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FINAL
CONTRACT REPORT

REDUCING FOG-RELATED CRASHES ON THE AFTON AND FANCY GAP MOUNTAIN SECTIONS OF I-64 AND I-77 IN VIRGINIA

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16. Abstract

The Fancy Gap and Afton Mountain interstates have a long history of fog-related, multivehicle crashes. Within a 3-week period in 1998, two major fog-related crashes occurred on I-64 where it crosses Afton Mountain. The first involved 65 vehicles and 40 injuries and lasted almost 20 minutes. The second occurred 17 days later and involved 21 vehicles. Similar crashes have occurred on I-77 over Fancy Gap Mountain in Carroll County, Virginia.

Because of its involvement in evaluating the original Afton Mountain fog mitigation system, the Virginia Transportation Research Council created an expert panel of decision makers from the Virginia Department of Transportation and the Virginia State Police and with the help of the Virginia Tech Transportation Institute staffed the panel. After detailed crash analyses, a review of the literature on fog and its effects, and an extensive survey of fog mitigation systems in the United States and abroad, the panel issued the following recommendations: (1) Install variable message signs *immediately prior* to the most fog-prone areas to warn drivers of detected incidents or fog-related vehicle stops or slowdowns ahead. Use highway advisory radio within the fog zone to communicate with drivers. (2) Install video cameras in the Afton and Fancy Gap fog areas. Explore the use of ultra-low-temperature, infrared video cameras to penetrate fog. (3) Increase police visibility, including increased patrols and possible staff assignments to I-77 at Fancy Gap and I-64 at Afton. (4) Seek authorization for experimental use of advisory and regulatory variable speed limits on I-77 as part of the new Fancy Gap fog mitigation system. (5) Conduct research to improve the legibility and visibility of variable message signs in fog. Study the effectiveness of static signs augmented with strobes and lasers to warn drivers of detected incidents and slowdowns in the fog zone.

Because the panel included experts from numerous levels of the Virginia Department of Transportation and the Virginia State Police and had extensive knowledge and experience with the fog problems under consideration, they were able to discuss their disagreements and come to a consensus on how to proceed. Because the group also had ITS representatives with extensive technical expertise to advise them, they had confidence that their recommendations were workable and effective. It may be that this method of building consensus and support can be used as a model to promote deployment of ITS technologies.

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ABSTRACT

The Fancy Gap and Afton Mountain interstates have a long history of fog-related, multi-vehicle crashes. Because of its earlier involvement in the installation and evaluation of the original Afton Mountain in-pavement fog guide light system, and concerns about continuing fog crash problems, the Virginia Transportation Research Council (VTRC) created an expert panel made up of decision makers from the Virginia Department of Transportation (VDOT) and the Virginia Department of State Police (VSP). Personnel from the Virginia Tech Transportation Institute and VTRC staffed the panel. After detailed crash analyses, a review of the literature on fog and its effects, and an extensive survey of fog mitigation systems in the United States and abroad, the panel issued the following recommendations:

- Install variable message signs (VMSs) *immediately prior* to the most fog-prone areas to warn drivers of detected incidents, fog-related vehicle stops, or slowdowns ahead. Use highway advisory radio within the fog zone to communicate with drivers.

- Install video cameras on the Afton and Fancy Gap fog areas to allow police and VDOT officials to confirm the presence of high-density fog areas and to allow the public to better plan their travel routes. Explore the use of ultra-low temperature, infrared video cameras to penetrate fog.

- Increase police visibility in the fog areas to improve compliance with posted speed limits and advisory limits, including increased patrols and possible staff assignments to I-77 at Fancy Gap and I-64 at Afton.

- Seek authorization for experimental use of advisory and regulatory *variable speed limits* on I-77 as part of the new Fancy Gap fog mitigation system.

- Conduct research to improve the legibility and visibility of VMSs in fog. Also, study the effectiveness of static signs augmented with strobes and lasers to warn drivers of detected incidents and slowdowns in the fog zone.

Because the panel represented multiple levels of VDOT and VSP and had extensive experience with the fog problems under consideration, a wide variety of solutions were offered for consideration, and each was judged from a variety of perspectives. The result was that only practical, applicable, and highly effective solutions were chosen for implementation. Because the group had representatives with extensive technical expertise in intelligent transportation systems (ITS) to advise them, they had confidence that their recommendations would be both workable and effective. It may be that this method of building consensus and support can be used as a model to promote deployment of ITS technologies to serve site-specific safety problems.

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INTRODUCTION

Within a 3-week period in 1998, two major fog-related crashes occurred on I-64 where it crosses Afton Mountain in Virginia. The first involved 65 vehicles, 40 injuries, but no fatalities (Table 1). At the time of the crash, visibility was reduced to 5 to 10 feet. The crash began at 12:42 p.m. and continued for almost 20 minutes. The second less serious crash occurred 17 days later and involved 21 vehicles and no fatalities. Similar crashes have occurred on I-77 over Fancy Gap Mountain in Carroll County, Virginia, as recently as May of 2001, when a 50-vehicle accident occurred. Another Fancy Gap crash (March 1997) lasted for 1 hour and 5 minutes. Such multi-vehicle crashes have also occurred on interstate highways in the other states and in Europe.

Table 1. Multi-Vehicle Fog-Related Crashes on Virginia Interstate Highways

Date	Location	Number of Vehicles	Number of Fatalities	Number of Injuries
5/22/01	I-77, Fancy Gap Mountain, VA	50	0	12
10/5/98	I-77, Fancy Gap Mountain, VA	46	0	13
5/7/98	I-64, Afton Mountain, VA	21	0	unknown
4/20/98	I-64, Afton Mountain, VA	65	0	40
3/19/97	I-77, Fancy Gap Mountain, VA	15	0	4
2/14/97	I-77, Fancy Gap Mountain, VA	56	0	12
2/24/96	I-64, Afton Mountain, VA	16	0	0
4/20/92	I-64, Afton Mountain, VA[a]	50	2	11

[a]One fatality in this crash was the result of a heart attack and was not due to injuries sustained in the crash.

Both the Fancy Gap and Afton Mountain interstates have a long history of fog-related problems. From the time the Afton Mountain portion of I-64 opened in December 1972, drivers reported serious problems crossing Afton Mountain during foggy conditions. In fact, the dedication ceremonies were shrouded in fog, and 12 days after opening, the first 10-car crash occurred.[1] The fog at this particular segment on I-64 tends to be relatively dense and is unusually uniform for significant periods of time. Motorists encountering this type of fog often found visibility reduced to a few feet and prior to the initial installation of fog guidance lights sometimes reported being forced to navigate by opening the driver side door and following the edge or centerline. The situation was similar on I-77 over Fancy Gap Mountain. When the various segments of roadway were opened to traffic between 1975 and 1978, the designers were aware that the section between milepost 2 and milepost 9 was prone to heavy fog and that when in the southbound lane, drivers approached areas of dense fog with little or no warning of what was ahead.

Almost as soon as I-64 opened on Afton Mountain, traffic engineers at the Virginia Department of Transportation (VDOT) began to explore the possibility of providing positive guidance to motorists using fog lights embedded in the pavement. It was hoped that this type of system would aid in highway delineation, reduce run-off-road crashes, and enhance motorist comfort and safety. This system was installed between May 15, 1974, and March 15, 1976, and covered a distance of 5.8 miles. In 1997, when the system was approximately 20 years old, a $5.3 million upgrade was implemented by VDOT.

The initial installation of the pavement lighting system on Afton Mountain was expected to reduce the incidence of crashes. A short-term evaluation of the effect of the fog lights on crashes was conducted in 1977 by the Virginia Transportation Research Council (VTRC) comparing the 19-month period prior to beginning the installation with the 19-month period after the installation was complete. Crashes occurring during inclement weather decreased after installation, while clear weather crashes increased slightly.[2] However, the severity of the crashes that occurred increased, as indicated by the increase in injury crashes from 8 to 13. These findings are based on a relatively small number of crashes, which would be expected to vary from year to year. No long-term analysis was conducted to confirm these findings.

In the years that have followed, a number of multi-vehicle crashes occurred. Since no detailed crash analyses had been conducted on all accidents on I-64 over Afton Mountain or I-77 over Fancy Gap, the factors that result in fog-related crashes in these areas could not be identified with certainty.

These crashes on Afton and Fancy Gap highlighted the fact that fog-related problems existed in both locations and that on Afton, although the guide lights significantly improved roadway visibility, they may have created problems in terms of speed and driver complacency. In order to study and address problems in both areas, the VTRC staff contacted researchers at the Virginia Tech Transportation Institute (VTTI) to initiate a collaborative effort.

PURPOSE, SCOPE, AND LIMITATIONS

The purpose of this project was to evaluate the nature and severity of the fog-related crash problem on Afton and Fancy Gap Mountains, to identify alternative solutions and technologies to address the problems, and to assist VDOT decision makers in selecting the most cost-effective set of solutions. As an additional objective, technologies to alert motorists to the presence of a primary crash ahead were examined to help reduce the probability of secondary crashes.

Once work on the study had begun, citizens and VDOT representatives in Wise County asked that a fog-prone portion of Rt. 23 in Wise be included in the study. Although not an interstate, this roadway was built to near-interstate standards. Rt. 23 was included in the accident analysis, but it was found that the problems noted by citizens were not specifically fog-related but were rather the result of a visibility problem during all types of weather. Several recommendations concerning this site were made to the local VDOT resident engineer, but due to the fact that the Rt. 23 crashes were not primarily due to fog, this site was not included in the rest of study.

METHODS

To assist in developing and evaluating fog mitigation countermeasures, VTRC created an expert panel made up of decision makers from VDOT and the Virginia Department of State Police (VSP). The panel of experts was formed to make sure that all possible solutions were available for consideration and that each was judged from as many different viewpoints as possible, so that only practical, applicable, and highly effective solutions were chosen for implementation. Personnel from VTTI and VTRC staffed the panel.

The following tasks were conducted as part of this project:

Task 1: Conduct an Analysis of Crash History: A detailed longitudinal review of the crash history of the Afton Mountain and Fancy Gap Mountain interstate corridors was conducted, including the characteristics of crashes and crash-involved vehicles, drivers, and passengers.

Task 2: Review the Literature and State of the Practice: In addition to conducting bibliographic searches of the literature on fog-related crashes and countermeasures, personnel involved in the development, implementation, operation, and evaluation of fog-site safety installations on both the state and federal level were interviewed.

Task 3: Convene a Panel of Experts: The panel of experts was asked to consider all aspects of the Afton and Fancy Gap Mountain fog-related crash problem and develop a set of coordinated, cost-effective countermeasures to address the problems. This panel played an integral role in all stages of this project from its initial meeting until an action plan for implementing fog-related countermeasures was completed. The panel included

VDOT decision makers at the central office, district, and residency levels; persons with first-hand experience in operating and maintaining the current visibility equipment; experts in intelligent transportation systems (ITS); and state troopers who handle enforcement on the Afton and Fancy Gap Mountain corridors. The panel met three times.

Task 4: Develop Alternative Countermeasures for Consideration and Conduct a Trade Study: Trade study methodologies are often used to evaluate the merits of various systems and concepts before recommending that they be implemented or studied further. The technique uses a panel of experts to develop and weight the criteria by which a system will be judged and then, to rank the alternative systems. During task 4, the panel determined the criteria that should be used to rate which countermeasures would best address the fog-related problems on Afton Mountain and Fancy Gap. These criteria included cost, technical feasibility, accuracy, sensitivity, reliability, and durability of fog crash solutions. The expert panel, based on 18 weighted criteria, rated each possible solution.

Task 5: Program Fog Countermeasures for Afton and Fancy Gap: Based on the experience of the panel members, traffic engineering principles, and ITS expertise, the panel selected a set of countermeasures for near-term implementation and for future consideration.

RESULTS

Task 1: Analysis of Crash History

Police accident reports for crashes occurring between 1995 and 1998 on I-64 over Afton Mountain and I-77 over Fancy Gap Mountain were collected from VDOT archives of FR300 accident report forms. (This was the period of time for which crash data were available at the time of the panel's first meeting.) These accident reports provided detailed information for all accidents that occurred on I-64 between milepost 98 and 104, the fog prone area, in addition to a 5-mile segment on either side of the area. On I-77, data on crashes occurring between milepost 2 and milepost 9 were collected, with additional crashes from the Virginia/North Carolina border to milepost 14. Accident reports for the additional areas were collected to provide a comparison with the fog-prone stretch of road.

Results indicated that in both locations, almost all of the primary fog crashes occurred in a fairly restricted area (see Appendix A for more a more detailed description of these crashes). On I-77 over Fancy Gap, 70% of the fog-related accidents occurred between mileposts 6 and 8, the most fog-prone area, and 93% occurred between mileposts 5 and 9. On I-64 over Afton, 89% of the fog crashes occurred between mileposts 99 and 101.

Many of the fog-related crashes involved secondary or "follow-on" crashes. For instance, on I-64 at Afton, of 40 fog crashes, 9 were primary crashes and 31 were secondary. Many of these secondary crashes involved as many as 60 vehicles and occurred as long as 1 hour and 25 minutes after the primary crash. For these reasons, fog crashes resulted in more damage and more injuries than non-fog crashes. Based on these findings, the panel recommended that any action taken to avert fog crashes at these mountainous locations should include specific countermeasures to reduce the number of secondary crashes. It was also recommended that countermeasures that would reduce the variation in speed among vehicles traveling through fog be investigated, because speed variation is related to crash occurrence.

Task 2: Review of the Literature and State of the Practice

An extensive survey of states was conducted, with 49 responding. Many states have some sort of fog mitigation system located at sites that have a history of fog crashes, especially spectacular, multi-vehicle crashes. These systems consist of some combination of visibility sensors, static or variable message signs (VMSs), traffic or speed monitoring devices, communications lines, and a central control area. The systems differ with regard to their degree of automation. Some are equipped with algorithms that analyze the visibility and traffic conditions and automatically take action, e.g., display fog warning messages on the system's VMSs or set variable speed limits. Others require that a human operator confirm the lack of visibility, either in person or using closed circuit television (CCTV), and/or make the determination as to what action is called for.

In the United States, only a few evaluations of the impact of installing these fog-detection systems have been conducted. Most of the evidence of system effectiveness is anecdotal. (For example, the I-5 system in Stockton, California, displays fog messages as visibility decreases and highway advisories as average traffic speeds decrease. According to officials, in the years before the system was installed in 1996, there had been numerous multiple-car accidents, and since the system has been installed, there has been only one multiple car accident.) Utah's Adverse Visibility Information System Evaluation (ADVISE) system displays fog-warning messages and displays an advisory speed limit, which has been shown to reduce speed variance by 22% when activated.

In Europe, however, numerous fog and other weather systems have been in use for many years and have been extensively evaluated. Many of them have been shown to be effective in terms of crash reduction and reduction in speeds or speed variance. (For more information on these systems and their evaluations, see Appendix B.)

Task 3: The Panel of Experts

Panel members were chosen to represent decision makers throughout VDOT, as well as VDOT personnel experienced with the operation of the Afton fog system. The panel also included representatives from VSP from the Fancy Gap and Afton areas. The panel met three times, December 13, 1999; May 15, 2000; and November 6, 2000; and included the following members:

Representing VDOT:

Tillman G. Branson, Resident Engineer, Wise Residency
Leland Branham, Former Resident Engineer, Wise Residency
Jim B. Diamond, District Traffic Engineer, Staunton District
Jon C. DuFresne, ITS Operations Engineer, ITS Division
Junior H. Goad, Resident Engineer, Hillsville Residency
Vernon D. Hoke, Assistant Resident Engineer, Verona Residency
Jeffrey S. Hores, District Traffic Engineer, Culpeper District
Ronnie M. Hubble, District Traffic Engineer, Bristol District
Eugene A. "Gene" Martin, ITS Senior Demo Project Engineer, ITS Division
Christopher D. McDonald, Assistant District Traffic Engineer, Salem District
H. William Mills, Assistant Resident Engineer, Charlottesville Residency
Mark G. Richards, Transportation Engineer Sr., Traffic Engineering Division
Leon S. Sheets, Transportation Engineer Sr., Staunton District
Rod E. Turochy, Transportation Research Scientist, Virginia Transportation Research Council
Jerry R. VanLear, Resident Engineer, Verona Residency
Robert J. Yates, District Traffic Engineer, Salem District

Representing VSP:

1st Sgt. Jason Miles, Fourth Division
Sgt. Mike Musser, Fourth Division
Sgt. Joseph Rader, Third Division, Area 17

Advisors to the panel:

Col. W. Gerald Massengill, Superintendent, VSP
Capt. G. Howard Gregory, Division Commander, Third Division, VSP
Capt. W. Ken Paul Jr., Division Commander, Fourth Division, VSP
Tom Dingus, Director, VTTI
J. R. Robinson, Director, ITS Division, VDOT
Wayne S. Ferguson, Research Manager, VTRC

Task 4: Alternative Countermeasures for Consideration and the Trade Study

Prior to the first meeting of the expert panel, a list of potential fog countermeasures was created based upon information on what other states and countries have implemented and on other technologies that are available. This list was amended by the panel at its first meeting and was then expanded in order to make it as specific as possible. The panelists then determined which criteria would be used to judge each of the possible countermeasures and the weight each criteria would have in the judging. (Each weight represented a number of points out of 100.) The 18 criteria and their associated weights follow:

Technical Criteria

1. The system is technically feasible at the present time (11.5).
2. VDOT currently has individuals with the necessary expertise to support the technology (7.7).
3. The system has a potentially long lifetime (9.4).
4. The technology may be used for multiple purposes (8.7).

Operational Criteria

5. The system is reliable (14.8).
6. The system has a low potential for false alarms (10.9).
7. The system can easily attract the attention of all passing motorists (9.5).
8. Motorists will easily understand the countermeasure (13.9).
9. The system has an acceptable response time (11).
10. The system can decrease the potential for primary fog crashes (14).
11. The system can decrease the potential for secondary fog crashes (12.8).

Economic Criteria

12. The initial implementation costs of the system are low (6.8).
13. Subsequent operating costs are low (6.8).
14. Subsequent maintenance costs are low (6.3).

Policy, Legal, and Other Issues

15. The security of the system is high (7.3).
16. The system is considered favorable/acceptable by non-VDOT personnel (6.7).
17. The measure is enforceable by police/legal system (2.8).
18. The system will not create liability issues for VDOT (10.0).

Finally, the panel rated each countermeasure on the criteria and the possible fog solutions were rank ordered, as shown in Table 2.

Task 5: Fog Countermeasures for Afton and Fancy Gap

After the presentation and discussion of the results of the trade study, the expert panel voted on action plans for Afton Mountain and Fancy Gap. Some countermeasures were removed from the ballot prior to voting, specifically those that had not received 20 or more points and thus were not favored by a consensus of panel members, as well as rumble strips (which were already being implemented) and guardrail speed guides (which had not been proven to work in fog conditions). Several countermeasures were combined, since they were similar (1 & 4, 6 & 15, 12 & 14, 13 & 16, and 8 & 17). The panel then voted on the countermeasures, placing each countermeasure in one of four categories: immediate implementation, begin planning to implement, conduct more research before making final decision, and do not implement at this time. The results of the voting appear in Table 3.

Table 2. Rankings for Each Countermeasure in Each Criterion Category

Countermeasure	Overall Rank	Technical Rank	Operational Rank	Economic Rank	Other Rank
Pre-fog VMS messages based on traffic volumes, average speed	1	2	2	17	13
Highway Advisory Radio (HAR) for fog conditions	2	1	8	3	10
Increased police enforcement	3	20	3	11	1
Pre-fog VMS messages based on fog levels and average speed	4	3	1	19	21
Rumble strips	5	4	9	1	2
Static flashing light sign for fog warning	6	13	10	2	8
In-pavement fog lights flash as fog warning	7	5	5	25	7
In-fog VMS messages based on traffic volumes, average speed	8	7	4	21	20
Decreased spacing of in-pavement fog lights	9	10	7	18	3
VMSs for variable speed limits	10	14	6	9	25
Change color of fog lights	11	6	15	13	4
Static strobe light sign as fog warning	12	16	12	8	8
Static laser sign based on traffic speed and volume	13	15	13	5	18
Static strobe light sign based on traffic speed and volume	14	12	16	6	15
Static flashing light sign based on traffic speed and volume	15	11	17	6	15
Static laser sign as a fog warning	16	21	14	4	14
In-fog VMS messages based on fog levels and average speed	17	17	11	22	29
Guardrail speed guides activated by traffic volumes and average speed	18	22	20	14	11
Video cameras	19	9	23	16	6
Strobe lights activated by traffic volumes and average speed	20	19	18	29	22
In-pavement running lights activated by traffic volumes and average speed	21	18	21	20	19
Strobe lights activated messages based on fog levels and average speed	22	25	19	28	24
Drone radar	23	8	27	10	17
Guardrail speed guides activated by fog levels and average speed	24	27	22	24	23
Fog horn	25	29	24	12	26
Photo-enforcement based on radar	26	24	28	26	12
Photo-enforcement based on loop detector data	27	23	29	23	5
Audible traffic sign activated by traffic volumes and average speed	28	26	26	15	28
In-pavement running lights set to run toward the driver	29	28	25	27	27

Table 3. Results of the Expert Panel Action Plan Vote

Countermeasure	Immediate Implement	Begin Planning to Implement as Soon as Possible	Conduct More Research Before Making Final Decision	No Implementation at this time
(19) Video cameras (one abstained)	12	0	0	1
(1 & 4) VMSs prior to the fog-prone area warning drivers of detected incidents and fog events	8	5	1	0
(2) HAR for fog conditions	8	2	3	1
(3) Increased police visibility, including increased patrols and possible staff assigned to Afton	4	10	0	0
(10) VMSs with variable speed limits	1	1	12	0
(12 & 14) Static strobe-equipped light sign warning drivers of fog or stopped/slowed traffic	3	1	9	1
(13 & 16) Static laser sign warning drivers of fog or stopped/slowed traffic	1	0	8	5
(8 & 17) VMSs in the fog zone warning drivers of detected incidents and fog events	1	3	7	3
(7) Current fog lights flash on and off when stopped/slowed traffic detected	2	1	5	6
(9) Decrease spacing of fog lights	0	0	6	8
(11) Change color of fog lights	0	0	6	8
(6 & 15) Static flashing light warning drivers of fog or stopped/slowed traffic (one abstained)	5	1	3	4

Four countermeasures were not programmed for implementation as a result of the balloting. Three dealt with using the guide lights embedded in the pavement on Afton Mountain either to communicate to drivers concerning conditions ahead or to reduce driver complacency and comfort during fog (changing their color or spacing them further apart). The fourth dealt with static signs in the fog area warning of stopped vehicles ahead. This countermeasure received votes in several categories, but there was no consensus among panel members.

CONCLUSIONS AND RECOMMENDATIONS

Countermeasures Programmed for Immediate Implementation

1. Install Video Cameras on Afton and Fancy Gap Fog Areas

The countermeasure that received the highest number of votes for immediate implementation was the installation of CCTV at the fog sites. Installation of the "AftonCam" is in the planning stages. Images from the Afton-Cam will be available to the public on the VDOT or TravelShenandoah web sites, allowing the public to plan trips more safely. In addition, CCTV has been used extensively to confirm visibility detector readings in fog mitigation systems prior to taking action, and the Afton-Cam could eventually serve this purpose on I-64.

This is a relatively inexpensive measure for Afton Mountain, since the fiberoptic spine already exists and local wireless communications companies have shown an interest in participating in this installation. The budget for the camera and installation is $12,000. The panel recommended that CCTV also be included in any system implemented on I-77 at Fancy Gap. In addition, it is recommended that VDOT look into new, low-temperature, infrared camera technology that is purported to be able to record images through fog.

2. Install VMSs Prior to the Fog Prone Area Warning Drivers of Detected Incidents and Fog Events

The countermeasure receiving the second highest number of votes for immediate implementation involved installing VMSs along the roadside in the areas just prior to the fog zone. On I-64 at Afton, this would mean installing VMSs at least between milepost 98 and 99 and from milepost 101 to 104, since the major fog prone area extends from milepost 99 to 101. On I-77 at Fancy Gap, this would mean, at least, installing VMSs between milepost 2 and 6 and from milepost 8 to 9, since the most fog prone area extends from milepost 6 to 8. Consideration should also be given to extending the signing into the pre-fog area adjacent to both locations. These VMSs would be tied to visibility detectors and to some form of incident detection or speed monitoring device to identify vehicle slowdowns or stoppages ahead.

It should be noted that the panel *did not* include installing VMSs inside the fog prone area among the countermeasures for immediate implementation, since little is known about the legibility and visibility characteristics of VMSs in fog. Instead, they recommended that highway advisory radio (HAR) be used in the fog zone and that more research be done on the subject of VMS legibility and visibility in fog.

The cost of fog mitigation systems depends upon the type and amount of equipment installed and the level of automation involved (Table 4). Systems extending over long segments of highway or making intensive use of sensors and signs tend to cost more than shorter or simpler systems. Those that use complex algorithms to determine the action that needs to be taken also tend to cost more, as do systems requiring fiber optic or wireless communications. Among the existing fog systems for which there were figures available, the costs ranged from $18,000 for individual components to $4.460 million for a complete system. (It should be noted that since these systems were installed at different times, the value of the dollar differs among systems.)

Construction of a fog mitigation system on I-77 at Fancy Gap Mountain has already begun. Therefore, the panel has recommended that VDOT's Central Office ITS personnel and the engineers in the Salem District work together to include both fog detection and incident/speed detection in the system, as well as VMSs and HAR to communicate with drivers both as they approach the most fog prone area and as they travel into it. It is also recommended that the fog mitigation system on Afton Mountain be upgraded to include incident/speed detection, as well as VMSs and HAR.

3. Use Highway Advisory Radio for Fog Conditions

Rather than the option of visually communicating with drivers trying to navigate in dense fog, the panel chose the option of installing HAR on Fancy Gap and Afton. HAR has not often been used in Virginia fog systems to date but seems to be a relatively low cost option. In Tennessee, the cost of adding HAR to their extensive fog system was estimated at about $28,000. However, according to Pennsylvania figures, the low bid for including HAR in their system was $160,000. This discrepancy may be due to whether the HAR was portable or permanent, the power and range, and the number of broadcast units.

A more meaningful estimate of costs comes from VDOT's Richmond District, where five HARs (along with the six sign control systems) were recently installed. Each of these units was permanent and had a minimum range of 3 miles in each direction, based on 4 watts of power. The total cost was about $152,000. Since the two Virginia fog sites are in mountainous areas, it is likely that separate HARs would have to be installed on each side of the mountain to ensure adequate coverage.

It is recommended that VDOT also include HAR in its plan for the Fancy Gap Fog Mitigation System for use in the most fog-prone area, milepost 6 to milepost 8. It is recognized that to some drivers, radio becomes a distraction when they try to navigate in dense fog or in other complex driving tasks. It is also recognized that many drivers' chief complaint about HAR is that obsolete messages remain active after conditions have changed. It is therefore recommended that the posting (and removal) of HAR messages be a totally automated part of the I-77 system. In addition, it is recommended that the use of HAR and its utility to drivers in fog on I-77 be evaluated by VDOT.

Countermeasures Programmed for Planning Efforts As Soon As Possible

4. Plan to Increase Police Visibility in Both Fog-prone Areas, Including Increased Patrols and Possible Staff Assignment to Afton Mountain

Several fog systems in use in the United States are augmented by a 24-hour police presence to help control speeds, verify visibility problems, and assist in emergencies. Some fog systems in other states are actually run by state or local police.

Table 4. Cost Data for Fog Mitigation Systems in the United States

Location	Length	Visibility/Weather Detectors	VMSs	Traffic/Speed Detectors	Cost
I-10 (Mobile, Alabama)	6.2 miles	6 visibility sensors	4 VMSs, CCTV	Loop detectors	$18,000 excluding VMSs and loops
Rt. 99/I-5 (San Joaquin Valley, California)	Unknown	15 Road Weather Information System (RWIS) stations, plus fog detectors, visibility test signs	80 VMSs	None	$3,600,000
I-5/Rt. 205 (Stockton, California)	16 miles	9 RWIS stations	9 VMSs	36 inductive loop sensors	$2,750,000 -- $2,770,000
Planned I-75 (Georgia/Florida border)	2 miles	19 visibility sensors	Light emitting diode (LED) VMSs	5 loop detectors	$1,410,500
I-25 (Colorado)	Unknown	None, visibility reported by CDOT personnel	6 roadside VMSs, overhead VMSs	None	$275,000
I-69 (Fort Wayne, Indiana)	¾ mile	1 visibility sensor	LED VMSs	None	$155,000
I-40 (Haywood County, North Carolina)	5 miles	3 visibility sensors	2 VMSs	None	$1,100,000
Rt. 22 (Crescent Mountain, Pennsylvania)	2 miles	1 RWIS	VMSs, Highway Advisory Radio	None	$411,010 plus $1,200,000 in upgrades
I-75 (Calhoun, Tennessee)	19 miles	8 fog detectors, 2 RWIS stations	20 VMSs	22 speed detectors	$4,460,580
I-215 (Salt Lake City, Utah)	Unknown	4 fog sensors	2 VMSs	6 loop detectors	$461,000

Currently, Virginia state troopers patrol the Afton and Fancy Gap corridors as often as possible, but personnel limitations preclude 24/7 coverage. In order to increase police presence, troopers must be moved from areas where they are now assigned; however, they are already assigned to areas that have a demonstrated need. For instance, on the west side of Afton Mountain, troopers are often assigned to patrol I-81. Troopers assigned to the east side of Afton in Charlottesville patrol I-64 exclusively but often are called to areas away from Afton Mountain. During inclement weather, the troopers assigned to the west side of Afton are authorized to patrol I-64 as far east as Crozet, and Charlottesville troopers are authorized to patrol as far west as Waynesboro, creating an overlap in responsibilities. Even so, there are significant periods of time when no troopers are patrolling the Afton Mountain area.

Clearly, if state troopers are to be assigned to patrol the Afton and Fancy Gap areas, the number of state troopers authorized by the General Assembly will have to be increased. Therefore, it is recommended that VDOT strongly support efforts by VSP to increase the number of state troopers available to patrol I-64 over Afton Mountain and I-77 over Fancy Gap Mountain.

In addition, VSP has shown an interest in establishing a post on Fancy Gap Mountain. It is further recommended that VDOT also support these efforts by VSP.

Countermeasures Programmed for Further Research

5. Investigate the Use of VMSs Displaying Variable Speed Limits

From the review of traffic management and incident detection systems, variable speed limits seem to be used with two purposes in mind: (1) to reduce congestion and speed variance in non-weather-related systems, and (2) to respond to specific hazardous conditions for which the fixed speed limits may be inappropriate, such as low-visibility conditions. A number of the fog mitigation systems in the United States and Europe use variable speed limits. (For more information on how variable speed limits are currently viewed in Virginia law, see Appendix C.) Most systems have used loop detectors to determine speed, although a few, like Tennessee, have also used speed-monitoring devices, specifically pole-mounted radar units. According to a survey of eight manufacturers, the presence or density of fog does not affect the accuracy of standard police radar but can reduce the range under which it can operate. Rainfall of about 2 inches per hour reduces the range from the normal 3,500 feet down to as little as a few hundred feet. Fog, even heavy fog, does not have as serious an effect as does rain. In addition, the presence of fog has less of an effect on "across the road" radar than it does on "down the road" radar, since range is less of an issue. This might be a lower cost option than the installation of loop sensors.

In the European systems, variable speed limits have been effective in reducing speed variance and creating a more uniform speed distribution. A more uniform distribution results in fewer secondary crashes.[3,4] However, due to the high cost of instituting variable speed limit systems (between $400,000 and $1,000,000 in 1996 dollars), the Federal Highway

Administration recommended that such systems be implemented in areas where the environment and/or traffic conditions result in significant fluctuations in the desired speed.[5]

The expert panel recommended that VDOT further investigate the feasibility and effectiveness of using variable regulatory speed limits or variable advisory speed limits in Virginia by including this capability in the I-77 visibility system. This may mean the increased use of portable VMSs or specific variable speed limit signs. Initially, the use of variable speed limits will apply only to advisory speeds, since these do not require legislative authorization. However, the panel recommends that VDOT support legislation that would authorize the experimental use of regulatory variable speed limits on I-77 during fog events for a specific time period for the purpose of evaluation.

6. Study the Impact of VMSs, Static Strobe-Equipped Light Signs, Static Laser-Augmented Signs, and Static Flashing Light Signs Inside the Fog Zone to Warn Drivers of Detected Incidents and Fog Events

Very few studies on the legibility and visibility of VMSs have included fog conditions. Thus, the usefulness of these signs in communicating with drivers while they are traveling though fog is unknown. In addition, there may be changes in the intensity, size, location in relation to the roadway, and viewing angle with respect to the direction of traffic that might improve the utility of VMSs in inclement weather. It is recommended that VDOT undertake an evaluation of the use of VMSs in fog and possible VMS design alternatives to improve legibility and visibility. In addition to research on VMSs in fog conditions, the panel recommended that VDOT undertake additional research on static signs equipped for special visibility in fog.

The Use of Expert Panels in ITS Deployment

In the early days of development of ITS solutions to traffic problems, little thought was given to the issue of deployment. Promoting deployment of ITS countermeasures still lags behind the development of the technology itself in many cases. Reluctance on the part of transportation professionals to embrace new and untried technological solutions was based on experience. In the early days of ITS, the technology was expensive, it often ignored the human factors components of development, and in many cases, it did not work reliably. Thus, rather than promote the aims of VDOT, these new technologies eroded VDOT's credibility with the public and caused headaches for its administrators.

Although the quality and reliability of current transportation technologies have caught up with the needs of transportation professionals, many still unintentionally follow the maxim of "once bitten, twice shy," especially since VDOT and its decision making is under such scrutiny by the media and the public.

Although it was not the intention of this effort to evaluate the use of expert panels, the positive aspects of this experience may indicate that this method could be used to promote more extensive ITS deployment. This panel met only three times. At the first meeting, the panel was presented with background information on the nature of fog events, the characteristics of crashes at the two fog-prone sites, and countermeasures that might prove effective in mitigating the effects of fog. At that same meeting, they clarified their objectives for the fog-prone areas and finalized a list of possible solutions for consideration. At the second meeting, they heard an updated report on the effectiveness of the selected countermeasures in other states and countries, and they then voted on programming and scheduling options for each countermeasure. At their final meeting, they discussed and amended their recommendations. Because the panel represented experts from all levels of VDOT, as well as from VSP, and had extensive knowledge and experience with the fog problems under consideration, they were able to develop a comprehensive list of fog countermeasures and assess each from their various points of view. Because the group also had ITS representatives with the extensive technical expertise to advise them, they had confidence that their recommendations were both workable and effective.

It may be that this method of building consensus and support for ITS deployment can be effectively used to promote the use of ITS technologies.

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APPENDIX A

RESULTS OF CRASH ANALYSES FOR FANCY GAP, AFTON MOUNTAIN, AND RT. 23 IN WISE COUNTY

Prior to the first meeting of the expert panel, crash analyses were conducted to determine the frequency and severity of fog crashes on Afton Mountain and Fancy Gap, as well as the characteristics of these crashes. In addition to these two sites, a section of Rt. 23 near Norton in Wise County was included in the analysis due to public concerns about a perceived fog problem in that area. The results of these analyses were presented at the first meeting of the expert panel on December 13, 1999.

Analysis of Fog-Related Accidents on I-77 near Fancy Gap

The stretch of I-77 between mileposts 2 and 9 has a long history of problems associated with fog. This analysis was carried out to determine the number and location of fog crashes, as well as the number and severity of injuries in fog crashes compared to non-fog crashes.

Methods

Police accident reports totaling 218 accidents were collected from the VDOT archives for the years 1995 through 1998. These accident reports provided detailed information for all accidents that occurred on Interstate 77 between the Virginia/North Carolina border and milepost 14. The area that is prone to fog lies between mileposts 2 and 9. Accident reports for the additional areas were collected to provide a baseline for the fog-prone stretch of road.

The accident reports were then separated into two groups: accidents that occurred in the fog-prone area and accidents that occurred in the baseline region. Accident reports were further separated into accidents that were fog related and those that were not fog related. There were two criteria for determining whether fog was a contributing factor to an accident. First, the box on the FR300 Accident Report Form corresponding to existing weather conditions had to indicate foggy weather. Second, the officer had to report that fog was a contributing factor to the accident. This happened in one of two ways: (1) the box corresponding to driver vision would state that the driver's vision was obscured (normally this occurred by the officer entering the number corresponding to "other"), or (2) the officer would indicate in the narrative that fog was a factor.

Results and Discussion

Analysis of the accident reports showed that there were 218 total incidents between the North Carolina/Virginia border and milepost 14. Of those incidents, 139 (or 63 percent) occurred in the fog-prone area between mileposts 2 and 9. Furthermore, as Figure A-1 shows, 61 percent of the accidents that were not attributable to fog occurred in the fog-prone area. This suggests that the area of roadway between mileposts 2 and 9 is a relatively dangerous area even when fog is not present.

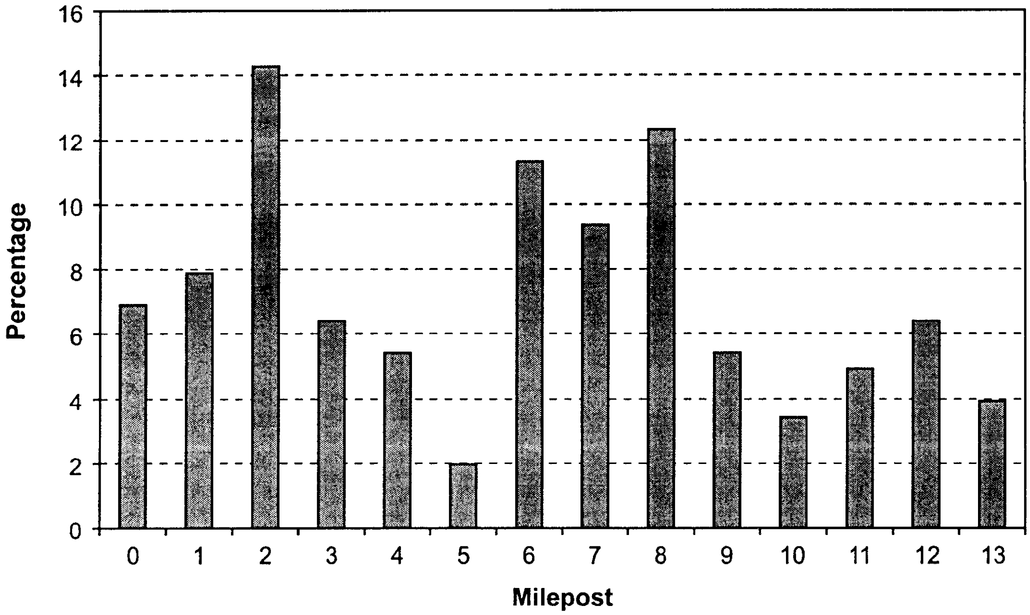

Figure A-1. Milepost where non-fog-related accidents occurred on Interstate 77.

A total of 14 accidents, 6 percent of all crashes, were attributable to fog. All of these accidents occurred between miles two and nine. The most severe of these accidents are presented in Table A-1. The incident which occurred on Valentine's Day of 1997 involving 56 vehicles stretched for one mile (from mile 6.5 to 7.5) and a half hour passed in this chain reaction accident between the time that the first vehicles collided and the last vehicles struck. The incident on March 19, 1997 stretched for 0.7 miles with one hour and five minutes between the first and last collisions. The third, on October 5, 1998, stretched for 0.9 miles with only 15 minutes between the first and last collisions. Clearly, it is the many chain-reaction or secondary crashes that constitute the major crash problem on Fancy Gap, rather than the 14 primary crashes that caused the secondary crashes to occur.

The 14 fog-related incidents accounted for ten percent of all incidents that occurred in the fog-prone area. These accidents however, had a disproportionate amount of damage associated with them. The 14 fog accidents involved a total of 157 vehicles, or 44 percent of all the vehicles that were involved in accidents between miles two and nine. Figure A-2, which shows the average number of vehicles per incident, demonstrates that fog-related accidents involved on average more than seven times the number of vehicles as non-fog-related accidents. Fog-related incidents averaged 11.21 vehicles per incident, while non-fog-related incidents between miles two and nine average 1.55 vehicles per incident, and the baseline region averaged 1.46 vehicles per incident.

Table A-1. Multi-vehicle Fog-related Crashes on I-77, Fancy Gap Mountain

Date	Time	Milepost/Direction	Number of Vehicles	Number of Injuries
2/14/97	12:15 PM	6.5 S	56	12
3/19/97	9:30 AM	5.2 N	15	4
10/5/98	11:30 AM	7.0 N	46	15

Fog-related incidents also accounted for a disproportionate amount of injuries per incident. There were a total of 168 injuries that occurred in accidents during the period studied. Thirty-seven of these injuries were a result of fog-related accidents. This accounts for 22 percent of all injuries and 31 percent of all injuries that occurred between mileposts 2 and 9.

As shown in Figure A-3, fog-related incidents averaged 2.64 injuries. Non-fog-related incidents in the fog-prone area averaged 0.67 injuries and in the baseline region averaged 0.59 injuries per incident.

However, this does not necessarily reflect the danger of fog-related accidents accurately. It would be expected that the number of injuries in fog-related accidents would be higher than in non-fog-related accidents since there are on average a greater number of vehicles involved. The more vehicles involved, the more people involved, and therefore there are more chances for injury. Another measure of the severity of fog-related accidents is the number of injuries per vehicle. As shown in Figure A-4, fog-related incidents had a slightly lower ratio of injuries per vehicle than non-fog-related incidents. Fog-related incidents averaged 0.24 injuries per vehicle involved, while other incidents averaged 0.43 injuries per vehicle and accidents in the baseline area averaged 0.41 injuries per vehicle.

Another measure of the severity of fog-related accidents is the severity of the injuries that occur in these incidents. Police accident reports break down injuries into five categories:

1. died before report made
2. visible signs of injury (such as bleeding wound)
3. other visible injuries (such as bruises, abrasions, and swelling)
4. no visible injuries but complains of pain or momentarily unconscious
5. died at a later date.

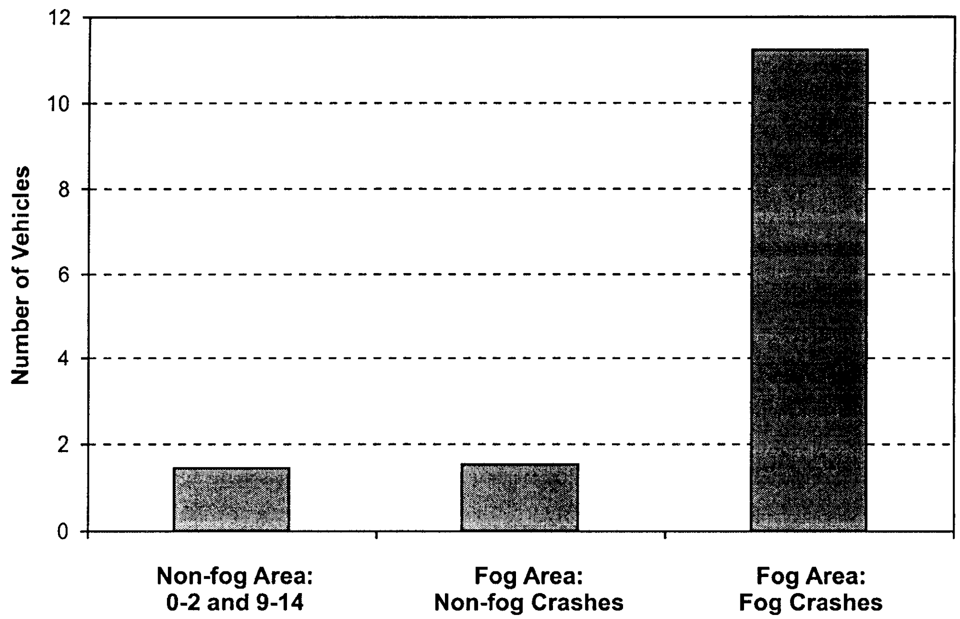

Figure A-2. Average number of vehicles per incident for Fancy Gap Mountain.

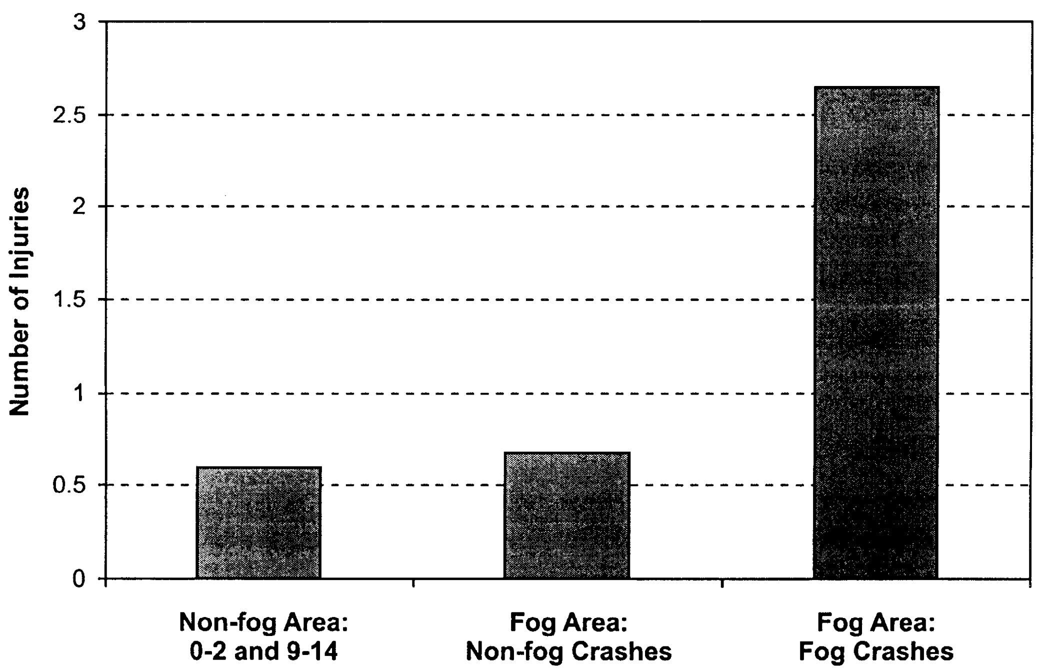

Figure A-3. Average number of injuries per incident for Fancy Gap Mountain.

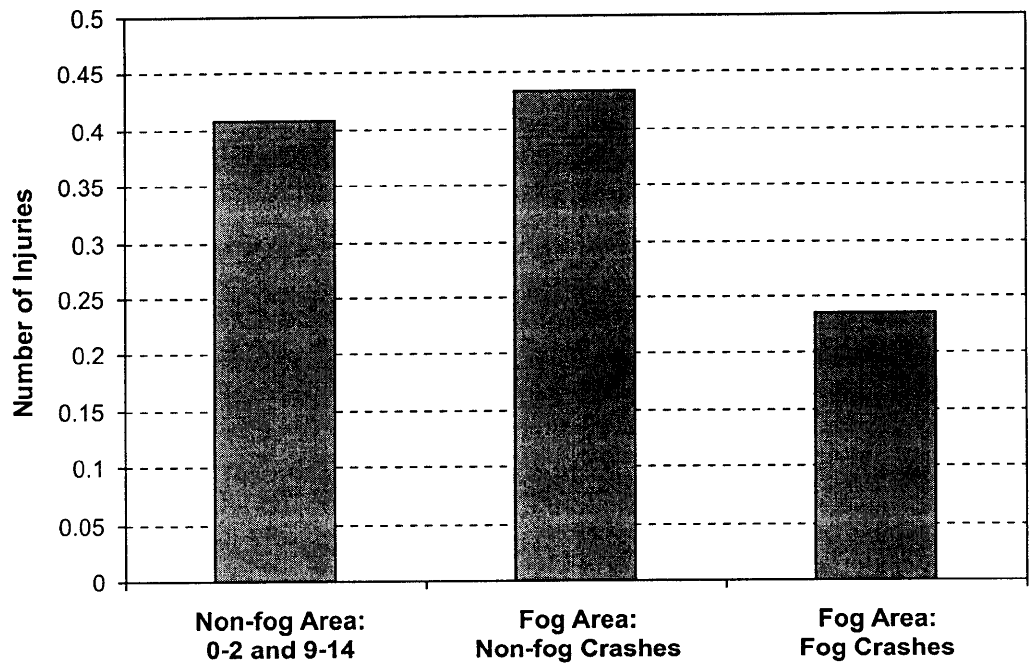

Figure A-4. Average number of injuries per vehicle for Fancy Gap Mountain.

No injuries in any accidents that were studied fell in the fifth category. For this analysis, all non-fog accidents were combined into one category. As shown in Figure A-5, the pattern of injuries between fog-related accidents and non-fog-related accidents is overall quite similar but with a few differences. Fog-related accidents had a lower percentage of more serious category 2 injuries (46 percent for fog-related incidents compared to 56 percent for non-fog-related incidents) and a slightly higher percentage of category 4 injuries (46 percent for fog-related incidents compared to 33 percent for non-fog-related incidents). This is probably because secondary fog crashes occur at lower speeds than do non-fog crashes.

Fog accidents become dangerous because of their chain reaction nature. There is a primary accident, and then due to poor visibility, other motorists are unable to see the accident until it is too late, and one or more secondary accidents may occur. An analysis was conducted to determine the severity of the primary accidents compared to the severity of the secondary accidents. Again, injury data were used. The results are shown in Figure A-6. Secondary accidents resulted in more injuries. This is due to a greater number of secondary accidents than primary accidents. However, primary accidents resulted in more serious injuries than secondary accidents. Eighty-three percent of all injuries in primary accidents were category 2 injuries, compared to only 28 percent of injuries in secondary accidents. Sixty percent of secondary accident injuries were in the less serious category 4.

The results of the analysis up to this point have shown the frequency and severity of fog-related accidents on Fancy Gap Mountain. If countermeasures are going to be implemented to reduce the likelihood of future fog-related accidents, it would be helpful to know if there is a particular area where these accidents occur. Figure A-7 shows where fog-related accidents occur. There was a clear pattern. Seventy percent of all fog-related accidents occurred between mileposts 6 and 8, and 93 percent occurred between mileposts 5 and 9. Therefore, it would be prudent if any countermeasures that were developed focused on this area.

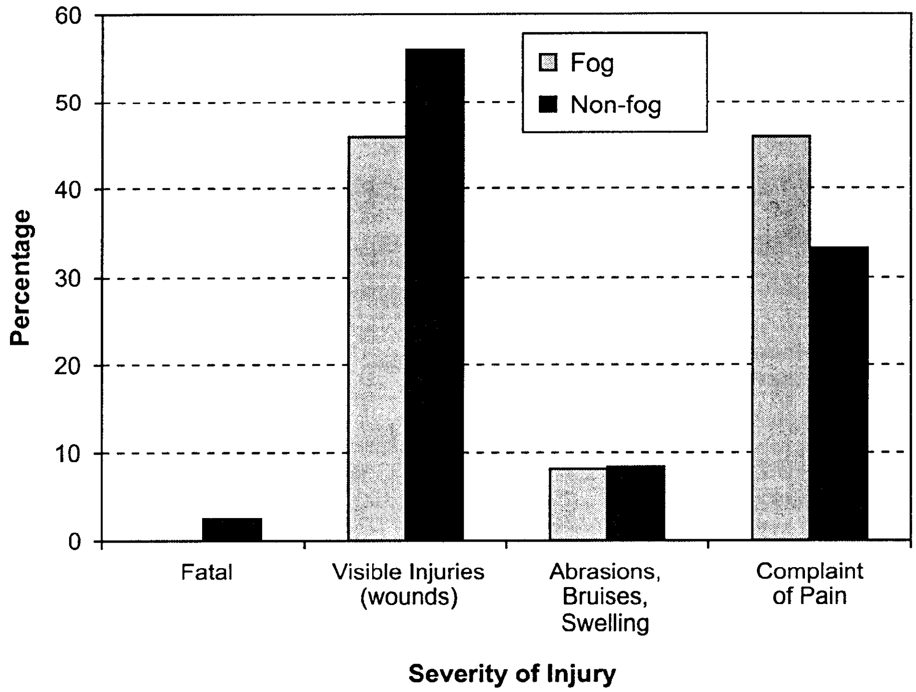

Figure A-5. Severity of accidents, fog vs. non-fog for Fancy Gap Mountain.

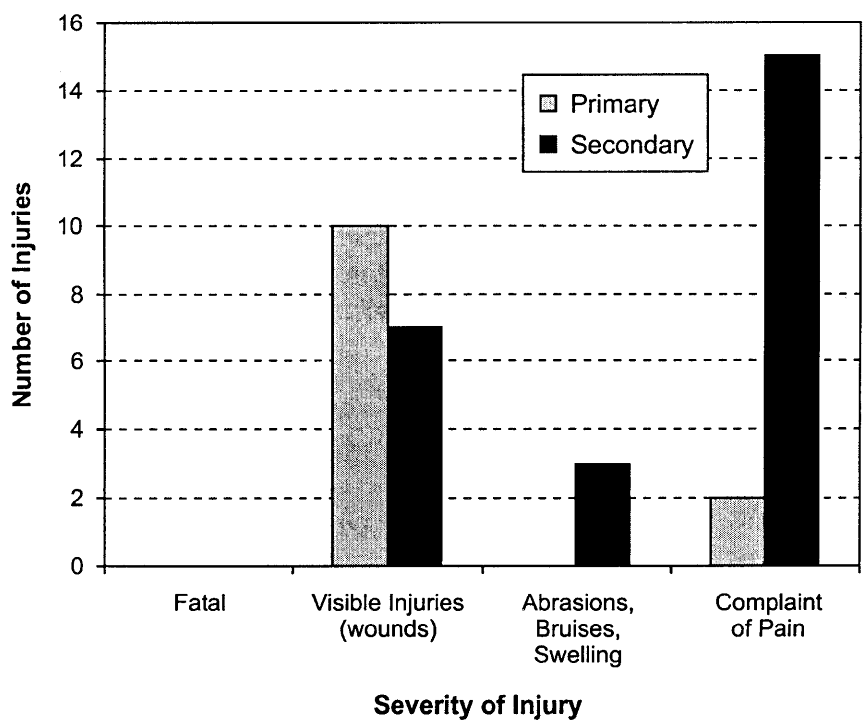

Figure A-6. Number and severity of injuries: primary versus secondary fog accidents for Fancy Gap Mountain.

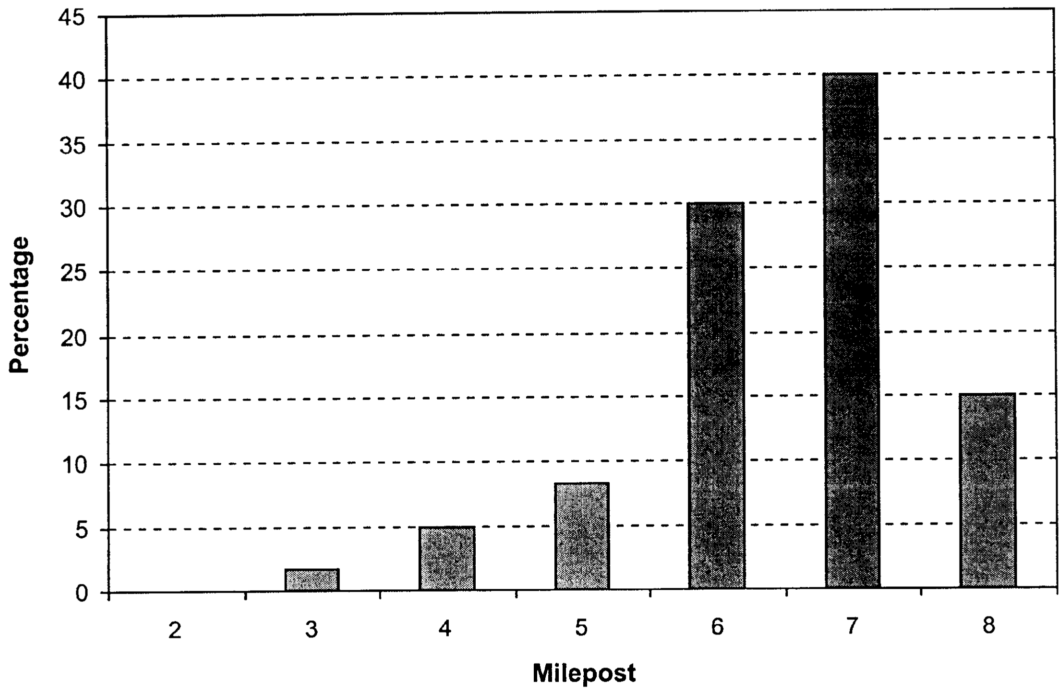

Figure A-7. Where fog-related accidents occurred on Fancy Gap Mountain.

Analysis of Fog-Related Crashes on I-64 over Afton Mountain

Almost as soon as I-64 opened on Afton Mountain in December 1972, it became clear that the long-standing fog problem on Route 250 would apply to I-64 as well. In fact, the dedication ceremonies were shrouded in fog, and 12 days after opening, the first 10-car crash occurred. Thus, between May 15, 1974, and March 15, 1976, a 5.8-mile segment of I-64 over Afton was equipped with fog guidance lights, and in 1997, when the system was approximately 20 years old, a major upgrade was implemented by VDOT. As part of this upgrade, the edgeline lights were made brighter and five new visibility sensors were installed, which will be tied to 10 VMSs, 2 on I-64 at interchanges prior to Afton Mountain and 8 on I-64 feeder roads.

Based on the 1970s evaluation of the fog guidance system, between 2/28/73 and 9/30/74 (the 19-month period before the installation of the fog lights), there was a total of 40 crashes in the 5-mile fog project area, 4 of which were fog related (see Table A-2). This dropped to 31 crashes and 1 fog crash between 2/28/75 and 9/30/76, the 19-month period after installation. Between 2/27/95 and 9/30/96, another 19-month period, there were 60 crashes in about the same area, 5 of them fog related. In the 19 months preceding the end of 1998, there were 54 crashes, only 2 of which were fog crashes.[1]

Table A-2. Number of Fog Crashes on Afton Mountain

	2/28/73 to 9/30/74	2/28/75 to 9/30/76	2/27/95 to 9/30/96	6/1/97 to 12/30/98
Total Crashes	40	31	60	54
Fog Crashes	4	1	5	2

Methods

For this analysis, the same definitions and methods were used as were employed in the analysis of the I-77 accident data. There were 332 total crashes in the three segments of I-64 over Afton Mountain in 1995 through 1998. The fog-prone area ran from mileposts 98 to 204; the non-fog comparison areas ran for 5 miles on either side of the fog area. Of the 40 fog-related crashes, 9 were primary crashes and 31 were secondary.

Results and Discussion

As seen in Table A-3, of the nine fog crashes, only one—the nighttime crash—occurred outside the fog prone area. Five of the crashes were one- and two-vehicle accidents, while four were of the spectacular, multi-vehicle variety. Figure A-8 shows that most of the crashes occurred in areas that were high-accident locations overall—eight occurred between mileposts 99 and 101. About 20% of all non-fog-related crashes occurred in this interval, while about 89% of the fog crashes occurred there.

Table A-3. Summary of Primary Fog Accidents on Afton Mountain

Date	Time	Milepost/Direction	Number of Vehicles	Number of Injuries
02/27/95	6:10 p.m.	99.05 W	2	1
03/05/95	8:50 a.m.	104.5 E	1	0
11/14/95	3:40 p.m.	100.1 E	2	2
02/23/96	3:15 p.m.	99.5 E	16	1
03/28/96	12:25 p.m.	100.2 W	1	0
05/26/96	11:50 a.m.	99.8 E	18	9
04/19/98	12:30 p.m.	99.05 E	62	22 (40)
05/07/98	4:10 p.m.	99.7 W	21	7
Non-Fog Area				
03/29/96	2:10 a.m.	99.08 E	1	0

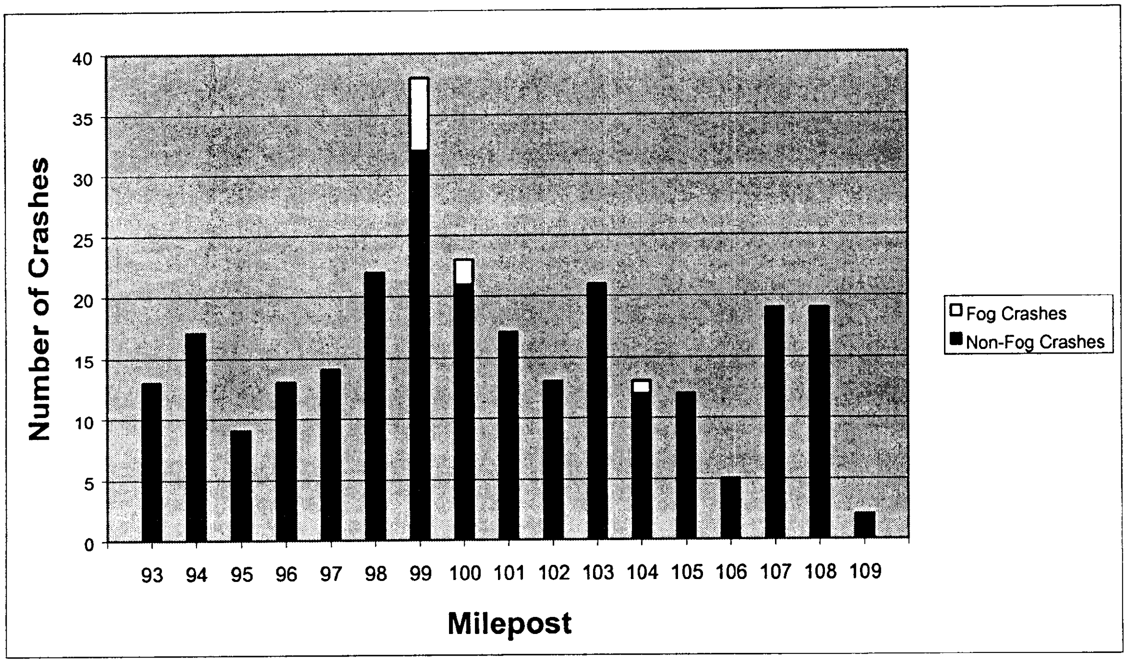

Figure A-8. Milepost at which accidents occurred on Afton Mountain.

As seen in Figures A-9 and A-10, on average, the fog crashes involved many more vehicles and more injuries. Of course, this is largely due to the contribution of the four multi-vehicle fog crashes. However, as seen in Figure A-11, the number of injuries per vehicle within the fog-prone area was lower than outside the fog area. Vehicles in the crashes outside the fog zone were traveling at higher speeds, due probably to the topography of the area. In addition, in the multi-vehicle crashes, many of the follow-on crashes occurred at lower speeds.

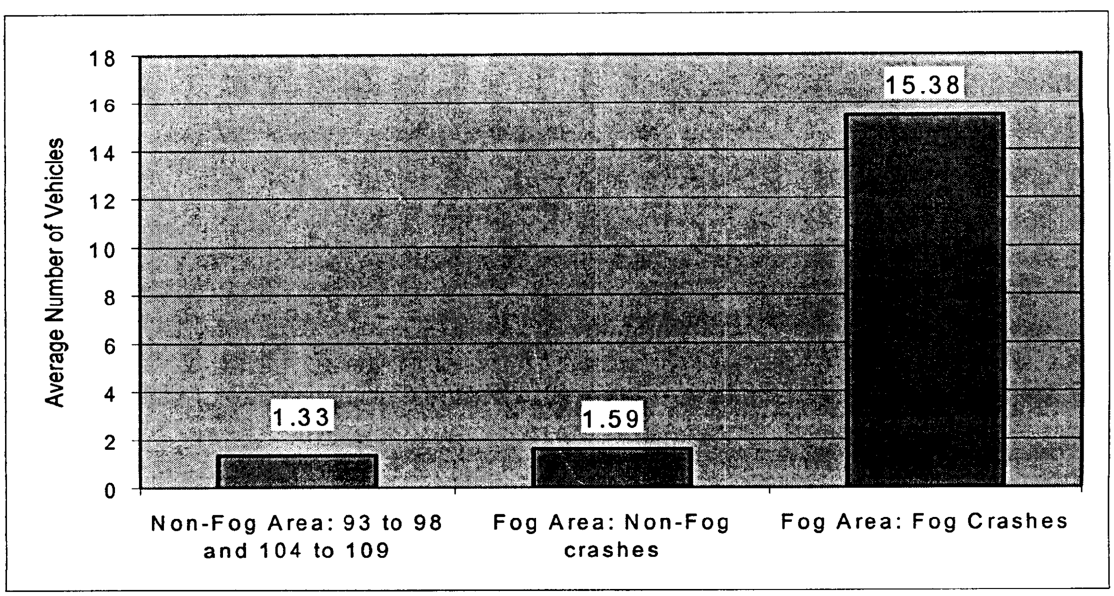

Figure A-9. Average number of vehicles per fog accident on Afton Mountain.

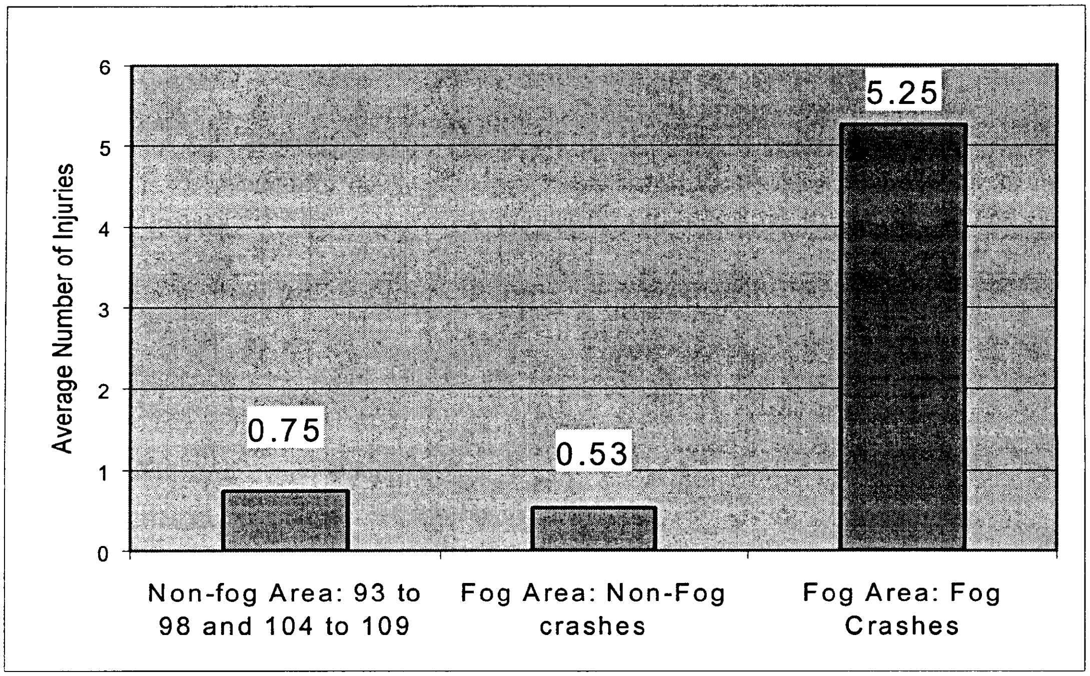

Figure A-10. Average number of injuries per fog accident on Afton Mountain.

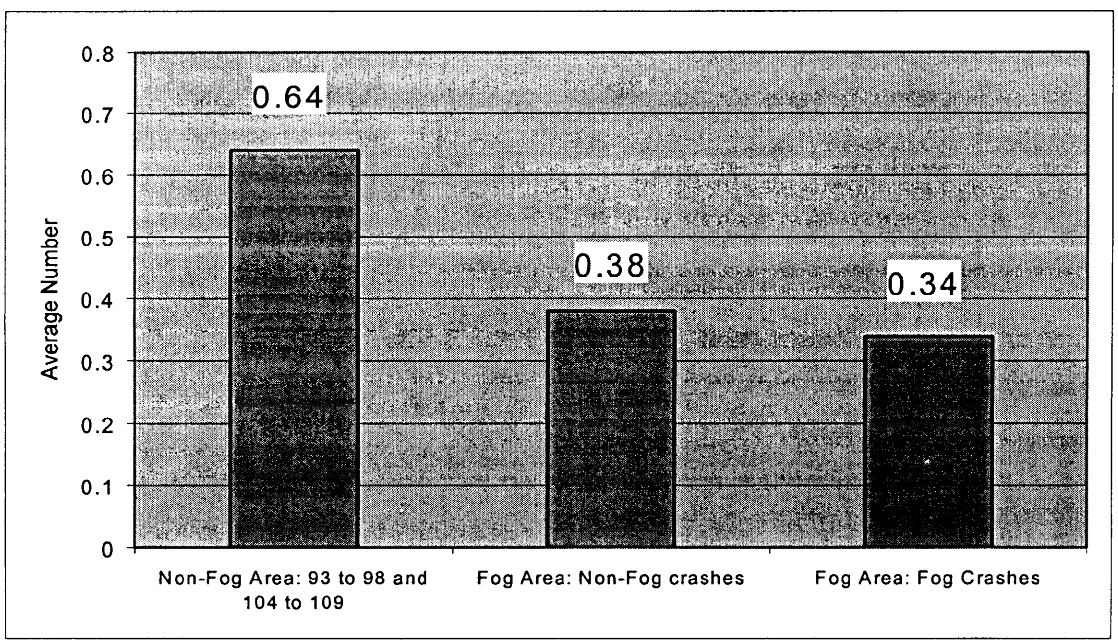

Figure A-11. Average number of injuries per vehicle for Afton Mountain.

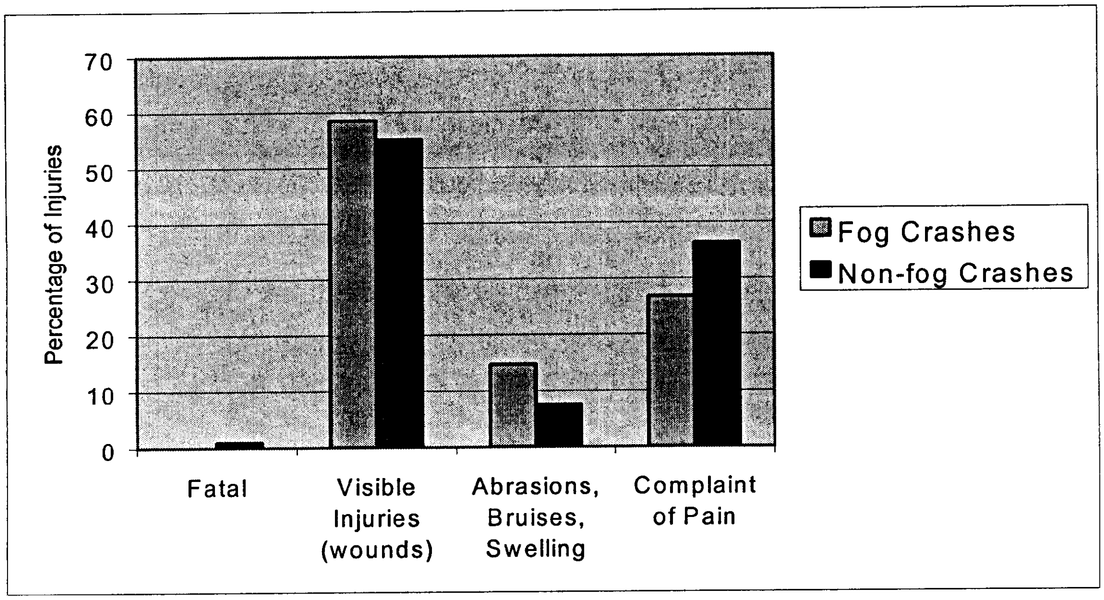

Figure A-12. Percentage of each type of injury for fog and non-fog crashes for Afton Mountain.

Another measure of the severity of fog-related accidents is to break down the injuries that occur. For this analysis, all non-fog crashes were combined into one category. As shown in Figure A-12, fog-related crashes had a slightly higher percentage of visible injuries (bleeding, abrasions, swelling) and a lower percentage of complaint of pain than non-fog-related crashes. In addition, because there were 31 secondary crashes resulting from nine primary fog crashes, secondary crashes generated more injuries than did primary ones.

Possible Causes of Fog-Related Crashes

In order to substantiate that the weather was a causal factor in fog-related crashes, a number of other possible contributing factors were examined. These included drinking, driver fatigue or illness, roadway defects, and vehicle defects. As seen in Table A-4, none of these factors was present in the fog crashes. However, in five of the nine crashes, excessive speed was considered to be a factor. This was true in all four of the large, multi-vehicle crashes.

Possible Countermeasures to Address the I-64/Afton Crash Problem

There are a number of possible solutions that might reduce crashes on Afton Mountain. First, since there are so many secondary fog crashes arising out of primary ones,[9] some sort of incident detection system that could warn drivers of crashes or stopped/slowing vehicles ahead could be useful. In addition, depending on why drivers are traveling above the safe speed in the Afton fog zone, variable speed limits might be useful as a way of alerting drivers to the dangers of high speed. Also, if the drivers' false sense of security is contributing to the speed problem, human factors solutions to reduce complacency without endangering drivers could be applied.

Table A-4. Type of Crash and Factors Involved in Each Fog Accident on Afton Mountain

Date	Time	Number of Vehicles	Collision Type	Other Factors
02/27/95	6:10 p.m.	2	Fixed Object/Rear-end	
03/05/95	8:50 a.m.	1	Fixed Object	
11/14/95	3:40 p.m.	2	Rear-End	
02/23/96	3:15 p.m.	16	Rear-End/Angle	Speed
03/28/96	12:25 p.m.	1		
05/26/96	11:50 a.m.	18	Rear-End/Angle	Speed
04/19/98	12:30 p.m.	62	Rear-End/Angle	Speed
05/07/98	4:10 p.m.	21	Rear-End/Angle	Speed
Non-Fog Area				
03/29/96	2:10 a.m.	1	Overturned	Speed

Analysis of Fog-Related Crashes on Rt. 23 near Norton in Wise County

The fog crash problem on Rt. 23 near Norton is very different from the problems on I-77/Fancy Gap and I-64/Afton. One difference is that it is a primary route, even though portions are built to near interstate standards. Another difference is how the route came to be evaluated in this study. While both Afton and Fancy Gap had experienced spectacular, multi-vehicle crashes, most of the crashes on Rt. 23 involved only one or two vehicles. It was the perception of citizens that Rt. 23 was hazardous in fog that brought the roadway to the study team's attention.

Results and Discussion

Characteristics of crashes on Rt. 23 are also quite different from these on Afton and Fancy Gap. There were 147 crashes in the study area from 1995 through 1998. Of those, 6 were fog related and 136 were not. Interestingly, unlike the other two sites, it was the non-fog-related crashes that resulted in follow-on, secondary crashes, albeit very few.

As seen in Table A-5, most of these crashes occurred in early morning or during afternoon drive time. Most were single vehicle crashes with few injuries. Many occurred at intersections, particularly two: the intersections of Rt. 23 with Rts. 757 and 10.

Originally, fog-prone and non-fog-prone areas were set up for Rt. 23 as they were on I-77 and I-64, but as seen in Figure A-13, there were as many fog-related crashes outside the fog-prone area as inside. Thus, for further analysis, all three areas were combined and fog-related and non-fog-related crashes were compared.

As seen in Figure A-14, the average numbers of vehicles per crash were almost identical, but as seen in Figures A-15 and A-16, the non-fog crashes on Rt. 23 had, on average, more injuries per crash and per vehicle. This is probably due to the fact that the vehicles involved in the non-fog-related crashes were traveling faster then those in the fog-related crashes (Figure A-

17). As seen in Figure A-18, on those occasions when there were injuries, fog-related crash injuries tended to be somewhat worse. One must remember that these figures are based on very low numbers.

When other factors involved in fog crashes on Rt. 23 were examined, there was no evidence that drinking, vehicle or roadway defects, or driver fatigue or impairment was factor in these crashes (Table A-5). Three involved traveling above the safe speed, and failure to yield and following too close contributed to rear-end crashes. It is clear that in a number of cases, fog was not the only contributing factor, especially at intersections. Several crashes also involved running into fixed objects, particularly Jersey barriers, especially on Rt. 610.

Table A-5. Collision Type and Factors Involved in Fog Accidents on Rt. 23

Date	Time	Number of Vehicles	Collision Type	Other Factors
02/08/96	6:30 p.m.	1	Fixed Object	Speed
07/20/96	5:35 a.m.	1	Fixed Object	
07/21/96	6:00 a.m.	1	Fixed Object	Speed
03/19/97	4:06 p.m.	3	Rear-End/Angle	Follow too close
06/10/97	6:10 a.m.	1	Angle	Failure to yield
05/28/98	6:10 a.m.	2	Rear-End	Speed, Failure to yield, Failure to use headlights in fog

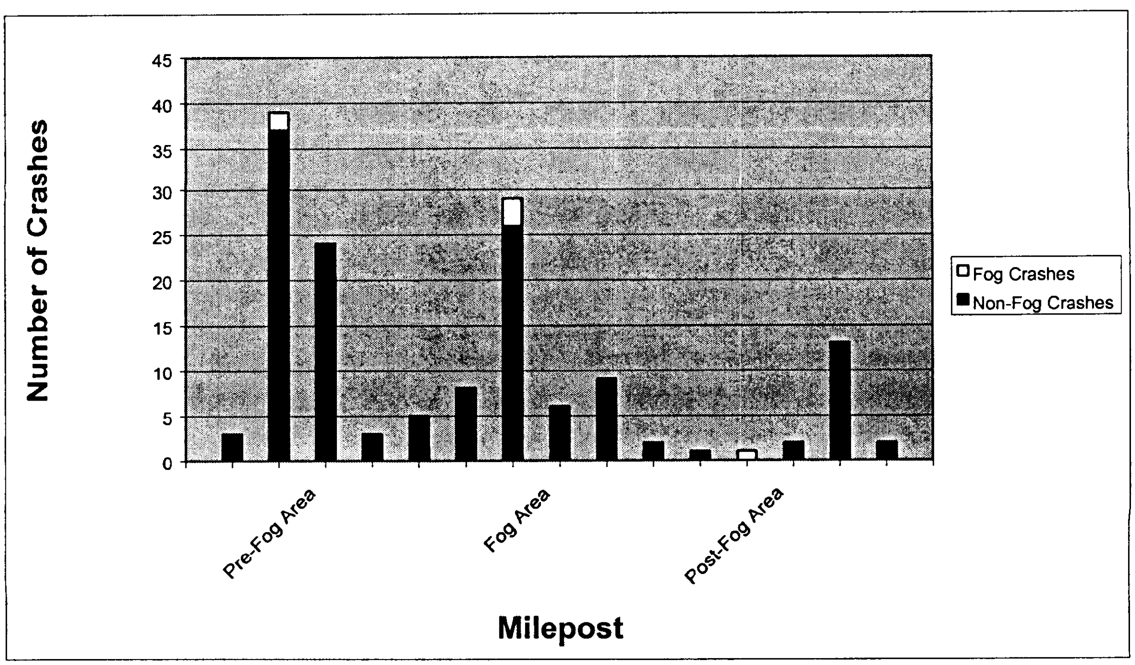

Figure A-13. Milepost at which accidents occurred on Rt. 23.

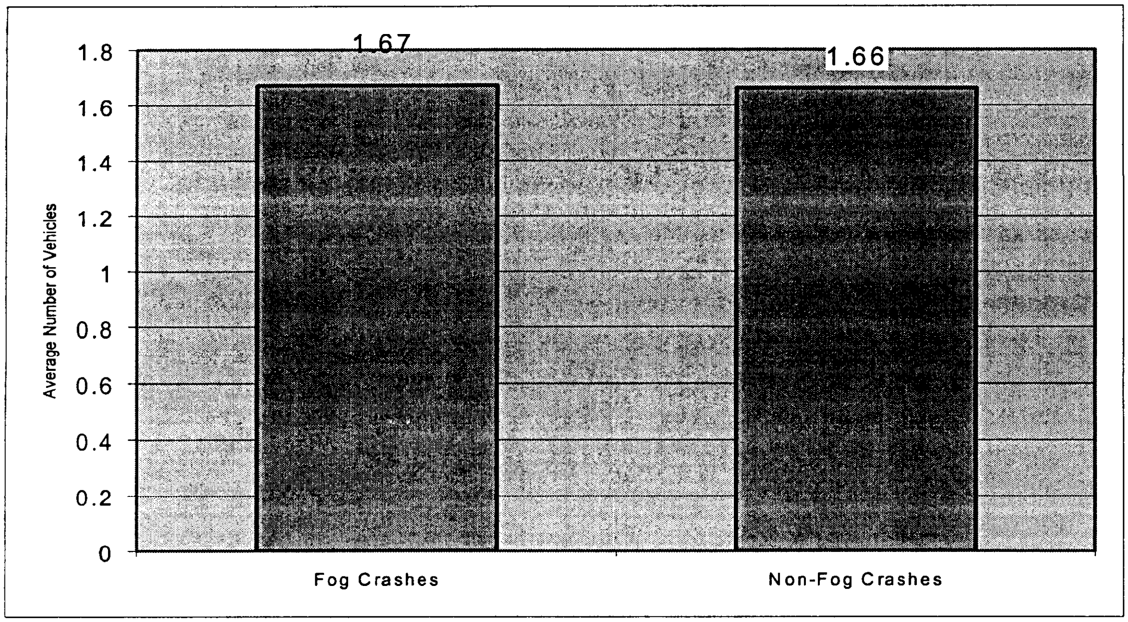

Figure A-14. Average number of vehicles per accident on Rt. 23.

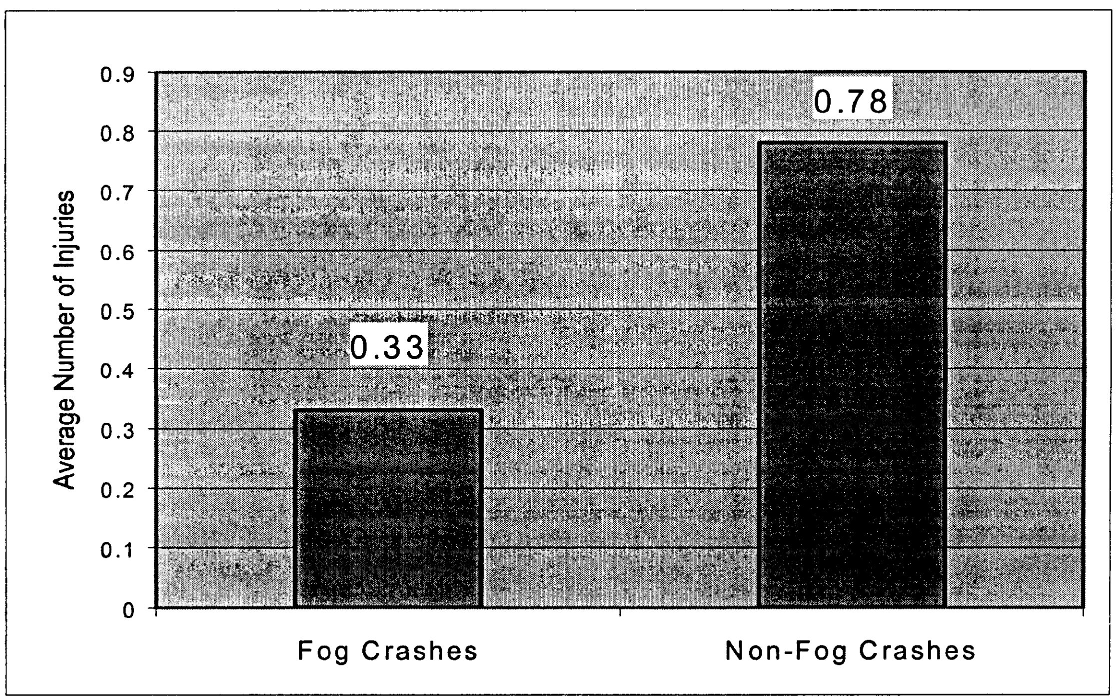

Figure A-15. Average number of injuries per accident on Rt. 23.

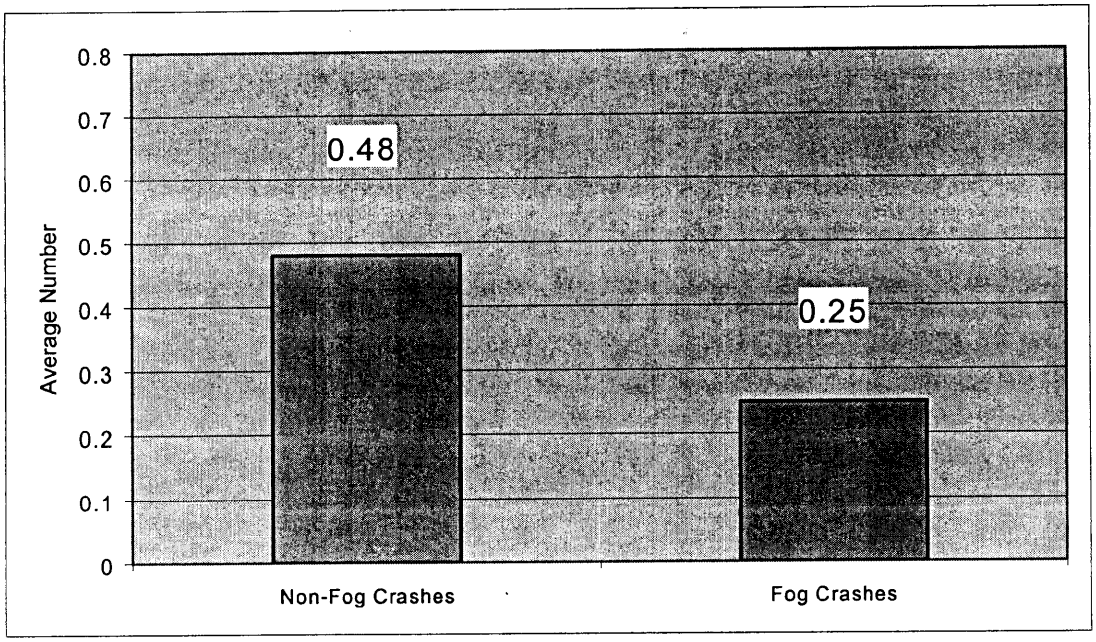

Figure A-16. Average number of injuries per vehicle on Rt. 23.

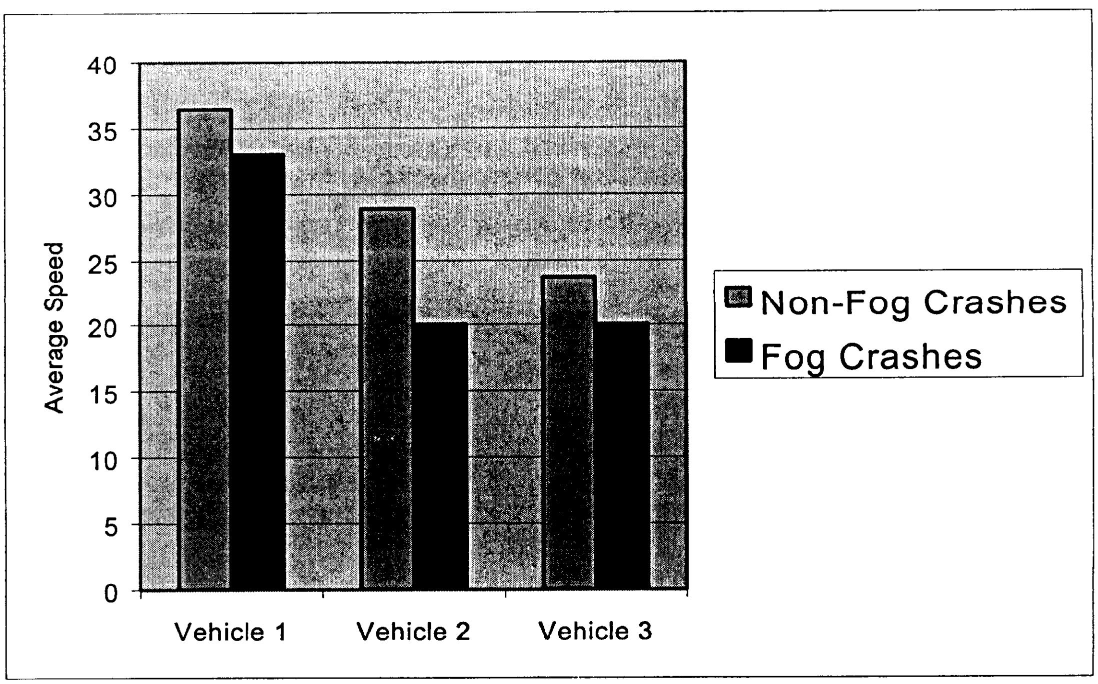

Figure A-17. Average speed for vehicles in fog and non-fog crashes on Rt. 23.

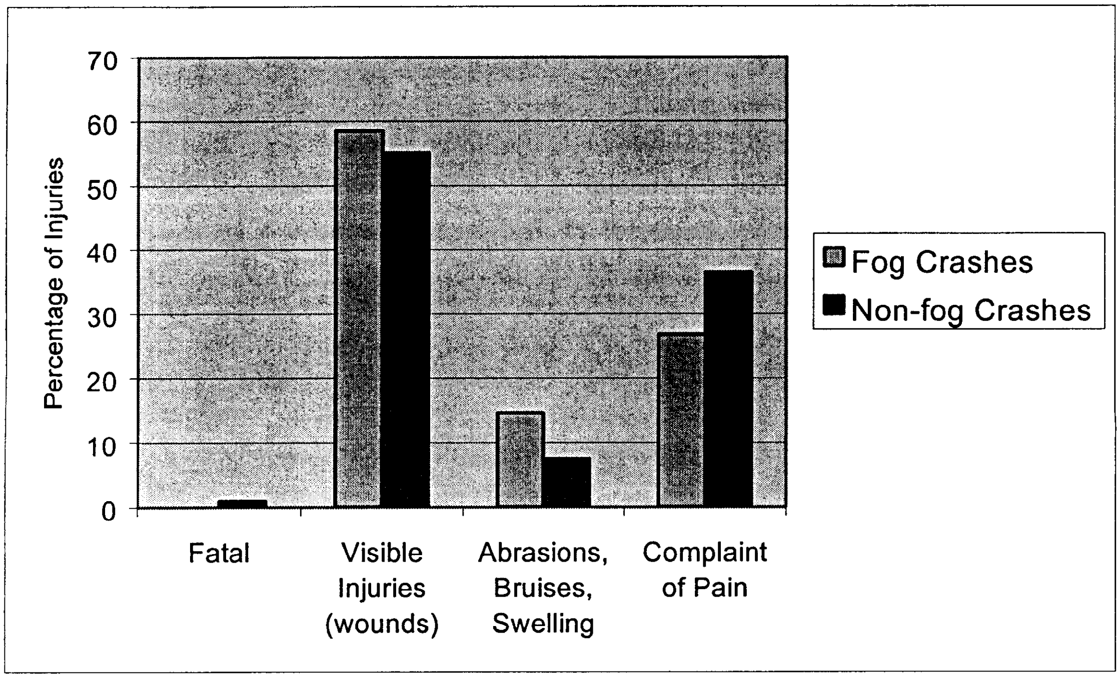

Figure A-18. Severity of injuries on Rt. 23.

Possible Solutions

A number of citizens contacted the Wise Residency of VDOT and VTRC concerning the perceived fog problem at the intersection of Rt. 610 and Rt. 23. In discussing these crash data with representatives of VSP, they agree that this area is a problem in all types of weather, not just fog, due to (1) poor sight distance and (2) the Jersey barrier positioned at the crest of a hill obscuring drivers' vision. It is possible that some sort of collision avoidance equipment that provides drivers with information concerning the speed and distance of oncoming traffic might be useful at this site. However, because the Rt. 23 section is significantly different from the Afton and Fancy Gap mountain interstate section, and because the problems on the Rt. 23 section are not primarily fog related, this site was excluded from subsequent consideration.

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APPENDIX B

A SURVEY OF WEATHER-CONTROLLED TRAFFIC AND INCIDENT MANAGEMENT SYSTEMS IN OTHER COUNTRIES

In searching for data on the effectiveness of fog-related traffic systems, it became clear that a number of very complex systems driven by real-time weather and/or traffic data exist here and in other countries and have existed for some time. Many of the current systems use some form of variable speed limits. This section describes these systems.

The A16 Fog Signaling System

After an infamous 100-vehicle fog crash near Breda in The Netherlands, in which 8 were killed and 27 were injured, a fog countermeasure system was devised for the A16. The goal of this signaling system was to warn drivers to reduce travel speeds in the fog.[1]

The experimental section of dual lane freeway was 12 km (7.4 mi) long, running from just south of Moerdijk Bridge to just south of Breda. The ADT was 75,000, with 20% to 30% being buses and trucks. The speed limit was 100 km/h.[1]

The system became operational in October 1991 and consisted of:

- 20 visibility sensors measuring visibility distance once each minute. The sensors measured the extinction coefficient, which was translated into visibility distance.

- 37 outstations linked to VMSs at 700 to 800 m (763 to 872 yd) intervals. Each outstation was attached to two or three surrounding sensors, near or downstream. In case of dense fog, the speed limit is lowered. At each outstation, a variable speed limit sign was installed, along with a triangular exclamation point sign with the word "Mist" underneath.[1]

- A central computer to log in all events and displays.

If the visibility distance is more than 140 m (152.6 yd), the posted speed prevailed (and the signs are left dark). If the visibility distance is between 70 and 140 m, the speed limit is 80 km/h (49.6 mph). When the visibility distance is less than 70 m, the limit is 60 km/h (37.2 mph). Signs are sequenced to slow down vehicles gradually.[1]

In November 1992, the Motorway Control Signaling System with Automatic Incident Detection (AID) was added to the system. The purpose of this system is to improve traffic flow by reducing speed variance. If slow traffic (speeds less than 35 km/h or 21.7 mph) is detected, the AID imposes a variable speed limit of 50 km/h on the next sign and 70 on the second upstream. If both the fog signaling system and AID generate variable speed limits simultaneously, the most restrictive is imposed.[1]

The evaluation period for the system began in February of 1992 and ended in March of 1994. Four sets of loop detectors were installed in the experimental portion of the roadway being evaluated, and another two sets were installed in the control portion outside the system area. Data on lane number, time, speed, length, headways, following distance, and time-to-collision for each vehicle were collected. The local road administrator's office collected special event data for crashes, lane closures, maintenance, etc. Meteorological data were collected from the nearest station about 5 to 8 miles away. Data were collected when the visibility remained unchanged for at least 15 minutes, as long as no events were underway. Similar non-fog data collection periods were selected on the control section.[1]

In about 1.4% of the time, visibility was less than 140 m in the experimental section. Fog was most common at night and during the winter months. Low visibility, slow lane position, and decreased flow had the most impact on speed. Speeds were slower when the system was called into operation, although not at all visibility distances. Comparing the experimental and control data, the system had a significant speed-reducing effect.[1]

However, there was a reversal of this trend at the most restrictive visibility distances—less than 35 m (38.1 yd). Under these very low visibility conditions, speeds for drivers operating under the variable speed limit system were closer to the speed limit and were higher than speeds in the control section. Even though lower variable speed limits resulted in lower speeds at all visibilities, the mean speed was always higher than the speed limit.[1]

The system also resulted in a small but significant reduction in the standard deviation of the speeds, which is one of the goals in Virginia. Mean speeds were reduced by 8 to 10 km/h during fog conditions after system installation, and a small but significant reduction in the percentage of vehicles with headways less than 1 second was noted.[1]

Finnish Weather-Controlled System

The E18 is a major highway linking Northern Finland with the Russian border.[2] At high accident locations on the E18 in Finland, it was determined that crashes were 20 times more likely in icy conditions than in dry; 10 to 20 times more likely in salted, slushy conditions; and 3 times higher on snowy roads.[3]

The Finnish weather-controlled system runs from Siltakyla to Summa, Finland, a 25-km segment.[2] A 14-km (8.7-mi) experimental segment was set up for evaluation, running from Kotka to Hamina. Twelve kilometers (7.5 mi) was newly constructed, divided motorway (limited access highway) and 2 km (1.2 mi) was older, two-lane highway.[3] The road was opened in November 1994. The period during which speed limits were lowered according to weather conditions extended from October 1994 to April of 1995.[4]

The system consists of:

- 5 Visalia automatic weather stations with two integrated visibility meters. The system measures wind speed and direction, air temperature and pressure, and relative humidity. The four road sensors embedded in the roadway measure road surface condition and road temperature, as well as electrical conductivity of the road and precipitation intensity.[2]

- 5 traffic flow detection subsystems[3]

- 1 camera for visual monitoring by a control center[3]

- a central storage and analysis unit, which collects data every 5 minutes, analyzes road conditions, and recommends an appropriate speed limit. Data are transmitted by cable, and the recommended speed limits are then transmitted to the VMS' logic control equipment. There is also an area control room for manual control of the system, if necessary. Traffic is controlled by a dedicated control logic system.

- 36 variable speed limit signs and five other message boards that warn against other hazardous conditions, and message symbol signs for slippery road surfaces, hazardous conditions ahead, and road construction ahead. When there is nothing of significance to report, the air and road surface temperature is displayed.[3] The brightness of the signs is automatically controlled according to ambient light levels.[4]

When road conditions worsen, the speed limits listed on the VMSs are reduced immediately. As conditions improve, there is an adjustable delay (usually 15 minutes) before the speed limit is increased. The system is especially useful in detecting black ice and rimes (accumulation of granular ice tufts on the windward side of the road).

Speed limits on the roadway are 120 km/h in summer and 100 km/h in winter. On the experimental segment, speed limits may be 80, 100, or 120 km/h, depending on conditions. From November to February, only 80 and 100 km/h are used. The roadway is divided into five speed-controlled sections.

In summer or winter, under dry or slightly moist conditions, the highest speed limit prevails. When there is ice or snow in the roads, the lowest speed limit is put into effect. Under normal winter conditions, the limit is 100 km/h. Heavy rain reduces the limit from 100 to 80 km/h and visibility below 280 m also results in a reduction in the speed limit to 80 km/h. The speed limit is also lowered to 80 km/h when wind velocities exceed 12 to 17 m/s.

Motorist Acceptance

Motorist surveys were conducted in January, February, September, and December of 1995 at a rest area about 1 minute downstream. Of the motorists surveyed, 91% remembered the speed limit posted,[4] compared to the 76% to 80% recall rate for static speed limit signs in other Nordic countries.[5] Most respondents knew the sign was a variable speed limit sign, and 55% to 65% knew all of the winter speed limits. About 66% remembered the "slippery when wet" static symbol sign (the first one they saw). About 40% reported that the sign influenced their behavior. The temperature sign (steady state) had little reported effect.

About 93% knew that weather conditions and road conditions affected the choice of speed limit on the road, 81% indicated that the prevailing speed limit was appropriate, and 95% said that varying speed limits by road conditions was useful.[4]

Distraction Effects

The evaluators noted that the variable speed limit signs had an effect on motorists' recall of static signs in good weather. Limits of 60 and 80 km/h were imposed in free flow traffic (the criteria were 5-second headways and at least 50 km/h). Both static and dynamic types of signs resulted in slowed traffic, but the fiber optic signs produced more reductions.

About 91% of drivers remembered the fiber optic sign compared to 71.6% for the other signs.[5] In addition, the fiber optic sign was remembered more often than a fixed speed limit sign (82.5% vs. 67.2%). Fewer drivers remembered a general warning sign when a VMS variable speed limit sign was present, indicating that the variable speed limit signs distracted driver attention from static signs.[6] However, the variable speed limit sign also resulted in slower traffic speeds than did the fixed speed limit sign (69.8 km/h vs. 71.7 km/h).

M25 MIDAS (Motorway Incident Detection and Automated Signaling)

MIDAS (Motorway Incident Detection and Automated Signaling) in Great Britain was installed on the southwest quadrant of M25 over a 22 km (13.7 mi) long segment with four lanes in each direction. The purpose of the system was to reduce the speed of traffic at times of heavy flow using mandatory motorway signals and automated enforcement of speed limits. This system was also designated to reduce the breakdown of flow, and thus reduce crashes, and to reduce pollution and noise and increase driver comfort.[7] The Road Traffic Act of 1991 authorized the use of variable mandatory speed limits and the use of photo-radar. The theory behind the system was that reductions in speed variance over time at a given location should reduce traffic crashes.[8]

The system opened in September 1995 and consisted of loop detectors at nominal 500-m intervals.[7] As the system detected slow-moving traffic, it sent an alert to the Police Control Office and set appropriate speed limits on VMSs. Later, photo-enforcement of variable and static speed limits was added to the system, with automated enforcement required on all four lanes in each direction. In an 18-month period, about 26,000 drivers were fined for speeding.[11]

After installation, lane utilization improved, with traffic in the lanes that had been underutilized increasing by 15%.[7] Incidences of lane changing decreased, largely because there was no benefit to it, and drivers were also more likely to stay in the same, inside lane, keeping proper distances between vehicles. This resulted in smoother traffic flow, fewer short headways, and fewer long headways.[7] In a 2-year study, speed compliance was found to be very high. Injury crashes were reduced by 28%, and property damage crashes were reduced by 25%.[7] Interestingly, the majority of the M25 drivers preferred to drive on the controlled freeways and stated that they would support wider use of the system.[9] The administrators of the program cited two key elements that contributed to the success of the variable speed limit system: the accuracy of the limit appropriateness and automated enforcement. Most variable speed limits in Europe are regulatory.[9]

Sydney Fog Warning and Advisory Speed System

Installed in 1993, the Sydney Fog Warning System extends along an 11-km (6.8-mi) four-lane-divided motorway on the F6 tollway south of Sydney. The system consists of 12 fiber optic sign locations, each with loop detectors and visibility detectors. Vehicle speeds are measured over a 200 m (656 ft) distance, and this is used to present an advisory speed to the next passing vehicle, with the advisory speed based on previous car speed and visibility. The system was specifically designed to reduce rear-end crashes. In addition, the system included dynamic signs that sent a reminder to slow down to individual drivers traveling 10 km/h over the 110-km/h speed limit. After installation, the number of speeders was reduced by 60%, but the effect was temporary—300 m (984 ft) downstream there was no reduction.[10]

Other Overseas Systems

The Motorway Traffic Management (MTM) is installed at the Lundby tunnel in Gothenburg, Sweden. The MTM system uses loop detectors and video cameras for incident detection. The system measures volumes, classifies vehicles, and detects incidents including wrong-way drivers and disabled vehicles.[9]

A system identical with the MTM was installed in Amsterdam and resulted in a decrease in overall accident rates by 23%. In addition, serious crashes were reduced by 35%, and secondary crashes were reduced by 46%. Traffic flow improved by 5% to 15%. Another speed-reducing technique was applied in The Netherlands. Perceptual narrowing of a roadway (making it look narrower while not changing the width) reduced speeds by 5 to 10 km/h on rural roads.[10]

The Immediate Detection of Stopped Vehicles (DIVA) system installed on the A5 autobahn between Bad Homburg and Frankfurt/West uses video cameras and pixel pattern movements to generate alarms for specific incident types. Typically, there are only 30 seconds between the detection of the incident and the issuance of the alarm.[9] The system also controls variable speed limits and lane control signals. After installation, crash rates fell by 20% while crashes increased by 10% on the control section.[9] Some sections experienced crash reductions of up to 50%. Serious injury crashes were reduced by 29%, worth an estimated $4 million savings annually. Secondary crashes decreased by 66%.[9] As of 1996, Germany had 70 traffic management facilities with fog, ice, and wind detection capabilities covering 500 km (310.7 mi) and planned to expand another 60 systems and 300 km (186.4 mi).[10]

The Taiwan Freeway Surveillance and Control System runs the 80 km (49.7 mi) from Keelung to Yangmei. Opened in November 1984, the system contains three subsystems: (1) roadway terminal equipment systems, which collects traffic information via vehicle detection and CCTV; (2) a central control system; and (3) the information transmission and communication system. In addition, the system includes VMSs, variable speed limits, increased enforcement, and emergency telephones. Based on 6-month pre/post installation statistics, fatalities were reduced by 68% and injuries by 27%. The average queue length was reduced from 2.34 km (1.45 mi) to 1.49 km (0.93 mi), and the accident clearance time decreased from 62 to 43 minutes.[11]

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APPENDIX C

THE USE OF VARIABLE SPEED LIMITS AND RADAR IN WEATHER AND TRAFFIC MANAGEMENT SYSTEMS

Perhaps the most controversial countermeasure used in other fog systems is variable speed limits. From this review of traffic management and incident detection systems, variable speed limits seem to be used with two purposes in mind: (1) to reduce congestion and speed variance in non-weather related systems, and (2) to respond to specific hazardous conditions for which the fixed speed limits may be inappropriate, such as low-visibility conditions.

As noted above, variable speed limits have been effective in reducing speed variability and creating a more uniform distribution. A more uniform distribution results in fewer secondary crashes.[1,2] However, due to the high cost of instituting variable speed limit systems (between $400,000 and $1,000,000 in 1996 dollars), the Federal Highway Administration recommends that such systems should be implemented in areas where the environment and/or traffic conditions result in significant fluctuations in the desired speed.[3]

Although shown to be effective, it was unclear whether the use of variable speed limits was allowed under current Virginia law. Therefore, this concern was examined. Three questions in particular were addressed: (1) Does Virginia law allow variable speed limits on highways? (2) Are variable speed limits on highways permissible under other states' laws? (3) Have courts taken judicial notice of any means of speed limit enforcement other than radar?

Does Virginia law allow variable speed limits on highways?

In Virginia, fixed speed limits are the general rule by law. Virginia law does allow for the enforcement of variable speed limits on bridges and in tunnels, but not for other highways. There is one exception. The Commonwealth Transportation Commissioner (or another authority with jurisdiction) may establish different speed limits for daytime and nighttime driving based on an engineering study. The *Code of Virginia* allows for variable speed limits on bridges and tunnels under conditions such as darkness, congestion, inclement weather, and other situations that may affect driving safety. Since there is no provision for the use of variable speed limits outside of tunnels and bridges, the *Code* would need to be amended to allow for variable regulatory speed limits as a fog countermeasure on Afton Mountain and Fancy Gap Mountain.

Are variable speed limits on highways permissible under other states' laws?

Currently, only California allows the enforcement of regulatory variable speed limits. The California Code allows the California Department of Transportation to establish variable speed limits if traffic engineering studies indicate that they would facilitate the safe and orderly movement of traffic. Appropriate signage must be displayed to give motorists adequate notice of the appropriate speed limit. Variable advisory speed limits are allowed in other states.

Have courts taken judicial notice of any means of speed limit enforcement other than radar?

The *Code of Virginia* allows as court evidence determination of speed checked by laser, radar, or certain microcomputer devices as long as the microcomputer device is connected to an odometer cable and determines vehicle speed by measuring distance traveled and time elapsed. In addition, air enforcement was approved in 2000.

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