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ROADWAY WARNING SYSTEM STUDY

FOR THE

MICHIGAN DEPARTMENT OF
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DIVISION

December, 1995
(PHASE ONE)

May, 1996
(PHASE TWO)



Roadway Warning System

Phase I Report

1. Transmittal Letter

Mr. John J. Kanillopoulos, P.E.
Traffic and Safety Division
Michigan Department of Transportation
425 West Ottawa Street
Lansing, MI 48909

December 28, 1995

Dear Mr. Kanillopoulos:


We are pleased to submit this report titled Roadway Warning System, pursuant to our Contract Number 94-1520 with the Michigan Department of Transportation. This section formally transmits this report and provides both phase one and phase two of our study. The remaining sections are as follows:

2. Introduction
 3. Michigan DOT's Practices Related to Warning Systems
 4. Crash History
 5. Enabling Technologies
 6. Motorist Warning System Analysis
 7. Findings
 8. Conclusions
 9. Recommendations
- Appendices A-D and Bibliography

The objective of the study was to determine if a system is currently available, or could be developed, that could warn motorists about the presence of preferential icing and/or the presence of an incident on the roadway ahead. Such a system, if available, would be intended for application on the westbound I-696 to southbound I-275 ramp. In particular, the bridge deck over I-96, a part of the ramp, was the specific site for application.

This report details the research and findings related to the investigation of a roadway warning system. We conclude that, in general, and in regard to the specific bridge deck that is the subject location of this study, there is currently no operational roadway warning system available for advance warning to motorists of icy road conditions or crashes.

Cordially,
Midwestern Consulting, Inc.



Karl L. Kleitsch, P.E.
Project Manager

2. Introduction

The I-275/I-696/I-96 interchange consists of grade-separated roadways with multiple access ramp connections. As part of their effort to improve motorist safety along these routes, the Michigan Department of Transportation (MDOT) has contracted with Midwestern Consulting, Inc. and the Environmental Research Institute of Michigan (ERIM) to evaluate the reliability and effectiveness of ice prediction, detection, and warning systems. Both domestic and international efforts in this area were taken into consideration. Most of the information used in this study has been collected from reports published by state and federal transportation agencies, both domestic and foreign, through questionnaires, and vendor literature.

A significant amount of effort has already gone into the evaluation and testing of "ice detection" and related weather information systems, both on the state and federal levels. Dating back to the early 70's, various elements of these systems have been studied to determine their reliability and usefulness for improving maintenance response time, decreasing the amount of chemical usage, and in general decreasing accident rates and travel times due to inclement weather. Most of the research to date, however, has been directed toward improving roadway maintenance functions with the anticipation that an improvement in safety would result as a natural by product.

For this report, the results of these previous studies and evaluations were reviewed and queries were made to determine if new data, specifically related to the problem of preferential icing, has come available in the interim. The search for information extended beyond the U.S. to international transportation agencies and consortiums.

DISCLAIMER: Vendor and product names are used when the information is judged to be useful to the reader, but should not be taken as an endorsement of any kind.

2.1. Problem Statement

The crash history for the westbound I-696 to southbound I-275 ramp bridge has been compiled by the Michigan Department of Transportation and the data indicated evidence of crashes, especially crashes involving multiple cars during winter month periods. Additionally, the Department has been involved in eight litigation cases. Consequently, the Transportation Department has authorized this study to determine whether a roadway warning system could realistically be implemented to improve safety at this location. Specifically, the Department asked whether a "realistic, practical, reliable" system could be installed "to improve warning for motorists using the high level structure of preferential icing and/or congestion or accidents on the bridge."

Necessity of Study

There is a need for this study since the type of system being requested is not common among the type of roadway traffic control devices that have been operated and studied sufficiently to elevate their use to a common standard of practice. The publication that defines the standard of practice for traffic control devices is the Michigan Manual of Uniform Traffic Control Devices (MMUTCD) as published by the Department of Transportation and the Department of State Police. This manual is based on the National Manual of Uniform Traffic Control Devices and is authorized in Michigan by the Michigan Vehicle Code (Act 300, P.A. 1949). The intent of the manual is to provide guidance for road agencies to achieve desired uniformity in the application of traffic control devices. The advantages of traffic control device uniformity were recognized as long ago as the 1920s. Benefits of traffic control device uniformity increases safety by providing the road user with required information for vehicle guidance or control at the right time and place and in the proper manner. While the advantages of uniformity far outweigh the disadvantages, there may be some unwanted effects when complete uniformity is maintained. One disadvantage is that strict uniformity may result in the failure to adopt an improved, new device or procedure simply because it is not in common use. This is recognized in the MMUTCD which indicates that warning signs other than those specified may be needed under special conditions (section 2c-1). Indeed, the "Bridge May Be Icy" (W8-6a) signs in place at the subject bridge deck is not in the manual, but is authorized for use based on an MDOT Traffic and Safety Division Note. In an Oakland County Circuit Court ruling (case number 89-378840 NI), that court's opinion was that this sign is "just not sufficient." It may be, therefore, that the only way to provide a "sufficient" message, at least in the opinion of that court, to inform approaching drivers of a condition or situation on the subject ramp bridge would be through the use of a variable message sign (VMS). The 1994 manual recognizes that roadway systems that involve variable message signs are "gaining widespread use"; however, the manual is silent in regards to the variable-condition recognition and real-time warning uses for this type of system. Furthermore, the manual recognizes the developmental nature status of roadway information systems by stating in section 2a-4 that "Highway and Transportation organizations are encouraged to develop and experiment with variable message signs and to carefully evaluate installations where used so that specific manual standards may be incorporated in the future."

Foundation Principals for Study

The fact that there are no standards of practice currently in place for roadway information and warning of the type requested for this study location does not mean our research is complete and that there is no roadway warning system that can be identified and recommended for implementation. What it does mean, however, is that we must determine if a system capable of providing the type of warning requested by MDOT for this location can be found which meets reasonable performance criteria for traffic control devices and systems of devices that will be necessary for such an installation. We believe and recommend that the foundation for the requirements and performance criteria must parallel those established in the MMUTCD.

The principal requirement discussed in the MMUTCD is effectiveness. This manual states that there are five basic performance requirements necessary for a traffic control device to be effective (this would also include traffic control systems):

1. Fulfill a need
2. Command attention
3. Convey a clear, simple meaning
4. Command respect of road users
5. Give adequate time for proper response

The main difficulty for the system that we are investigating is in relation to the type of warning required for this location. We must determine if a roadway warning system can be implemented that has as a primary goal the warning of motorists about a current event; i.e., an incident on the bridge and/or the presence of ice rather than of a static condition as is the case with the devices and systems of devices currently listed in the MMUTCD. In other words, when you look at the warning sign section of the manual you see signs that warn about curves, winding roads, intersections, stop ahead conditions, lane ends, etc. These are all non-changeable, static roadway conditions present twenty-four hours a day; -day in, day out. Conversely, the roadway warning system that is the subject of this study will be required to warn about variable conditions, which requires sensing (surveillance) to determine if a particular condition exists, some sort of analysis (identification) to send a proper message (notification), and all of this in a timely fashion to allow adequate response (by drivers and/or others). Additionally, we would add one more performance criteria that we believe is inherent in the manual philosophy. This sixth performance criteria would be enhancing driver safety as determined by a measurable reduction of vehicle crash incidents in terms of frequency and severity.

Critical Study Definitions

Building upon the manual principles as described above we have prepared the following performance based "Roadway Warning System" description that will form the blueprint that a system must be judged against to be considered implementable.

A "Roadway Warning System" is a system that provides advance notice to motorists and appropriate public service agencies. It is a system that has demonstrated, through operational study, that it is effective. To be effective, it is a system that has demonstrated through verifiable operational data records its ability to address the following critical performance requirements:

1. The system design identifies sign placement and location requirements in relation to the surveillance area (commands attention).
2. The system provides a message that results in driver operation modification (convey a clear, simple meaning).

3. The system is reliable (commands respect of road users).
4. The system provides a real time warning to motorists (gives adequate time for proper response).
5. The system provides notice to the appropriate public service agency for appropriate actions (road maintenance or on-the-scene assistance to traffic problem).
6. The system enhances motorist safety.

Another independent criteria that we will be assessing, if the study concludes that there is an implementable system, is the practicality or feasibility of placing the system into service. The definition of this term usually carries with it a cost-benefit type of description. Cost-benefit analysis will certainly vary from installation to installation depending on the severity of the traffic problems at each location. However, for the purposes of this report, that feasibility is restricted to this study location only. Feasibility would then be determined in regard to lifecycle system operation timelines and the associated benefits from the operation of the system over this period of time (system lifecycle). The benefits will primarily be derived from the reduction of crash incidents and identifiable related cost savings (maintenance cost, enforcement activities, medical, litigation, etc.).

Two other descriptors that will be important in regard to identifying an implementable system are "reliable" and "effective." Both these words appear in the above "Road Warning System" description. Again, we believe the proper definitions of these words, for the purpose of this report, are founded in the MMUTCD philosophy. While the word "reliable" is not directly used in the manual, it is apparent that a system would have to be reliable in order to satisfy the manual's performance requirement of "Command respect of road users." In order to command respect from the road users, the system would have to be reliable from the operational aspect and the road user must be confident the system will convey an accurate message, otherwise they would soon ignore the system. Consequently, the following definition for "reliable" is required to adequately describe a system consistent with the MMUTCD :

- **Reliable** - Giving the same accurate results after repeated trials and being operationally durable (applies to both components and systems).

Effective has been directly discussed in the manual and in the paragraphs above. The following definition summarizes the discussion in the manual and above regarding "effective":

- **Effective** - When used in relation to a roadway warning system describes a system that meets all the performance requirements as described in the MMUTCD (1a-2 Requirements of Traffic Control Devices) and produces a measurable reduction in the rate of crashes in the area serviced by the system.

Other terms used frequently in this report are defined below:

- **Area Detector** - a sensor that measures a physical parameter over a large field-of-view; for example, a radiometer that overlooks a roadway and senses surface temperature over two lanes for 40 feet down the roadway.
- **Current State of Practice** - technology and/or equipment that is being effectively utilized in operational settings.
- **Frost** - a covering of minute ice crystals on a cold surface.
- **Glaze Ice** - ice that forms at temperatures near freezing. The freezing process is more gradual and water fills most existing air spaces. The resulting ice formation is generally clear and smooth, but sometimes contains air pockets. When this type of ice is transparent and free of air pockets, it is often referred to as clear or black ice [Rosemount Aerospace].
- **"Ice Detection"** - when enclosed in quotation marks, refers to ice prediction, detection and warning systems in general. When not enclosed in quotation marks, refers specifically to components or systems intended for detecting ice on a roadway, but not prediction or warning components.
- **Point Detector** - a sensor that measures a physical parameter only over a small area; for example, an in-pavement ice detector measures the surface conditions only over the detector element (usually a 6 inch diameter, or less).
- **Preferential Icing** - a natural condition which results in ice forming on the bridge deck before or without ice on the approach or departing roadway.
- **Roadway Agency** - public agencies (state, county, municipality) with jurisdiction over roadways.
- **Road Weather Information System (RWIS)** - systems that may incorporate surface condition (pavement) sensors, meteorological sensors, roadway temperature profiles, site-specific forecasts, remote processing/communications units, and a central processing/display unit, or a combination of the above, to monitor and communicate weather/road conditions to a decision-making unit.

Summary

Based on the foundation principals established in the MMUTCD as described in the above sections, this study will determine whether or not there exists an implementable "Roadway Warning System" for the study location and recommend a course of action as part of a Phase 1 study report. The Phase 2 study and report will then outline one of two possible courses of action:

1. The Phase 2 report would develop implementation alternatives and a cost-benefit analysis; or,
2. The Phase 2 report would provide recommendations for future action. This assumes the Phase I report concludes that no system is implementable.

2.2. Background

The problems presented by ice on the roadway are well known by motorists in most, if not all, of the continental United States and Canada. As most motorists are also aware by the prevalent utilization of warning signs, ice formation on bridges can occur faster than on roadways. The problem, understandably, is compounded on bridges, where there is generally the least amount of shoulder or median space for vehicles to maneuver in case of an incident. Under these circumstances, it is not surprising that multiple-car collisions are more likely to occur on or near elevated stretches of roadway that are ice covered. Section 4 of this report contains a crash history analysis of the 1.4 mile long westbound I-696 to southbound I-275 ramp connection.

Castle Rock Consultants reported that between 25% - 35% of all interurban crashes occur during adverse weather conditions and the risk of crashes increases by a factor of between 2 and 5 compared to fair weather conditions (ref DTFH61-92-C-00012 and Pauwelussen, J.P., "Conditions of Road and Weather Monitoring, DRIVE Project V1058, Executive Summary." TNO Road-Vehicles Research Institute, The Netherlands, October 1991). Adverse weather includes ice, snow, rain, fog and wind, as well as combinations of these events. The effect on motorists can be described in terms of reduced surface friction, reduced visibility, reduced stability or combinations thereof.

The pavement conditions that determine whether or not surface friction will be reduced during adverse weather conditions are typically characterized as follows:

- dry
- wet (above 0°C)
- wet (not frozen but at or below 0°C)
- snow/ice (at or below 0°C)
- dew
- frost

Ice prediction, detection and warning can be addressed at two different levels. The component level and the system level. In this report, a *component* refers to a specific type of sensor (or sensors), such as an in-pavement ice detector(s), while a *system* refers to a combination of two or more different components integrated together for a common purpose.

There is a significant distinction, besides the obvious, when trying to determine the reliability and effectiveness of components and systems, that are made up of multiple components. Several reports exist that describe the reliability of components and systems and how well they perform in terms of maintenance functions, but very few have been found that quantify the effectiveness of the systems with regards to reducing crash rates.

This study encompasses the following aspects of "ice detection":

- detection and prediction of ice on roadways
- methods for determining traffic characteristics resulting from ice conditions or other traffic impeding causes
- methods of warning motorists prior to or during ice events

Several vendors sell weather information systems (referred to as Road Weather Information Systems - RWIS) that incorporate roadway surface condition sensors, atmospheric sensors, remote processing units and a central processing unit, or a combination thereof. Such systems can be considered as a component, although often stand alone, in a higher level roadway warning system.

Physical Parameters and Bridge Crash History

The I-96, I-696 and I-275 interchange was constructed in 1976. The westbound I-696 to southbound I-275 ramp includes a two lane 50 foot high bridge. Critical to the determination of whether there is an implementable roadway warning system to warn motorists regarding incidents (vehicle and/or ice detection and warning) is understanding the physical parameters associated with the bridge and approach ramp. Pertinent bridge and roadway parameters were provided by MDOT and are as follows:

Bridge Roadway Parameters

Degree of Curve	2° - 45'
Length of Bridge	629 ft
Superelevation Rate	0.06 ft/foot
Width of Clear Roadway	40 ft
Lane Width	2 @ 12 ft
Inside Shoulder Width	6 ft
Outside Shoulder Width	10 ft
Design Speed	65 mph
Average Daily Traffic	41,400

Operational And Geometric Modifications

There have been eight litigation cases as a result of the crashes that have occurred at this location. The latest case involved icing on the bridge deck and resulted with awards to three plaintiffs.

MDOT has in recent years made several operational and geometric modifications to the structure and ramp as follows:

- A. Removed the aluminum railing attached to the top of the bridge parapet to improve sight distance.
- B. Roughened the pavement texture of the bridge deck.
- C. Installed two advisory "limited sight distance" signs on the bridge approach ramp with a 45 mph supplemental advisory speed plate.
- D. Installed flashing strobes on the two existing advisory "Bridge May Be Icy" signs located on the bridge approach ramp.
- E. Installed a bridge deck ice detection system consisting of roadway and environmental sensors together with local computer hardware to transmit deck conditions to the maintenance control center. The electronic system, manufactured by Surface Systems, Inc., reports pavement temperatures.

The flashing lights were not installed prior to the occurrence of the latest crash incident. They were installed because the latest court decision (case no.89-378840 NI) concluded that a large flashing sign may have been of some use in prohibiting similar crashes. However, most of the other changes were apparently not considered by that court to be effective.

3. Michigan DOT's Practices Related To Roadway Warning Systems

Michigan has been one of the forerunners in evaluating roadway surface and atmospheric sensor systems, now generally referred to as Road Weather Information Systems (RWIS). Over the past decade, systems produced by two different vendors were installed and evaluated. The results of these evaluations are described in Section 5.1.6, *Effectiveness of Ice Detection Systems*.

The following sections describe MDOT's historical and current practices regarding ice prediction and detection, traffic surveillance and motorist warning systems. The planned expansion of the Michigan Transportation Center (MTC) infrastructure is also described.

3.1 Current Practices

The following traffic control devices are currently being used on the westbound I-696 to southbound I-275 ramp:

- Flashing yellow warning lights
- "Bridge May Be Icy" signs
- "Limited Sight Distance" signs with advisory speed plate

Two SCAN systems, including in-pavement ice detectors, are currently in operation at the site in question. They are used by Oakland County to aid in planning winter maintenance operations.

3.2 Planned Expansion

The Michigan Department of Transportation is actively involved in an Intelligent Transportation System (ITS) program. This project known as the Southeastern Michigan ITS - ATMS/ATIS Development Program will cover 180.5 miles of major roads, including the I-696/I-275 area. In particular, for the westbound I-696 to southbound I-275 ramp, ITS will provide four Closed Circuit Televisions (CCTV) to visually cover all directions in the interchange area. Further, CCTV Number One will basically be over the bridge deck that is the subject of this study. MDOT also intends to utilize HAR Radio at this interchange. Motorists will be informed of the presence of HAR by a sign on westbound I-696 approximately one and one-half miles upstream of the ramp. Finally, loop detectors will be installed in the interchange to detect variations in traffic flows.

4. Crash History

The computerized crash records for the ramp from westbound I-696 to southbound I-275 for the ten year period between 1982 and 1991 were obtained from the Michigan Department of Transportation and examined for patterns of occurrence.

In all, 131 crashes were recorded on the ramp in the ten year period. A crash being defined as a single record in the data base, including single-vehicle and multi-vehicle crashes. The number of crashes by type over the ten-year period is shown in Table 4.1. Of these crashes, 55 percent were single-vehicle crashes and 45 percent involved two or more vehicles. The number of vehicles involved in the multi-vehicle crashes was not available from the computerized records, but other documents (ref 1) report that on one occasion over 30 vehicles were involved in one crash, and crashes involving 18, 12, and 11 vehicles have also occurred in this time period.

Table 4.2 shows the severity of crashes type. Overall, 72 percent of the crashes involved property damage only, 27 percent involved injuries, and one percent involved a fatality. Multi-vehicle crashes were more likely to involve an injury than single-vehicle crashes. Injury or fatal crashes accounted for 34 percent of multi-vehicle crashes and 22 percent of single-vehicle crashes.

Table 4.3 shows the distribution of the crashes by month and surface condition. It can be seen that the majority of the crashes occurred between November and April, and that most of these crashes occurred in icy surface conditions. In all, 68 percent of the crashes occurred on an icy surface, 24 percent on a dry surface and eight percent on a wet surface. Table 4.4 shows the surface conditions by crash type. The proportions of crashes by surface conditions are similar for both single-vehicle and multi-vehicle crashes.

Further examination of the dates of the crashes showed that during the ten-year period there were 18 days on which two or more separate crashes occurred somewhere on the ramp. Table 4.5 shows the frequency of occurrence of such days by month. Days with two or more crashes were more likely to occur in November and December than in any other month. A check of the crash records indicates that the surface conditions were icy on all but two of these days. The exceptions occurred on a day in August when the surface was dry and on one day in November where the surface condition was recorded as icy for one crash and wet for another.

The occurrence of the crashes by time of day and surface conditions is shown in Table 4.6. Almost a fourth of all crashes occurred between 6 and 9 AM, that is, during the morning peak period. And nearly 40 percent of the crashes occurred in the evening between 6 PM and midnight. More than 70 percent of the crashes that occurred during these time periods were associated with icy surface conditions.

Fixed-object crashes were found to be the most prevalent type of single-vehicle crash as shown in Table 4.7. Table 4.7 also shows that 22 percent of these crashes were associated with an injury or fatality. Guardrails were the most frequently struck object, accounting for approximately two-thirds of all the fixed-object crashes on the ramp. In three-fourths of the fixed-object collisions, the impact area of the vehicle was the front, right front, or left front surface. The distributions of the objects hit and area of impact for single-vehicle crashes are shown in Tables 4.8 and 4.9.

Table 4.10 shows that most of multi-vehicle crashes were of the rear-end straight category. Tables 4.11 and 4.12 show the distribution of the primary and secondary impacts for the multi-vehicle crashes. Almost half of the primary impacts were either on the front or the right front of the vehicle. The majority of the primary and secondary impacts were front and rear.

One important question about the patterns of crashes on the ramp is whether there is a relationship between the crashes and their locations on the ramp. The ramp is 1.4 miles long with changes in grade and horizontal curvature along its length. The ramp roadway includes a bridge deck over I-696, another bridge deck over M-102, an on-ramp from westbound, and an off-ramp to eastbound M-102. For this exploration, the length of the ramp was divided into seven 0.2 mile segments. The segments are shown on Figure 4.1, an aerial photograph of the ramp. The following list gives the main features of each segment:

Segment 1: tangent, begins upgrade;

Segment 2: tangent to P.C. of 2° 45' horizontal curve, 3.2% upgrade;

Segment 3: 2° 45' horizontal curve, crest of vertical curve;

Segment 4: 2° 45' horizontal curve, includes bridge deck over I-696;

Segment 5: tangent, 3.0% downgrade, on-ramp from M-102;

Segment 6: tangent, downgrade then level, includes bridge over M-102, off-ramp to M-102;
and

Segment 7: tangent, level.

It should be noted that the precise locations of the crashes from the crash data file are, most likely, not all accurate. The location in the computerized crash record is taken from the police crash report and coded to a mileage, within one hundredth of a mile, along a road segment called a control section. However, the location in the crash file depends on the precision of the original placement of the location by the police for the crash report and also on the precision of the person coding the location into the crash file.

Descriptions of some of the crashes that occurred on the ramp during the ten year period were available in the original UD10 crash reports and in summary forms from court exhibits. The location of crashes from these descriptions was compared to the location in the crash file. Several inconsistencies in the data file were found and corrected for this analysis. However, such additional information was not available for all 131 crashes.

These caveats should be noted in the interpretation of any patterns of crashes by location. However, even with these caveats it is still worthwhile to look for indications of spatial patterns in the data describing the crashes on the ramp.

Table 4.13 shows the distribution of crashes by segment. The highest concentration of crashes occurs on segment 6, the segment with the bridge deck over eastbound M-102 and an off-ramp to M-102. The data records indicate that 27 percent of all the crashes occurred on this portion of the ramp. A possible explanation for this high concentration of crashes is that there are many weaving maneuvers associated with the off-ramp and with the on-ramp that is just before this segment. The next highest concentrations of crashes were on the first and last segments of the ramp with 17 and 24 percent of the crashes respectively. A possible explanation is that these concentrations of crashes are due to weaving maneuvers begun before the vehicle entered these segments. An alternate explanation is that the concentrations at the beginning and end of the ramp are a result of the coding of the location into the data file, for example, a crash somewhere on the first part of the ramp may have been simply coded to the beginning of the ramp. It can be noted that segment 4, which contains the bridge deck location that is the subject of this study, had only 8 percent of all ramp crashes, an average of approximately one per year.

Table 4.15 shows the distribution of crashes by segment and by a single or multi-vehicle crash. Table 4.16 shows the distribution of the single-vehicle crashes by segment and type. The table again shows that most of the single-vehicle crashes involve the collision with a fixed-object. Table 4.17 shows the distribution of the crashes by segment and severity. No clear patterns can be identified.

Summary

The review of the crash records shows that 131 crashes occurred on the ramp between westbound I-696 and southbound I-275 in the ten years between 1982 and 1991. Nearly 80 percent of these crashes occurred between November and April, and nearly 70 percent of the crashes occurred on icy surfaces. November and December are more likely than other months to have days with two or more separate crashes on the ramp. In the ten-year period between 1982 and 1991 there has been only one fatal crash on the ramp. Approximately three-fourths of the crashes involve property damage only and almost a fourth involve an injury.

Just under half of the crashes involve two or more vehicles. Large multi-vehicle crashes involving as many as 12, 18 and 30 vehicles have occurred in the ten-year period. Most of the multi-vehicle crashes were of the front/rear type. Just over half of the crashes involved only one vehicle. Collisions with guard rails are the most prevalent single-vehicle crash, with the front (including right and left front) part of the vehicle striking the guard rail.

Examination of crash patterns by location on the ramp is tempered by the accuracy of the location information in the data file. The ramp was divided into seven segments 0.2 miles in length. Two-thirds of the crashes are recorded to have occurred in the first segment and the last two segments of the ramp. This could be a result of weaving maneuvers or simply a result of the coding accuracy. No distinct patterns between crash location and surface conditions, type of crash or severity were suggested by this spatial analysis.

References:

1. Miller, Paul F., Office Memorandum to Robert Welke, Deputy Director - Highways, Michigan Department of Transportation, October, 23, 1992.

Table 4.1

Crashes by Year and Type
(WB I-696 to SB I-275, 1.4 Mile Long Ramp
for 1982-1991)

Year	Type		Total
	Single-Veh	Multi-Veh	
1982	7	3	10
1983	7	3	10
1984	3	1	4
1985	2	2	4
1986	18	5	23
1987	13	12	25
1988	10	10	20
1989	5	15	20
1990	4	5	9
1991	3	3	6
Total	72	59	131
%	55.0%	45.0%	100.0%

Table 4.2

Crashes by Type and Severity
(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Crash Type	Severity			Total
	PDO	Injury	Fatal	
Single-Vehicle (%)	55 76.4%	16 22.2%	1 1.4%	72 100.0%
Multi-Vehicle (%)	39 66.1%	20 33.9%	0 0.0%	59 100.0%
Total (%)	94 71.8%	36 27.5%	1 0.8%	131 100.0%

Table 4.3

Crashes by Month and Surface Condition

(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Month	Surface			Month Total	% of Total
	wet	dry	ice		
January	1	3	8	12	9.2%
February	2	1	7	10	7.6%
March	0	0	11	11	8.4%
April	1	2	18	21	16.0%
May	0	2	0	2	1.5%
June	1	4	0	5	3.8%
July	1	5	0	6	4.6%
August	0	4	0	4	3.1%
September	0	4	0	4	3.1%
October	1	3	2	6	4.6%
November	4	3	20	27	20.6%
December	0	0	23	23	17.6%
Total	11	31	89	131	100.0%
%	8.4%	23.7%	67.9%	100.0%	

Table 4.4

Crashes by Type and Surface Condition

(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Crash Type	Surface			Total
	wet	dry	ice	
Single-Vehicle (%)	7 9.7%	17 23.6%	48 66.7%	72 100.0%
Multi-Vehicle (%)	4 6.8%	14 23.7%	41 69.5%	59 100.0%
Total (%)	11 8.4%	31 23.7%	89 67.9%	131 100.0%

Table 4.5
Number of Days with Two or More
Crashes by Month

(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

February	No. of days with two or more crashes
January	0
February	0
March	1
April	4
May	0
June	0
July	0
August	1
September	0
October	1
November	6
December	5
Total	18

Table 4.6
Crashes by Time of Day and Surface Condition

(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Time Period Hours	surface			Total for time period	% of Total
	wet	dry	ice		
0000-0300	1	5	10	16	12.2%
0300-0600	0	0	1	1	0.8%
0600-0900	4	4	22	30	22.9%
0900-1200	1	4	4	9	6.9%
1200-1500	1	3	5	9	6.9%
1500-1800	2	8	5	15	11.5%
1800-2100	0	3	25	28	21.4%
2100-2400	2	4	17	23	17.6%
Total	11	31	89	131	100.0%

Table 4.7

Single-Vehicle Crashes by Type and Severity

(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Crash Type	Severity			Total
	PDO	Injury	Fatal	
Fixed-object	46	12	1	59
Overturn	4	4	0	8
Other object	2	0	0	2
Other	3	0	0	3
Total	55	16	1	72

Table 4.8

Fixed-Object Single-Vehicle Crashes by Object Hit

(WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Object Hit	Number
Guardrail	40
Concrete Barrier	6
Sign	3
Bridge Rail	3
On-road	2
Ditch	2
Tree	1
Unknown	1
Off-road	1
Total	59

Table 4.9

Fixed-Object Single-Vehicle Crashes by Impact
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Impact	Number
Front	20
Right front	9
Left front	15
Right rear	6
Left rear	5
Right side	4
Total	59

Table 4.10

Multi-Vehicle Crashes by Type
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

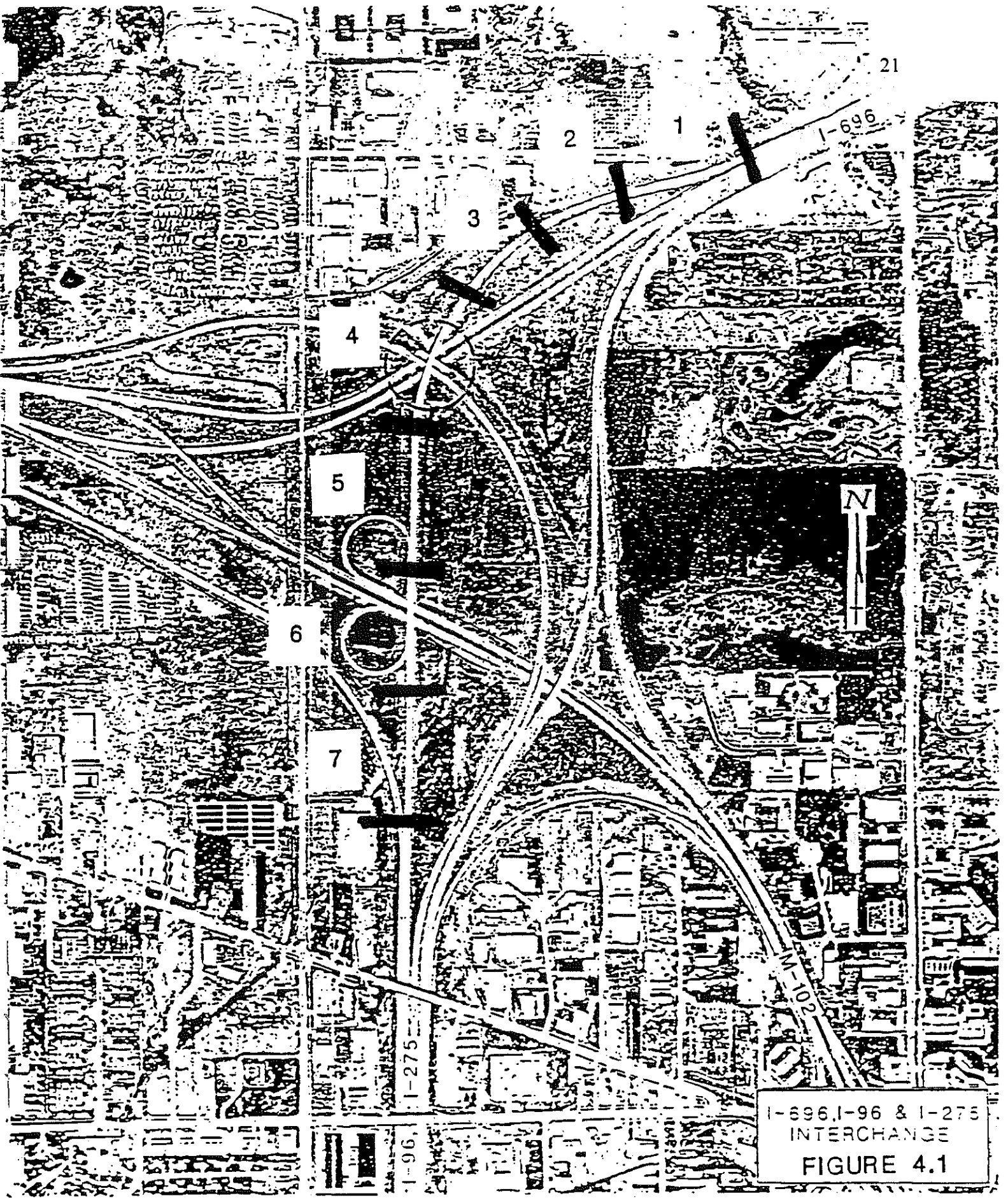
Crash Type	Number
Rear-End Straight	55
Side Swipe Same	2
Side Swipe Opposite	1
Head-On	1
Total	59

Table 4.11
Multi-Vehicle Crashes by Primary Impact
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Primary Impact	Number
Front	17
Left front	9
Right front	12
Left side	7
Right side	1
Rear	5
Left rear	3
Right rear	2
Other	3
Total	59

Table 4.12
Multi-Vehicle Crashes by Secondary Impact
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Secondary Impact	Number
Front	14
Left front	6
Right front	4
Left side	2
Right side	6
Rear	13
Left rear	8
Right rear	3
Other	3
Total	59



I-696, I-96 & I-275
INTERCHANGE
FIGURE 4.1

Table 4.13
Crashes by Segment
 (WB I-696 to SB I-275, 1.4 Mile Long
 Ramp for 1982-1991)

Segment	Crashes	% of Total
1	22	16.8%
2	11	8.4%
3	8	6.1%
4*	11	8.4%
5	12	9.2%
6	35	26.7%
7	32	24.4%
Total	131	100.0%

Table 4.14
Crashes by Segment and Surface Condition
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Segment	Surface			Total
	Wet	Dry	Ice	
1	2	9	11	22
2	2	3	6	11
3	0	1	7	8
4*	0	1	10	11
5	1	2	9	12
6	3	7	25	35
7	3	8	21	32
Total	11	31	89	131

* Segment with Bridge over I-96

Table 4.15
Crashes by Segment and Type
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Segment	Single-Vehicle	Multi-Vehicle	Total
1	14	8	22
2	5	6	11
3	6	2	8
4*	6	5	11
5	3	9	12
6	20	15	35
7	18	14	32
Total	72	59	131

Table 4.16
Single-Vehicle Crashes by Type
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Segment	Fixed-Object	Overturn	Other Object	Other	Total
1	9	3	1	1	14
2	3	1	0	1	5
3	6	0	0	0	6
4*	5	1	0	0	6
5	3	0	0	0	3
6	18	1	0	1	20
7	15	2	1	0	18
Total	59	8	2	3	72

Table 4.17
Crashes by Segment and Severity
 (WB I-696 to SB I-275, 1.4 Mile Long Ramp for 1982-1991)

Segment	Severity			Total
	PDO	Injury	Fatal	
1	15	7	0	22
2	8	3	0	11
3	7	1	0	8
4*	5	5	1	11
5	8	4	0	12
6	29	6	0	35
7	22	10	0	32
Total	94	36	1	131

* Segment with Bridge over I-96

5. Enabling Technologies

5.1 Ice Prediction and Detection

Because of the nature of ice formation and the interdependence on other conditions, ice detection systems usually take into account the pavement conditions, as well as other atmospheric parameters (such as wind speed and direction, air temperature, relative humidity and derived measurements). Approaches to the problem of ice detection can vary considerably. This is evident, not so much from the standpoint of technology, but in how the technology is applied operationally. For example, in U.S. implementations, ice detection information is used typically as input to maintenance crews as part of their de-icing or anti-icing strategies. Whereas, in Europe, ice detection information has also been used, in one case, and at one location to automatically activate thawing agent sprayers located on the roadside and, in conjunction with other sensors, used to warn motorists of reduced speed limits through variable message signs; this in addition to alerting maintenance crews. Details on all of these implementations can be found in the following sections.

While ice detectors certainly can be implemented without taking into account other atmospheric conditions, most implementations involve Road Weather Information Systems (RWIS) integrated with ice detectors. In both the U.S. and Europe, ice detection is usually just one element, albeit an important one, of a larger environmental monitoring system.

5.1.1 Literature Research

Methodology

Several literature searches were performed to identify reports related to ice prediction, detection, and warning. A DIALOG on-line search was conducted of the INSPEC, NTIS, Ei Compendex*Plus and Aerospace Databases. Because of the similarities between roadway and airport applications of ice detection, sensors that have been proposed for aircraft were also investigated for possible application to roadways.

In addition to the on-line search, references cited in previously published reports were reviewed. Finally, key individuals within state DOTs, Federal Highway Administration, Turner-Fairbank Highway Research Center, university researchers, and vendors were contacted to inquire about research and reports on this topic.

The reports and documentation obtained as a result of the literature search were reviewed with the following goals in mind:

- Identify what agencies (domestically and internationally) are currently doing to aid in ice prediction, detection and warning of motorists
- Determine what technology is available for ice prediction, detection and warning
- Determine if anyone has explored the advantages and disadvantages of warning motorists in real-time
- Determine how reliable and effective (quantitatively and qualitatively) this technology is, both on a component and system level
- Determine where the technology is headed and what can be expected in the next five years

U.S. Pre-1980

By the mid-1970's, weather information systems (including "ice detection" systems) became commercially available. In response to this new technology, FHWA and several state agencies (including the Michigan Department of Highways and Transportation) began conducting evaluations of these systems. The results of these initial reports were generally in agreement that, while promising, several problems needed to be addressed before the technology could be considered for wide-scale implementation.

In a report published in *Transportation Engineering* in 1977, C. Brinkman of FHWA reported that FHWA studies had concluded that ice detector technology was not "sufficiently reliable or accurate to operate a motorist warning system." [Brinkman, 1977, Mawhinney 1975]. He also suggested that detectors that cover a wide area would eliminate some of the problems associated with point detectors (accumulation of debris, damage caused by physical and chemical exposure). In 1978, a microwave radiometer was evaluated, showing promise for snow and ice detection over large areas. Also, in a report published in 1978, traffic and meteorological data were used together to provide early detection of ice on bridges [Eldon, 1978]. The integration of ice and traffic detectors with other sources of weather information was seen as a way to improve the reliability and effectiveness of the system as a whole.

In the mid-1970's, a study by MB Associates suggested that sensors that measured existing road conditions would be more useful for state DOT applications than predictive sensors, primarily

because predictive sensors did not appear to provide sufficient reliability and accuracy at that time. The study determined that detectors should meet the following requirements:

- The system should perform reliably with a negligible false alarm rate
- The system should distinguish distant levels of hazard detection
- The system should function in the presence of chemicals likely to be found on the roadway
- The system should be compatible with all standard snow removal equipment

Accurate sensing of a condition was defined as 99 percent correct, but the degree of acceptable accuracy and reliability would vary depending on the application [Castle Rock, 1995; MacWhinney, 1975].

U.S. Post-1980

The technology evaluated in the mid-70's did show enough promise to encourage more development in both sensors and the infrastructure necessary to communicate with remote processing units. Since then, point detectors and area detectors have undergone significant improvements. Turn-key RWIS systems, with ice detection capability, became available commercially and several states began implementing these systems.

Castle Rock Consultants reports that the primary difficulties with existing approaches to utilize weather information appears to be "lack of localized, short-term weather forecasts to support the sensor information and the lack of compatibility between commercial systems." [Castle Rock Consultants, 1995].

Europe

Many European countries have been extremely proactive in researching, developing and implementing the technologies described in this report. Much of the work is initiated through collaborative efforts and consortiums that include many countries and a diverse group of organizations. The major programs that drive these efforts are described in Section 5.1.4.

5.1.2 Vendor/Product Search

An initial vendor list was prepared based on references in reports, as well as information provided by state and federal DOT staff [SHRP-H-350, 1993; CastleRock, 1995]. This list includes domestic and international vendors. We have also included companies that have developed ice detection products intended for aircraft or airport runways that may be applicable to roadways. A DIALOG on-line search was performed to obtain new product announcements

related to ice prediction, detection and warning (DIALOG(R)File 621:PTS New Prod. Annou.(R), (c) 1995 Information Access Co.). Every reasonable effort was made to identify all vendors that offer products in this area. Vendors were then contacted to obtain information regarding the accuracy and reliability of ice detection components or systems.

Vendors include:

Aanderaa Instruments, Inc.

73 Second Avenue, Burlington, MA 01803

Boschung Mecatronic

3185 Schmitten, Switzerland

Campbell Scientific, Inc.

815 W. 1800 N., Logan, Utah 84321-1784

Climatronics Corporation

140 Wilbur Place, Bohemia, New York 11716

Raton Technology Research

848 Clayton Road, P.O. Box 428, Raton, New Mexico 87740

Rosemount Aerospace

14300 Judicial Road, Burnsville, MN 55306-4898

Soluse Systems, Inc.

741 S.W. Lincoln St., Portland, Oregon 97201

Surface Systems, Inc.

11612 Lilburn Park Road, St. Louis, MO 63146

Vaisala

100 Commerce Way, Woburn, MA 01801-1068

Vibro-Meter Corp.

11240 Megwood Drive, Charlotte, NC 28277

5.1.3 Sensor and System Descriptions

Based on the results of the literature searches, several reports provided descriptions or evaluations of ice detection technology, including commercial and laboratory-grade sensors. A comprehensive review of currently available environmental sensor systems can be found in the Castle Rock report [Castle Rock, 1995]. While focusing primarily on an evaluation of visibility sensors, Castle Rock Consultants also reviewed the state of the art in pavement sensors.

The ultimate goal of pavement sensing is to be able to predict surface friction on the roadway. To accomplish this, several physical conditions of the roadway must be measured, including temperature, precipitation and the amount of deicing chemicals. Sensors placed within the pavement (in-situ point detectors) or sensors that operate remotely (area detectors) are used to make these measurements. To aid in the prediction of pavement conditions, Road Weather

Information Systems (RWIS) that measure atmospheric conditions are often used in conjunction with pavement sensors. A report by the Strategic Highway Research Program (SHRP) provides detailed information on Road Weather Information Systems and how they can be applied to support snow and ice control [SHRP-H-350, 1993].

Both the Castle Rock and *Conditions of Road and Weather Monitoring* (CROW) reports provide a review of basic operating principles for pavement sensors, with the Castle Rock report being the more comprehensive of the two [Castle Rock, 1995; CROW, 1995]. Pavement sensors can be classified in several different ways, such as mode of operation or active/passive. For the purposes of this study, pavement sensors will be classified according to the area over which they make their measurements, i.e. the amount of roadway surface area covered by the sensor.

In-Pavement Sensors (Point Detectors)

- Passive Thermal (thermistor, resistance thermometer, or thermocouple) [Solus/Texas Electronics]
- Capacitance
- Conductance
- Freezing Point (active heating/cooling)
- Vibration [Rosemount Aerospace; Feely, 1994]

Remote Sensors (Area Detectors)

As described in the previous section, one of the drawbacks of in-pavement or point detectors is the small area over which they perform their measurements. When conditions vary across a roadway, point detectors could be misleading, unless the spatial area covered by the individual sensor is representative of the surrounding area. To cover a larger area, more point detectors must be used. Depending on the road surface to be monitored, this may or may not be economically feasible. Remote (area) detectors have been proposed as a solution to this problem since the early 1970's. The most recent applications have taken place as part of the Dedicated Road Infrastructure for Vehicle Safety in Europe (DRIVE) program and are discussed in the CROW report [CROW, 1995]:

○ **Non-Contact Microwave**

Microwave reflections enable the distinction of water levels up to 10mm, with reducing accuracy for lower frequency. Since this sensor is not suitable for identification of icy road conditions, a prototype sensor that combines the non-contact microwave and infrared detectors has been developed under the DRIVE program.

◦ **Non-Contact Infrared**

The three road surface conditions of dry, wet and icy can be clearly distinguished from the IR reflection characteristics.

Both water levels (tested up to 2mm) and ice thickness can be clearly distinguished from IR reflection characteristics.

A combination of non-contact infrared and in-situ conductivity sensor, used to measure surface moisture and the presence of deicing chemicals, is reportedly operational in Germany.

◦ **Laser-based Black Ice Detector**

Image identification techniques are used to distinguish between different road conditions using a laser reflection from the road surface [Chen, 1991].

Commercial Products

Many commercial products are available today for measuring various roadway conditions. These products include individual sensors as well as fully integrated Road Weather Information Systems. Descriptions of Value-Added Meteorological Services (VAMS) are not provided here, but can be found in the SHRP-H-350 report. The following products are described in the Castle Rock report [Castle Rock, 1995]:

Climatronics (U.S.) - FRENSOR

Surface Systems, Inc. (U.S.) - SCAN

Vaisala (Finland) - Road Surface Sensor DRS12

AANDERAA Instruments - Road Surface Temperature Sensor (3304) and Conductivity Sensor (3330)

Findlay Irvine (Scotland) - Road Surface Sensor

BG Engineering (Holland) - Road Condition Sensor

Rails Company (Sweden) - Road Condition Sensor

Vibrometer SA (Switzerland)

Hokkaido Development Bureau (Japan) - Dielectric Pavement Sensor

Boschung Mecatronic (Switzerland) - GFS2000 Ice Warning System

Schrack Systems, Inc. (Austria) - Road Condition Radar

RENSTAR - Road Temperature Monitoring System

5.1.4 Test and Evaluation Programs

U.S. Programs

Two recent U.S. programs have included ice detection as part of their evaluations and have provided much of the background for this report. The FHWA Test and Evaluation Project 11, "Ice Detection and Highway Weather Information Systems Summary Report," addresses the usefulness, effects on highway safety and cost-saving aspects of ice detection and weather information systems. The FHWA study (DTFH61-92-C-00012) by Castle Rock Consultants assesses the functional requirements for environmental sensors and evaluates the state-of-the-art in sensors and sensor systems. These reports are summarized below.

◦ Ice Detection and Highway Weather Information Systems FHWA Test and Evaluation Project 11

This was one of the first attempts at documenting the effectiveness of ice detection and road weather information systems, rather than just the performance of the equipment. Eight state agencies participated in the study and evaluated their systems during the 1989 and 1990 winter months. They were asked to document how useful their systems were in helping to maintain safety and improve snow and ice control efficiency.

The following state agencies participated in the project:

- District of Columbia Department of Public Works
- Idaho Transportation Department
- Kansas DOT
- Michigan DOT
- National Park Service, National Capital Region
- New Jersey DOT
- Virginia DOT

Michigan's DOT was one of the agencies participating in the project and the following is an excerpt from the report on Michigan's results:

"An attempt was made to relate the number of ice related crashes to use of the system. Accident data for the two winters showed a decrease in the proportion of ice related crashes to total crashes during the second winter. It was speculated that perhaps resolution of the equipment problems by the second winter increased the effectiveness of the system. Lack of

information on the severity of the winters and on accident experience prior to using the systems made it impossible to draw a conclusion on the usefulness of the system in reducing crashes. There was consensus among the users that the pavement sensors provided useful information which increased winter maintenance efficiency and that more should be installed."

It was reported that four of the agencies involved in the study attempted to determine the safety benefits. Though no quantifiable accident statistics were compiled, "there was consensus that use of the system enhanced safety by enabling more timely treatment of icing conditions. The consequent decrease in the number of black and glaze ice occurrences results in a concurrent decrease in the number of ice-related crashes." [Eng, 1993].

Nearly all agencies included information from their RWIS/ice detection systems in the maintenance decision process. Each agency that did this also reported a reduction in personnel, material, and/or equipment as a result of using the information. All agencies reported general satisfaction with the accuracy of their systems and are either planning to expand or have expressed a desire to expand the systems.

Some of the conclusions stated in the report are as follows:

"Proactive use of ice detection and highway information systems to aid in planning winter maintenance operations can:

1. Result in reductions in personnel, material and equipment needs,
2. enable more timely treatment of icing conditions and reduce the potential for crashes by reducing the incidence of black and glaze ice pavement surface conditions,
3. result in reductions in the amount of corrosive or environmentally harmful chemicals used for snow/ice control."

In addition, "Ice detection and highway weather information systems for improved highway operations and safety are considered to be proven technology."

o **Environmental Sensor Systems for Safe Traffic Operations** **FHWA DTFH61-92-C-00012**

Castle Rock Consultants performed an in-depth review of environmental sensors, including those used for measuring roadway surface conditions and reported on the results of a series of field tests of visibility sensors.

Those sections of the Castle Rock report relevant to Roadway Warning Systems, include a description of the functional requirements of environmental sensors, a state-of-the-art review of

atmospheric, pavement, visibility, and wind sensors; an overview of research and development activities and a functionality assessment of sensing technologies.

One of the conclusions of the Castle Rock report was that significant benefits could be realized by integrating environmental sensor systems, such as RWIS and roadway surface sensors, with Intelligent Vehicle-Highway Systems (IVHS). Some of the recommendations are as follows:

"Environmental sensors should be designed to readily communicate with other traffic control and monitoring devices. This requires the adoption of open interfaces and use of standard communication protocols. Compatibility between manufacturers' systems would greatly benefit users."

"Systems integration is recommended if the full benefits of environmental sensors are to be achieved. Data from the sensors on pavement conditions and visibility need to be combined with general meteorological information to allow short-term forecasts to be made."

"Better use needs to be made of the information available from environmental sensor systems and meteorological forecasts. Training of system users is therefore a key requirement. Although beyond the scope of this study, it is recommended that a comprehensive training program be developed."

o **Road Weather Information Systems SHRP-H-351**

The Strategic Highway Research Project (SHRP) has been investigating snow removal and ice control policy, methods and technology and has generated several reports involving Road Weather Information Systems (RWIS) and sensors. One of those reports, "Road Weather Information Systems," provides information on snow and ice control practices, road weather information currently available to agencies, data communication issues, and how to apply road weather information systems to snow and ice control activities including installation recommendations.

The RWIS technologies described above were evaluated during the 1990/91 winter by states under Contract SHRP-87-H-207, "Storm Monitoring/Communications." A cost/benefit analysis was performed based on the results of that evaluation. The report concluded that "the use of RWIS can be a cost-effective method to reduce costs and improve roadway snow and ice control." Specific recommendations were made with regard to the type of technology that is available and how, when and where to make use of it.

◦ Notes on Other Related Testing Programs

Advanced Driver and Vehicle Advisory Navigation Concept (ADVANCE), Chicago, Illinois:

"This project involves equipping private and commercial vehicles in Chicago, Illinois, with in-vehicle route guidance systems. During this Field Operational Test involving a 300-mile square area, an RWIS will provide weather and pavement condition information used by a control center to direct traffic flow to safer road surfaces" [Morris, 1994].

Travel Aid, Washington State:

"The state DOT plans to implement variable message and speed signs with an in-vehicle display system for a 38-mile section of Interstate 90 at Snoqualmie Pass. An RWIS will be used to monitor the pass, known for its extreme weather conditions" [Morris, 1994].

European Programs

The European Community (EC) has been very proactive over the past twenty years by conducting joint projects in many areas of the transportation field. In combining resources from industry, academia, and government, the members of the EC have been able to make great strides not only in research and development, but in the deployment of the systems and collection of valuable field data. The major programs are described below.

◦ COST

The European "Co-Operation in the Field of Scientific and Technical Research" (COST) project is primarily focused on the cost-benefits of winter maintenance. These benefits include monetary savings from reduction of unnecessary stand-by time for staff, and a reduction in materials and equipment usage. It also refers to reducing the negative impact of winter maintenance on the environment [CROW, 1995].

One of the projects within COST, COST-30, had the objective of improving traffic safety and flow conditions using traffic sensors for detecting and monitoring traffic conditions and communicating with motorists. One of the nine research areas within COST-30, Theme 8, involved the relationship between traffic and weather. The result of Theme 8 led to several new projects, including COST-309 with the goals of investigating highway weather detection, forecasting, statistics and service strategies [Castle Rock, 1995].

Regarding road weather information, the COST-309 report states:

"The benefits to be gained from such systems are many fold and include:

1. Cost savings on raw materials
2. Improved safety

3. Less environmental pollution
4. Streamlining of maintenance strategy (this could lead to a reduction in capital expenditure)
5. Less stress on the roadmaster
6. Archived data (useful for indexing and future strategic planning)

Studies have shown that savings are often in the order of 30% and can lead to a return on the original investment within 1 or 2 years."

"It is generally recognized that modern ice detection and prediction systems should form the basis of an integrated winter maintenance strategy. Despite relatively high installation costs, their implementation will soon reap benefits in terms of better safety, long term cost savings, optimal response to critical weather situations and minimizing of environmental damage."

"One effect of the road weather service system could be a 50% prompter salting, e.g., If the salting normally begins 3 hours after confirmation of the change in road conditions, it would now begin 1.5 hours after confirmation. This kind of improvement in maintenance activities would decrease the amount of crashes 3% - 17% depending on the district and the winter (according to the research made in Finland, 1988)" [COST-309, 1992; SSI, 1994].

◦ **PROMETHEUS**

PROMETHEUS is a collaborative effort involving the European automotive industry, government transportation agencies, research institutions and academia. Started in 1986, PROMETHEUS was created to make vehicles safer and more economical by combining basic level research from universities with applied research from industry. Common European Demonstrator (CED) programs were then established as platforms to compare technology and approaches, evaluate system performance and identify cost/benefit drivers [Castle Rock, 1995].

One CED2 program, "Proper Vehicle Operation," was initiated to:

"Improve vehicle safety and therefore traffic safety ensuring better control of the vehicle and the driver, in all road and traffic situations."

This program involved detection of road conditions from the vehicle, observation of driver performance and vehicle dynamics status, and determination of safety margin and vehicle control. Most of the research focused on autonomous, in-vehicle systems.

◦ **DRIVE, CROW and ROSES**

The DRIVE program began in 1988 and is funded by the European Community. DRIVE I had the following objectives:

- improving road safety
- increasing road transport efficiency
- reducing environmental impact

The *Conditions of Road and Weather Monitoring (CROW)* project is a multidisciplinary effort within the DRIVE initiative. The intent of CROW is to enhance the motorists safety under bad weather conditions. CROW consisted of the following elements:

- a technique to predict the onset of aquaplaning based on extrapolation of radar imagery
- a knowledge-based system to provide fog warnings
- prototype microwave, infrared and laser-based sensing systems for monitoring the conditions of road surfaces
- an improved integrating nephelometer to assess road visibility
- a CROW road/weather Control Center (CCC)
- an algorithm to define safe traffic levels in bad weather conditions, based on road, weather and traffic data

DRIVE II involves testing, evaluation, pilot projects and field trials of systems that resulted from the research performed under DRIVE I. A follow on to CROW, the Road Safety Enhancement System (ROSES) is a DRIVE II project with the objective of improving inter-urban traffic safety under adverse weather and road conditions using a fully integrated safety monitoring system. To this end, the ROSES system provides motorists with information, warnings and support. Operationally, ROSES implements the road and weather monitoring systems developed in DRIVE I CROW and the PROMETHEUS CED2 "Proper Vehicle Operation." The monitoring system for ROSES is implemented at two pilot locations. At this time, however, before/after crash studies are not a part of the ROSES program.

5.1.5 Reliability of Ice Detection Sensors and Systems

Sensors

Environmental sensors measure meteorological parameters and roadway surface conditions, either directly or indirectly through measurements derived from other measurements. Typical parameters measured by these sensors include [Castle Rock, 1995]:

- Atmospheric pressure
- Ambient temperature
- Wind speed, direction, and gust
- Humidity, dew point temperature
- Relative humidity
- Precipitation type, rate, and depth

- Solar radiation/cloud cover
- Visibility (fog, smoke, dust, etc.)
- Pavement surface temperature
- Pavement moisture
- Snowy or icy pavement conditions
- Amount of deicing chemical present on pavement

The performance criteria for environmental sensors established in the Castle Rock Report include the following:

- Accuracy
- Sampling rates
- Calibration
- Reliability and robustness
- Power requirements

Existing standards that address many of the above performance criteria include the FAA Advisory Circular 150/5220-16A which contains values for meteorological measurements obtained by automatic weather observing systems and a specification for a national ice prediction network developed in the UK by the Department of Transport.

The Castle Rock report contained a comprehensive, though only qualitative, assessment of various sensor technologies, including those used in ice detection. This assessment was performed to "determine the extent to which they (sensor technologies) fulfill the functional requirements of a condition-responsive driver information and warning system." The results of this assessment are reproduced here with permission of Castle Rock Consultants. These results are useful in that they depict the relative strengths and weaknesses of the varying technologies. Together with the specific evaluations of systems conducted by state DOTs in the next section, it is possible to obtain a reasonable estimate of pavement sensor accuracy and reliability.

The following definitions apply to Figure 5.1.5.A, Pavement Temperature Sensors, and Figure 5.1.5.B, Pavement Moisture Sensors:

- **accuracy** - the sensor's ability to provide a high correlation between its measurements and actual conditions.
- **reliability** - the sensor's ability to maintain its specified degree of accuracy over a typical range of severe weather, traffic, and other environmental conditions.
- **real-time response** - the time taken to determine parameters given the needs of users.
- **wide-area coverage** - the spatial area covered by a single sensor.
- **high spatial resolution** - the ability to provide measurements representative over a small area or point, so that accurate spatial profiles of an environmental parameter can be obtained.
- **durability** - the ability of the sensor to operate for long unattended periods, requiring only occasional maintenance and/or calibration.

- **high cost/benefit ratio** - a high degree of benefit, satisfying all requirements, for a relatively low cost.
- **compact** - relatively small size, for the given application.
- **low power consumption** - offering the possibility of portable operation, battery powered, battery backup, solar power (in remote locations), etc.
- **minimal traffic disruption** - minimal impact to traffic during installation, calibration and maintenance procedures.
- **identify type** - for pavement moisture sensors, the ability to detect the type of moisture present, e.g, rain, snow, ice, frost, etc.

The ratings in Figures 5.1.5.A and 5.1.5.B range from low to high. Since variants of a particular technology may also vary in their performance, some technologies may be given a range of scores, such as low to medium or medium to high. The box is left blank when the ability of a particular technology to meet a given performance requirement is unknown.

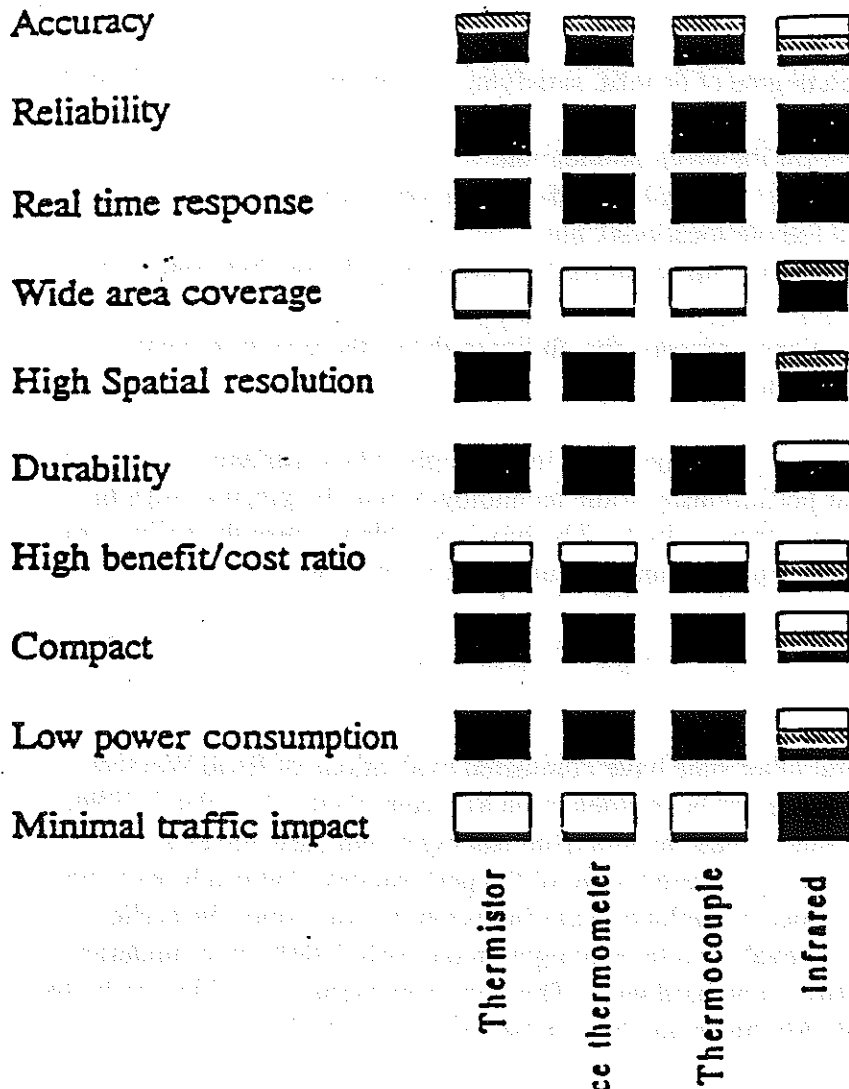
Systems

Michigan, New Jersey and several other state have conducted evaluations of Road Weather Information Systems that included ice prediction/detection as a component [Maryland, 1994; Spica, 1984, 1988; Balgowan, 1988]. These results from Michigan and New Jersey are described below and are believed to be representative of the performance that can be expected for this type of technology. The dates of evaluation are important to note, since the earlier systems, such as the SCAN system evaluated by Michigan in the early 1980's, have undergone significant improvements in software and hardware. These improvements are evidenced by the increased accuracies seen by both Michigan and New Jersey in the late 1980's.

○ Michigan

SCAN 16 - Moisture, Frost, Ice Early Warning System

From the conclusions of this report, reliability and performance of the system were found to be "excellent." Accuracy of the system was reported according to four segments. The first segment being the winter of 1982-83 and the other three segments during the winter of 1983-84. During each of the segments, upgrades were made to the software and in some cases, to the hardware.



KEY

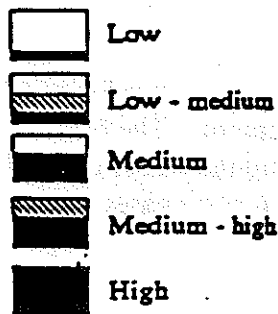


Figure 5.1.5.A Pavement Temperature Sensors

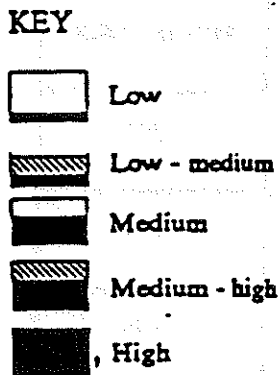
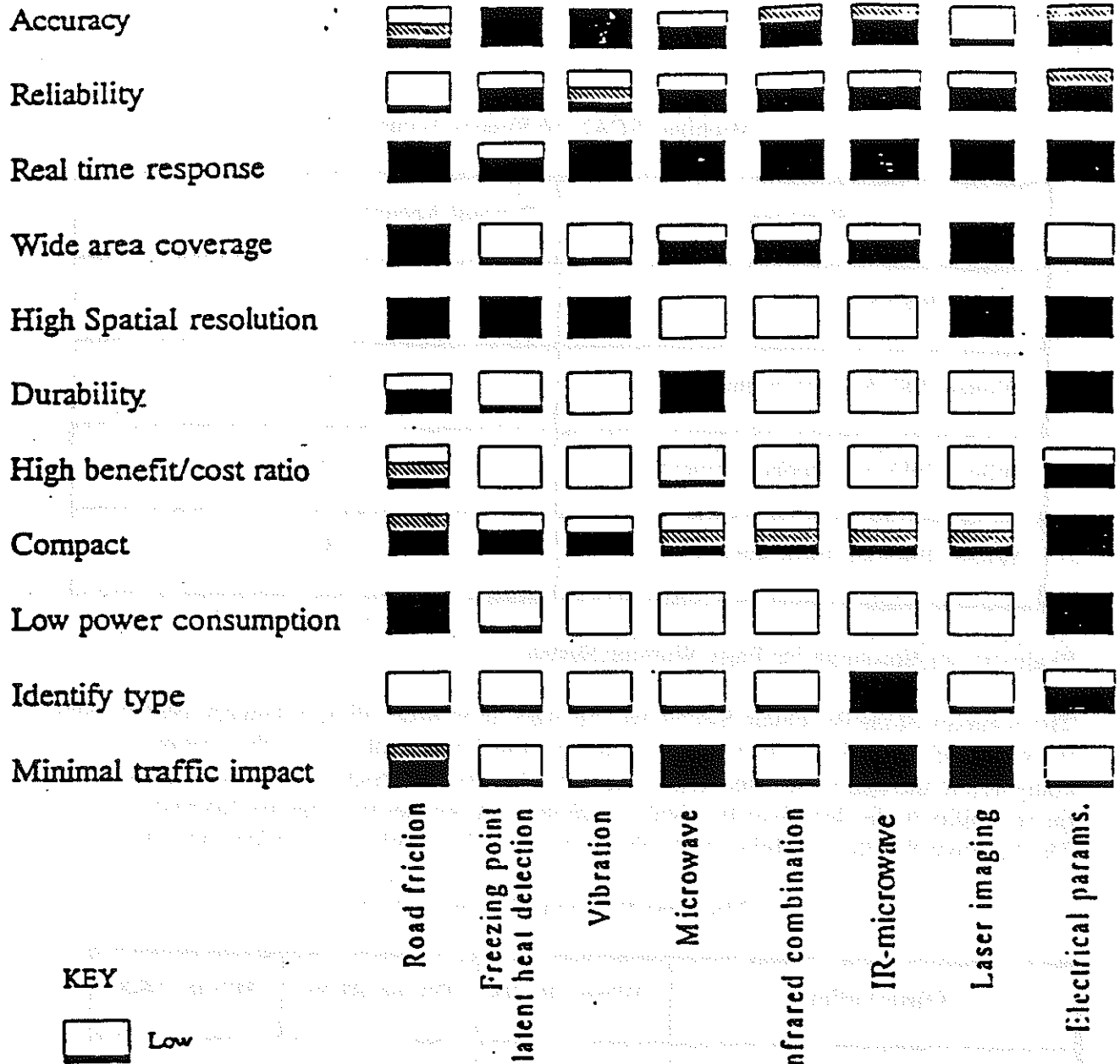


Figure 5.1.5.B Pavement Moisture Sensors

Michigan SCAN 16 System Accuracy

Segment	Percent Accuracy
Winter 1982-83	78.2
Winter 1983-84, first segment	67.3
Winter 1983-84, second segment	66.7
Winter 1983-84, third segment	83.5

Evaluation of Boschung Ice Early Warning System

The accuracy of the Boschung System was recorded from installation in January 1984 through the winter of 1987. Since the winter of 1983-1984 had only a total of 34 observations as compared to the following winters (331 and 207 observations, respectively), it is believed that the reliability of the data from the final two winters was greater than that for the first winter. This assumes that the reliability of the data increases with number of (random) samples.

Michigan Boschung System Accuracy

Observations	Winter 84-85	Winter 85-86	Winter 86-87
Total Number of Observations	34	331	207
Total Usable Observations	34	310	197
Number of Agreements	22	261	173
Number of Disagreements	12	49	24
Accuracy Rate (Percent)	64.7	84.2	87.8

o **New Jersey DOT**

The New Jersey DOT evaluated the accuracy and reliability of their SCAN 16 EF Moisture, Frost and Ice Early Warning System in 1985/1986. Four sites provided pavement and atmospheric data via RPUs. By comparing field observation data to the data provided by the SCAN system, overall system accuracy was found to be 91%. System hardware, software and peripherals were found to be highly reliable in terms of breakdowns; although phone line communications were less reliable than radio communications.

The table below contains the comparison between field observations and SCAN system data.

New Jersey SCAN System Accuracy

Pavement/Atmospheric Category	Total Number of Observations	Tolerance	% Accuracy
Roadway Status	287	0	90
Precipitation	305	0	87
Wind Direction	54	0	100
Air Temperature	264	±4 degrees	94
Surface Temperature	12	+1 degrees	92
Overall Weighted Average			91

5.1.6 Effectiveness of Ice Detection Systems

Many state DOTs have taken the initiative to implement extensive roadway information systems, including ice detection and prediction as one element, and have published reports on the results of those activities. Some of these reports are summarized below.

U.S. Programs

o Colorado

On an elevated portion of I-70 in Denver, accident data was collected from 1983-1990. A SCAN ice detection system was installed early in 1987 and was used extensively for the first time during the winter of 1987/1988. Since then, it has become a standard tool used in winter maintenance activities [Woodham, 1991]. Thus far, the system has been used to inform maintenance agencies responsible for snow and ice control, but has not been used to directly warn motorists.

At the time of this report, the ice detection system consisted of eight instrumented locations linked by radio and phone lines to a central computer.

To normalize the accident data with respect to severity of the winter, a multiple regression technique was used to predict the number of crashes based on the number and intensity of winter storms and the amount of snowfall. The actual number of crashes due to snow and/or ice were recorded and plotted graphically. Compared to the predicted number of crashes, the actual number of crashes dropped in each year after the ice detection system was installed. It was also noted that there were no major multi-car crashes on the elevated portion of I-70 since the system was installed. Prior to the installation, several multi-car crashes had occurred.

Two uncontrolled variables, however, occurred with respect to the reporting of crashes. After 1988, the reporting threshold for crashes was raised from \$500 to \$1000. Additionally, during an "accident alert", where large number of crashes are occurring (e.g. in a winter storm), accident reports do not need to be filed on the scene if no injuries occurred and alcohol was not involved. The motorists can then call the information in to police within 24 hours. These crashes were not included in the database and, therefore, not reflected in this study.

The actual numbers may have been influenced by other factors as described above, thus it is difficult to make a definitive statement about the reduction of crashes due to implementation of the ice detection system. The trend, however, is consistent with the qualitative assessments of other reports. Additionally, this trend is supported by the reduction of multi-car crashes and/or injury crashes (since injury crashes had to be reported at the scene and are more likely to involve damage above the \$1000 threshold).

o Maryland

In Maryland, four sites are instrumented with 14 pavement sensors and they additionally subscribe to a pavement temperature/precipitation forecasting service during the winter months. Plans include a traffic management system that will integrate snow and ice control operations with traffic management/information systems. Approximately 50 sites using 200 sensors statewide are proposed. All of the current and planned sites are on bridges or superelevated overpasses and usually cover the approach, elevated deck and roadway below. Twenty-one sites are planned to be operational before the 1995-1996 winter season [Maryland Survey Response].

The DOT evaluated their SCAN system over the course of the 1993-1994 winter season. Both accuracy and reliability of the system were found to be high; though only qualitative assessments were available. Since most of the system will not be operational until June 1995, no quantitative evaluations have been performed with regards to motorist safety.

o Michigan

The Michigan DOT evaluated two types of Road Weather Information Systems, each with an ice detection component, in 1984 and again in 1988. The results of these evaluations are described below.

SCAN 16 - Moisture, Frost, Ice Early Warning System

One of the earlier versions of a SCAN system by Surface Systems, Inc. was installed on four parallel bridges in Lansing, Michigan, with final installation occurring in January 1983. Four roadway sensors, three atmospheric sensors and a remote processor unit were located at the site. The roadway sensors measured surface temperature, moisture content and the amount of de-icing chemicals present. Atmospheric sensors measured relative humidity, air temperature and precipitation.

The primary objective of this evaluation was to document the ability of the system to predict and detect the formation of ice on the bridge deck and also to:

1. Evaluate the durability of sensors, electronic equipment, and other system components in Michigan's climate.
2. Obtain experience and information on conditions which result in bridge deck icing.
3. Evaluate the methods used to detect the formation of ice on the bridge deck.
4. Determine if the information output from the detection system can be used to effect a reduction of bridge icing crashes.

5. Determine the feasibility of implementing a district-oriented grid of sensors on strategically located bridges to monitor the movement of changing weather conditions across the state for the initiation of pavement salting.

To determine the effectiveness of the system at reducing crashes, the percentage of icy crashes relative to total crashes were recorded before and after the system was installed.

Before and After Accident Statistics

Before	Total	Icy	Percent
January 25, 1980 to January 24, 1981	59	15	25.4
January 25, 1981 to January 24, 1982	77	28	36.4
January 25, 1982 to January 24, 1983	41	13	31.7
After			
January 26, 1983 to January 25, 1984	66	23	34.8

The ADT figures for the same years shows a steady increase each year.

ADT on I-496

Year	West of Site	At Site	East of Site
1980	38,631	32762	41435
1981	40,145	33034	42683
1982	40,171	32998	43446
1983	42,468	33972	47324

An extremely mild winter in 1982 could have contributed to the relatively low icy accident count that year as could the slight decline in traffic volume. Excluding that year, the percentage of icy crashes has declined even though ADT numbers have increased.

From the conclusions of this report, it was stated:

"One of the stated objectives of this report was to determine if the information output from the detection system can be used to effect a reduction of bridge icing crashes. The shorter the time period a road surface remains in a slippery condition, the less chance an ice-related accident will occur. Since this system does give information related to the road surface, it should assist maintenance personnel during winter storms.

Since the Scan 16 system has proven its durability, and its accuracy is constantly being improved with software updates, it is recommended that the system presently in operation be expanded. Further, it is the recommendation of this report that the SSI system no longer be considered experimental but rather an operating system with the understanding that neither this system nor any other can ever be 100 percent accurate. Improvements will continue to be made but here are too many variables to expect 100 percent accuracy" [Spica, 1984].

Evaluation of Boschung Ice Early Warning System

In 1984, Boschung Co. offered to install and maintain their Ice Early Warning System for a period of two winters on a site in Michigan. The DOT selected the westbound I-696 to southbound I-275 ramp and the deck below carrying I-275 traffic to I-96. Installation was completed in January of 1985 and evaluated over the remaining 1984-85 winter through the winter of 1987. A separate system was installed for each of the two structures, with each system consisting of two atmospheric probes for air temperature and precipitation and one surface probe that measured surface temperature, moisture content and amount of de-icing chemicals present.

During the time when the system was installed, it was noted that no multiple-car crashes occurred on the bridge. Other improvements were also made to the bridge during this time, however, such as texturizing and aluminum railing removal in 1984 and a latex overlay in 1985. The report states, "It is, therefore, difficult to say the system was solely responsible for this accident reduction but it probably played a part in it." [Spica, 1988].

o New Jersey

New Jersey installed a road weather information system in 1984 which became operational in the winter of 1985/1986. The system includes moisture, frost and ice early warning components installed on four bridges. A typical site consists of pavement and atmospheric sensors that are hard-wired to a Remote Processing Unit (RPU). The RPUs can be queried and also transmit the data to a central computer via radio whenever a significant change in the data occurs.

One of their conclusions regarding the safety benefit is as follows:

"Since accident data is not yet available for the period from January 1986 to the end of the evaluation, a conclusion cannot be reached concerning whether the system results in a reduction in snow and ice related crashes; however, it appears that a significant reduction in snow and ice related crashes could be realized" [Balgowan, 1988].

By winter of this year, New Jersey is planning on manually activating at least one VMS based on roadway conditions. They have also expressed a strong interest in using automatically activated message signs.

o Virginia

In Virginia, 42 RWIS stations have been installed state-wide. Motorists are informed of roadway conditions via a "Highway Helpline" toll-free number, the media, Highway Advisory Radio, and variable message signs (VMS). Installation of these systems began four years ago and is continuing with additional stations being added each year.

Four sites are instrumented with ice detection systems, with data from these systems being transmitted to control stations. Two sites have yellow flashing beacons attached to "Bridge May Be Icy" caution signs that are activated manually by maintenance personnel, based on road surface sensor information. At two bridge-tunnel locations, operators at the control station manually activate a VMS under the appropriate conditions. The operator may or may not do a visual verification of the site before activating the sign, depending on the current observable weather conditions. Messages including "WARNING: ICY ROAD AHEAD," or "WARNING: POSSIBLE ICY ROAD AHEAD" are displayed to warn motorists. Based on our study, Virginia is the only state that directly informs the motorist based on data from their ice detection systems on an operational, but delayed, basis. They have been operating these systems over the past two years. No quantitative results are available on the effect that those systems have on improving motorist safety since no before/after studies are being conducted.

European Programs

o Germany

An automatic deicing spreader system [Boschung-Mecatronic] was installed along a 6 km length of the Sauerlandlinie Autobahn (Federal Motorway A45) in Germany. An analysis by the Federal Highways Institute (Bundesanstalt für das Strassenwesen, BAST) indicated a reduction in crashes of 57.9% during wintry road conditions, after the system was installed [Traffic Technology International, 1994]. Other accident statistics were reported as follows:

- crashes involving slight injuries decreased by 85%
- crashes involving slight material damage decreased by 60%
- crashes involving heavy material damage decreased by 25%

Since there are many facets to the system, it is not evident how much of the reduction in crashes is due to the any individual component (e.g., deicing sprayers, motorist warning, etc.). These details may be contained in the original report which is available only in German and has not been fully translated [Durth, 1993].

5.1.7 Research and Development

Research and development is strong in several different areas related to ice prediction and detection. Driven by the need to reduce maintenance costs and improve safety at the same time, many state DOTs are implementing RWIS and road surface detection systems in an effort to become more efficient and responsive. Much of the systems level research taking place today is in the development of forecasting models that will allow accurate and timely prediction of roadway conditions based on the data coming from surface and/or atmospheric sensors [Takle, 1990]. Many state agencies that have RWIS and related equipment are now concentrating on developing better ways to make use of the data in terms of their snow and ice control decision making strategies.

Sensor development is also continuing, with a significant amount of effort being placed on remote (area) detectors, such as thermal and microwave radiometers, as well as sensors on vehicles [CROW 1995]. At least one manufacturer of an RWIS system is looking at adding video capability to verify roadway conditions. In other areas, FHWA and the National Weather Service are exploring ways to more efficiently disseminate weather information among transportation agencies.

Anti-icing, which has been used extensively by European transportation authorities and airports for many years, involves application of chemicals on the pavement before or immediately after ice or snow has started falling to prevent formation of a bond with the pavement. This approach requires weather and pavement condition information on a real-time basis. In the U.S., research in this area is being conducted through the FHWA Anti-icing Project No. 28 [SHRP FOCUS, 1995].

5.2 Traffic Surveillance

A review of recent reports and technology assessments made by ERIM, the FHWA and other research institutions have provided the necessary data for the assessment of past, present and emerging detector technologies. Referring to the referenced assessment studies, that are

summarized in this section, will serve to provide details on tests of specific detectors. These references will also contain more details on testing procedures employed as well as details on specific vendor models.

New ITS (Intelligent Transportation System) technologies require different demands for accuracy and reliability. These technologies and their data requirements are presented. They are discussed in terms of specific traffic parameters that are needed by specific applications. Specific traffic parameters that can be provided and/or estimated by specific detectors are also described.

5.2.1 Literature Research

ERIM performed a DIALOG on-line search to verify that its traffic surveillance database was current and that there were no newer results since the FHWA-sponsored *Detection Technology for IVHS* Project [FHWA Task A 95] was performed. The literature research indicated that this FHWA Project represents the most recent and comprehensive work in the evaluation and characterization of traffic surveillance technologies. Thus, this report will draw heavily upon that study and will summarize their findings in terms of the needs for this application. A surveillance technology study was also performed for MDOT in 1991 by ERIM [Gilbert 91] and the FHWA Study did not identify any newer technologies.

FHWA Task A Report

The Task A Report is a result of the previously mentioned FHWA project. A major goal of that entire project included the determination of appropriate traffic parameters needed for future IVHS (now called ITS) applications. Another major goal was to evaluate detector technologies through laboratory and field tests. The focus of the Task A report was on the development of IVHS traffic parameter specifications. The data needs of some current and future ITS applications were considered. The suitability of various detector technologies to these applications were then analyzed. The analysis was based on the ability of a detector technology to provide key traffic parameters. Performance was based on:

- accuracy,
- precision, and
- repeatability

The importance of either is dependent on the application. Communications (vehicle to road) and vehicle identification (AVI systems) are covered as they assist in the gathering of some key traffic parameters, but were not part of the technology study.

Traffic Flow Characterization

In the past, traffic data was used to gather historical information useful for off-line studies and calculations. ITS applications involve many real-time data needs which also have a need for higher accuracy. Real time data requirements vary from application to application and from measure to measure. Some measures in some applications require updates every fifteen minutes, some require second by second update, and others require detectors positioned to generate predictive data

The three most basic fundamental measures are:

- *flow* (f),
- *speed* (v), and
- *density* (k).

Their fundamental relationship is defined as:

$$f = v * k$$

Flow is typically measured as vehicles per hour per lane. Speed is measured in miles per hour and density is measured in vehicles per mile per lane. Travel times for vehicles in urban traffic is influenced by intersections and traffic signals. Thus, additional measures like delay, number of stops a vehicle makes, and turning movements at intersections are important for evaluation.

There are additional measures. Occupancy is measure that is the percentage of time that any vehicle is present at a particular location or link. Headway (h) is the temporal spacing between two vehicles. Average headway on a link is the inverse of average flow ($h = 1/f$).

Flow (volume), demand rate from one origin to a destination, headway between vehicles and throughput are measures that help determine the quantity of vehicles. Speed, density, delays and stops can be used to assess how well traffic flows. Other items to measure are where the traffic is moving and distinguishing between different types of vehicles. The need for these measures is made more clear by considering ITS applications.

Vehicle type or class is needed information. The importance will be evident when several ITS applications are presented. It should be noted now that vehicles can be categorized and or identified using weight, height, length, passenger occupancy and/or function.

The following list summarizes measures needed for current and future surveillance applications. Some detector technologies and specific products can measure these directly. Other measures have to be estimated from more basic data. Still, other measures have to be gathered using vehicle probes that communicate with a roadside computer.

- | | | |
|------------------------------|------------------|---------------------------------|
| ◦ Vehicle Passage & Presence | ◦ Vehicle Counts | ◦ Flow & link travel times |
| ◦ Queue lengths | ◦ Vehicle Type | ◦ Instantaneous & average speed |

Current Applications (ITS and conventional)

This partial lists enumerate ITS technologies heavily reliant on accurate and reliable sensors:

- Incident Detection
- Adaptive Traffic Control
- Dynamic Route Guidance
- Variable Message Signs & other traffic advisory
- Bus and Emergency Vehicle Priority Systems
- Traffic Enforcement

Adaptive traffic control systems alter signal timing plans based on the surveyed traffic conditions. Examples of real-time adaptive traffic control systems that have been implemented in cities are:

- SCATS, (Australia, Ireland, Oakland County Michigan)
- SCOOT (Oxnard, California, Toronto) , and
- OPAC (Tucson and Arlington)

SCATS and SCOOT represent fixed-cycle control systems that modify cycle-length, offsets, and green splits based primarily on flow and occupancy data. Measurements of headways and occupancy are used to predict delay, queue sizes and saturation flows. The saturation flow is the rate of departure from the light once vehicles can proceed is also needed.

Traffic responsive (non-fixed cycle) systems like OPAC need to predict measures like queue sizes to determine an optimal signal plan. This is done in advance of soon to arrive vehicles. It requires special detectors that are located upstream of each link approaching the controlled intersection. It is a good example of schemes that require predictive data. Detection of the presence of a vehicle as it enters a link is needed so that its time of arrival to the intersection can be estimated. The flow on the link is also needed to make this travel time estimation. Effectiveness of the plan derived is closely tied to the accuracy of the measured and/or predicted values.

Some traffic control strategies (SCATS, SCOOT, PRODYN) attempt to coordinate signal plans in order that the number of stops per vehicle is minimized. The idea is generally to yield "green-waves" or green bands so that platoons on high demand links flow through without stopping. There is communication overhead required to communicate detector information and control decisions from each intersection to a central location for processing.

Incident detection is also based on measuring occupancy and other detector data and applying an algorithm. Two frequently used algorithms are the California and the McMaster algorithm. The McMaster algorithm needs flow, lane occupancy, and speed to identify an incident and the California algorithm requires a occupancy of neighboring detector stations.

Detector data has several categories of use for these conventional and ITS technologies:

- Data enabling real time system operation
- Data supporting off-line calculations (i.e. TRANSYT¹)
- Data serving as measures of effectiveness for off line evaluation

Measures for the latter two are as follows:

- | | |
|---------------------------------------|--|
| ◦ Average Number of Stops per Vehicle | ◦ Average Delay in Seconds per Vehicle |
| ◦ Average Queue Length | ◦ Average Demand |
| ◦ Total Travel Time | ◦ Total Vehicle Miles Traveled |
| ◦ Average Travel Speed | ◦ Vehicle Delay |
| ◦ Total Minute-Miles of Congestion | ◦ Accident Rates |
| ◦ Average Speed in MPH | |

Priority vehicle detection systems allow emergency vehicles the ability to gain immediate right of way at an intersection by preemption. Less severely, transit vehicles may receive priority by extending a green phase or shortening a red phase. These systems require the detection of a vehicle by its type. This can be done by a roadside detectors that receives transmissions from vehicles and/or detectors that can measure a characteristic of a vehicle (height, weight, length, magnetic signature, etc.). Digital loop and radar detectors that can identify a bus, for example, would not necessarily eliminate the need for transmitters and receivers since priority needs are determined by the driver. For example, in Bremerton, Washington, there is a 3M Opticon priority system which uses infrared transmitters to enable transit vehicle operators to extend a green or shorten a red light [American 94].

Like priority systems, route guidance systems will require vehicle to roadway communication. Travel times on links will be required. This is facilitated by vehicle probes that can report location and time at two different points for the calculation. The Ali-Scouts route guidance system incorporates this concept. Using travel times reported by probes to roadside computers, fastest path calculations are used to transmit routing information back to equipped vehicles. An Ali-Scout system is being evaluated as part of the Oakland County FAST-TRAC program.

¹TRANSYT is a widely used program used to develop signal plans off-line. Green times, cycle times, and offsets are determined via an iterative process.

Detection Technologies

The following detector technologies have been described and are tested in references cited in this section:

- ILD (inductive loop detector)
- Piezoelectric
- Microwave Radar
- Passive Infrared
- Active Infrared
- Imaging Infrared
- Ultrasonic
- Video Image Processor
- Magnetic

5.2.2 Vendor/Product Search

As part of the FHWA Study [FHWA Task D 94], a comprehensive survey of vendors was performed. The criteria used to select vehicle detectors were:

- Availability in time for field tests.
- Demonstrated capability by a municipality of the vendor.
- Compatibility and interface ability with on-site controllers.
- Representative of the current technology.

The latter criterion defines detectors capable of:

- Responding to moving and/or stationary vehicles of different sizes and colors.
- Operate in light and heavy traffic flows under most weather conditions.
- Operate in nighttime as well as daytime.
- Immune from shadows and glints.
- Immune from false detections from shoulders, and adjacent lane objects/vehicles.

A multi-step process was used in the FHWA study to select detectors. ITS detector requirements were enumerated and used to rank different products. The original idea was to screen detectors that satisfied all of the ITS requirements. Initially, no detector satisfied all ITS requirements. Thus, existing detectors were surveyed and the best candidates were chosen and screened. The screening involved laboratory tests and field site compatibility tests that included tests for possible interference with one another, see Appendix D.

5.2.3 Sensor and System Descriptions

The detection technologies listed in the previous section are now briefly summarized. More comprehensive descriptions can be found in the following references [Gilbert 91, Chachich 1994, FHWA Task D 94].

Inductive Loops

The most common detector is the roadway imbedded inductive loop. They are a standard for long term measurement of traffic volume and speed. The wire loop placed in a cutout in the road notices any decrease in inductance caused by a vehicle present over the loop. Data supplied by inductive loop sensors include vehicle presence (counts), headway, vehicle length and occupancy. Speed can be measured when the loops are used in pairs. Although initially low cost, their location in the roadway makes them vulnerable and require traffic disruption to install [Duckworth 94].

Piezoelectric

This device is an axle sensor that is embedded in the road surface. Using two sensors, both speed and vehicle class can be measured and detected.

Active Infrared

Active infrared sensors can be mounted overhead and detect vehicle (moving and stationary) presence, vehicle type and measure vehicle speed. Vehicle presence is indicated by a reduction in range reading from the roadway. Vehicle speed is computed from the measured time interval between the interceptions of two laser beams. A real time clock is used to time tag data to provide vehicle count and average speed for each hour of the day. A vendor for an active infrared detector is Schwartz Electro-Optics (SEO).

Passive Infrared

Passive infrared detectors emit no radiation or fields. Vehicle presence detection can be provided. Cars, cyclists or pedestrians penetrating into or crossing a field of view can be detected within a limited range. These objects (cars, etc.) emit infrared energy as a function of their surface temperature. Temperature contrast of an object with the background are focused by a lens and converted into electrical signals by a sensitive pyroelectric detector. No radiation is emitted by the device. Thus interference with neighboring detectors is not a concern nor is alignment of emitter/receiver pairs. Eltec provides two models that respectively detect stationary and moving targets.

Microwave Radar

Microwave radar detectors are overhead (or side mounted) sensors to detect vehicle presence in one direction over a single or multiple lanes. Speed detection is also possible using Doppler sensors. A longer detection range (100-200 ft for smaller vehicles, 350 for trucks) is provided relative to infrared devices.

Doppler radar works by emitting a signal and measuring the phase shift of the reflected signal. The phase shift is proportional to the speed of the object reflecting the signal. Vendors for this type of detector are Microwave Sensors, Whelen, and Electronic Integrated Systems.

Microwave Balometer

This detector is a passive device that detects sky reflection. Presence, occupancy, headway, length, class (by length) are measurable. It is an overhead sensor that suffers obvious disadvantages in tunnels, and from shadows and sun glints.

Video Image Processing (VIP)

VIP provides real time video images. When combined with image processing techniques, it can detect vehicle presence in multiple lanes and multiple directions. Vehicle presence and certain traffic parameter averages can be computed in the daytime like volume per lane, flow rate, lane occupancy, vehicle type, headway and speed. A more limited set of parameters can be measured at night with reduced accuracy. Econolite, Computer Recognition Systems, Traficon, EVA and Sumitomo are some vendors for this type of detector.

There are two approaches to extracting measures from video data. One is called the "tripwire" method. An entry and exit line is defined across each lane being monitored. Changes detected at these lines are interpreted as cars, and speed is derived from the time taken to pass between the lines [Hockaday 91]. Another method is known as "vehicle tracking". The entire image is analyzed and vehicle-like masses are identified and tracked. Econolite's Autoscope and the Devlonics Control CCATS rely on this method.

Acoustic Arrays

Passive acoustic microphone arrays can be used for vehicle counts, speed estimation and vehicle classification. They are above ground sensors. Passive acoustic data can be taken on a vertical array of microphones. The concept is that the time delay between arrival of sound on the upper and lower microphone changes with time as the vehicle emitting the sound passes under it [Duckworth 94]. A passive acoustic detector is produced by AT&T.

Ultrasonic Detectors

Ultrasonic detectors can measure volume, occupancy, presence and queue length by transmitting sound waves (between 20Khz and 200Khz) above the human audible range. The waves are subject to attenuation and distortion from weather effects. In particular, snow covered vehicles are harder to detect [Mills 93].

As an active device, the Doppler effect can be exploited to estimate speed. A Doppler Ultrasound sensor operates the same as a Doppler Radar sensor except the shift per mph is different (i.e. 50 Hz/mph) and the range is more limited (radar may have ten times the range) [Duckworth 94].

A Pulsed ultrasonic detector is a pulse-echo distance measurement sensor. The transducer looks down on each lane to measure the distance from the sensor to the pavement or the top of a vehicle in case of occupancy. Vendors for ultrasonic devices include Sumitomo and Microwave Sensors.

Magnet Devices

Magnetometers are used for detecting vehicular traffic. The detector measures the horizontal and vertical component in the earth's magnetic field. When a vehicle approaches the detector, the earth's magnetic field is distorted and the resulting change is detected and transmitted. The device is small but has to be buried is inserted in the ground. Vendors include 3M and Midian. The detectors are less resistant to weather changes and not susceptible to interference by other detectors or other detector types.

Fiberoptic Sensors

The use of fiberoptic sensors is a new, untested technology. Axle counts and weights can be determined from, a sensor. With two sensors, speed and class can also be determined.

5.2.4 Test and Evaluation Programs

One freeway and one surface street arterial site were chosen in each of three states to test and evaluate alternative detector technologies for the FHWA study. The states chosen were Florida, Minnesota and Arizona. This enabled testing in different weather condition extremes. The detector technologies evaluated were:

- ultrasonic
- microwave radar
- infrared laser radar

- imaging and non imaging passive infrared
- video image processing with visible spectrum imagery
- acoustic array
- high sampling rate inductive loop
- microloops
- magnetometers

The Arizona test site was located I-10 in Phoenix and a surface street in Tucson. These sites were selected for warm and hot dry weather testing. The tests took place in August of 1993 and the summer of 1994. Inductive loops and magnetometers were installed in lanes and overhead detectors installed as close as possible. The idea was to place all detectors within proximity of each other for fair performance comparisons. Marks on the road surface were painted to help with video image processing. A Minneapolis freeway and surface street was used in the winter of 1993 to test under cold, snowy, sleet, and foggy conditions. An Orlando freeway and surface street were used in the summer of 1993 to test detectors under hot, humid and rainy conditions. Truth data will be obtained for measuring accuracy. Video tapes of the test site will assist in extracting these values. The test details can be found in the Task C Report. A final report by the FHWA is being reviewed.

5.2.5 Reliability of Surveillance Sensors and Systems

Reliability and accuracy of detectors directly affects the accuracy of the technology it supports. Incident detection is a good example of an ITS technology whose success is heavily tied to the accuracy and reliability of the detector. Real-time adaptive traffic control is another example. While inductive loops are the standard in accuracy under all conditions, not all locations (like bridges) can use inductive loops.

Inductive loops at all sites in the FHWA test were found to have the most accurate count. Errors were within 0.5 % of the manual count obtained through video recording. Some anomalies occurred when cross-talk between two adjacent loops took place. Some inaccurate counting took place due to turning vehicles that crossed multiple lanes in the process.

The following tables list the performance of different technologies relative to either the truth data recorded at the site or relative to the data measured by the inductive loop detector. Table 1 contains data taken in Phoenix from 4 to 5 PM on a warm clear sunny day. The measured data in Table 1 is benchmarked against truth data. The data measured in all the tables are vehicle counts.

Table 1.

Detector Technology	Vender and Model	Percent Error
Video Image Processor	Econolite Autoscope 2003	0.06 %
Microwave Radar (Doppler)	WhelenTDN-30	2.6 %
Ultrasonic	Microwave Sensors TC-30C	2.9 %
Ultrasonic	Sumitomo SDU-300	3.8 %
Passive Infrared	Eltec 833	4.1 %

The net two tables list the performance of different technologies relative to the inductive loop at the Tucson test site. Table 2 is for a middle lane and Table 3 for a curb lane. The climate was warm and sunny and the data was taken between 4:40 PM and 9:15 PM. The data measured were vehicle counts.

Table 2.

Detector Technology	Vender and Model	Percent Error
Microwave Radar	EIS RTMS	0.07 %
Passive IR	Eltec 842	-2.8 %
Microwave Radar	EIS RTMS	-3.3 %
Passive Infrared	Eltec 833	-3.5 %
Video Image Processor	Econolite Autoscope 2003	-6.7 %

Table 3.

Detector Technology	Vender and Model	Percent Error
Microwave Radar (Doppler)	WhelenTDN-30	0.8 %
Magnetometer	Midian Self Powered	-2.6 %
Ultrasonic (Doppler)	Sumitomo SDU-200	-3.1 %
Ultrasonic	Microwave Sensors TC-30C	-5.0 %
Video Image Processor	Econolite Autoscope 2003	-5.7 %

These tables represent the type of data that was accumulated by these tests. This data should not imply overall performance throughout all test runs. A final FHWA report on these tests should be referenced. Lawrence Klein of Hughes Aircraft is the principal investigator that should be contacted for further information.

The California Department of Transportation contracted the Transportation Research Group at California Polytechnic State University to research, acquire, and test VIP systems applicable to

traffic situations. Cal Poly developed a Vision Laboratory facility and equipped it to perform standardized tests for evaluating VIP systems. The objective of the tests was to collect videotaped traffic images at several locations to comprehensively test the capabilities of a number of prospective vision systems. A final report was issued in 1991.

Candidate systems were surveyed. Systems that seemed applicable were tested in house. A subset of those detectors evaluated in-house were field tested. These are eight systems that were field tested:

- Autoscope
- CCATS (Camera and Computer Aided Traffic Sensor)
- TAS (Traffic Analyses System)
- ATAS
- Sigru
- Titan
- Traffic tracker
- Tulip

The first three (Autoscope, CCATS, and TAS) were considered deployable at the time of the tests. The remainder were considered development systems not necessarily suited for practical use. Tests data was collected for the following conditions: (1) Day, (2) Night, (3) Oncoming Traffic, and (4) Departing Traffic (4) Side camera (6) Steep Camera, and (7) Shallow camera. The systems were quantitatively evaluated on their ability to perform traffic counts and measure average velocities. An overview of the tests is provided in the 1991 ERIM report and further details should be sought from the 1991 Cal Poly report [Hockaday 91].

Other comparative studies including both video and other "non-intrusive" monitoring sensors have recently been reported. Tests and comparisons by Duckworth et. al. [Duckworth 94] from an overpass on a lane on Rt. 2 in Littleton, Massachusetts yields the following Table:

Sensor Type	Sensor Cost	Comm. Bandwidth	Detection Performance	Speed Performance	Classifying Performance
Video Camera	High (\$150-500)	Medium-Hi (10-4500kbs)	Good	Very Good	Very Good
Doppler Radar	Medium (<\$100)	Medium/ (2-10kbs)	Fair/Good	Excellent	Poor
Doppler Ultrasound	Low (<\$75)	Medium (8 kbs)	Good	Fair	N/A
Pulsed Ultrasound	Low (<\$75)	Very Low (0.32 kbs)	Very Good	N/A	Good
Passive Acoustic	Low (<\$25)	Medium (10 kbs)	Poor	fair	Poor
Passive Infrared	Low (<\$30)	Very Low (0.32 kbs)	Very Good	N/A	N/A

5.2.6 Effectiveness of Surveillance Systems

Detectors can be effective in terms of detecting changes in traffic flow but cannot determine the cause for changes in traffic flow. Direct inspection is required to determine cause. Video surveillance can be effective for verifying any change in traffic flow. In addition, road surface conditions (i.e. from an ice prediction/detector sensor) can also be verified.

With regards specifically to traffic surveillance for a Motorist Warning System, two situations apply:

1. An accident has occurred and fast detection and driver warning is necessary (detection takes place via vehicle in/out counts).
2. Interchange throughput is decreasing as a result of degraded conditions on the bridge (detection takes place via many different technologies because precise counts are not required in this case).

Both systems have value because of the increased total system reliability through redundant detection systems.

Following are two examples of evaluations made by state DOTs of traffic surveillance/management systems:

◦ Minnesota

From Survey Response: "We have data which indicates Mn/DOT's traffic management program has been successful in terms of increasing motorist safety. Our studies indicate that the peak-period accident rate has been reduced over 40% during the past five years on those freeway sections where traffic management systems have been installed. We have not been able to differentiate to what extent various traffic management initiatives should be attributed to this reduction in crashes, but we think that it is primarily the ramp metering systems and, to a lesser degree, the traveler information services and Highway Helper emergency response vehicles."

◦ New York DOT

The New York Department of Transportation participated in the FHWA INFORM Evaluation, which addressed the reliability and effectiveness of motorist warning signs for both mobility and driver safety using various traffic flow surveillance systems [FHWA-RD-91-075, 1992]. The system allows varying degrees of manual and automatic control of message signs based on roadway sensors. INFORM is one of the most advanced variable message sign (VMS)-based motorist information systems in the U.S. and offered considerable insight into traffic flow surveillance and communication with the motorist.

Unfortunately, the accident statistics collected to date have been inconclusive regarding the effectiveness in terms of motorist safety. The lack of quantitative data, however, has not deterred the use of traffic flow devices and the increasing use of VMS for warning motorists in many states.

5.2.7 Research and Development

The majority of the published research is in the area of video-based systems. The 1991 ERIM Report [Gilbert 91], the FHWA Study, and the Cal Poly study should be referenced for further details. R & D associated with other sensor studies is usually related to product development and proprietary, thus limiting the information available in the public domain. When products materialize from publically funded research, the information is generally available.

Econolite's Autoscope was born out of research efforts at the University of Minnesota and is being evaluated as part of the Guidestar Program [Guidestar 90] in Minnesota and the FAST-TRAC program in Oakland County, Michigan [Rockwell 94].

5.3 Survey Responses

State DOTs

Based on our initial literature searches, a significant amount of activity was found to be taking place both on the federal and state levels with regards to roadway warning systems, and in particular, RWIS and ice detection systems. To obtain a better picture of what was occurring in the various states, a questionnaire was developed and sent to the 48 contiguous states plus Alaska and several Canadian provinces. The purpose was twofold; to find out what the state DOT's are implementing and to determine how successful they have been. Appendix A contains a copy of the questionnaire and Appendix B contains a complete list of the names and addresses of respondents.

The following table summarizes responses given by the various states that responded to the survey². The number in each column reflects the number of states that responded affirmatively to the particular device or procedure. The terms operational, field tested, and studied are defined as follows, respectively:

- Operational: in operation or in the process of being implemented
- Field Tested: being field-tested to determine operational feasibility
- Studied: being studied or analyzed

² Based on 23 survey responses received to date.

Devices and Procedures	Operational	Field Tested	Studied
Surface/subsurface sensors which monitor pavement temperature and surface conditions, including presence of ice, frost, water, snow or chemical concentration	12	3	5
Atmospheric sensors which monitor air temperature, dew point, relative humidity, precipitation, wind direction, and wind speed (i.e., Road Weather Information Systems - RWIS)	13	2	5
Area/remote sensors (e.g., infrared, microwave, or laser) which monitor roadway surface conditions, including presence of ice, frost, water, snow, etc.	2	0	2
Closed Circuit TV (CCTV) for monitoring and/or analyzing road conditions and traffic flow for possible ice conditions	6	0	1
Traffic flow sensors used in conjunction with ice detection sensors for monitoring traffic flow conditions (slowing/stopped traffic)	2	0	1
Traffic flow sensors used for incident detection (not restricted to ice-related incident detection)	5	0	2
Communications infrastructure to allow transmission of sensor data (surface sensors, atmospheric sensors, video, etc.) to a central control facility	14	2	3
Any procedures (automated or manual) that utilize this data to predict the formation of ice and/or detect the presence of ice	10	1	4
Driver information systems (e.g., variable message signs) that provide motorist warnings of existing or possible ice conditions and/or resulting traffic impediments	14 ³	2	4

³ A detailed review of the survey responses found that only Virginia actually provides warning information to the motorist (on a delayed basis) based on ice condition information. The other public agencies that answered affirmatively to this question did so on the basis that they inform motorists of traffic conditions based on traffic flow information (not ice related).

Responses to most of the other questions in the survey are summarized below and some interesting examples are provided. A complete listing of responses to the survey questions is contained in Appendix C. Unless otherwise noted, the responses to each question are direct quotations from the surveys.

Survey Question 2: Can you provide data on the number of ice-related incidents over the past 5 years? Please state in terms of: (1) fatalities, (2) injuries, (3) property loss, and (4) frequency, if possible.

Summary

The 1990 NASS records of crashes on U.S. highways indicates that approximately 35% of all crashes occurred during slick road conditions or during periods of reduced visibility and drivers are three times more likely to be involved in a crash during adverse weather conditions. Additionally, 25% of all crashes are rear-end crashes, and of these, 27% occur during adverse environmental conditions. Of the 27%, 23% occurred in wet conditions and 4% in ice or snow conditions [Castle Rock, 1995].

In many states, statistics are not available for the percentages of snow and ice crashes.

Example Responses

During the 5-year period between 1989-1993, there were 437.3 billion vehicle miles of travel on PA roadways, and the following ice-related and snow-related crashes and statistics:

	Ice-related	Snow-related
Fatal crashes	195	221
Injury crashes	15,826	16,359
PDO crashes	13,135	14,581
Persons killed	217	212
Persons injured	22,985	24,364
Crashes/100 MVM	6.7	7.1

- Pennsylvania

6 YRS Snow & Ice Related Crashes

Year	Occurrences	% Total Acc.
1994	4410	9.93
1993	3695	6.99
1992	3491	6.56
1991	2332	4.64
1990	2573	4.84
1989	5438	9.79

- W. Virginia

Survey Question 3: What has been done or is currently being done in your state to aid in the detection of ice conditions, prediction of possible ice formation, and/or warning of motorists, as it relates to improving motorist safety?

Summary

Most states (16/23) that responded to the survey are taking proactive steps to predict and/or detect ice using some form of Road Weather Information System. The extent of these implementations varies widely from state to state, and only one is using this information operationally to manually warn motorists (on a delayed basis) through variable message signs (Virginia).

Example Responses

We have an installed RWIS (SSI, Inc.) as well as 24 hour EOL which monitors all weather sources. Information is transmitted to motorists by our "Highway Helpline" (toll-free 1-800-367-ROAD), the media, H.A.R. and V.M.S.

- Virginia

Currently, we have four locations with 14 pavement sensors which provided real time data of pavement conditions. A winter season pavement temperature and precipitation forecasting service is used in conjunction with the real time data. We foresee in the near future the ability to update Variable Message Signs (VMS) by computer to have traveler warnings based on sensor data.

- Maryland

We have weather monitoring stations with pavement sensors at strategic locations in the areas of the State with colder weather. They are not related to any warning devices to motorists. The SCDOT does, however, erect a "Bridge Ices Before Road" sign. This sign is intended for use to

warn motorists that icy conditions may occur on the bridge where such a condition does not exist on the adjacent roadway. The sign should be displayed on the righthand side of the road, and on divided roadways, an additional installation may be used in the median.

- South Carolina

Colorado is investing in the Road Weather Information System (RWIS). There are over 30 stations in Colorado with 11 stations in the Metro Denver area. The system provides roadway temperature predictions based on subgrade temperature and weather predictions, and is used to effectively mobilize de-icing and snow removal operations.

- Colorado

Survey Question 4: What is your perception of how ice detection/prediction and warning systems could impact motorist safety?

Summary

Almost all of the respondents believed that ice detection/prediction and warning systems could have a positive effect on motorist safety, if used properly. In states that cover a large and diverse geographical region, placement of the sites is critical since dense placement of pavement sensors and weather stations is not economically feasible.

Example Responses

Where such warning systems can be specific and creditable, considerably. Generalized cautions seem not to be terribly effective.

- Virginia

The information received from sensors is used to place traveler warnings on VMS and the Traveler's Advisory Radio, which serve to enhance public safety. Alerting motorists prior to entering an area with possible icing conditions is probably the best way to give immediate warning. These real time condition warning systems are also used for winter operations, giving the ability to direct crews to areas with ice warnings as conditions occur, improving the overall efficiency of winter operations.

- Maryland

We feel there is a very large potential safety benefits that can be realized from developing ice detection/prediction and warning systems. For this reason, we have a long term plan to invest several million dollars in developing this capability.

- New York

Warning systems could have substantial impacts on motorist safety when used properly. The combination of RWIS technology with a variable message sign can provide motorists with timely information on road conditions.

- W. Virginia

If the geographic sites where the ice occurs are so unique they may be the **first** and/or **only** places where ice occurs, the investment may be warranted. As an agency responsible for very large geographical areas, we are proactive and rely on forecasts and RWIS real time data to determine critical-ness. Timeliness is most important. Crews are expected to be on sites before snow and ice occur. Crews tend to know where to go first through experience.

- Illinois

Survey Question 5: What has been done or is currently being done in your state with regard to sensing, automated incident detection, and motorist warning of slowing/stopped traffic flow?

Summary

A wide variety of traffic management systems are being tested by a large number of states. VMS, highway advisory radio and the media are often used to warn motorists of traffic conditions based on traffic detectors. The types of detectors being applied include inductive loops, video, microwave (radar). At least one state is taking advantage of cellular phone call-ins for incident detection and has moved away from using an automated incident detection algorithm.

Example Responses

We are currently deploying a comprehensive traffic management system which will integrate both snow/ice operations and traffic management/information systems. The field elements of this system include 27 loops (for speed, occupancy, headway and volume), 96 wide beam radar traffic sensors (speed only), 21 closed circuit television cameras, 40 VMS, and 24 Traveler Advisory Radios (on 530 and 1610 AM).

- Maryland

A number of incident detection, motorist warning and mobility projects have been initiated in the state; the most notable is documented in FHWA-RD-91-075, January 1992, **INFORM EVALUATION** Volume I: Technical Report. That publication presents some of the mobility and safety benefits that have been associated with early detection and warning systems. Highway systems with similar components and /or functions are anticipated for the future.

- New York

Information from Mn/DOT's Traffic Management Center: We no longer use an automated incident detection algorithm, as this has been made obsolete by the proliferation of cellular phone calls reporting incidents. We are cooperating with FHWA on a research project to investigate the integration of automated incident detection with cellular calls.

To warn motorists of slowing/stopped traffic flow conditions we use changeable message signs, portable changeable message signs, a metro area highway advisory radio program (a partnership with a public radio station on KBEM FM, 88.5 FM), and a cable tv traffic channel. We are also involved in several ITS operations tests to evaluate innovative concepts for traveler information.

- Minnesota

Survey Question 6: For each item check-marked in the table, please provide the following details, if applicable (feel free to attach additional pages if necessary):

- o Data or results indicating the reliability and/or effectiveness of the systems, such as before/after comparisons (please attach information or include references to reports and/or recommendations, if available).

Summary

Very little quantitative data is available that addresses the effectiveness of ice detection systems at improving motorist safety. A greater amount of data is available regarding the reliability of the systems and cost effectiveness. Beyond what has been discovered through the literature searches, no new information regarding quantitative data was uncovered from the survey. Though not directly related, fog detection systems have been implemented in several states, some providing warning of motorists directly through variable message signs.

Example Responses

We have not yet performed a before and after study to establish the effectiveness of these systems, since the majority of the system will not be in operation until June of this year.

- Maryland

Item 2. As far as atmospheric sensors are concerned, there is a fog monitoring system at the Cooper River Bridge over I-526 in Charleston, SC. The department installed this system to warn motorists of foggy conditions at the river crossing. The system consists of closed circuit TVs, variable message signs, fog detectors, weather instruments, lighted pavement markings, street lights, and an operator alert system. Once the central system detects fog, it will activate a warning system in the control center, and the control center will make appropriate response. There are no before/after studies available as of this date.

Item 4. There is CCTV for monitoring road conditions at the Cooper River Bridge over US 17 in Charleston. This surveillance unit includes five cameras, each of which is mounted to permit the observation of traffic by means of monitors. There are no before/after studies available as of this date.

- South Carolina

Survey Question 7: Please describe your agency's snow and ice control policy (maintenance) and how it involves the use of ice detection/warning systems, if applicable.

Summary

Most states have a "bare pavement" policy concerning snow and ice, where roadways are to be cleared within a specified period of time after a storm occurs. When available, ice detection systems are primarily used in conjunction with other weather information sources to alert maintenance departments so that anti- or de-icing measures can be taken.

Example Responses

The Maryland State Highway Administration has a bare pavement policy. When roadway accumulation is 1-2 inches, plowing begins with application of chemicals and abrasives, and the pavement is kept as close to bare as possible. This continues until the end of the storm. Use of pavement sensors aids in the decision of when to reapply chemicals to critical areas.

- Maryland

The Department currently uses weather forecast instruments which communicates with computers via modems. Upon detecting conditions which may cause icing of roads and/or bridges the system warns the operators of the conditions so that appropriate steps can be taken.

- South Carolina

Survey Question 8: Do you have access to data, not necessarily specific to ice detection, but that describes the reliability or effectiveness of driver warning systems in terms of motorist safety (in particular, warning drivers of dynamic conditions on a real-time basis)?

Summary

Driver warning systems are used extensively to warn motorists of impending traffic conditions due to construction. In some cases, VMS and HAR are also used to warn motorists of slow/stopped traffic due to congestion, crashes, and in at least one state, pavement conditions. Some quantitative data is available that shows an increase in motorist safety as a result of a traffic management system.

Example Responses

FHWA-RD-91-075, January 1992, INFORM EVALUATION Volume I: Technical Report addresses the reliability and effectiveness of advance warning signs for both mobility and driver safety. Driver safety is briefly expressed as a comparison of accident rates.

- New York

We do not use ice detection systems to activate warning signs (too much liability).

- Nebraska

We have data which indicates Mn/DOT's traffic management program has been successful in terms of increasing motorist safety. Our studies indicate that the peak-period accident rate has been reduced over 40% during the past five years on those freeway sections where traffic management systems have been installed. We have not been able to differentiate to what extent various traffic management initiatives should be attributed to this reduction in crashes, but we think that it is primarily the ramp metering systems and, to a lesser degree, the traveler information services and Highway Helper emergency response vehicles.

- Minnesota

Survey Question 10: Please provide any other comments or ideas you may have concerning this or related topics.

Example Responses

We would like to emphasize the success Maryland is having by developing an integrated Traffic Management and Winter Storm Management system which allows the two programs to benefit from each other's capabilities. We would also like to emphasize the importance of working with the media (and planning for media interfaces) in disseminating road condition information.

- Maryland

We believe strongly in early detection systems for snow and ice control. At present, we are not comfortable with directly linking these systems to a motorist information system (variable message signs, etc.). Instead we feel that trained staff should confirm and interpret sensor data prior to issuing public advisories.

- New York

Mn/DOT intends to implement a statewide RWIS system in the next two years. We are partnering with the Swedish National Road Administration in this effort, using their expertise as a benchmark in our development.

- Minnesota

6. Motorist Warning System Analysis

Previous sections have discussed detection/prediction systems, accident analysis, RWIS, traffic flow surveillance techniques, and the real-time use of this data and information. It is clear from all the material presented that, while much progress has been made in the areas of pavement sensor technology, weather information data collection, and the ability to communicate this information to selected sites (roadway agency maintenance facilities, transportation system centers, roadway road informational services), the effectiveness of using real-time data to inform drivers directly has not been documented (quantitatively). One potential method is through the use of variable message signs (VMS's).

Currently, the Michigan Manual of Uniform Traffic Control Devices (MMUTCD), as well as the FHWA Manual, recognizes the existence of variable (changeable) message signs. However,

the Manual has not elevated this sign type to the status of a standard traffic control device. Currently, these signs and their application are considered to be experimental in nature. The Manual does encourage their use and study of their benefits in an experimental mode so that, over time, guidelines and standards can be developed.

Five categories for the application of real-time displays utilizing VMS have been identified and are listed below:

1. Traffic management and diversion which includes traffic advisories and incident management.
2. Control at crossings, such as bridge/tunnel controls, weigh station control, mountain pass control and toll station control.
3. Control during construction and maintenance activities which can provide path and routing control, warning and information and speed control.
4. Special lane use control for exclusive lanes and reversible lanes.
5. Warning of adverse weather and/or road conditions, such as high winds and their effect on high trucks, fog, high water, slippery pavement and others.

For the location of this particular study, the westbound I-696 to southbound I-275 ramp connection and bridge over I-96, category 1 (for incident management) and category 5 (for slippery pavement) represent the objectives for improved motorist information.

Highway VMS's are traffic control devices used for traffic regulation, warning, routing, and management and are designed to affect the behavior of motorists by providing real-time highway-related information. The objective, of course, is to improve the efficiency and safety of traffic flow. Indeed, the proposed MDOT S.E. Michigan ITS Deployment Program identifies the use of a VMS on westbound I-696 positioned about equal distance between Orchard Lake Road and the I-96/I-275 bifurcation. This conforms to the traditional and accepted practice of locating VMS's that provide information to motorists in a manner that allows drivers to process the message and to make an informed decision as to whether to select an alternative route or not.

Important considerations in successfully operating a VMS system are to maintain credibility and the driver's faith in the system. This is extremely important because once driver confidence is lost, even the most elaborate and costly system can quickly become an operational dilemma. When this occurs, overall safety is decreased. In contrast to fixed-messages on regulatory, warning, and guide signs that always apply, variable message displays elicit different driver expectations. Drivers expect VMS's to provide reliable, accurate and current information. Ways that motorists may lose faith in the system include 1) displaying information too late for drivers to make an appropriate response; 2) telling a driver something that they already know; 3) displaying inaccurate or unreliable information; 4) presenting messages that are too long for motorists to read and understand with prevailing highway speeds.

Among the critical elements in utilizing VMS's is selecting the proper location to present information to drivers. The most critical locations are in advance of interchanges or off-ramps where drivers can take action either in response to specific instruction displayed on the VMS, or voluntarily. When the VMS is located beyond decision points, the only thing that can be accomplished is to slow or stop traffic flow.

Based on information reviewed and collected as part of this research report, it is concluded that the single weakest link in achieving a complete roadway warning system (at the subject site) is the difficulty in properly locating a VMS. Another important aspect is the content of the displayed message. To be effective, the sign must be located some distance in advance of the site (the bridge deck in this case). This advance distance is required to allow the driver adequate time to read and comprehend the sign message and then to make an informed decision to do or not to do something. In the case of this study, preferential icing on the ramp bridge deck, it seems impossible to satisfy all system design parameters if the goal is to activate the VMS when, in fact, preferential icing is detected. Operating under this mode (given the high ADT on this ramp), it is highly probable that some vehicles will be located between the just-turned-on sign and the icy bridge deck. These would be the very vehicles that would be most important with which to communicate. One possible solution is to predict ice formation before it occurs. If the operational mode utilizes a predictive model, some portions of the roadway may vary from clear to completely ice-covered, with a variety of possible intermediate conditions. With this range of possibilities, the selection of the sign message becomes critical.

The final chapter in NCHRP Report 61 titled *Variable Message Signs*, from which some the information presented in this section was found, concludes with a lengthy listing of technology voids associated with VMSs. The report indicate that further research is necessary to gain a better understanding of VMSs. This report concurs with that recommendation.

7. FINDINGS

The purpose of this study was to evaluate whether a reliable and effective system could be found that would improve motorist safety and contain all or part of the following components;

1. Roadway ice prediction/detection
2. Traffic surveillance
3. Motorist warning (VMS component of a warning system)

This study was to be specific in regard to improving safety on the westbound I-696 to southbound I-275 ramp connection, and in particular, the bridge deck over I-96.

An extensive information gathering operation was undertaken involving a literature search, survey questionnaire, and inquiries sent to both equipment manufacturers and academia to determine the extent of motorist warning system activity specific to icing, traffic congestion and crashes on public roadway networks. This section of the report presents our findings resulting from analysis of the collected data as presented in the body of this report.

Findings Regarding Roadway Ice Prediction/Detection

No "roadway agency" (see definition page 6) is currently using ice detection for the automatic activation of a site specific motorist warning system. Roadway weather information systems with ice detection components (see definition RWIS page 6) are being used by many roadway agencies, including MDOT, to predict potential icy conditions for the sole purpose of alerting and scheduling of winter roadway maintenance activity. This is being done in an attempt to help increase both efficiency and effectiveness of winter maintenance operations through the more timely application of de-icing or anti-icing chemicals. Out of 23 respondents, we found the Virginia D.O.T. to be the sole roadway agency operating a RWIS system for monitoring roadway surface and weather conditions for the purpose of scheduling winter maintenance activities, and also for motorist warning. The motorist warning component of their system is manually activated and delayed due to their operational mode which generally involves actual field verification of road surface conditions. Further, they have no data regarding the reliability or effectiveness of this system as no studies have been or are currently being conducted.

We found a significant amount of data that demonstrates the effectiveness of an RWIS system at reducing maintenance response time and saving maintenance labor and material expenses. Qualitative assessments from state and federal agencies were also found emphasizing the safety benefits of the RWIS support to maintenance activities with one report concluding the "Proactive use of ice detection and highway information systems to aid in planning winter maintenance operations can enable more timely treatment of icing conditions and reduce the potential for accidents by reducing the incidence of black and glaze ice pavement surface conditions." There is, however, no site specific information or data that indicates the existence of a motorist warning system that can prevent multi-vehicle crashes at the subject location as a result of icy road conditions.

Some data is available showing the strengths and weaknesses of both components and subsystems for ice detection purposes (not including any motorist warning component) , including their accuracy and reliability. In particular, at least two states, Michigan and New Jersey, have documented the performance of commercially-available ice detection subsystems. The overall accuracies of the measurements were found to range in the high eighties or low nineties, once the subsystems had been in use for a year or two (Section 5.1.5) There is some question, however, about the method of observing the status of roadway surface conditions. The number of observations of roadway status (clear, ice- covered, etc.) may have been much greater when conditions were clear or not suitable for ice formation. This may have resulted in a higher overall accuracy due to a higher number observations during benign conditions. The reliability of these components seems to vary considerably, with results from different states ranging from a limited amount of down time to requiring significant upkeep and repair.

Additionally, based on the survey responses, two states are investigating roadway heating systems to reduce ice information on bridges, but we found no data regarding any U.S. agencies using or evaluating chemical sprayers or other types of automatic de-icing systems.

Findings Regarding Traffic Surveillance

The effectiveness of using traffic surveillance systems to detect incidents and warn motorists in time to prevent crashes has not been conclusively demonstrated. There is some quantitative data that describes the effectiveness of the traffic management systems, of which traffic surveillance and motorist warning is one component, at improving motorist safety. This data, however, is not definitive in that one case (Mn) it was not possible to separate which component of the system contributed the most to the improved safety results and, in the other situation (NY) the results were not entirely conclusive.

Findings Regarding Variable Message Sign Component

Variable message signs are commercially available and can provide a large array of potential messages. The use of the variable message sign component in a motorist warning system has been recognized by the MMUTCD as still in the developmental stage. We found no source of recommended standards, including the Federal Highway Administration MUTCD. There is consequently a lack of standards regarding sign placement and message. Additionally, we were able to make no findings that any road agency is currently monitoring and collecting data regarding the reliability and effectiveness of sign message types and location in regard to the use of variable message signs to warn motorists of icy road conditions and/or vehicle crashes.

8. CONCLUSIONS

We have concluded that, in general, and in regard to this specific location, there is currently no operational Roadway Warning System available for advance warning to motorists of icy road conditions or crashes meeting the performance requirements as specified in the "roadway warning system" description. Additionally, we have concluded that it would be impossible, without further study and testing to combine individually available technologies and component hardware with any degree of predictability as to the reliability and effectiveness of the resulting system. The following paragraphs detail the individual conclusion elements that have gone into the above described overall conclusion.

Conclusion Regarding Roadway Ice Prediction/Detection

No quantitative data was found that demonstrates the effectiveness of either an automated or manual roadway warning system to warn motorists of site specific icy roadway conditions, based on road surface and/or atmospheric data. Consequently, we have concluded that there is no ice prediction/detection subsystem that we can recommend for implementation at the subject location as part of a motorist warning system.

Conclusion Regarding Traffic Surveillance

We did not find any traffic surveillance systems which were demonstrated to be effective at providing site specific motorist warning of traffic crash occurrences. Consequently, there is no traffic surveillance subsystem that we can recommend for implementation at the subject location as a part of a motorist warning system for either a vehicle incident or icy road warning.

Conclusion Regarding Variable Message Sign Component

There currently is no body of standards or data from existing operational systems that would indicate what warning messages would be effective in regard to warning motorists regarding a site specific icy roadway condition and/or crash incident. Additionally, there currently is no body of standards or data from existing operational systems that would indicate what sign location would be effective in displaying a motorist warning for a site specific icy roadway condition and/or crash incident. Consequently, there is no sign message or location which we can recommend for implementation at the subject location as a part of a motorist warning system.

May 22, 1996

Roadway Warning System Phase II Report

9. Recommendations

This section presents our recommendations based on information developed in phase one, as follows:

- I. Since no real-time operational system for the automatic detection of preferential icing coupled with a motorist warning has been demonstrated (quantitatively) to be effective, as presented in the problem statement, there cannot be any recommendation to install one at the subject location (or any other Michigan site) at this time.
- II. MDOT should continue to utilize existing ice detection systems as an aid to winter maintenance operations and to continue monitoring data to evaluate the accuracy, reliability, and effectiveness of the systems.
- III. Develop and maintain communications with Virginia Department of Transportation to gather additional information on their system and procedures, and to track their program and progress.
- IV. Based on potential advantages of directly informing motorists of hazardous roadway conditions (e.g., ice or stopped/slowing traffic) in real-time or near real-time, it is recommended that a concurrent two-part plan be implemented as follows:
 - A. Initiate a simulation study utilizing test subject drivers to determine response to a comprehensive experimental study related to sign messages as a function of variable environmental (e.g., ice conditions) and traffic flow (e.g. speed) conditions.
 - B. Due to the nature of the elevated structure at the WB I-696 to SB I-275 interchange, it may not be feasible to use inductive loops beyond the entrance

and exit ramps. Therefore, to provide traffic flow monitoring for the elevated stretch of roadway, a video-based detection system is recommended for a feasibility study. The feasibility study is necessary to determine the coverage area of the camera and location of the support pole for the camera. If the system proves feasible, it can be installed in lieu of, or in addition to, the video camera that is planned for that location as part of MDOT's ATMS program. The video system's potential for informing motorists of traffic conditions can then be evaluated.

- V. Develop a warrant that identifies a variety of parameters that, when utilized by designated MDOT professional staff, will identify whether a roadway warning system should, or should not, be installed at a particular location (contingent upon the satisfactory development of a roadway warning system). Probable parameters would include the following:
- A. Single or multi-lane bridges
 - B. ADT over X,000
 - C. Peak hour volume over X,000
 - D. Tangent versus horizontal curved bridge
 - E. Superelevated versus normal crown section
 - F. Superelevation over 0.0X
 - G. Number of freeze/thaw cycles (possibly develop a map with iso-contours to identify zones)
 - H. Accident history
 1. X accidents during the last A years
 2. Y multi-vehicle accidents during the last B years
 3. Z fatalities during the last C years
 - I. Ability to place a variable message sign at a location that will allow motorists to 1) adjust their route; 2) adjust their speed; or, 3) both
 - J. Locations with insufficient stopping sight distance
 - K. Bridges with speed limits greater than XX miles per hour

- L. **Bridges with limited shoulder width**
- M. **Average percentage of larger vehicles in traffic stream exceeds XX**
- N. **Bridge deck located in a weaving section less than X,XXX feet in length**
- O. **Bridge deck with a downgrade that exceeds X percent**
- P. **Rural area versus Urban area**
- Q. **Lane(s) on bridge less than 12 feet wide**
- R. **Bridge deck within XXX feet of an on- or off-ramp**
- S. **Previous techniques ineffective (e.g. increased pavement friction, grooved pavement)**
- T. **Other**

Appendix A

ROADWAY WARNING SYSTEM SURVEY

Cover Letter

The Michigan Department of Transportation is evaluating the reliability and effectiveness of roadway ice detection/prediction and motorist warning systems, as they relate to improving motorist safety¹. In particular, we are interested in the detection of preferential icing as it occurs on bridge decks. The effect on improving maintenance response and lowering maintenance costs, though related, is not the focus of this survey.

Midwestern Consulting, Inc. (MCI) and the Environmental Research Institute of Michigan (ERIM) are under contract to assess the current technical and operational practices for alerting drivers about potential or existing roadway ice conditions and the resulting traffic flow characteristics.

This survey will help us determine what technology and procedures have been applied in the past and how successful they have been. It will also help us assess current and emerging technologies that may result in improved motorist safety.

As a part of this effort, we would greatly appreciate your assistance in completing the following survey. Please feel free to attach any information or reports that you believe could be useful.

If at all possible, we would greatly appreciate a response by April 15, 1995. Responses can be mailed, faxed, or e-mailed to the address below. A representative from ERIM will be contacting you to assist and/or clarify any of the survey questions. Thank you in advance for your time and assistance in this important survey. To show our appreciation, everyone that responds to this survey will receive a copy of the final report summary (expected completion date September 1995).

PLEASE RETURN COMPLETED SURVEY TO:

Mr. Peter Tchoryk, Jr.
ERIM
P.O. Box 134001
Ann Arbor, MI 48113-4001
(313) 994-1200 x2879 phone
(313) 994-0944 fax
tchoryk@erim.org

¹ For the purposes of this survey, *reliable* is defined as "giving the same accurate results after repeated trials as measured by the ability to sense, process, communicate and display data, either on the component or system level" and *effective* is defined as "producing a measurable reduction in the rate of crashes, when used in relation to system performance."

Respondent's Name: _____

Address: _____

Telephone/Fax Numbers: _____

E-mail Address: _____

Job Title: _____

Brief Job Description: _____

(1). In your state, how large of a concern is roadway icing and its associated impact on motorist safety?

(2). Can you provide data on the number of ice-related incidents over the past 5 years? Please state in terms of: (1) fatalities, (2) injuries, (3) property loss, and (4) frequency, if possible.

(3). What has been done or is currently being done in your state to aid in the detection of ice conditions, prediction of possible ice formation, and/or warning of motorists, as it relates to improving motorist safety?

(4). What is your perception of how ice detection/prediction and warning systems could impact motorist safety?

(5). What has been done or is currently being done in your state with regard to sensing, automated incident detection, and motorist warning of slowing/stopped traffic flow?

(6). Please place a check mark in the appropriate column(s) if any of the devices or procedures listed in the following table are:

- in operation or in the process of being implemented
- being field-tested to determine operational feasibility
- being studied or analyzed

Devices and Procedures	Operational	Field Tested	Studied
Surface/subsurface sensors which monitor pavement temperature and surface conditions, including presence of ice, frost, water, snow or chemical concentration			
Atmospheric sensors which monitor air temperature, dew point, relative humidity, precipitation, wind direction, and wind speed (i.e., Road Weather Information Systems - RWIS)			
Area/remote sensors (e.g., infrared, microwave, or laser) which monitor roadway surface conditions, including presence of ice, frost, water, snow, etc.			
Closed Circuit TV (CCTV) for monitoring and/or analyzing road conditions and traffic flow for possible ice conditions			
Traffic flow sensors used in conjunction with ice detection sensors for monitoring traffic flow conditions (slowing/stopped traffic)			
Traffic flow sensors used for incident detection (not restricted to ice-related incident detection)			
Communications infrastructure to allow transmission of sensor data (surface sensors, atmospheric sensors, video, etc.) to a central control facility			
Any procedures (automated or manual) that utilize this data to predict the formation of ice and/or detect the presence of ice			
Driver information systems (e.g., variable message signs) that provide motorist warnings of existing or possible ice conditions and/or resulting traffic impediments			

For each item check-marked in the table, please provide the following details, if applicable (feel free to attach additional pages if necessary):

- Locations of systems (in particular, please identify the locations of any systems intended for a bridge or bridge ramp). Include a description of the climate, significant weather events, geography of the area, and roadway geometry, if notable.

- Operational status (date of implementation or planned implementation; number of systems involved)
- Type of equipment (include names of vendors, if available)
- Data or results indicating the reliability and/or effectiveness of the systems, such as before/after comparisons (please attach information or include references to reports and/or recommendations, if available)

(7). Please describe your agency's snow and ice control policy (maintenance) and how it involves the use of ice detection/warning systems, if applicable.

(8). Do you have access to data, not necessarily specific to ice detection, but that describes the reliability or effectiveness of driver warning systems in terms of motorist safety (in particular, warning drivers of dynamic conditions on a real-time basis)?

(9). Are you aware of any studies recommending the optimum placement of variable message/warning signs?

(10). Please provide any other comments or ideas you may have concerning this or related topics.

Appendix B

Survey Respondents Address List

Alaska

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Colorado

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Professional Engineer I
George Demos
Engineer Intern
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Denver, CO 80222
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Connecticut

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Deleware

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New York

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Illinois

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Ames, IA 50010
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Kansas

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Maryland

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Montana

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New Brunswick

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 /453-2213
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N. Carolina

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Pennsylvania

Amar Bhajandas
Maintenance Division Chief

[Faint, illegible text, possibly bleed-through from the reverse side of the page]

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Tennessee

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Texas

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 Texas Department of Transportation
 Construction & Maintenance Division
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 Austin, TX 78704

Vermont

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Virginia

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 Director, Emergency Operations
 Commonwealth of Virginia
 Department of Transportation
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W. Virginia

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 Traffic Engineering
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 Fax: 304/558-1209

Wyoming

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 Maintenance Staff Engineer
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 Cheyenne, WY 82003-1708

Appendix C

Survey Responses

(2). Can you provide data on the number of ice-related incidents over the past 5 years? Please state in terms of: (1) fatalities, (2) injuries, (3) property loss, and (4) frequency, if possible.

Virginia

No direct data available. I would judge that when ice events occur (4-5 times/yr) we have over 150 incidents/day. Fatalities are rare. Most damage is of the "fender bender" variety.

Maryland

A tabular response was provided.

New York

No. The current State Accident Surveillance System (SAS) identifies snow & ice accidents only.

Nebraska

Not available.

Minnesota

A tabular response was provided. This includes accident information for all roads in Minnesota (125,000 mile system).

South Carolina

	Fatalities	Injuries	Total Accidents
1993	2	126	401
1992	2	55	122
1991	1	48	138
1990	1	0	10
1989	5	435	1466

North Carolina

Ice Related Crashes in NC 1990-1994

Total number of persons killed	67
Total number of persons injured	5,800
Total number of PDO crashes	7,103
Total number of ice related crashes	11,120

Montana

MDT (Montana Department of Transportation) has no database with information on ice-related incidents. For 1993, the following investigated traffic accident data with icy, road surface conditions are available:

9 fatal traffic accidents

900 injury accidents, and

2,983 Property Damage Only (PDO) accidents

i.e. 3,892 investigated traffic accidents out of 18,839.

For the analyses of safety improvements, MDT uses costs of

\$500,000 per fatal accident

\$11,000 per injury accident, and

\$2,000 per PDO accident.

This yields accident costs on icy roads in 1993 in the order of 20 million dollars.

Delaware

Data collected on accidents during the winter season is not provided for any particular weather condition. We do know that many accidents are due to ice related roads.

Pennsylvania

During the 5-yr period between 1989-1993, there were 437.3 billion vehicle miles of travel on PA roadways, and the following ice-related and snow-related accidents and statistics:

	Ice-related	Snow-related
Fatal accidents	195	221
Injury accidents	15,826	16,359
PDO accidents	13,135	14,581
Persons killed	217	212
Persons injured	22,985	24,364
Accidents/100 MVM	6.7	7.1

Kansas

No.

Connecticut

Information not available.

Iowa

We do not collect this data.

W. Virginia

6 YRS Snow & Ice Related Accidents

Year	Occurrences	% Total Acc.
1994	4410	9.93
1993	3695	6.99
1992	3491	6.56
1991	2332	4.64
1990	2573	4.84
1989	5438	9.79

Additional data breakdowns are not available.

Colorado

A tabular response was provided.

Wyoming

A tabular response was provided.

Texas

The data for ice-related incidents over the past 5 years can be retrieved from the Traffic Operations Division at (512) 416-3118.

Vermont

Year	Fatalities	Injuries	Property	Total
1992	8	795	842 crashes	19.6%
1991	12	751	804 crashes	16.7%

This is the only published data available.

Illinois

No.

New Brunswick

A lengthy descriptive response was provided.

Alaska

Not kept in this format.

Saskatchewan

Our accidents category is Packed Snow/Ice. Some of the accidents may have been on packed snow.

The 5 yr total is:

- | | |
|------------------|------|
| 1. Fatalities | 34 |
| 2. Injuries | 1100 |
| 3. Property loss | 3458 |

Missouri

Not available.

Tennessee

Not available.

(3). What has been done or is currently being done in your state to aid in the detection of ice conditions, prediction of possible ice formation, and/or warning of motorists, as it relates to improving motorist safety?

Virginia

We have an installed RWIS (SSI, Inc.) as well as 24 hour EOL which monitors all weather sources. Information is transmitted to motorists by our "highway Helpline" (toll-free 1-800-367-ROAD), the media, H.A.R. and V.M.S.

Maryland

Currently, we have 4 locations with 14 pavement sensors which provided real time data of pavement conditions. A winter season pavement temperature and precipitation forecasting service is used in conjunction with the real time data. We foresee in the near future the ability to update Variable Message Signs (VMS) by computer to have traveler warnings based on sensor data.

New York

We begin by making extensive use of weather forecasting and storm tracking systems which are available. (e.g., The Weather Channel, Accu-weather, Storm-Track, SSI/WSI, Kavouras, DTN, WSC, etc.) We also have extensive interstate and intrastate communications networks to give early warning of storm conditions. Finally, we have begun installing Road Weather Information Systems to provide site specific, real time weather and pavement condition information. Use of message signs and radio/tv announcements are selectively available.

Nebraska

Scan system by surface systems installed in 3 locations.

Minnesota

Mn/DOT presently has 16 RWIS reading stations, located generally in two areas - Duluth and Minneapolis/St. Paul. These are not integrated into a centralized system. Most areas rely on weather forecasts and observations to detect slippery road conditions. Road conditions information is provided to motorists through telephone systems and media.

South Carolina

We have weather monitoring stations with pavement sensors at strategic locations in the areas of the State with colder weather. They are not related to any warning devices to motorists. The SCDOT does, however, erect a "Bridge Ices Before Road" sign. This sign is intended for use to warn motorists that icy conditions may occur on the bridge where such a condition does not exist on the adjacent roadway. The sign should be displayed on the righthand side of the road, and on divided roadways, an additional installation may be used in the median.

North Carolina

Currently, NC has no method to aid in the detection of ice conditions or the prediction of possible ice formation (aside from weather forecasts). The only warning we currently deploy is a "Bridge Ices Before Roadway" (W1712) sign.

Montana

The MDT has installed 13 remote weather information systems(RWIS). They assist maintenance personnel select when ice is forming on the roadway and determine the de-icing strategy. In terms of motorist warning, MDT has installed signing "Watch for Ice on Bridge". In collaboration with the Montana Broadcasters Association, MDT has installed Radio Information Signing on the major highways, as per MUTCD Section 2F-36. These signs give radio frequencies. The radio stations have agreed to give periodic weather warnings at no more than 15 minute intervals, during periods of adverse weather, and road condition information affecting the roadway being traveled once every half hour when required. MDT is investigating the use of variable message signs to alert motorists of hazardous conditions.

Delaware

We are presently using vehicle mounted portable road temperature sensors to monitor road temperature. The use of highway advisory radio has been helpful to warn the public.

Pennsylvania

Pennsylvania has installed Roadway Weather Monitoring Information Systems at locations throughout the state to provide snow and ice detection. These sites are experimental and are being evaluated.

Kansas

Pavement sensors on bridge decks and pavement surfaces, and weather forecasts. The most effective so far is the close watch our maintenance supervisors and superintendents keep on pavement and weather.

Connecticut

We have two twenty-four hour Operations Centers equipped with cameras and radar detectors to monitor traffic flows and speeds. We rely heavily on various weather services, storm monitors and field personnel to provide updates. A Road Weather Information System is in the planning stage.

W. Virginia

Recently, the Division of Highways (DOH) installed an RWIS on a bridge with a demonstrated icing problem. The DOH is evaluating its effectiveness in the decision making process.

Iowa

Iowa has started a 3 yr, 5 million dollar project of installing a Road Weather Information System consisting of 47 Remote Processing Units providing information to all Highway Supervisors.

Colorado

Colorado is investing in the Road Weather Information System (RWIS). There are over 30 stations in Colorado with 11 stations in the Metro Denver area. The system provides roadway temperature predictions based on subgrade temperature and weather predictions, and is used to effectively mobilize de-icing and snow removal operations.

Wyoming

Road weather information system has been in place since 1990. The system is expanded yearly. Road and travel info has been provided to the motoring public for 20+ years.

Texas

Currently, the use of electrical warming devices in bridge decks is being researched. However, at this time we use traditional sanding, clearing, signs, and digital warning signs.

Vermont

No action at this time.

Illinois

Illinois has installed a Roadway Weather Information System by a competitively bid contract with Surface Systems, Inc. in two northernmost districts. Illinois plans to expand the RWIS to include the central part of the state over the next two years. The district office responsible for the Chicago area has installed Viasala sensors for ice detection at three sites for the "gates" for the reversible lanes on the Kennedy Expressway in addition to eight SSI sites.

New Brunswick

We have not yet utilized any remote sensing devices or variable signage. We do sign bridges "Bridges Freeze Before Roads." We have had Environment Canada develop local forecasts and weather graphs similar to many aspects of an RWIS. We are continuing to try and obtain better predictions of weather.

Alaska

Nothing - no major research. Use variable message signs for advising motorists of maintenance observations.

Saskatchewan

Operate a province wide "hotline" service throughout the winter to provide the public on a 24 hour basis with accurate and timely information on driving conditions. The information is available by phone. Also provide the media with bulletins on adverse driving conditions.

Missouri

Early detection is done by sending out patrols to observe bridge decks and roadways when conditions are such that icing may occur. No measures are taken to warn motorists.

Tennessee

Tennessee contracts with a private weather forecaster for specific weather forecasts. We also have a weather data 1-800 number which is updated frequently.

(4). What is your perception of how ice detection/prediction and warning systems could impact motorist safety?

Virginia

Where such warning systems can be specific and creditable: considerably. Generalized cautions seem not to be terribly effective.

Maryland

The information received from sensors is used to place traveler warnings on VMS and the Traveler's Advisory Radio, which serve to enhance public safety. Alerting motorists prior to entering an area with possible icing conditions is probably the best way to give immediate warning. These real time condition warning systems are also used for winter operations, giving the ability to direct crews to areas with ice warnings as conditions occur, improving the overall efficiency of winter operations.

New York

We feel there is a very large potential safety benefits that can be realized from developing ice detection/prediction and warning systems. For this reason, we have a long term plan to invest several million dollars in developing this capability.

Nebraska

Provides current roadway conditions to maintenance people.

Minnesota

Localized, real-time road condition information and reliable forecast of slippery conditions will change the decisions made by supervisors; becoming more proactive and less reactive. This will result in changes to methods, equipment, and materials and will give the motorist a better product - a road surface with friction.

South Carolina

Improvements in detection and warning devices will reduce the chances for motorists' involvement in collisions.

Montana

Based on the accuracy and overall success of the original RWIS Sites, MDT is implementing a statewide RWIS Plan. The plan will include installation of 47 (additional) sites MDT believes the RWIS provide maintenance personnel timely information to determine the best de-icing strategy.

Delaware

We believe that early detection and reaction to winter ice conditions would be a positive impact on motorist safety.

Pennsylvania

PA anticipates the use of these systems will help in managing the state's winter operations program and provide for motorist safety.

Kansas

System could impact safety if used where unexpected icing occurs. Where it abruptly occurs after a stretch of dry or wet pavement.

Connecticut

Ice detection/prediction and warning systems could enhance motorist safety by giving maintenance personnel the ability to take action prior to the condition rather than reaction to it (anti-icing vs. de-icing).

W. Virginia

Warning systems could have substantial impacts on motorist safety when used properly. The combination of RWIS technology with a variable message sign can provide motorists with timely information on road conditions.

Iowa

The Highway Supervisor will be able to detect and treat snow and ice conditions quicker which will reduce the time the roads are not normal because of snow and ice. Knowing pavement condition will aid the supervisors in snow and ice decisions.

Colorado

Improves motorist safety by providing timely response of snow removal operations, reduces labor and material usage during de-icing operations.

Wyoming

Can be a significant tool in advising motoring public by forecasts, public broadcast, radio notices and telephone messaging.

Texas

Ice detection, prediction, and warning systems could save lives, insurance claims, and financial losses to the traveling public.

Vermont

It would be helpful and might improve motorist safety.

Illinois

If the geographic sites where the ice occurs are so unique they may be the **first** and/or **only** places where ice occurs, the investment may be warranted. As an agency responsible for very large geographical areas, we are proactive and rely on forecasts and RWIS real time data to determine critical-ness. Timeliness is most important. Crews are expected to be on sites before snow and ice occur. Crews tend to know where to go first through experience.

New Brunswick

Because of our low AADT these systems do not seem to be economically feasible at this time in our area.

Alaska

Could provide a great service.

Saskatchewan

The use of an early warning system that would allow our staff to treat icing condition prior to icing or at the time of icing would greatly reduce the ice related accidents.

Missouri

They can only be effective if motorists pay attention to the warnings.

Tennessee

A good system should impact motorist safety in the following ways:

Better performance by state forces

Better information provided to traveling public

Proper detour development

More economical ice and snow removal

(5). What has been done or is currently being done in your state with regard to sensing, automated incident detection, and motorist warning of slowing/stopped traffic flow?

Virginia

We have a pilot project on Intelligent Highways for automated detection/warning commencing next FY. All other systems in effect are essentially manual.

Maryland

We are currently deploying a comprehensive traffic management system which will integrate both snow/ice operations and traffic management/information systems. The field elements of this system include 27 loops (for speed, occupancy, headway and volume), 96 wide beam radar traffic sensors (speed only), 21 closed circuit television cameras, 40 VMS, and 24 Traveler Advisory Radios (on 530 and 1610 AM).

New York

A number of incident detection, motorist warning and mobility projects have been initiated in the state; the most notable is documented in FHWA-RD-91-075, January 1992, INFORM EVALUATION Volume I: Technical Report. That publication presents some of the mobility and safety benefits that have been associated with early detection and warning systems. Highway systems with similar components and /or functions are anticipated for the future.

Nebraska

Nothing.

Minnesota

Information from Mn/DOT's Traffic Management Center:

We no longer use an automated incident detection algorithm, as this has been made obsolete by the proliferation of cellular phone calls reporting incidents. We are cooperating with FHWA on a research project to investigate the integration of automated incident detection with cellular calls.

To warn motorists of slowing/stopped traffic flow conditions we use changeable message signs, portable changeable message signs, a metro area highway advisory radio program (a partnership with a public radio station on KBEM FM, 88.5 FM), and a cable tv traffic channel. We are also involved in several ITS operations tests to evaluate innovative concepts for traveler information.

South Carolina

We have currently two congestion management studies underway (in Charleston and in Greenville/Spartanburg) which address incident management techniques such as incident detection, verification, response, removal, traffic management, and information to motorists.

North Carolina

Video surveillance. VMS to warn motorists of traffic status.

Montana

Use of RWIS.

Delaware

We are considering the use of road sensors to monitor pavement temperatures and chemical concentration.

Pennsylvania

PA has installed CCTV on I-95 in the Philadelphia area. The traffic control center is manned during peak travel periods.

Kansas

Nothing.

Connecticut

The two Operations Centers have access to approximately 75 variable message signs to advise motorists.

W. Virginia

Currently, no projects of this type are being developed.

Iowa

Changeable Message Signs are being used.

Colorado

Automated incident detection is currently being investigated and developed along I-25 through the City of Colorado Springs (See attached article from the Mar 1995 issue of the ITE Journal). The Interstate Highway ramp metering system is also being expanded (to subsequently support incident detection) in the Metro Denver area. A fully automated incident detection system is operational in the Hanging Lake Tunnels on I-70 in Glenwood Canyon.

Wyoming

Nothing formally in effect. Traffic volumes are relatively light.

Texas

The state of Texas has built an IVHS system in the city of San Antonio with minimal sensing devices, full automation detection, and traffic flow controlling. This proto-type may be implemented statewide in all urban areas once completed.

Vermont

Vermont Agency of Transportation installed a permanent variable message sign on I-89, north bound, advising of road/traffic conditions. The sign is telephone/computer actuated and is located at the highest 3 mile accident location on I-89 in Central Vermont.

Illinois

With the responsibility for 45,000 lane miles of state maintained roads, we believe sensing, automated incident detection and motorist warning of slowing/stopped traffic flow is economically infeasible on any roadways except the expressways in Chicago. (E.g. 200,000 ADT's). On those expressways an extensive surveillance, communications and traffic control system has been developed and installed for several years.

New Brunswick

See number 3.

Alaska

Nothing.

Saskatchewan

Have done very little in the way of Road Weather Information Systems. We still rely on our maintenance staff for providing road condition. This past year we started looking at a value-added meteorological service for weather forecasting.

Missouri

Nothing is being done at this point with regard to sensing and warning in icing situations. We do use changeable message boards to warn motorists of slowed/stopped traffic in construction zones.

Tennessee

TN only has the 1-800 weather data phone system.

For each item check-marked in the table, please provide the following details, if applicable (feel free to attach additional pages if necessary):

- Locations of systems (in particular, please identify the locations of any systems intended for a bridge or bridge ramp). Include a description of the climate, significant weather events, geography of the area, and roadway geometry, if notable.

New York

Regions 1 and 4 include bridges. Climate, geography and road geometries vary.

Connecticut

I-95, Route 8; I-84; I-91

- Operational status (date of implementation or planned implementation; number of systems involved)

Virginia

A lengthy descriptive response was provided.

New York

Two regions fully operational, 2 regions partially operational. Four more regions in the advanced planning stages.

Kansas

Implemented in 1989, 40 KDOT RPU sites statewide. Turnpike has 10 cities; counties have an estimated 10.

Connecticut

I-84/I-91 (1993)

I-95 (1994/1995)

CCTV Cameras

VMS - Daktronics, Flip-Disc & LED

WHELAN Radar Detectors

- Type of equipment (include names of vendors, if available)

New York

Surface Systems, Inc. is vendor for all regions noted.

Montana

Surface Systems, Inc.

- Data or results indicating the reliability and/or effectiveness of the systems, such as before/after comparisons.

New York

Only region 4 has detailed historical data. Contact Gene Taille at 716/733-5548.

Kansas

Mixed opinion on cost effectiveness. No hard data.

Connecticut

Before/after studies will be done.

Maryland

A lengthy descriptive response was provided.

Nebraska

All bridge locations. 1 on US-275 by Valley, 2 on I-80 at Shelton and Grand Island. Scan Systems.

Minnesota

A lengthy descriptive response was provided.

South Carolina

Item 2. As far as atmospheric sensors are concerned, there is a fog monitoring system at the Cooper River Bridge over I-526 in Charleston, SC. The department installed this system to warn motorists of foggy conditions at the river crossing. The system consists of closed circuit TVs, variable message signs, fog detectors, weather instruments, lighted pavement markings, street lights, and an operator alert system. Once the central system detects fog, it will activate a warning system in the control center, and the control center will make appropriate response. There are no before/after studies available as of this date. Item 4. There is CCTV for monitoring road conditions at the Cooper River Bridge over US 17 in Charleston. This surveillance unit includes five cameras, each of which is mounted to permit the observation of traffic by means of monitors. There are no before/after studies available as of this date.

W. Virginia

Location: I-79 Kanawha County & Little Sandy Bridges

Geometry: 2 Parallel 1,000 Ft. Bridges. 3.5 degree left hand horizontal curve. 5% sag vertical curve. Receives little direct sunlight during winter months.

Climate: typical of region.

Equipment: remote processing unit with 1 sub-surface and 3 surface sensors. Atmospheric sensors and a precipitation classifier are part of the system.

Data: (None available. RWIS only operational during 1 winter month).

Colorado

A lengthy descriptive response was provided.

Texas

A tabular response was provided.

Illinois

A lengthy descriptive response was provided.

(7). Please describe your agency's snow and ice control policy (maintenance) and how it involves the use of ice detection/warning systems, if applicable.

Virginia

We have a clear pavement policy (all major routes to be clear within 24 hours of a storm). Ice detection is not directly connected to this; though icy patches will be treated 'as soon as possible.'

Maryland

The Maryland State Highway Administration has a bare pavement policy. When roadway accumulation is 1-2 inches, plowing begins with application of chemicals and abrasives, and the pavement is kept as close to bare as possible. This continues until the end of the storm. Use of pavement sensors aids in the decision of when to reapply chemicals to critical areas.

New York

A lengthy response was provided on snow and ice maintenance guidelines. An ice detection/warning systems policy is under development.

Nebraska

Nebraska has a bare pavement policy. The systems monitor icing conditions and salt levels.

Minnesota

Maintenance snow and ice operations in Mn/DOT are decentralized to eight districts. Therefore, the procedures to implement the policy (attached) vary somewhat. The Metro (Minneapolis/St. Paul) area has personnel on duty 24 hours a day during the winter season (Nov 1 - April 15) to observe and confirm roadway conditions and to respond as needed. Outstate locations may have people on duty for less hours and rely on the State Patrol for observations at other times (nights and weekends). All areas have access to various forms of weather forecasts (NWS, media or customized) that are used to schedule personnel and plan the methods used. Weather radar is also utilized where available. Mn/DOT has 16 RWIS stations (Metro and Duluth) that provide real-time information.

South Carolina

The Department currently uses weather forecast instruments which communicates with computers via modems. Upon detecting conditions which may cause icing of roads and/or bridges the system warns the operators of the conditions so that appropriate steps can be taken.

North Carolina

No current policy. DOT does scrape, salt, and sand major roadways during ice conditions.

Montana

Since de-icers and RWIS systems are new to the MDT, present policy is currently under review and change.

Delaware

It is our policy to provide a bare pavement to motorists for safe passage along the interstate. We react to most winter weather before it becomes a problem. Our salt trucks are in operation before the start of most storms. We continue to monitor the storm with our portable road sensors.

Pennsylvania

To date, they have not been interpreted.

Kansas

Removal is by priority based on AADT; we use the sensor data as additional information to the supervisors and superintendents observations plus forecasts.

Connecticut

A lengthy descriptive response was provided.

W. Virginia

Use of chemicals and abrasives to achieve the end results of clear pavement.

Iowa

A lengthy descriptive response was provided.

Colorado

A lengthy descriptive response was provided.

Wyoming

RWIS is used to deploy maintenance forces and to react predictions of ice and/or snow. Pretreatment, treatment, or plowing are done as necessary.

Texas

The state of Texas has a snow and ice control policy. Early warning systems use the traditional signs or digital signs.

Vermont

Vermont Agency of Transportation does not use any ice detection/warning systems. We use infrared pavement temperature sensors to help us with salt application rates, but not for ice detection.

Illinois

A lengthy descriptive response was provided.

New Brunswick

We have a 3 level of service policy depending on traffic and road class: bare full width, bare centre strip, snow packed. No ice detection systems used.

Alaska

Ice detection not used - no 'bare roads' policy - 50% of maintenance and operations budget spent on snow and ice control.

Saskatchewan

Our snow and ice removal policy is still in the react to the condition as soon as possible state.

Missouri

Missouri's policy is to remove snow and provide skid protection as necessary on all state maintained routes as rapidly as possible and insofar as available manpower and equipment will permit. This policy does not involve nor utilize ice detection/warning systems.

Tennessee

Tennessee has a bare pavement policy.

(8). Do you have access to data, not necessarily specific to ice detection, but that describes the reliability or effectiveness of driver warning systems in terms of motorist safety (in particular, warning drivers of dynamic conditions on a real-time basis)?

Virginia

No.

Maryland

We are not aware of any data/studies providing this information.

New York

FHWA-RD-91-075, January 1992, INFORM EVALUATION Volume I: Technical Report addresses the reliability and effectiveness of advance warning signs for both mobility and driver safety. Driver safety is briefly expressed as a comparison of accident rates.

Nebraska

We do not use ice detection systems to activate warning signs (too much liability).

Minnesota

We have data which indicates Mn/DOT's traffic management program has been successful in terms of increasing motorist safety. Our studies indicate that the peak-period accident rate has been reduced over 40% during the past five years on those freeway sections where traffic management systems have been installed. We have not been able to differentiate to what extent various traffic management initiatives should be attributed to this reduction in accidents, but we think that it is primarily the ramp metering systems and, to a lesser degree, the traveler information services and Highway Helper emergency response vehicles.

South Carolina

The SC Department of Transportation (SCDOT) has the responsibility for this area. Any data of this nature is not readily available.

Montana

No.

Delaware

No.

Pennsylvania

No.

Kansas

No.

Connecticut

No.

W. Virginia

No.

Iowa

No.

Colorado

No.

Wyoming

No.

Vermont

No.

Illinois

No.

Alaska

No.

Saskatchewan

No.

Missouri

No.

Tennessee

No.

Texas

We do not have any data available for ice detection at this time.

New Brunswick

Yes, our library has some information.

(9). Are you aware of any studies recommending the optimum placement of variable message/warning signs?

Virginia

Yes. VA Traffic Research Advisory Committee report of Nov. 16, 1994. Also Highway Advisory Radio. Contact: Transportation Research Council, 530 Edgemont Rd., Charlottesville, VA 22909

Maryland

A reference list was provided. Additionally, Wyoming prepared a study titled "Motorist Information Needs and Changeable Messages for Adverse Winter Travel" in July 1992.

New York

NYS Manual of Uniform Traffic Control Devices, section 230.2 addresses the appropriate placement of advance warning signs based on 85 percentile speeds. Virginia Transportation Research Council, Final Report, "Development of Manuals for the Effective Use of Variable Message Signs" presents additional issues (message content, text, readable distance) associated with variable message signs.

Nebraska

No.

Minnesota

The most comprehensive studies on changeable message signs have been conducted by the Texas Transportation Institute under sponsorship of the Federal Highway Administration. There are a series of reports that summarize this research, and these reports should be available via contacting either FHWA or TTI. Dr. Conrad Dudek of TTI has been the principal investigator on most of these projects.

South Carolina

No studies are underway in SC that we are aware of.

North Carolina

No.

Montana

Dr. Jonathan Upchurch, Arizona State University, did research on the legibility of variable message signs.

Delaware

No.

Pennsylvania

No.

Kansas

No.

Connecticut
 Virginia Department of Transportation
 I-95 Corridor Coalition

W. Virginia

No.

Iowa

No.

Colorado

Yes. "Guidelines on the Use and Operation of Changeable Message Signs", Texas Transportation Institute Research Report 1232-9.

Wyoming

No.

Texas

We have had informal studies on the optimum placement of variable message signs.

Vermont

No.

Illinois

No.

New Brunswick

No.

Alaska

No.

Saskatchewan

No.

Missouri

No.

Tennessee

No.

(10). Please provide any other comments or ideas you may have concerning this or related topics.

Maryland

We would like to emphasize the success Maryland is having by developing an integrated Traffic Management and Winter Storm Management system which allows the two programs to benefit from each other's capabilities. We would also like to emphasize the importance of working with the media (and planning for media interfaces) in disseminating road condition information.

New York

We believe strongly in early detection systems for snow and ice control. At present, we are not comfortable with directly linking these systems to a motorist information system (variable message signs, etc.). Instead we feel that trained staff should confirm and interpret sensor data prior to issuing public advisories.

Minnesota

Mn/DOT intends to implement a statewide RWIS system in the next two years. We are partnering with the Swedish National Road Administration in this effort, using their expertise as a benchmark in our development.

Montana

MDT has a project looking at possibly heating a bridge deck on the Interstate System.

Kansas

I suggest input from management, headquarters, field equipment operators, supervisors and superintendents. Field input is critical. They should be used on a committee for any agency that is considering new or different technology.

Wyoming

The Wyoming system map is attached for information.

Texas

Any further information may be solicited by the use of our phone directory attached for your convenience.

Saskatchewan

In our province we will probably go with a value-added meteorological service for weather forecasting before proceeding with a full RWIS.



U.S. Department
of Transportation
Federal Highway
Administration

Development of IVHS Traffic Parameter Specifications

**Task A Report for
Detection Technology for IVHS
Contract Number DTFH61-91-C-00076**

Prepared by

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April 1995

Table A-1. Traffic Detector Technology Comparison Matrix

Type	Observable	Installation	Location	Advantages	Disadvantages	Reliability
Inductive Loop Detector (ILD)	<ul style="list-style-type: none"> Count Presence Occupancy Average vehicle speed (with use of data processing algorithm) Queue length using multiple detectors 	Embedded in roadway	Freeways and surface streets	<ul style="list-style-type: none"> Low per unit cost Large experience base 	<ul style="list-style-type: none"> Not compatible with use on bridges, viaducts, poor roadbeds Traffic interrupted for repair and installation Susceptible to damage by heavy vehicles, road repair, and utilities 	<ul style="list-style-type: none"> High for ILD itself if installed properly (0.12 to 0.29 failures per detector per year) Most failures occur in connections of ILD to pull box or pull box to controller
Piezoelectric	<ul style="list-style-type: none"> Count Axle weight Wheel weight Speed 	Road surface mounted or embedded in roadway	Freeways and surface streets	<ul style="list-style-type: none"> Low per unit cost Easy to install and repair All weather Multi-lane capable 	<ul style="list-style-type: none"> Traffic interrupted for repair and replacement No presence output 	<ul style="list-style-type: none"> High (estimate) 5-year estimated life span (may be limited by snow plowing, salt)
Radar (Microwave and millimeter-wave)	<ul style="list-style-type: none"> Count Presence Occupancy Speed Range Instantaneous traffic density 	Overhead or to side of roadway	Freeways and surface streets	<ul style="list-style-type: none"> Install and repair do not disrupt traffic All weather, day/night operation Direct measurement of speed Multi-lane operation Compact size 	<ul style="list-style-type: none"> May have vehicle masking in multiline application Resolution impacted by FCC-approved transmit frequencies 	<ul style="list-style-type: none"> Moderate (estimate)
Passive IR (Non-imaging)	<ul style="list-style-type: none"> Count Presence Occupancy 	Overhead or to side of roadway	Freeways and surface streets	<ul style="list-style-type: none"> Day/night operation Installation and repair do not disrupt traffic Better than visible wavelength sensors in fog Compact size 	<ul style="list-style-type: none"> Early sensors had unstable detection zone May require cooled IR detector for high sensitivity Susceptible to atmospheric obscuration and weather One per lane required 	<ul style="list-style-type: none"> Moderate (estimate)

Table A-1. Traffic Detector Technology Comparison Matrix (continued)

Type	Observable	Installation	Location	Advantages	Disadvantages	Reliability
Active IR (Non-imaging)	<ul style="list-style-type: none"> •Count •Presence •Occupancy •Range 	Overhead or to side of roadway	Freeways and surface streets	<ul style="list-style-type: none"> •Same as for Passive IR 	<ul style="list-style-type: none"> •Same as for Passive IR (except cooled IR detector not required) 	•Moderate (estimate)
Acoustic (Audible frequency range)	<ul style="list-style-type: none"> •Count •Presence •Occupancy •Speed with multiple detection zones and signal processing 	Overhead or to side of roadway	Freeways and surface streets	<ul style="list-style-type: none"> •Easy to install and maintain •Surface mounding option in the future •May allow accidents and crime reports to be heard 	<ul style="list-style-type: none"> •Signal processing from array req'd to remove extraneous sounds and identify vehicle •Focusing detector on area of interest 	•Moderate (estimate)
Ultrasonic	<ul style="list-style-type: none"> •Count •Presence •Occupancy •Speed •Queue length with multiple det 	Most accurate when mounted overhead	Freeways and surface streets	<ul style="list-style-type: none"> •Compact size •No traffic interruption for installation and repair •Beam well focused •Large experience base in Japan 	<ul style="list-style-type: none"> •Accuracy is affected by variations in air temperature & water concentration and by air turbulence •One per lane required 	•High (estimate)
Video Image Processor	<ul style="list-style-type: none"> •Count •Presence •Occupancy •Instantaneous traffic density •Incident evaluation •Queue length •Turning movements 	Overhead or to side of roadway	Freeways and surface streets	<ul style="list-style-type: none"> •Roadside processing allows low data rate transmission •Imagery for rapid incident management •Multiple lanes obsrv'd •No traffic interruption for installation & repair •Vehicle tracking 	<ul style="list-style-type: none"> •Different algorithms usually req'd for day and night use •Possible errors in traffic data during transition period •Susceptible to atmospheric obscuration and adverse weather 	•Moderate (estimate)
Magnetic (Magnetometers and passive magnetic detectors)	<ul style="list-style-type: none"> •Count •Presence •Occupancy •Speed with multiple detectors 	<ul style="list-style-type: none"> •Magnetometers are embedded in roadway •Magnetic detectors are surface or subsurface mounted 	Bridges, viaducts, freeways	<ul style="list-style-type: none"> •Small vehicle or obstacle detection (bicycles) •Magnetic detectors provide multiple lane coverage •Arrays of magnetometers provide vehicle classification 	<ul style="list-style-type: none"> •Traffic interruption for installation and repair •Passive magnetic detectors require vehicle to be moving 	•Moderate (estimate)



U.S. Department
of Transportation
Federal Highway
Administration

Select and Obtain Vehicle Detectors

Task D Report for
Detection Technology for IVHS
Contract Number DTFH61-91-C-00076

Prepared by

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Revised December 1994

Table 7. Detector Selection Matrix

Detector Technology and Model	Data						Environment					Other			
	Count	Presence	Speed	Speed Binning	Occupancy	Vehicle Length	Incident Detection	Detection Range	Rain	Fog	Snow	Day	Night	Availability	Interfaces Specified
<i>Ultrasonic</i>															
Sumitomo SDU 200	x		x		I	x	I	x	x	x	x	x	x	x	x
Sumitomo SDU 300	x	x			x		I	x	x	x	x	x	x	x	x
Microwave Sensors TC-30	x	x			I		I	x	x	x	x	x	x	x	x
Microwave Sensors TC-30C	x	x			I		I	x	x	x	x	x	x	x	x
<i>Infrared (Active)</i>															
Schwartz Electro-Optics	x	x	x		I	x	I	x	?	?	?	x	x	x	x
<i>Infrared (Passive)</i>															
Etecc 842	x	x			I		I	x	?	?	?	x	x	x	x
Etecc 833	x						I	x	?	?	?	x	x	x	x
<i>Microwave Radar</i>															
Microwave Sensors TC-20	x							x	x	x	x	x	x	x	x
Microwave Sensors TC-26	x		x	x			I	x	x	x	x	x	x	x	x
Microwave Sensors TC-31		x						x	x	x	x	x	x	x	x
Whelen TDN-30	x		x				I	x	x	x	x	x	x	x	x
Whelen TDW-10	x		x				I	x	x	x	x	x	x	x	x
Electronic Integ Systems RTMS	x	x	x		x		I	x	x	x	x	x	x	x	x
<i>Video Image Processing</i>															
AutoScope 2003	x	x	x	x	x	x	x	x	?	?	?	x	x	x	x
Computer Recog Systems TAS	x	x	x	x	x	x	x	x	?	?	?	x	x	x	x
Golden River Traffic C-CATS	x	x	x	x	x	x	x	x	?	?	?	x	x	x	x
Sumitomo IDET-100	x	x	x	x	x	x	x	x	?	?	?	x	x	x	x
EVA 2000	x	x	x	x	x	x	x	x	?	?	?	x	x	x	x
Cond Monitor'g Sys Mobilizer	x	x	x	x	x	x	x	x	?	?	?	x	x	x	x
<i>Inductive Loop Detectors</i>															
	x	x	I		x		I	x	x	x	x	x	x	x	x
<i>Magnetometers</i>															
	x	x	I		x		I	x	x	x	x	x	x	x	x

x represents either (1) data that are measured directly, (2) acceptable operating environments, or (3) other conditions that are satisfied.

I represents information available through processing of detector data, i.e., indirectly available information.

? represents a possible degradation in performance dependent on the severity of the environment.

The performance under these conditions will be measured during the field tests.

Models of inductive loop and magnetometer detectors will be given after the field test sites are selected, and the states identify the specific models of these detectors that will be used.

Evaluation of Modern Traffic Detector Technologies for IVHS Applications

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ABSTRACT

One freeway and one surface street arterial site were chosen in each of three states to test and evaluate alternative detector technologies. The states were selected to be representative of extremes in climatic conditions. Accordingly, Minnesota was chosen for its cold winter environment, Florida for its summer thunderstorms, lightning, and humidity, and Arizona for its dry desert summer heat. Sites were located on roadways that had high traffic density and suitable structures for mounting the overhead detectors. The detector technologies evaluated were ultrasonic, microwave radar, infrared laser radar, imaging and nonimaging passive infrared, video image processing with visible spectrum imagery, acoustic array, high sampling rate inductive loop, conventional inductive loop, microloop, and magnetometers. Approximately 5.9GBytes of digital and analog vehicle detection data and more than three hundred video tapes of the corresponding traffic flow were recorded. The detector outputs were time tagged and recorded on 88MByte replaceable magnetic cartridges by using a data logger specifically designed and built for this project. Data analysis software was written to convert the data into an easily accessible Paradox data base format compatible with a Windows personal computer operating system. Traffic volume ground truth data, obtained by counting vehicles in the recorded video imagery, were compared with the counts from the detector outputs. Speed ground truth data, obtained by driving probe vehicles through the field of view of the detectors and noting the vehicle speed as measured by the vehicle instrumentation, were compared with the speed measurement from the detectors.

INTRODUCTION

Traffic monitoring detectors supply data to real-time, adaptive signal control systems and incident detection and notification systems that are an integral part of nearly every modern traffic management system. In recent years, continuing traffic growth and limited construction of new highways have combined to require the maximum utilization of the existing transportation network. This includes both the urban street system and freeway facilities. Newer detection technologies have the potential to increase the efficiency of the roadway network by filling the growing need for more accurate and more types of real-time data for area-wide surveillance and control of signalized intersections, freeways, and motorist information services.

Current vehicle detection predominantly relies on inductive loop detectors (ILDs). The ILDs provide a baseline for evaluating more advanced detector systems. Alternative detector technologies are being developed with the potential to be installed and maintained without disrupting traffic flow. Some can directly measure a wider variety of parameters, such as density, travel time, and vehicle turning movements, in addition to the more common parameters of flow, speed, and occupancy. The less obtrusive, buried detectors will continue to find applications in the future, as for example, where aesthetic concerns are dominant.

This paper summarizes the detector technology and data evaluation methods and results from field tests conducted in three states with diverse climates as part of the Federal Highway Administration (FHWA) sponsored *Detection Technology for IVHS* program under contract DTFH61-91-C-00076. Testing in Minnesota occurred during winter 1993, in Florida during the summer of 1993, and in Arizona during fall and winter of 1993 and summer of 1994. Desired IVHS traffic parameter and accuracy specifications (7)

Table 1. Detectors used during field tests

Symbol	Technology	Manufacturer	Model
U-1	Ultrasonic Doppler	Sumitomo	SDU-200 (RDU 101)
U-2	Ultrasonic Presence	Sumitomo	SDU-300
U-3	Ultrasonic Presence	Microwave Sensors	TC-30C
M-1	Microwave Radar Motion Medium Beamwidth	Microwave Sensors	TC-20
M-2	Microwave Radar Doppler Medium Beamwidth	Microwave Sensors	TC-26
M-4*	Microwave Radar Doppler Narrow Beamwidth	Whelen	TDN-30
M-5	Microwave Radar Doppler Wide Beamwidth	Whelen	TDW-10
M-6	Microwave Radar Presence Narrow Beamwidth	Electronic Integrated Systems	RTMS
IR-1	Active IR Laser Radar	Schwartz Electro-Optics	780D1000
IR-2	Passive IR Presence	Eltac	842
IR-3	Passive IR Pulse Output	Eltac	833
IIR-1**	Imaging IR	Grumman	Car Eye
VIP-1	Video Image Processor	Econolite	Aeroscope 2003
VIP-2	Video Image Processor	Computer Recognition Systems	Traffic Analysis System
VIP-3***	Video Image Processor	Golden River Traffic	Marksmen C-CATS 810
VIP-4**	Video Image Processor	Sumitomo	IDET-100
VIP-5*	Video Image Processor	EVA	2000
A-1**	Passive Acoustic Array	AT&T	SmartSonic TSS-1
MA-1	Magnetometer	Midian Electronics	Self Powered Vehicle Detector
L-1**	Microloops	3M	701
T-1**	Tube-Type Vehicle Counter	Timemark	Delta 1

* M-3 was a TC-31 microwave radar presence detector, in development by Microwave Sensors, and was not available for evaluation in this program.

** Used at Tucson Arizona test site only.

*** Used at all Arizona test sites.

+ Used in Phoenix Arizona 7/94 test only.

++ Used in Phoenix 11/93 and Tucson tests.

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