accidents involving 44 vehicles with 25 injuries and 3 fatalities in March 1968. In November 1968 the variable message sign installation was completed.

The signs have been used on a number of occasions for reasons other than fog including during periods of highway construction, smoke, vehicle accidents, ice and other adverse weather conditions. State patrolmen have indicated that the signs are very helpful to support their activities and we feel that much of the success to date of the signing system should be attributed to the State Police for their cooperation and discreet judgment in using the signs.

To factually measure the effectiveness of the signs, loop detectors have been installed. In the past, equipment problems have caused some of the data to be unusable and the 55 MPH Maximum speed changed the normal operating speeds which also limited the amount of usable information available. A preliminary analysis of speeds and headways also did not provide conclusive information.

However, one of the most dramatic and encouraging results shown by the study has been the decrease in fog-related accidents. No chain reaction type accidents have occurred during fog since the signs were installed. In the 5 years before the signs were installed, there was a total of 34 fog accidents involving 135 vehicles with 75 injuries and 5 fatalities. In a 5 year period after the signs were installed only 2 fog accidents occurred involving 4 vehicles with no injuries or fatalities.

The "Before" and "After" accident rates in the fog sign section were 0.94 accidents per million vehicle miles and 0.57 accidents per million vehicle miles. Based on the accident records, we are very pleased with the positive effects the signs appear to have had.

One of the problems with utilizing a visibility detector controlling the signs and which could also be a problem in providing consistent information to drivers is that parameters for setting speeds have not been established. This is one of the concerns being studied in the study entitled, "Speed Advisory Information for Reduced Visibility Conditions". An off-road test track has been utilized with a fog producing machine in this project. The road has been striped and signed to simulate a 2 lane one-way type road. Although the situation may appear somewhat artificial, we have tried to minimize the differences in both appearance and operation. There still will be some differences, however, trends may be established that will be applicable in systems on a public highway.

Literature searches before and during this study have indicated research needs in a number of areas. As a result, the fog producing system at Camp Adair was developed and installed. This system used water and is made up with special nozzles on PVC lines 1,000 feet in length. Leading up to and through the fog zone, radar meters with pneumatic road tubes were used to continuously track speeds for each vehicle. Drivers were randomly selected and supplied the vehicle driven in the tests so that they would not have to adjust to driving an unfamiliar car.

Some of the areas which were studied are as follows:

The effect of fog on driving speeds for various levels of visibility under normal conditions without special signing or guidance.

How to measure visibility is an area that has been of much concern in this study and is an area that is still being researched.

The effects of posting speeds based on visibility and different speed parameters were studied. A number of different signing schemes were investigated as were the effects of having additional vehicles in the test area. This included different amounts and types of information. Since credibility of information to drivers is thought to be important, the effects of displaying unrealistic versus realistic information were studied.

After thoroughly investigating different methods which others have used for measuring visibility, it was decided that meteorological type targets would be used. Unfocussed white lights of approximately 25 candle power were used for nighttime conditions. The lights were spaced 50 feet apart and post mounted at the side of the test track in both directions from the center of the fog zone.

As a base for comparative purposes, with clear conditions, it was found that the average 85% speeds varied from approximately 54 MPH to 49 MPH in the fog zone. These speeds are 5 to 13 MPH lower than prevailing speeds on rural State Highways in Oregon. Part of the difference may be due to the off road test track.

The average mean speed for State Highways based on all stations utilized in monitoring the 55 MPH speed in 1976 was 55.9 MPH. The average minimum mean speed in the fog section with clear conditions was approximately 43 MPH. With no special signing the average minimum mean speeds for vehicles in the fog zone were approximately 19 MPH for 400 foot visibility, 16 MPH for 300 foot visibility, 13 MPH for 200 foot visibility and 9 MPH for 100 foot visibility. Posting the 15%, 50% and 85% speeds at different levels of visibility did not provide conclusive evidence of speed signing alone having significance in improving traffic flow with respect to speed measurements on the test track.

It is anticipated that the final report for this project will be completed early next year and the findings will be discussed in more detail in the report.

VISIBILITY IN BLOWING SNOW AND APPLICATIONS IN TRAFFIC OPERATIONS

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INTRODUCTION

In cooperation with the Wyoming Highway Department, Dr. R. A. Schmidt of the Rocky Mountain Forest and Range Experiment Station developed a visual range monitor as described in a separate paper at this symposium (6). Operational application of this device on Interstate Highway 80 (I-80) since January 1974, has demonstrated the accuracy and reliability of the data; but it has also raised the question of how visibility information should be interpreted and used. This paper presents results of experiments exploring the relationship between wind and visibility, with emphasis on changes accompanying snow cover depletion, and shows how this information is used for traffic operations.

The Visual Range Monitor

As described by Schmidt (6), the visual range monitor (VRM) uses a photoelectric particle counter to measure size and frequency of blowing snow particles. Given certain assumptions, visual range (V) can be calculated from these data using the equation

$$V = \frac{KU}{FX^2} \qquad \text{Eq. [1]}$$

where U is windspeed, F is particle frequency, X is particle diameter and K is a constant. A generating anemometer is used to measure wind speed. Although the particle counter measures a light path only 25 mm long, averages from even a period of minutes appear representative of conditions over the longer but varying sight distance of a motorist.

The Wyoming Highway Department has installed VRM units at two locations (Arlington and Elk Mountain) on I-80 between Laramie and Walcott Junction. Data are telemetered via a combination of radio, microwave, and landline to highway department offices in Laramie, where wind and visibility are continuously recorded on strip charts.

After the first year of operational testing, the need for visibility standards in highway operations became apparent. A corollary observation was that relatively subtle changes in the wind/visibility relationship that existed over the course of a drifting event would have to be taken into account in the development and application of a standardized decision criteria.

For a given windspeed, visibility was poorer when there was ample fresh snow on the ground, but improved near the end of an event when the ground had "bared up". Evident in retrospect, this relationship between visibility and snow availability is difficult to recognize on the charts during an event, and impossible to quantify because wind is seldom steady long enough to allow conclusive comparisons. The relationship between wind and visibility can change rapidly, as during a period of snowfall, but more subtle gradual changes equally relevant to highway safety can extend over many hours or even days.

For these reasons, a computer was utilized to analyze the data real-time and provide the complex interpretations that boggled the mind of radio operator, scientists and engineer alike.

RELATIONSHIP BETWEEN WIND AND VISIBILITY

Snowfall with Light Winds

The relationship between wind and visibility during snowfall with light (< 7 m/s) winds is relatively easy to deduce from Eq. [1]. If size of snow particles remains constant, visibility will vary inversely with precipitation intensity. If particle frequency also was independent of wind, then visibility would improve in direct proportion to wind.

Because visibility attenuation is usually not severe for light winds, the remainder of this paper is directed to the more critical case where snow previously deposited on the ground is relocated by winds > 7 m/s (as measured at 10-m height), with or without concurrent precipitation.

Antarctic Studies

It is not as clear how visibility might vary with wind for the case of relocated snow, because both frequency and mean diameter of particles increase with windspeed.

Data presented by Budd (2) suggest particle diameter increases (approximately) as the square root of windspeed (U). Mellor (5) has shown from other Antarctic data that the mass flux of snow particles tends to increase according to U^7 at heights above 0.5 m, and $U^{5.4}$ at lower levels. Equation [1] suggests that visual range should vary as a negative power of windspeed, so that

$$V = AU^{-B} \qquad \text{Eq. [2]}$$

where V is visibility at observer height, U is windspeed at 10-m height, and A and B are constants for a given snow condition. Moreover, the above relationships indicate an expected value for B of about 5 at 0.5m height. This deduction is substantiated by the visual measurements of target extinction in the Antarctic reported by Liljequist (4) and Budd et al. (3). Liljequist specifically concluded that visibility at observer height (2 m) was related to the -5th power of windspeed over his range of data.

Since both of these experiments were conducted where snow supply on the ground was essentially unlimited, we are left with the problem of how A and B might change as snow cover is depleted. This important question led to the following experiments using the visual range monitor.

Experimental Procedure

Our studies were conducted at two separate locations. The Cooper Cove site (elevation 2,360 m) is a nearly level area covered by short grass vegetation. The Elk Mountain monitor station (elevation 2,220 m), with low-growing brush vegetation averaging about 20 cm in height, served as a second study site.

The electronic data acquisition system used electronic peak detectors to sample the maximum values of wind and visual range signals output from a VRM over a 5-second (s) interval. This method of sampling helped assure matching of visibility and wind values, since the anemometer was installed 10 m above the ground, while the particle counter was at a a height of 0.5 m and located about 15 m upwind from the anemometer. An electronic calculator served as system controller for selecting channels, controlling peak detectors and digital voltmeter, and storing data on magnetic tape. The least-squares value for A and B in Eq. [2] were calculated at 10-min. intervals and output on a printer and X-Y plotter. Visibility and wind were continuously recorded throughout six separate drifting events totalling 234 hours, over a wide range of weather conditions.

Air temperature and humidity at 2-m height were recorded with a hygrothermograph; precipitation was measured with recording gages located in tree-sheltered spots near the study sites. Characteristics of the snow cover were observed and photographed throughout each run.

Results from Wyoming Studies

The power function (Eq. [2]) is an empirical approximation for the complex relationship between wind and visibility. Over the narrow range of windspeeds encountered in a 10-min sampling period, the power B was quite variable and ranged from 2 to 8, with the lower values generally associated with lower visibilities. To provide the widest possible range in the variables, data were grouped into periods having essentially uniform snow conditions and up to several hours in length. Results of this analysis over all snow conditions gave an estimate for B of 4.90 $\pm$ 0.20 (.95 confidence interval), determining an integer value of 5 for the mean.

Statistical analysis of individual storms by hourly intervals showed B to remain essentially constant as snow conditions changed.

Conclusions can be summarized as follows:

1. For practical purposes, it can be assumed that the function

   $$V = AU^{-5}$$

   applies to all winds strong enough to relocate snow, over the entire range of snow conditions, and with or without concurrent precipitation.

2. The A coefficient ranges from 10^8 for conditions of maximum snow availability, to $>10^{10} m^6/s^5$ in the final stages of a drifting event. A therefore provides a responsive index of snow availability.

3. Variance increases as snow supply diminishes, affecting reliability of the estimates for the A coefficient.

4. Visibility values obtained with the VRM are in reasonable agreement with published target observation data.

OPERATIONAL USE OF WIND AND VISIBILITY DATA

Interpretation of the A Coefficient

The preceeding evidence leads to the practical generalization that the power in the visual range Eq. [2] is constant and approximately equal to 5.0, while the A coefficient changes in response to snow availability. Even subtle variations in the character of the snow surface can bring about significant and identifiable changes in A. A striking example is the abrupt decrease in the A value with the onset of snowfall. Precipitation intensities as light as 0.1 mm of water-equivalent per hour have been observed to lower A from 10^9 to $2 \cdot 10^8$ m^6/s^5 over a period of 30 minutes. The reason snowfall is detectable from an analysis of the wind/visibility data output from the VRM is because older snow consists of subangular grains sintered to form a surface relatively resistant to particle dislodgement. Fresh snow, however, is quickly fragmented and easily transported, so particle frequency rapidly increases whenever new precipitation is received, even though the older snow may lie meters deep on the ground. Therefore, the A coefficient will continue to decrease as precipitation continues until, to use Liljequist's description, the air becomes "saturated" in relation to its snow transport capability. Once the input of fresh snowfall ceases, however, the metamorphosis of particles into "older" snow is rapid.

In general, an A value $\lesssim 1.2 \cdot 10^8$ m^6/s^5, or an abrupt decrease in this parameter, appear to be reliable indicators of precipitation. On occasion we have also observed smaller decreases in A without precipitation, presumably associated with the disruption of surface crusts at the onset of strong winds. Other changes occur with the arrival of snow from discrete contributing areas upwind, and each location has its unique characteristics that might provide useful information about the progress of a storm.

As demonstrated by Figure 1, the A value can be interpreted in terms of snow conditions and potential visibility attenuation. But the change in this parameter over time can provide additional information about trends in snow availability relevant to traffic operations decisions.

Sampling Visibility and Wind Data

Analog signals of wind and visibility are telemetered from the field monitoring stations at Arlington and Elk Mountain on I-80. Data processing, analysis, and peripheral hardware control are performed by a Hewlett-Packard 9825 calculator with 23k byte memory. The calculator controls the clock, scanner relay, and digital voltmeter used to measure instantaneous values of wind and visibility at the rate of one sample pair from both stations each second. This sampling frequency is sufficient to insure that extremes will be sampled within 5% of their maximum or minimum values.

Figure 1. Snow conditions at Cooper Cove. [Snow particle counter extends horizontally from pipe in foreground. A values (in $m^6 s^5$) refer to the coefficient of Equation 2 assuming B = 5].

15:50 February 21, 1976: $A \doteq 7 \cdot 10^8$

13:52 February 22, 1976: $A \doteq 1.2 \cdot 10^9$

11:50 February 27, 1976: $A \doteq 1.5 \cdot 10^{10}$

Every 8 s, the largest and smallest values of each variable are determined, and only these are retained for analysis. This allows wind values to be matched with their corresponding visibilities--a procedure made necessary by the fact that the anemometer is located about 10 m above the ground, while the snow particle counter (SPC) is typically installed at 0.5 m height. Both maximum and minimum values are used to provide the widest possible range of data for statistical estimation of the A coefficient in Eq. [2].

These paired visibility and wind values are accumulated over approximately 10minutes to provide an adequate sample number for estimating A by least-squares regression analysis, assuming B=5.

The Critical Visibility Statistic

In using visibility data for traffic operations decisions, one is faced with selecting the critical statistic. Should traffic operations be based on an average visibility? And if so, over what period of time? If minimum visibility is considered the limiting factor, over what time period? To the author's knowledge, this problem has not been resolved for the case of blowing snow where visibilities exhibit such a complexity of frequencies and amplitudes.

It can be shown that "stopping sight distance" (SSD) cannot exceed the minimum visibility if a safe vehicle speed is to be maintained. Since amplitude varies with time, a logical course is to base traffic operations on an average of several minimum visibility values measured over a specified time period. To reduce the weight given to anomalous or extreme gusts while providing a statistic representative of minimum visibilities, we have defined the hourly minimum visibility as the geometric mean (i.e., calculated from the logarithms) of the six 10-minute minimum values. This procedure simplifies programming for hourly reports and recommendations, and has given reasonable results in preliminary tests and operational trials.

In summary, although the statistical analysis to determine the A coefficient uses all the wind and visibility data (150 paired values) over each 10-minute period, only the lowest visibility value (and the strongest wind gust) are retained for traffic operations decisions. Although these 10-minute extremes are used to warn the computer operator of dangerous conditions, traffic operations are based on the hourly minimum visibility as defined above.

Use of Visibility Data for Traffic Operations

Traffic operations routines are included in the same program used for measurement and analysis of the wind and visibility data telemetered from the two field monitor stations on I-80. Warnings and notices are printed after each 10-minute sampling period as required. Summaries of visibility and wind conditions are output hourly, along with recommended regulations and warnings when minimum standards are exceeded.

Recommended speed limits are determined by equating SSD to the hourly minimum visibility, and solving for vehicle speed. The effect of grade can be ignored in view of the arbitrary definition of $\overline{V}_{min}$. Taking 2.5 s as the usual approximation for T, then

$$U_V = -88.35 f + 127.12 \left[0.48 f^2 + 0.016 f \overline{V}_{min}\right]^{0.5} \qquad \text{Eq. [3]}$$

Application of Eq. [3] requires that information on road surface conditions be kept current in the calculator's information file, and that appropriate friction factors are known for various road conditions.

Visibility information is used for road closure or opening decisions and consideration is given to snow availability as indexed by the A coefficient.

Forecast visibilities are calculated from the current A value and the latest wind forecast issued by the National Weather Service. This is a most important application of the wind-visibility relationship because it allows potential visibility hazard to be expressed in meaningful quantitative terms. As a hypothetical example, current winds speeds gusting to only 13 m/s with an A value of $3 \cdot 10^8 m^6/s^5$, would imply present visibilities to be more than 800 m. But a wind forecast for gusts reaching 25 m/s would mean visibilities as low as 30 m.

As described previously, visibility data are used to detect snowfall, and this information is also used in the decision logic. This feature is important when reports are not available from the field; in addition, it is often difficult for an observer to tell whether or not it is snowing during a heavy drifting event.

A final application of the wind/visibility analysis is for estimating the time required for visibilities to reach the prescribed standard for opening a road previously closed due to poor visibility. This is accomplished by extrapolating the current rate of change in the A value to determine the time required for the standard to be attained.

These examples show how on-line computer analysis of wind and visibility data can provide the engineer or foreman with essential information not otherwise available to him for making timely and sound decisions. Analysis of the relationship between these variables can provide the basis for objective traffic operations standards that are technically sound, unambiguous, and legally tenable.

ACKNOWLEDGMENT

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Abstract

MEASURING VISIBILITY IN BLOWING SNOW

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An electronic system that monitors visibility in blowing snow has been developed by the USDA Forest Service in cooperation with the Wyoming Highway Department. The sensor for blowing snow is a photoelectric particle counter that produces a voltage pulse for each snow particle which passes through a 3 by 25 mm area normal to the wind. The sensor's pulse train is electronically processed to give voltages proportional to five-second averages of particle frequency and diameter. These voltages are combined with the signal from an anemometer in an analog computer which simulates visual range according to the equation, $V = 5U/FX^2$ where V is the visual range in meters, U is windspeed in meters per second, F is the particle frequency in number per second through a 1 cm^2 area, and X is the particle diameter in centimeters.

Field calibration was accomplished by comparison with closed circuit television recording of visual range targets during drifting. The correspondence between theory and observed visual range was very satisfactory, and two such systems are now in use for traffic control in Wyoming, having proved reliable and useful during three winters.

IMPROVING THE CONSPICUITY OF HIGHWAY-RAIL GRADE CROSSING SIGNALS

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Highway-rail grade crossing "protection" is classified as being either "active" or "passive". Active protection includes swinging or flashing lights, bells and gate arms that are activated by an approaching train, while passive protection refers to stationary signs and pavement markings that indicate merely the presence of a crossing. There is clear evidence that active crossing protection provides a considerably higher degree of motorist safety than does passive "protection". Installation of flashing lights at certain passive crossings has been shown to reduce accidents by 60 to 70 percent, and flashing lights plus automatic gates have reduced accidents by as much as 95 percent.

Despite their obvious safety advantage, active crossings, which constitute approximately 20-25 percent of the nation's public crossings, are involved in some 40 percent of all train-involved crossing accidents. While this disproportion can be explained largely by the higher train and highway traffic volumes usually encountered at active crossings, the fact remains that an alarming number of accidents still occur at crossings that in theory, at least, employ state-of-the-art warning devices for motorist protection.

It is obvious that current active warning devices are not as effective as they should be, and one reason for this is that motorists often fail to see them in time. The present study, conducted for the Federal Highway Administration by MB Associates, sought to find ways to improve the conspicuity of active warning devices. By agreement between the contractor and FHWA, the study focussed upon development of add-on, rather than substitute warning devices, to permit retention of existing warning installations already familiar to the motorist. The present paper is an abridgment of a lengthy report that contains a detailed description of study methodology and findings (Ruden, R.J., Wasser, C.F., Hulbert, S. and Burg, A. Motorists Requirements for Active Grade Crossing Warning Devices. San Ramon, CA: MB Associates, Report No. MB-R-77/72, October 1977).

The study had three phases: literature review, laboratory investigation of conspicuity, and field tests of devices suggested by the laboratory tests.

The laboratory tests concentrated on the conspicuity of flashing lights (although retroreflectors and stop signs also were studied as add-ons to gate arms). Both incandescent bulbs and strobe lights (xenon flash tubes) were used, and the primary variables investigated were color, flashrate, brightness, size and placement.

Some 150 drivers of both sexes and all ages each viewed from 100 to 180 "displays". A display normally consisted of six elements - 3 pairs of flashing lights and three standard roadway signs. Subjects viewed each display for a brief interval from a distance of 420 feet, and each subject recorded the single element of the display that most attracted his attention. Tests were conducted under daytime, nighttime and 475-foot visibility daytime fog conditions. For the nighttime tests, normal low-beam automobile headlighting was provided. Displays were viewed against either a non-competitive rural or highly-competitive urban background.

The major laboratory findings were as follows:

1. Color: At equal luminance, red and blue are clearly best for daytime and nighttime, respectively (excluding white), while amber and orange are slightly better in daytime fog.

2. Flashrate: Flashrates of 70-90 cycles/minute for incandescent lights generally are more conspicuous than either higher or lower flashrates. For strobes, conspicuity increased as flashrate increased, with irregular flashing and apparent movement adding to conspicuity.

3. Brightness: Higher brightness yields greater conspicuity during the daytime and in fog; at night, little difference was found, suggesting that even the lowest luminance level tested (275 foot-Lamberts) was more than adequate.

4. Size: Increasing lens size from 8" to 12" increased conspicuity dramatically under all conditions, even more, proportionately, than did increasing brightness.

5. Placement: "High Center" (17' high cantilever) and "Low Right" (9' high roadside) positions were more conspicuous than "High Right" for all conditions, and "Low Right" was best for daytime fog.

6. Strobe vs. Incandescent: At 17 joules energy discharge per flash, red strobes are not as conspicuous as standard 8" red incandescent narrow-beam railroad flashers, blue strobes are more conspicuous, and white (clear) strobes are very much more conspicuous. For a given energy expenditure, white strobes provide the most conspicuity of any lights tested.

7. Gate Arms: Small red, white and blue low-powered strobes mounted along the top edge of a standard gate arm significantly add to its daytime and nighttime conspicuity when seen against a competitive background, with the blue and white strobes contributing nearly all of the increased conspicuity. (The gate arm configuration was not tested in the fog, because the gate arm itself could not be seen at 420 feet.)

Based on the laboratory findings, field tests were conducted utilizing two test configurations: (1) Three white 8" strobes mounted in a horizontal line 30 inches above the existing pair of 8" red incandescent railroad flashers at a busy urban crossing, and (2) Small, low-powered red, white and blue strobes mounted along the top edge of an existing gate arm installation in the California desert. In the first installation, the outside white strobes were 30" apart (as were the red flashers beneath them), and they each flashed 120 times/minute; the center strobe discharged 50 milliseconds after each of the outside strobes (i.e., 240 flashes/minute), yielding a combined flash rate for all three strobes of 480/minute. For the gate arm installation, the two outside strobes (red and blue) flashed simultaneously and irregularly at 240-300/minute, while the center (white) strobe flashed separately and irregularly, 180-240 flashes/minute.

The urban crossing evaluated had averaged 2.3 train/vehicle accidents per year for the prior 12 years. During the 3 1/2-month test installation, there were no accidents and no evidence of adverse driver reaction to the white strobes. Limited observation of the experimental gate arm installation revealed that the added strobes increased gate arm conspicuity in daytime, but did not appear to add anything to the nighttime conspicuity of the standard gate arm red incandescent lights against the high-contrast desert night background. The report concludes with recommendations for future research and for trial installations of the recommended devices.

A REVIEW OF ARIZONA DUST STORM SIGNING ON INTERSTATES 8 AND 10

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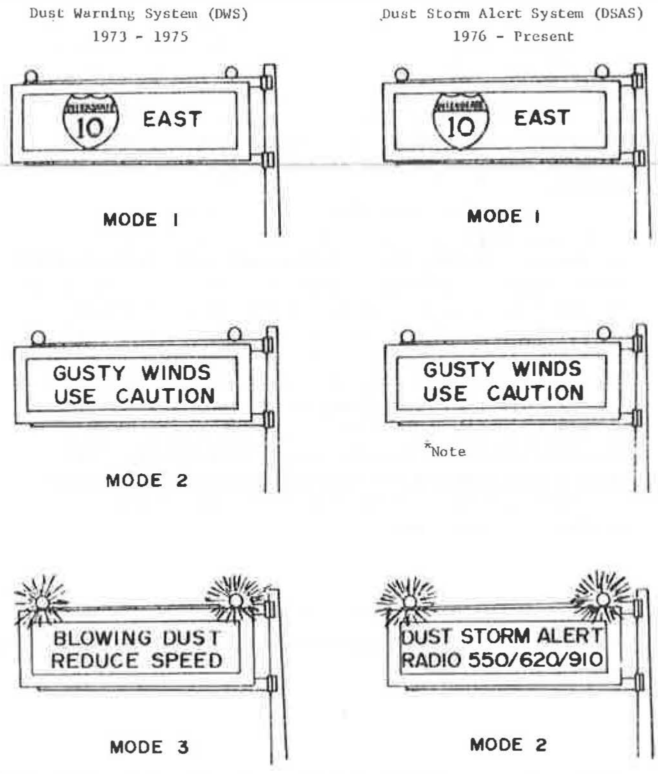
During a major dust storm in 1970, eight persons died in a multiple-vehicle accident on I-10 about halfway between Phoenix and Tucson. In 1971, eight more persons died when twenty-some vehicles were involved in two multiple-vehicle accidents which occurred during a blowing dust storm. As a direct result of those accidents, the decision was made to attempt to better alert the traveling public to driving hazards associated with Arizona dust storms.

Concurrent with vigorous public relations efforts, a search was undertaken to determine a type of warning sign that could be either automatically or manually activated to warn motorists of dust storms, with the hope that motorists would correctly respond to the instructions they had received from other sources.

After locating over ten years of dust-related accidents on a map of the state, it became apparent that the major concentration of Arizona dust-related accidents was in the corridor between Phoenix and Tucson along Interstates 10 and 8. On that basis, plans were developed for the installation of an experimental system of warning signs on about 60 miles of the two routes.

The resultant system consists of 40 changeable message signs. Sign structures are spaced approximately five miles apart in both directions, with at least one sign being in advance of each off-ramp in the area. This would allow motorists who encounter a sign in the warning mode an opportunity to leave the freeway and seek shelter on the cross road. Interstate signing standards were adhered to and the signs are either cantilevered above the road or mounted on the ground on breakaway supports.

Figure 1. Past and present dust warning sign legends.



*Note: This mode is not used as part of the DSAS; however, it is still operational and can be used at the discretion of the Highway Patrol.

A triangular drum, located inside the sign housing, permits the display of the three distinct messages. As originally conceived, the Dust Warning System (DWS) messages were as shown in Figure 1. The Mode 1 interstate route shield is the sign face normally seen by motorists, unless the system is activated. Under the DWS concept, an early warning message (Mode 2) carried the legend "GUSTY WINDS--USE CAUTION" in black copy on a yellow background. The actual dust warning message (Mode 3) had the legend "BLOWING DUST--REDUCE SPEED", also in standard warning sign colors. In this latter mode, the warning was further emphasized by two high-intensity amber strobe lights.

Each sign is a self-contained unit having its own direct current drive motor, control panel, battery pack, thermo-electric generator, and LPG gas tank. The signs are battery-powered and use the generator to maintain the battery charge. A radio control module, consisting of a 450 megacycle transceiver, is in each sign. The entire system of signs is controlled from a central console which is located in the Highway Patrol Headquarters in Phoenix. The console consists of a sign status display map, a printer to record diagnostic information and the date and time of sign activations, a control panel, and an equipment rack for the electronic circuitry.

The system became operational in July 1973. The operating strategy developed initially and used until 1976 was directed at providing spot warnings of specific wind and dust conditions in the immediate vicinity of each sign. In retrospect, this was an unrealistically ambitious undertaking for a system not equipped with automatic wind and dust sensors. As operated during three "dust seasons", highway patrolmen and maintenance men were tasked to report conditions from the field and request the appropriate sign modes.

In an attempt to provide more timely messages and more explicit information to motorists, the DWS was modified extensively prior to the 1976 dust season. While significant changes were made in the sign legends, the most profound change was the adoption of an entirely new strategy for operating the system. Rather than attempt to display selective signs warning of actual conditions at specific locations, as was done during previous dust seasons, a strategy was adopted which called for the activation of all 40 signs in the event of an alert.

This change in philosophy from a spot warning to an area-wide alert was prompted by the realization that the DWS was incapable of providing timely warnings of conditions at a specific location. Furthermore, comments solicited from motorists in an extensive questionnaire survey revealed an overwhelming desire on their part for more information on "what to do in a dust storm".

The modifications which went into effect on June 1, 1976, were intended to provide more guidance to drivers through "audio signing". One face of the triangular-shaped sign drum was modified to alert motorists to dust storms and direct them to tune their radios to one of three commercial radio stations. Prior to the 1976 dust season, it was established that three commercial radio stations in Phoenix would voluntarily broadcast a 60-second dust alert message at 10-minute intervals, once the dust storm alert system (DSAS) was activated. The three radio stations were chosen on the basis of a field survey of their broadcast signal strengths at various times of the day throughout the DSAS area.

As a consequence of the changes made, the signs now only operate in two modes, Mode 1 being the Interstate route shield used when the DSAS is inactive and Mode 2 being the "audio signing" alert message used when the DSAS is active. The change in the use of the sign panels is shown in Figure 1. Accident analyses have not shown that any statistically significant reductions in accidents have occurred. However, timeliness, viewed as a match between sign messages and prevailing weather conditions, increased from 65 percent to 98 percent. The increase in timeliness can be attributed to the more general message of "DUST STORM ALERT". The alert message was viewed as a warning of conditions under which a dust storm was likely to occur. Consequently, the modifications had the very favorable effect of showing a credible message whenever the system was activated.

To ascertain if modifications resulting in the DSAS had a more direct influence on evasive action taken by motorists, they were asked if weather, signs, radio broadcasts, or any other reason or combination of reasons, prompted their actions. The answers indicated that with the previous DWS method of operation, 21 percent of the drivers who took evasive action did so due to the system (signs) alone. With the present DSAS operation, 37 percent of the drivers who took evasive action attributed their responses to the system (signs and/or radio messages). This increase in evasive action taken was echoed by the increase from 8 to 12 percent for those stating they had pulled off the road.

Overwhelmingly, motorists' comments indicated that the present DSAS provides ample information concerning dust driving conditions and evasive action to be taken--a marked contrast to the requests for "more information" and "what to do if--" comments which were prevalent in the first questionnaire survey.

FOG WARNING ON MOTORWAYS IN THE FEDERAL REPUBLIC OF GERMANY

Juergen Behrendt, Federal Highway Research Institute, Federal Republic of Germany

SCOPE

In nearly all Western European countries, fog creates a particular danger to traffic. Even though only 2-3 percent of all accidents are caused by fog, fog accidents are considerably more severe than other types of accidents. Traffic flow conditions on motorways are particularly affected by fog, with delays and accidents often being the result. About 10 percent of the motorway network is reputed to be especially fog-prone (1) and radiation fog is a typically dangerous form of fog.

In order to reduce the danger connected with driving in fog, vehicle lighting facilities play a major role. A research project on the field of lighting engineering recently provided findings which added to the theoretical and practical knowledge gained on this special subject (2). In Germany, the Vehicle Code permits the use of a special rear fog lamp on motor vehicles (300 cd; 21.7 sq. in.). Road-related measures, such as pavement markings, reflective markers, delineators, and others, are indispensible as guiding facilities; in fog-prone areas, special care must be taken that they are kept in good condition. Lighting facilities mounted very low on the sides of river bridges are being tested in areas where fog is known to be very dense.

On several sections of the motorway network experiments were made with automatic fog warning systems. Road stretches in particularly fog-prone depressions were selected as test sections. They are characterized by the fact that drivers, not expecting a sight obstruction, unexpectedly run into a thick fog wall.

CONCEPT

Each section is about 4 km (2.5 mi) long. Several sight distance meters positioned along the roadway control illuminated message signs by means of a closed loop system and the fog warning is displayed on the latter. The remote-controlled message signs (Fig. 1) are positioned in pairs at a distance of about 400 m (1/4 mi) before entering the fog-prone zone. The sign for "danger spot" of the German Vehicle Code is used together with the sign for "fog". In addition, yellow flash lights are mounted to further increase drivers' attention.

Warning is given as soon as at least one of the fog detectors registers a standard sight distance of less than 150 m (500 ft); when the sight distance again exceeds the threshold value, the warning is stopped after a time lag of 5 minutes. For the sight distance measurements, instruments were used as they are known from their application on airports. Recently, experiments have started with a new type of instrument especially designed for highway conditions because a measuring distance of more than 320 m (0.2 mi) was considered as being irrelevant. Sight distances are registered on a continuous basis and the mechanical recording will be replaced by electronic means of operation.

The measurement of the standard sight distance (contrast threshold of 5 percent) can give too unfavorable values for warning purposes by day considering the normal visual acuity of the average driver and values at night which are too good considering that the tail lights of cars are generally seen from a larger distance than given by the standard visual range. It has therefore been suggested to make changes in the design of the instruments and compensate for the differences by means of a built-in minicomputer. Table 1 shows the relationship between standard visual ranges and actual visibility distances in fog.

RESULTS

The fog statistics of the fog-prone areas, covering a longer period of time, led to a better knowledge about the distribution and duration of particularly dense fog. Measurements conducted under conditions of unobstructed visibility vs. those of fog have shown that drivers do not significantly change their driving behavior as regards speed and vehicular gaps (3). At sight distances below 50 m (165 ft), the 85 percent speeds decreased from 123 to 96 km/h (76.5 to 60 mph) on the right lane and from 133 to 118 km/h (83 to 73 mph) on the left one. Although dangerously short gaps between vehicles decreased by 50 percent, the 10 percent of them detected on the passing lane can still be considered as being high.

Table 1. Fog density scale and visibility distances.

fog density scale	standard visual range 1)	max. visibility distances		tail-lights, night 4)
		vehicle-outline, day 2)	vehicle-outline, night 3)	
thin fog	1000 - 500 m *3,300 - 1,650 ft*	200 - 140 m *650 - 460 ft*	170 - 120 m (hb) *560 - 400 ft*	400 - 300 m (lb) *1,300 - 1,000 ft*
moderate fog	500 - 200 m *1,650 - 650 ft*	140 - 65 m *460 - 210 ft*	120 - 70 m (") *400 - 230 ft*	300 - 200 m (") *1,100 - 650 ft*
thick fog	200 - 100 m *650 - 330 ft*	65 - 30 m *210 - 100 ft*	70 - 40 m (") *230 - 130 ft*	200 - 125 m (") *650 - 410 ft*
very thick fog	100 - 50 m *330 - 165 ft*	30 - 15 m *100 - 50 ft*	40 - 25 m (lb) *130 - 80 ft*	125 - 75 m (") *410 - 245 ft*
fog wall	50 m *165 ft*	15 m *50 ft*	25 m *80 ft*	75 m (") *245 ft*

(hb) = high beams
(lb) = low beams
of succeeding vehicle

1) ATR/FG/VSS - Fog Report 1974 [1]

2), 3) not luminous, light coloured object, seen against the fog background [2]: day 10^3 cd/m^2, night 10^{-2} cd/m^2

3) lighted only bya succeeding vehicle

4) luminous intensity 2,5 cd; fog background luminance: 10^{-2} cd/m^2

Figure 1. Fog warning of the Highway 81.

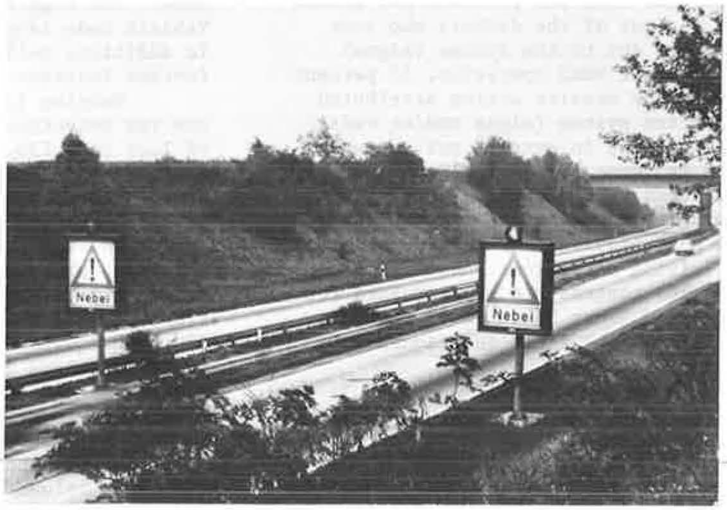
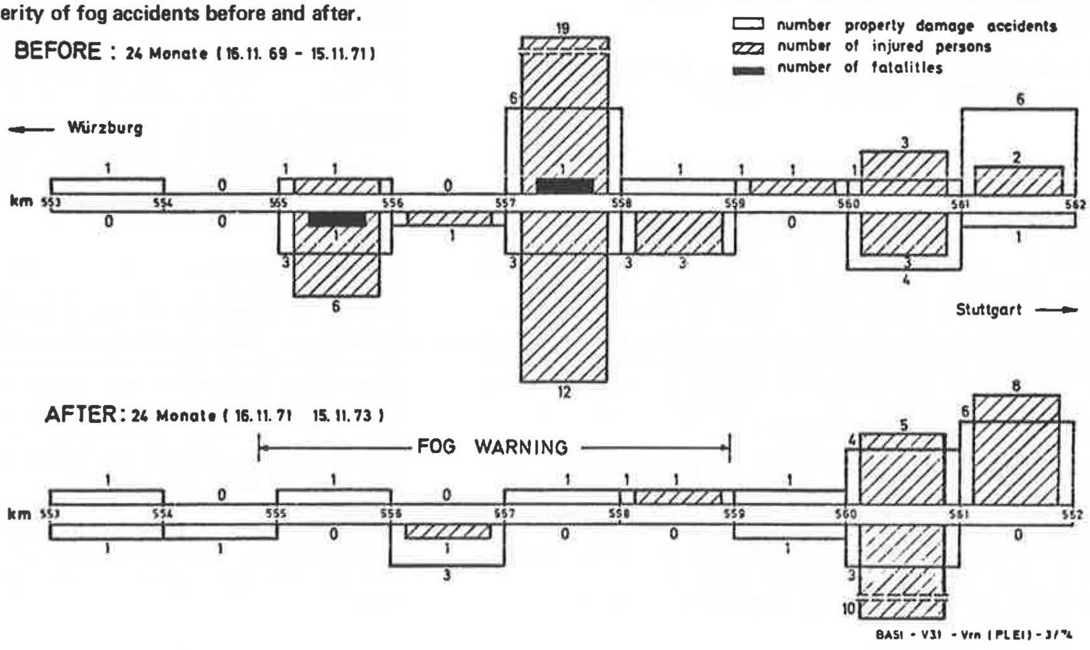


Figure 2. Number and severity of fog accidents before and after.



A comprehensive accident analysis has as yet been completed for only one test section. The comparison (Fig. 2) of the two year periods before and after the installation of the fog warning system showed that the number of fog accidents went down from 18 to 6, while remaining about constant in areas not affected by the warning system. A study of the severity of accidents revealed that the possible success may be estimated even higher. Before (without the warning system), as a result of 18 accidents, 39 injured persons and 2 fatalities had to be registered. After the installation of the warning system, only two persons were injured in a total of 6 accidents. Especially when the dreaded multiple vehicle collisions are avoided, important deviations may be found in the statistics. In order to eliminate the effects of the differences in metereological conditions of the various years, the time periods on which the comparison is based should be as large as possible. The experiments with fog warning systems are being continued using improved design concepts and more sophisticated equipment. The costs of multiple vehicle collisions in fog, occasionally involving more than 50 vehicles, are estimated to be about as high as the investment costs required by a fog warning system. The installation of such a system is therefore justified when it leads to the prevention of such multiple collisions on identifiable danger spots.

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OPERATION FOGBOUND AND COMMUNITY INVOLVEMENT

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An often-used quotation holds that "Everybody talks about the weather, but nobody does anything about it." There is an inaccuracy in the statement. At least this writer claims credit for having done something about overcoming a weather problem--the fog-related traffic accidents in the great Central Valley of California.

During winter months, dense fogs constitute an extreme hazard to vehicular traffic. The fogs are as bad as the famed Pea-soupers in London, England, and certainly must be counted as the worst tule fogs in the United States.

Tule fog shows up when rains are followed by cold, clear weather. Cool air sinking down to warmer, wet ground condenses moisture into heavy vapor. The fog thickens when the air is coldest, typically between midnight and dawn.

Fog, with moderate to critical visibility restrictions, accompanied by moderate to heavy vehicular traffic, all too often resulted in multi-vehicle accidents.

In 1970 I was Commander of the California Highway Patrol Stockton Area which has responsibility for patrolling some of the worst fog territory. A study of accident reports for the three previous years showed that the fog accident problem was greatest during morning hours along main highway routes.

Our studies determined that the principal cause of fog-related accidents was speed--going too fast for the existing driving conditions.

It was decided to initiate a special experimental project, code named "Operation Fogbound" and implemented on November 1, 1970. It was extremely successful, and subsequently has been continued each year since with relatively few changes.

The project had three objectives:

1. Reduction in the number of fog-related traffic accidents.

2. Reduction in the number of injuries and fatalities.

3. Reduction in both the number of vehicles involved and the number of vehicles involved per accident (chain reaction).

The basic approach called for emphasis on the three "E's"--Education, Engineering and Enforcement--in an effort to reduce the number and severity rate of fog-related accidents.

The initial move was to solicit news media assistance. Also contacted were employee publications issued by local firms, and auto club and trucking magazines. All agreed to assist in any way possible. It was a splended demonstration of total community involvement and cooperation.

The second phase involved developing fog predictions for advance motorist warnings to be released each evening on television and radio. The blare of the familiar maritime foghorn was used as an attention-getting theme for the broadcasts. The reports not only gave warning of probable fog, they reflected with reasonable accuracy the density to be expected.

The third phase in planning was to develop a method to provide timely and accurate fog hazard information for AM and FM radio broadcasts. Every radio station in the county agreed to broadcast fog alerts every half hour during the critical periods.

One of the later innovations was assignment within the CHP office of a special telephone number which the public could call for freshly updated fog condition reports.

The fourth phase involved engineering, which included identification of fog-prone locations and posting of warning signs in places which had proven to be the most troublesome during previous fog seasons.

Phase five was control of traffic and enforcement against unsafe driving practices during dangerous fog periods. To encourage drivers to slow down in accordance with existing conditions, a caravan system of escorting vehicles through hazardous areas was developed and named "Round Robin".

The mechanics of "Round Robin" were basically simple. Each morning when fog conditions were bad, officers were assigned to individual sectors with the number of units varying with the number of available personnel. Communication between the units was maintained by the use of a tactical radio channel which permitted car-to-car contact and did not interfere with emergency radio calls.

Generally, each sector started the "loop" of the "Round Robin" at the perimeter of a foggy area with one patrol unit merging with traffic and slowing to a speed determined by the Sector Commander to be safe for the current conditions.

After a short period of time, depending on traffic flow, the second unit would get underway at the predetermined speed. After clearing the fog belt, which was often eight to 10 miles, the pilot units turned around and followed the same procedure in the opposite direction. The caravanning would then be in operation in both directions.

As an indication of the cooperation accorded the project, many trucking firms adopted a voluntary "no roll" policy when the fog was thick. That was a major policy decision by truckers--common carrier, owner-driver and proprietary alike--to take positive action to reduce fog-related accidents.

Another form of community involvement was a policy adopted by many area employers not to dock employees who were late for work because of thick fog.

"Operation Fogbound" has been effective in reducing fog-related highway accidents in the seven seasons it has been in operation. Differences in the number of fog hours and the degree of reduced visibility from one winter to the next make it difficult to make meaningful comparisons of accident statistics from year to year.

Nevertheless, the trend over the seven years has been a reduction of fog-related accidents, particularly in those areas where "Operation Fogbound" convoys and procedures have been in effect.

With continued community involvement and support, the project is being retained on a regular basis and efforts are being made to develop improved techniques. In the Stockton area they not only talk about the foggy weather, they do something about it!

SUMMARY OF WORKSHOP SESSION

Albert Burg, University of California, Los Angeles, California

The Workshop was convened by Symposium Planning Committee Chairman Chuck Kaehn, with the eighteen attendees serving as a "committee of the whole". Fred Vanosdall was appointed Workshop Chairman, to lead the group in summarizing the findings of the just-completed Symposium and in discussing ways in which these findings could be implemented, as well as other future courses of action felt to be desirable.

An attempt was made to structure the discussion into a matrix consisting of "road", "vehicle" and "driver" on the one hand, and visibility degraders such as fog, snow, dust, rain and smoke on the other, with additional considerations such as "man-made vs. natural conditions" and "precipitation vs. aerosols". However, the spontaneous and spirited discussion that ensued resisted structure but, rather, touched briefly on a large number of topics, with more questions raised than answers given. Among the points discussed were the following:

1. The group felt that it was not necessary to specify the degree of visibility degradation at this point but, rather, was more concerned with the nature of and possible countermeasures for the degradation.

2. Making drivers aware of the problem through community involvement (as, for example, had been done by the California Highway Patrol in their fog convoying experiments) was felt to be an important element of any countermeasure program.

3. There is a need to make the driver more aware of vehicle and system capabilities, and how they are affected under different reduced visibility conditions.

4. Non-uniform behavior is a major cause of accidents in situations of degraded visibility. There appears also to be an increase in erratic behavior under these circumstances. There is a need, through driver education or other means, to condition drivers to behave uniformly in reduced visibility situations. This includes a need to tighten up the distribution of speeds, and to reduce the variability found in other types of driver actions (lane-changing, use of lights, etc.).

5. With on-board radar being advanced as a possible countermeasure, the question was raised as to whether the addition of radar would increase the already high task loading on the driver.

6. There is a critical need for hard data to accurately define the problem and to show just how much improvement is possible. A lengthy discussion took place as to just how much information is available. Unless and until we have a thorough understanding of the accident problem in adverse visibility conditions, it will be difficult to determine what potential countermeasures (if any) would be cost effective, since we have to be concerned with the trade off between accidents and traffic flow restrictions. It is felt that the problem may be a minor one, relative to all accidents, but without accurate data we can't be sure of the true magnitude of the problem, and the apparent magnitude will vary, depending upon whether we talk about rates or frequencies.

7. The basic issue appears to be that the driver does not respond properly (e.g., by reducing his speed) to reduced visibility conditions. A corollary issue is that of providing the driver with advance information about the condition, so that he can be prepared to respond properly. This calls for a capability to predict where the problem will occur in an accurate and timely fashion, with appropriate warning being passed along to the driver through any effective means available.

A discussion then took place summarizing what was felt to be necessary for dealing successfully with limited visibility conditions. The following were set forth as being desirable:

1. Increased public awareness of the problem, both immediate and long-range.

2. Increased public involvement in solving the problem. This means soliciting public support (as well as that of business and industry) for countermeasure programs.

3. Accurate prediction, if possible, of when and where problems will occur.

4. Timely and reliable detection of developed problem areas.

5. Timely and reliable decision-making regarding information to be relayed to the driver and other actions to be taken.

6. Timely and reliable communication of relevant information to the driver, through variable-message and speed control signs (and other means, if possible).

7. Expanded use of specialized enforcement techniques, such as convoying.

8. Improved driver aids in problem areas, such as delineation and fixed roadway illumination (plus unique special lighting, if possible).

9. Environmental modification, if possible.

10. Removal of the source of degraded visibility, if man-made.

Finally, each attendee was asked to provide a brief statement regarding research that he felt was necessary to shed further light on the entire problem area. Following is a listing of research topics mentioned by at least one of the attendees.

1. Determine the magnitude of the problem, through surveys of the states, or other means, that will provide hard data or at least estimates on the frequency and nature of low visibility accidents.

2. Using existing fog and snow and dust countermeasure installations, study the effect of reduced visibility on driver behavior, taking all relevant variables into account.

3. Study the effectiveness of vehicle-mounted driver aids, such as radar, special rear lighting, signalling devices, special headlighting or polarized headlights and windshields, etc.

4. Study enforcement techniques for inducing and maintaining conformity of driver behavior under reduced visibility conditions. Examples are convoying and specialized ticketing.

5. Study how to make drivers aware of the hazard involved in maintaining speed under lowered sight distance conditions.

6. Develop techniques to encourage uniform behavior and speed.

7. Study techniques to increase public awareness of the problem and support of countermeasure efforts. How do these techniques differ as a function of geographical area and population?

8. What measures of countermeasure effectiveness can be used besides accidents? What are reliable secondary criteria?

9. How can we bring about proper driver response to signs, etc.?

10. Study the effects of various types of delineation.

11. How can we best provide early detection and communication of problems?

12. There is a need to develop a standardized visibility target and method for measuring reduced visibility. The language used must be standardized.

13. What can be done from a driver education/training/licensing standpoint to insure that the driver knows what to do when encountering a restricted visibility area? There have to be general rules. Teaching materials must be developed that will be effective.

14. Study the feasibility of radio-controlled or automatically-controlled speed for the vehicle in hazardous areas.

15. There is a need for standardization of operational decisions in response to adverse visibility conditions (e.g., choice of advisory speed).

16. Study the effectiveness of signing in reducing speed variability.

17. Can real-time speed data be used as a means of detecting the incidence of a restricted visibility condition, and as a basis for a speed control information display?

18. Develop reliable techniques to measure driver responses to countermeasures.

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