SCAN 16 - MOISTURE, FROST, ICE EARLY WARNING SYSTEM
(Final Report)

MICHIGAN DEPARTMENT OF TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

SCAN 16 - MOISTURE, FROST, ICE EARLY WARNING SYSTEM (Final Report)

F. M. Spica

Research Laboratory Section
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This project was undertaken and executed in cooperation with the Traffic and Safety and the Maintenance Divisions. We particularly thank Maintenance Division personnel at the Mason Garage. Without their many, conscientious observations over the past two winters, this report would not have been possible.

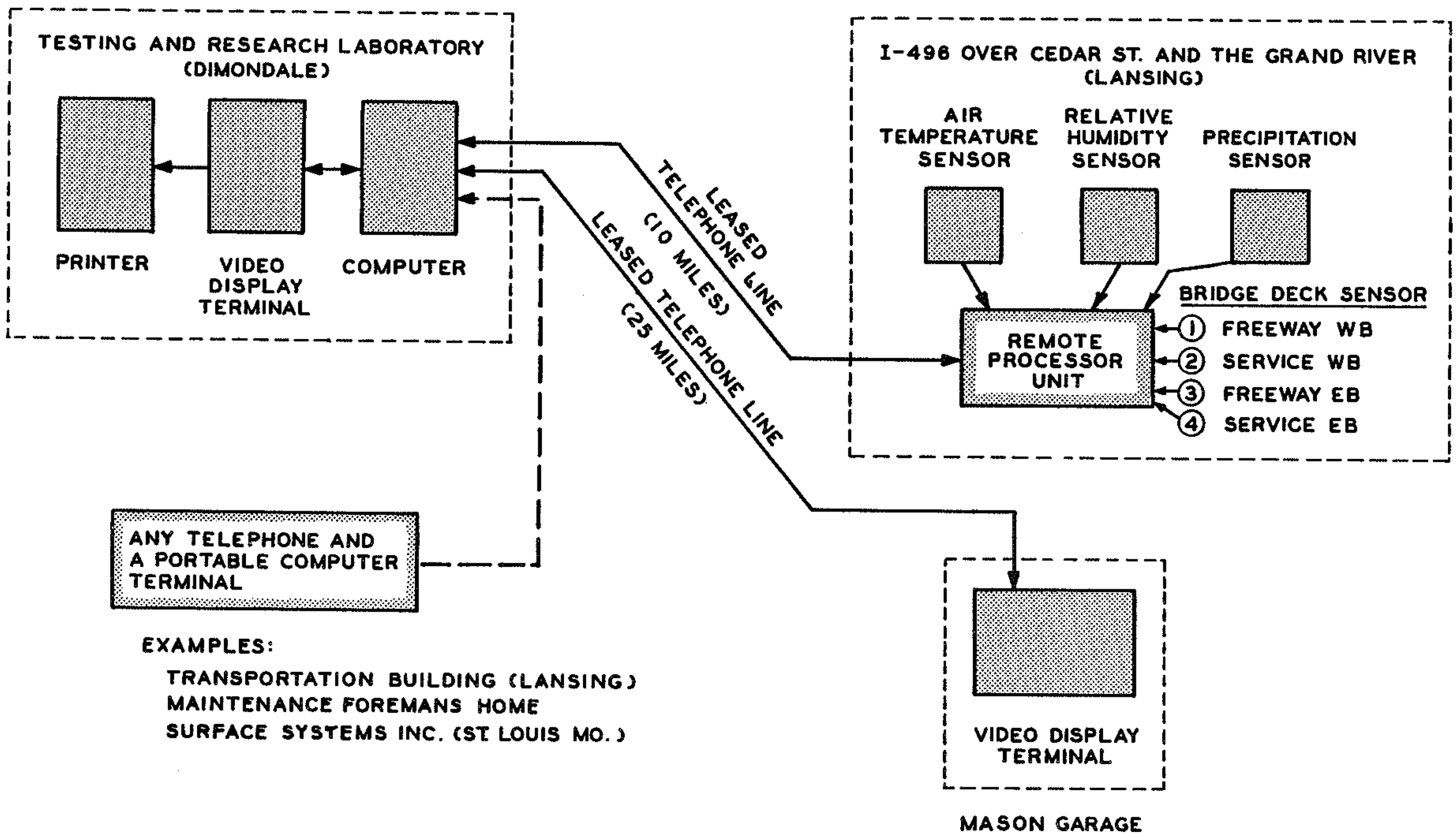

Figure 1. Scan 16 block diagram.

Problem

Motorists traveling on a roadway during the winter months may be subjected to the hazardous phenomenon known as bridge deck icing. This condition occurs when the bridge deck freezes prior to the adjacent roadway, and the sudden transition from the non-icy roadway to the frozen bridge deck may cause a motorist to lose control of his vehicle. It is difficult to predict when this condition will occur and as a result, maintenance personnel may often be sent out when it is not necessary, or not be sent out when it is. Surface Systems Inc. (SSI) of St. Louis, Missouri has developed a system for detecting these slippery conditions on bridge decks. An earlier version of this system has been available for a number of years and has been used by a number of agencies with varying results. This new version of the detection system, called 'Scan 16', has been available for only a few years and is still classified as 'experimental' by the Federal Highway Administration (FHWA).

Objectives

The main objective of this project is to verify and document the ability of the Scan system to detect and predict the formation of ice on the bridge deck. Further, we wish 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 accidents, and

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.

System Description

Scan 16 is a system for detecting moisture, frost, and ice on a bridge deck or road surface and relaying this information to a remote monitoring point. Since the control device for the system is a microcomputer, many different system configurations are possible. This report will describe the configuration of the system for monitoring surface conditions on four parallel bridges carrying I 496 and its service drives over Cedar St and the Grand River in Lansing. The block diagram of the system is shown in Figure 1 and Figure 2 shows details of the bridge site.

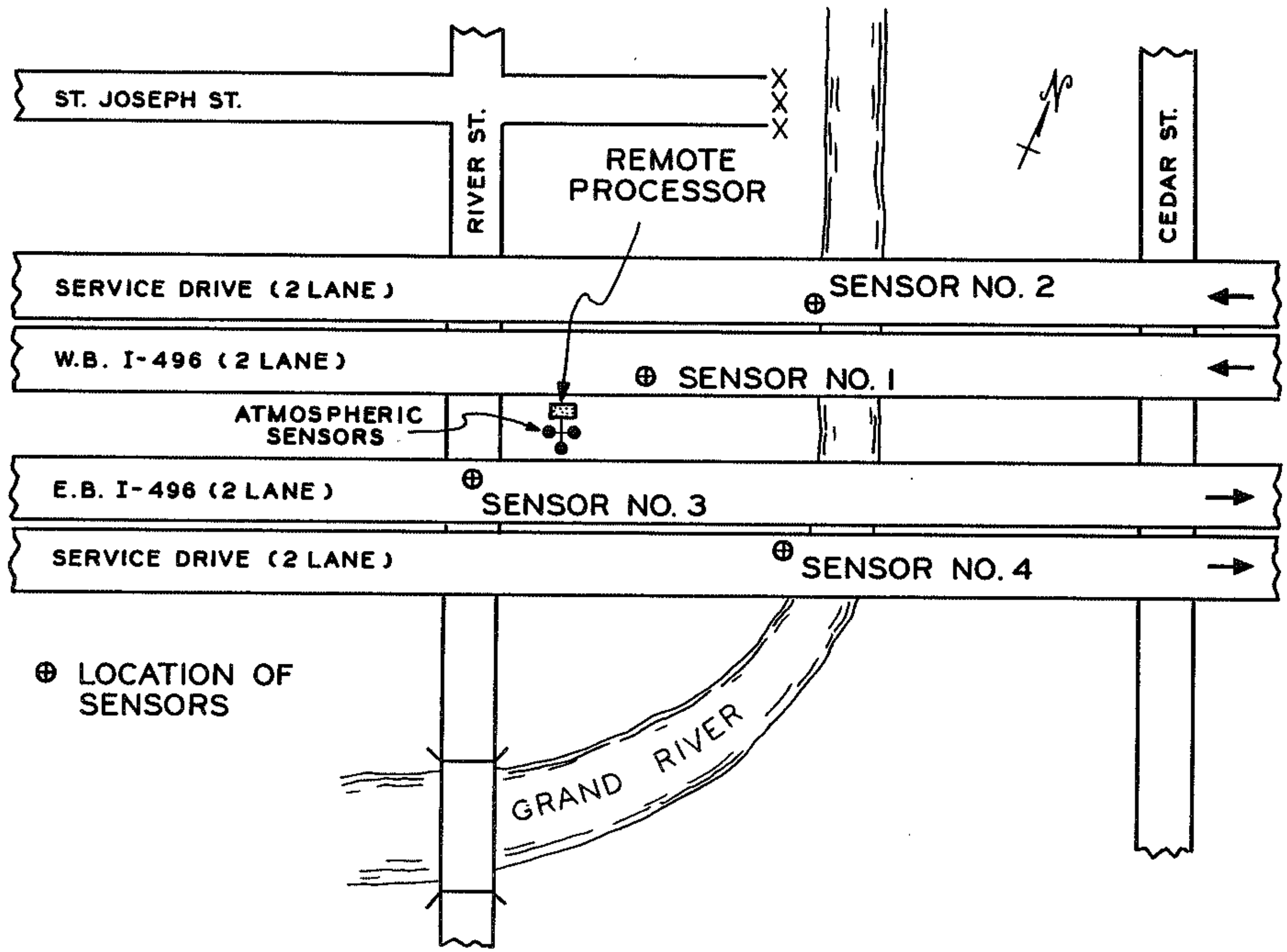

Figure 2. Location of ice detector sensors and remote processor unit.

The system uses four roadway sensors, three atmospheric sensors, and a remote processor unit all located at the bridge site. The roadway sensors determine the temperature of the surface and whether the surface is dry or if moisture is present. These sensors also indicate how much deicing chemical is present providing there is sufficient moisture on the surface to form a solution and the temperature is below 40 F. The atmospheric sensors measure the relative humidity, the air temperature, and detect precipitation.

The output from all sensors is routed to a microprocessor unit located near the bridge site. This remote processor unit (RPU) processes and stores the sensor data and transmits it to a central processing unit (CPU).

The central processor unit is located in the Testing and Research Laboratory and consists of a microcomputer and a cassette tape drive. The microcomputer gathers, processes, and stores data from the remote processor. It has the capability of handling up to 32 such remote processor units. The central processor also presents the data on a video display terminal and a printer located at the CPU site. There is also a video display terminal located in the MDOT Maintenance Garage in Mason.

Telemetry from the RPU to the central processor and from the central processor to the MDOT Maintenance Garage in Mason is accomplished by leased telephone lines. A standard dial-up telephone line and auto answer modem is also provided at the central processor. This allows access to the system from any telephone by using a portable computer terminal. This feature enables the maintenance foreman to take a portable terminal home at night and check on conditions by dialing into the system using his home phone. It also allows the vendor access to the system to upgrade the software or diagnose problems without visiting the site.

The system has five types of information display that are accessible from the video display terminal keyboard. They are:

1) Menu Page - explains each keyboard entry and how to use it,

2) Status Page - displays the latest surface and atmospheric data from each remote processor unit,

3) History Page - shows the last 15 significant changes for each surface sensor,

4) Graph of Air Temperature - depicts a graph of the air temperature for the last 60 minutes, and

5) Graph of Surface Temperature - displays a graph of the surface temperature measured by the requested sensor for the last 60 minutes.

It can also display a 'Summary Page' - a different form of the status page - that allows up to 16 sensor outputs to be displayed simultaneously.

System Installation

Surface sensor installation is well described in the installation instructions provided by the manufacturer. All materials necessary for the work were supplied by the vendor. The only difficulty encountered was getting the epoxy adhesive to harden, since the installation was done in late October and surface temperature had cooled to the point where it extended the epoxy curing time.

The installation of the atmospheric sensors and remote processor unit presented no unusual problems as the instructions provided by the manufacturer were quite descriptive.

The most time consuming aspect of the entire project was obtaining the telephone service. Installation was requested in the first part of October but was not completed until the middle of January. This service used standard telephone lines with auto-answer modems. Then, because telephone charges were assessed on a per-call basis, the resulting cost for the service was quite large. It was necessary to convert the system from standard phone lines to a leased line system. Surface Systems Inc. also has a radio telemetry option which can be used in this system. Although we did not use it, this may be the best alternative for short distances. This is especially true for the link between the remote processor and the central processor.

Throughout the entire installation process, SSI was very helpful. When it was time for the final hookup of the system, SSI personnel made all the necessary connections and checked-out the system to make sure all components were working correctly.

Final installation of the system was completed January 26, 1983. Total time devoted to the field work at the site amounted to about 300 MDOT man-hours. The surface sensor installation required about 130 man-hours which included a considerable amount of time for traffic control and waiting for the epoxy adhesive to cure. Another 100 man-hours was required to install conduit and cable for electric and telephone service. The remaining 70 man-hours were required to install the atmospheric sensors. These labor figures will vary considerably depending on the site and equipment available for installation. The above work was done by MDOT personnel. The time required to set up the central processor was about 16 man-hours. This time should not vary a great deal as all parts are modular and require a minimum amount of assembly. Surface Systems Inc. did this set-up with a minimum amount of assistance from MDOT personnel. Set-up of the remote monitor site at the Mason Garage required less than an hour.

PAVEMENT SURFACE CONDITION FOR
I 496 BETWEEN US 127 AND CEDAR STREET

Name of Observer:				Date:	Time: a.m. p.m.
Westbound Roadway		Eastbound Roadway		Road Surface Condition Between Wheel Tracks (✓)	
Freeway	Service Road	Freeway	Service Road		
				Dry	
				Damp (no standing water)	
				Wet (rain or melted snow)	
				Frost	
				Snow	
				Icy patches	
				Ice covered	

Remarks: ____________________

Figure 3. Surface condition evaluation form.

Michigan Department of Trans. — Time Ø1:38 January 14, 1984

I496 at Cedar Street — RPU #1 — Power on at: 12:42 on Ø1/Ø6/84; Last report: Ø1:37 on Ø1/14/84

Atmospheric conditions

Air Temperature	Dew point Temperature	Relative Humidity	Wind Direction	Wind Speed/MPH
16	13	89		

Surface conditions

No.	Sensor location	Status	Precip	Surface Temperature	Chem. Factor
1	W.B. Passing	Surface alert	Y	15	95
2	W.B. Service	Surface alert	Y	15	95
3	E.B. Passing	Surface alert	Y	15	95
4	E.B. Service	Surface Alert	Y	16	95

Figure 4. Typical printout of system's Status Page.

System Costs

Costs for this system are itemized as follows:

		Total Package Price
Remote Processing Unit Package		$25, 100
1 remote processor in weatherproof cabinet	*	
4 surface sensors with 150 ft of cable	$2,400 ea	
1 air temperature sensor	*	
1 relative humidity sensor	1,100	
1 precipitation sensor	*	
1 electronic rack	500	
1 modem	*	
Remote Monitoring Site Package		$ 4,660
1 video terminal	$1,685	
1 printer	1,575	
2 modems with portable board	1,400	
Central Processor Unit Package		$23,045
1 central CPU	*	
1 tape drive	*	
1 modem	*	
1 CRT	*	
Telephone Service Installation		$ 350
Electric Service Installation		$ 500
		$53,665

Monthly costs amount to $100 for telephone service and $10 for electricity.

*Individual component prices not available.

Method of Evaluation

Evaluation consisted of a direct comparison of visual observations made by Maintenance Division personnel with information provided by the system. The visual observations made by the maintenance personnel were recorded on a form similar to that shown in Figure 3. There were approximately three inspections every 24 hours. More were made in periods of bad weather, fewer in good weather periods. The information on these forms was subsequently compared to the information on the system print-out for the corresponding time of day (Figs. 4 and 5). Each visual observation notes the status of a particular lane at a particular time. Since all lanes were not recorded each time, it was necessary to count each lane as an independent observation.

Michigan Department of Trans. Time Ø1:39 January 14, 1984
Power on at: 12:42 on Ø1/Ø6/84
Sensor #3 History page E.B. Passing

Time	Day	Status	Precip	Rel. Hum.	Chem. Factor	Temperatures Surf.	Air	Dew pt.	Wind Dir/Vel
Ø1:37	14	Surface alert	Y	89	95 *	15	16	* 13	
Ø1:34	14	Surface alert	Y	89	95	16	16	* 13	
Ø1:29	14	Surface alert	Y	89	95	16	16	* 13	
19:3Ø	13	Surface alert	Y	89	95 *	19	17	14	
19:27	13	Surface alert	Y	89	95	2Ø *	17	14	
17:49	13	Surface alert	Y	89	95 *	21	18	15	
16:Ø7	13	Surface alert	Y	87	95 *	23	2Ø	16	
14:21	13	Surface alert	Y	84	95 *	25	19	14	
12:48	13	Surface alert	Y	8Ø	95 *	23	19	13	
12:23	13	Surface alert	Y	77	95 *	25	19	12	
11:58	13	Surface alert	Y	76	95	24 *	19	12	
11:35	13	Surface alert	Y	76	95 *	23	18	11	
11:Ø8	13	Surface alert	Y	74	95	22 *	17	1Ø	
1Ø:57	13	* Surface alert	Y	73	95 *	21	16	8	
1Ø:47	13	* Surface critical	Y	7Ø	Ø5	2Ø	16	7	

Figure 5. Typical printout of system's History Page.

An accuracy rate was calculated by taking the number of observations that agreed with the system printout divided by the total number of observations and expressing the quotient as a percent.

During the two winters of evaluation, three software revisions were made. During the first winter, 1982-83, the system operated using software version 8.0, the original software provided. This is the version on which the interim report was based. During the winter of 1983-84 three software upgrades were made. On November 21, 1983 software revision 9.0 was entered into the system. On December 8, 1983 software revision 9.1 was entered into the system and on January 6, 1984 the third software revision 9.2 was entered.

Since each of these software changes was an upgrade of the previous software, each software package will be evaluated separately. The improvements made in the system, particularly with the most recent software package are discussed in the Conclusions and Recommendations section.

The different pavement conditions displayed by the system are described as follows:

Dry: An absence of precipitation or moisture on the surface sensor.

Moisture: Precipitation moisture present in liquid form on the surface and surface temperature above 32 degrees Fahrenheit (0 degrees Celsius).

Damp/Light Frost: Moisture from the air being absorbed into chemicals or impurities on road when relative humidity is less than 90 percent and surface temperature is at or below 32 F (0 C). TYPICALLY this moisture on the surface does not present a traction problem.

Surface Alert: Precipitation/moisture present in liquid form on the surface and surface temperature at or below 32 F (0 C).

Surface Critical:

A. Precipitation/moisture in liquid form on the surface starting to freeze.

B. Precipitation/moisture on the surface which has frozen.

C. Heavy frost condition on the surface.

One additional status, "Absorption," appeared in one software version. This was intended to note the condition when there is enough chemical on the road surface to actually draw moisture to the surface from within the bridge deck. This is a very light moisture condition but it is still 'seen' by the system and if the temperature is below freezing, may account for a surface critical readout. It was later decided to make this condition read out as "Surface Alert" and drop the "Absorption" status.

To determine durability of the system, a failure rate was calculated using the total number of days the system has been on-line divided by the total possible days on-line. Total possible days were between January 25, 1983 to July 31, 1984, a total of 570 days. Failure rate was subtracted from 100 percent to yield a durability rate.

Data Presentation

Durability - The system has been running continuously for about 18 months including two winters. During that time the system was off-line a total of 29 days. This included one 13-day period in August 1983. At that time of year, repair of the system was a low priority item thus accounting for the length of time the system was off-line. A much fairer accounting would be to use only the one day the system was worked on during this 13-day period. Total, therefore, would be 29-13+1 = 14 days off-line. Using 570 days as the total number of possible days on-line, the failure rate becomes 2.5 percent. This translates to a durability rate of 97.5 percent. Not included in this was a total of two telephone line failures and four power failures, all of less than one day duration.

Almost all of the downtime was due to problems with either the cassette tape deck or the tapes themselves. Except for tightening one loose connection, the RPU has not required any maintenance. The precipitation sensor had to be replaced about three months after it was installed. However, the failure of this sensor was due to its placement too near the roadway where it was subjected to severe salt spray. The new precipitation sensor has been working fine since it was moved above traffic road spray.

Accuracy - Observations for the first winter began on January 28, 1983 and continued through March 1, 1983. During this time, 165 observations were made; five observations had to be discarded because of missing time or date, and 13 observations were made during times when all or part of the system was not operational. This left 147 valid observations. The following table shows the frequency distribution of the surface conditions as reported by the Scan 16 system and by visual observation during the test period.

1983 RESULTS
DISTRIBUTION OF CONDITIONS REPORTED

Scan 16		Observers	
Dry	65	Dry	66
Moisture	18	Damp	39
Surface Alert	36	Wet	24
Surface Critical	28	Frost	0
		Snow	5
		Icy Patches	10
		Ice Covered	3

A comparative interpretation of the data showed 115 observations agreeing and 32 disagreeing with the SSI system results; translating to a 78.2 percent accuracy rate. The 32 observations in which there was a disagreement are shown in the table below in which the following conditions were equated: frost, snow, icy patches, and ice covered are equated to 'Surface Critical.' Wet and damp at or below 32 F are equated to 'Surface Alert' and wet and damp above 32 F are equated to 'Moisture.'

Scan 16 Reported	Observer Reported	Number of Times
Surface Critical	Dry	10
Dry	Damp	8
Surface Critical	Damp	5
Dry	Wet	4
Dry	Icy Patches	2
Surface Alert	Ice Covered	1
Surface Alert	Dry	1
Moisture	Dry	1

There were 15 times the system reported Surface Critical when the observer reported it as Dry or Damp. Most important to note is the fact that only once did the observer report the roadway ice covered while the system remained in a Surface Alert condition. Further investigation showed the system did change to Surface Critical within 30 minutes of the time of the observation.

The second winter, as explained earlier, is divided into three periods corresponding to the three software upgrades. The first of these software upgrades was entered into the computer on November 21, 1983 and remained in effect until December 8, 1983. It was numbered software version 9.0. During this time 93 valid observations were made. Sixty-two observations agreed with the system and 31 disagreed. This translates to an accuracy rate of 67.3 percent. The frequency distribution of the conditions reported by the Scan 16 system and by the visual observers during this period is shown in the following table:

1984 RESULTS
DISTRIBUTION OF CONDITIONS REPORTED
USING SOFTWARE VERSION 9.0

Scan 16		Observers	
Dry	2	Dry	22
Damp/Light Frost	2	Damp	20
Moisture	11	Wet	20
Frost	-	Frost	8
Surface Alert	57	Snow	19
Surface Critical	21	Icy Patches	3
		Ice Covered	1

The 31 observations in which there was disagreement are shown in the table below. The same conditions are equated as in the previous period.

Scan 16 Reported	Observer Reported	Number of Times
Surface Critical	Dry	5
Surface Critical	Damp	1
Surface Critical	Wet	5
Surface Critical	Snow	4*
Surface Critical	Frost	2*
Surface Alert	Ice Covered	1
Surface Alert	Dry	14

The observations flagged with an asterisk (*) indicate that the system was switching every several minutes from Surface Critical to Surface Alert so these observations were counted as disagreements. Only once did the system miss an Icy Condition, although it did report Surface Critical when the observers reported Dry, Damp, or Wet eleven times. This would suggest that the system tends to be overly cautious.

The second software upgrade, software version 9.1, covered a period from December 8, 1983 to January 4, 1984. During this time 72 valid observations were made. Forty-eight observations agreed with the system and 24 disagreed. This translated to an accuracy rate of 66.7 percent. The frequency distribution is shown in the table below.

1984 RESULTS
DISTRIBUTION OF CONDITIONS REPORTED
USING SOFTWARE VERSION 9.1

Scan 16		Observers	
Dry	8	Dry	18
Damp/Light Frost	0	Damp	21
Absorption	3	Wet	7
Moisture	6	Frost	11
Frost	0	Snow	7
Surface Alert	33	Icy Patches	8
Surface Critical	22	Ice Covered	0

The 24 observations that disagreed are shown in the table below. The same pavement conditions are equated as previously.

Scan 16 Reported	Observer Reported	Number of Times
Moisture	Dry	1
Surface Critical	Damp	6
Surface Critical	Dry	8
Dry	Damp	2
Dry	Icy Patches	1
Surface Alert	Frost	1
Surface Alert	Snow	1

Again it is seen that the system missed one Icy Patches condition while 14 times it reported a Surface Critical when the observer reported Dry or Damp conditions. This further shows the cautiousness of the system.

The third software upgrade took place on January 5, 1984 and remained in effect through the end of the winter period, April 7, 1984. During this time 103 valid observations were made. Of these, 86 agreed with the system and 17 disagreed. This translated to an accuracy rate of 83.5 percent. The frequency distribution of the conditions reported during this period are shown below.

1984 RESULTS
DISTRIBUTION OF CONDITIONS REPORTED USING SOFTWARE VERSION 9.2

Scan 16		Observers	
Dry	24	Dry	41
Damp/Light Frost	6	Damp	8
Moisture	6	Wet	37
Frost	1	Frost	1
Surface Alert	48	Snow	16
Surface Critical	18	Icy Patches	0
		Ice Covered	0

The 17 observations that disagreed are shown below. Again, equating of conditions is unchanged from the previous periods.

Scan 16 Reported	Observer Reported	Number of Times
Surface Critical	Dry	10
Dry	Snow	1
Dry	Wet	5
Dry	Frost	1

Caution is again shown by the system when it reported Surface Critical 10 times while the observer reported Dry Conditions. It did miss one Frost Condition, reporting it as Dry.

Accident Data

Accident data were noted for the three years preceding installation of the system and for one year after installation. Total accidents were divided into icy accidents to determine the percentage of icy accidents relative to the total accidents.

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 for I 496 has shown a steady increase for these years. Permanent traffic recorders located just to the east and west of the site, along with one very near the site, have recorded the following:

ADT on I 496

Year	West of Site	At Site	East of Site
1980	38,631	32,762	41,435
1981	40,145	33,034	42,683
1982	40,171	32,998	43,446
1983	42,468	33,972	47,324

The low icy accident count in 1982 can be attributed to the extremely mild winter that year. There also was a slight decline in traffic volume which may have had some effect on the reduction. If that year is excluded, one can see that the percentage of icy accidents has declined even though the ADT has increased.

Conclusions and Recommendations

There are two aspects of the system that should be discussed, reliability and accuracy. The reliability of this system is excellent. The field equipment is particularly immune to the harsh environment in which it must function. As stated previously, there was only one problem with the RPU and that turned out to be a loose terminal connection.

The performance of the roadway and atmospheric sensors has also been excellent. The only failure, as discussed earlier, was that of the precipitation sensor. Its initial placement was on a mast attached to the bridge pier. The sensor was mounted on the mast at the same level as the pavement which subjected it to a constant salt spray from traffic, which destroyed the sensor. Since it was moved about 10 ft above the deck there hasn't been any failure.

To evaluate the accuracy it is really necessary to divide the evaluation period into four segments. The first being the 1982-83 winter and the other three during the 1983-84 winter.

Accuracy rate for the first winter was 78.2 percent. That winter, however, was extremely mild. More than half of the total observations occurred during dry weather. This probably inflated the accuracy rate somewhat. Further proof of this is borne out by the fact that the software used in the first evaluation segment of the second winter was basically the same with only changes made to accomodate a new relative humidity sensor. The accuracy rate calculated for this segment was 67.3 percent. This segment had a much better distribution of weather conditions and is probably more representative of the system's accuracy with software versions 8.0 and 9.0.

The software version 9.1 made some improvements in the detection of moisture being drawn to the surface by deicing chemicals. This condition was given the status of Absorption. However, at the same time a new precipitation sensor was also added. Since this was an experimental sensor for SSI they were in a learning situation. To properly interpret and assimilate data from this new sensor took some time. The gains made from the previous software version were offset by the learning process. Thus, the accuracy declined slightly to 66.7 percent.

Once the precipitation sensor was working properly, the software was again updated. This version, 9.2, showed the accuracy to be 83.5 percent. This is a significant improvement over the previous segments. This segment of the winter season had a good distribution of weather conditions and thus should be a good test of system accuracy.

SSI is continuing to improve software to increase system accuracy. A new version, 10.0 has already been written and should improve the rate to over 90 percent. Gains beyond this point, however, should be much more difficult to achieve. Most of the gains will be in reducing the number of times the system reports Surface Critical when there are no problems.

There will always be some inaccuracy in this system or any other that relies on spot detection to determine the condition of an entire bridge deck. On the other hand, spot detection is the only economically feasible way of setting up a detection system. As stated in the interim report one must use this system as a tool, it cannot make the decision as to whether to salt the road surface or not. That decision still must remain with Maintenance Division personnel. What the system does do, however, is provide maintenance personnel with an excellent source of information as to the conditions that exist at a remote site.

If maintenance personnel were able to look at a number of different locations spread over their area of responsibility, they would be able to determine where their forces were most needed.

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 accidents. 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 there are too many variables to expect 100 percent accuracy.