A New Paradigm for Winter Maintenance Decisions

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A universal challenge facing highway agencies and state departments of transportation (DOTs) today is simultaneously increasing productivity, quality, and environmental sensitivity while maintaining a constant or improved level of service on roads. These challenges are of major importance to three-quarters of the states' DOTs and local governments who must face the perils of winter as they strive to provide uninterrupted mobility to the road users. Snow and ice control procedures could benefit greatly from improvements in technology applications and equipment operator efficiency. Sensors and automated attachment controls could improve decision strategies for these agencies. Utilizing sensors that record roadway surface temperatures, computers may determine optimal timing and application rates of chemicals and abrasives. Automatic vehicle location systems can track the progress of maintenance vehicles and record winter maintenance operations. The paper will show a sample of the data plots that are transmitted from the vehicles. Initially, the data is referenced to GPS bearing or to the time from the beginning of the maintenance run. CTRE has adjusted the plots so they are referenced to milepost. This paper will focus on the critical factor in the winter maintenance decision process, pavement temperature, and discuss how accurate data presentation can alter the existing process. A critical ingredient to be recognized, when existing procedures or practices are evaluated for change, is the acceptance by the workers. This paper will provide the results of phone interviews with the vehicle operators to ascertain their evaluation of equipment performance and reaction to the advanced technologies. Key words: anti-icing, GPS, pavement, RWIS, temperature.

INTRODUCTION

A universal challenge facing highway agencies today and state departments of transportation (DOTs) is simultaneously increasing productivity, quality, and environmental sensitivity, while maintaining a constant or improved level of service on roads. These challenges are of major importance to three-quarters of the states' DOTs, who must face the perils of winter as they strive to provide uninterrupted mobility to the road user. Snow and ice control during winter storms includes highly complex tasks and long, stress-filled hours both for equipment operators and for their supervisors. Continued cutbacks in DOT staffs dictates that one equipment operator must now be able to drive a snow plow truck and manage all of its ancillary equipment. These staff reductions come at a time when road users require greater mobility and an increased level of service for winter driving. To address these issues, the concept highway maintenance vehicle project was undertaken by a consortium of three "snowbelt" state DOTs, Iowa, Michigan, and Minnesota, who have reputations for embracing innovation in highway maintenance management, maintenance operations practices, and research. The Center for Transportation Research and Education (CTRE), an Iowa State University center, provided support staff to the consortium. A key element of this project was the inclusion of private sector partners who brought many assets to the project, including staff with specialized expertise, business connections, manufacturing facilities, and the potential to participate in the funding and production of the vehicles.

Snow and ice control operations can benefit greatly from improvements in state-of-the-art on-board computer applications, enhanced safety systems, and improved equipment operator efficiency. Roadway surface temperatures may determine optimal timing and application rates of chemicals and abrasives. Automatic vehicle location systems can track the progress of single vehicles and fleets.

This paper will explore pavement temperature sensing devices that are used in conjunction with global positioning systems (GPS). Both of these technologies are included on the concept vehicles. The paper then presents the reactions of the equipment operators who were exposed to the advanced technologies during winter storm conditions.

PAVEMENT TEMPERATURE

According to the Transportation Research Board, "Demands on highway agencies for fast and effective deicing, however, sometimes results in indiscriminate salting. However, new developments in winter maintenance including deicer application techniques (e.g. salt prewetting), plowing and spreading equipment, and weather and roadway monitoring (e.g., pavement sensors) are making these priorities less confusing" (*1*).

Pavement temperature is the controlling item in the treatment of highways during winter storms (*2*). Using this fact, pavement temperature data may be used to customize the rates of material application and the type of material utilized to match road conditions. CTRE research recommends selecting a salt application rate using a curve adapted from "Smart Salting: A Winter Maintenance Strategy" provided by the Vermont Agency of Transportation (*3*). During the winter of 1993-1994, the Vermont Agency of Transporta-

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TABLE 1 Melting Capacity of Salt (*3*)

Temperature (°F)	Pounds of Ice Melted Per Pound of Salt
30	46.3
25	14.4
20	8.6
15	6.3
10	4.9
5	4.1
0	3.7

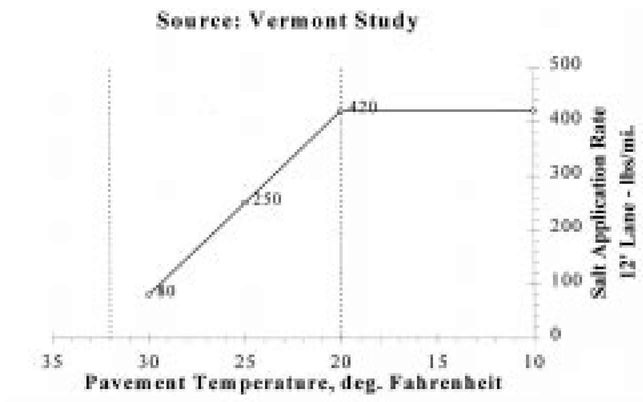

FIGURE 1 Vermont study recommended application rates (*3*).

FIGURE 2 The Iowa vehicle with temperature gauge.

tion (VAT) conducted a study and coordinated pavement temperature information with winter highway maintenance activities, resulting in an anti-icing and deicing strategy. Anti-icing is the application of liquid chemicals and materials early in the storm, or during plowing operations, that prevent the bonding of snow/ice to the road surface. By preventing the bond between snow/ice and the road surfaces the task of removing snow and ice is much easier. Estimates in Iowa indicate 50–60% reduction in the snow/ice removal effort when anti-icing procedures are utilized. De-icing is defined as the removal of snow/ice after the bond has formed. It is the procedure typically used in the past.

The Vermont study called for winter maintenance crews to do two things. First, determine pavement temperature before and during a storm, and second, determine salt application rates based upon the relationship between pavement temperature, melting capacity of salt, and the thickness of ice or snow on the pavement.

The Vermont Study generated a graph correlating recommended salt application rates with pavement temperatures. The Vermont Study identified an "economic salting range" which extends from 30°F to 20°F. The Iowa DOT estimates that 75 to 80 percent of their winter storms occur within this range.

Because the temperature of the pavement is such a critical variable in winter maintenance strategies, CTRE correlated the temperature values from the concept vehicles to another data source. All prototype vehicles were equipped with the same pavement and air temperature sensors. They have a road surface temperature range of -40° to 200° F and an air temperature range of -40° to 120° F. The sensors are accurate to within ±1% of full-scale or 1° F, whichever is greater. The response time is 1/10 second. The system is a passive infrared temperature indicator that uses infrared technology to read road surface energy and converts it to a temperature reading. The pavement sensor is mounted on the outside of the vehicle (typically on the driver side mirror) and reads the pavement temperature directly below the sensor.

To perform validity checks on temperature data, the following data was captured from the concept vehicle and from the Iowa Roadway Weather Information System (RWIS):

- Air temperature from the vehicle, stamped with time and GPS location
- Air temperature from nearby RWIS location stamped with time
- Pavement temperature from the vehicle, stamped with time and GPS location
- Pavement temperature from nearby RWIS location stamped with time.

The vehicle recorded temperature data nearly regularly and stored this data on the Rockwell PlowMaster. The data was transferred to CTRE and converted to a d-Base format for analysis in Microsoft Excel. CTRE then generated charts of pavement and air temperature readings. The initial data is referenced by GPS heading or by time from when the maintenance run began. Figure 3 shows the temperature plot versus time and later on we will see the time reference converted to milepost.

The data from the vehicle temperature sensors needed to be correlated to a known base data. It seemed that the most accurate and easiest way to do this was to compare the concept vehicle temperature data to data taken from RWIS located adjacent to the roadway.

The nearest RWIS site in Iowa was on I-80/I-35, on the north side of Des Moines, near mile marker 135. The location of this site is approximately two miles south of the Iowa concept vehicle's route, on I-35. It was ideal for comparing RWIS temperature data to the concept vehicle's.

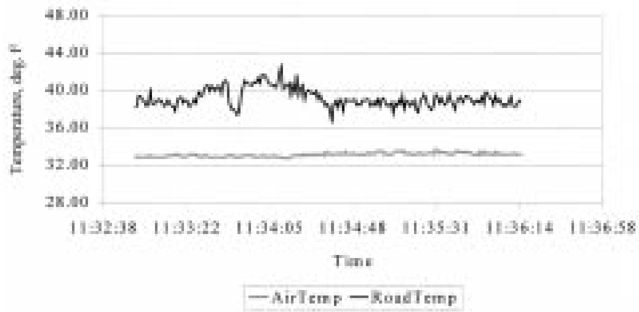

FIGURE 3 Temperature plot versus time.

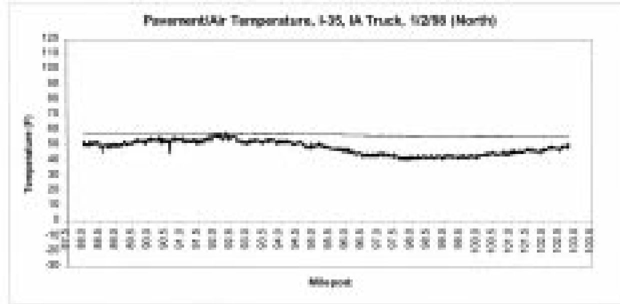

FIGURE 4 Temperature plot versus milepost.

TABLE 2 Temperature Sensor Comparison to RWIS

	Differences (PM:RWIS)			
Date	Deg Diff Air	% Error Air	Deg Diff Pavement	% Error Pavement
1/12/98	1.10	4.99%	-16.63	51.96%
1/14/98	0.56	3.71%	-26.29	87.62%
	-1.94	9.70%	-17.22	57.40%
1/21/98	-3.42	2.15%	-11.72	37.82%
1/22/98	18.44	55.87%	-17.11	55.19%
3/2/98	0.547	1.89%	-10.538	27.02%
	0.006	0.02%	-11.050	28.33%
	-0.890	3.18%	-12.706	33.44%
	0.542	2.01%	-10.945	28.80%
	-0.584	1.95%	-9.258	24.36%
3/7/98	1.43	4.46%	-1.15	2.95%
	-0.67	2.03%	-8.14	21.42%
	-0.31	0.93%	-7.95	20.91%
3/8/98	-0.61	1.85%	-8.20	21.57%
	-1.18	3.58%	-8.55	22.49%
	-0.90	2.73%	-9.15	24.08%
	0.93	3.00%	-7.41	20.02%
3/9/98	9.28	71.38%	-18.26	52.18%
	2.39	17.08%	-16.89	49.67%

The temperature data was collected during the winter of 1997-98 and then compared to the RWIS data for the same dates and times.

After comparing the two sets of data, the air temperature was accurate with a percent error of 10.13%. There were two runs, however, that had extremely high percent errors of 55.87% on 1/22/98 and 71.38% on 3/9/98. Taking these two readings out, the average percent error for the remaining runs was 3.84%. The other run on 3/9/98 also had a high degree of error of 17.08%. So far, nothing of significance has pointed to the reason behind the high percent error on any of those runs.

The pavement temperature, however, had an average percent error of 35.12% over all runs recorded and compared. The pavement temperature depends on the pavement material, surface conditions, treatment material applied, and sun conditions. Because of this, the RWIS site was not the most representative base data to use for comparison because it represents a point location on the roadway and the concept vehicle provides a linear temperature measure.

GLOBAL POSITIONING SYSTEM (GPS)

GPS uses a constellation of 24 satellites which orbit the Earth every 12 hours at an altitude of around 12,000 miles, arranged into six circular orbits inclined 55 degrees with respect to the Earth's equator. Their positions and orbits are always accurately known. Each satellite continuously transmits via a one-way radio communication channel the exact time. GPS antennas or receivers on the Earth use triangulation, with at least three GPS satellites, to establish a position. Each GPS receiver "listens" for the radio signal and calculates the elapsed time between radio signal transmission and reception. The GPS receiver then calculates the distance between the GPS satellite and receiver. More advanced GPS receivers can calculate vehicle speed using the difference in distance and elapsed time between two positions.

Since location data will be used for various functions of the concept vehicle, including pavement temperature plots, location of particularly icy spots on the road, location of material applications, etc, there is a need to compare GPS coordinates with baseline coordinate data supplied by the DOT. The concept vehicle established GPS locations, along I-35 in Iowa, from milepost 88 to 102. This was accomplished by stopping the vehicle at each milepost marker and recorded GPS coordinates. These coordinates were then compared to the officially published Iowa DOT milepost coordinates. CTRE corrected the concept vehicle coordinates to the Iowa DOT coordinates. This now allows the data coming from the concept vehicle to be reported by milepost. The following is an example plot of pavement temperature by milepost.

So far this paper has discussed the value of pre-treatment during winter storms and has presented salt application rates that are most economical. The paper has described how the maintenance concept vehicle can record the pavement temperatures and can locate these temperatures by milepost. But what do the people who used this technology think? The following section illustrates the positive response from the equipment operators.

RESPONSES FROM EQUIPMENT OPERATORS

The winter of 1997-1998 was an important evaluation period for the prototype vehicles, including their performance and identification of malfunctions while performing normal winter maintenance assignments. Each of the three prototype vehicles maintained and treated roads in Iowa, Minnesota, and Michigan. The prototype vehicle operators and mechanics had first-hand experience of vehicles performance and feedback from them was key in evaluating performance. They were an active part of the research team and participated in meetings and conference calls throughout the project.

Questionnaires and equipment performance log sheets were used to capture the reaction of the users to advanced technology applications. Interviews were conducted to determine if advanced technology has made the equipment operator's workload any easier, or if it has added to the job. The questions that were asked and a summary of the responses is provided.

1. "What element of the new technology worked the best?" The operators appreciated the user-friendliness of the PlowMaster computer. Equipment operators commented positively on the operation of the variable speed material applicators. With these tools, the equipment operators can set a prescribed amount at a given speed, and the material applicator compensates material application for changes in speed. One equipment operator termed the material applicator user variable and friendly. Although the material applicator is found on some other winter maintenance trucks, the equipment operators still appreciated the inclusion of the material applicator on the advanced technology vehicle.
2. "What element of the new technology worked the worst? Did this relatively poor performance have any negative impact on the operation of the other vehicle components?" Equipment operators faced continuous challenges with both the temperature sensors and the friction meter. At one point, the Iowa DOT reported the pavement temperature sensor as being off by as much as 30° F, prompting replacement of the sensor with a better functioning one. The Iowa and Minnesota DOTs reported problems with broken belts on the friction meter, in addition to problems associated with corrosion of the friction meter's parts. When equipment malfunctioned or failed, that particular piece of equipment was usually rendered out of service until the vehicle returned to its garage. However, even when the equipment malfunctioned, the drivers reported that they were still able to operate the truck at or above the same level of service with which they operated conventional snowplows. This fact is important and shows the advanced technology vehicle can still complete the basic assignment even when the technology is temporarily not available.
3. "Was the PlowMaster display easy to read while you were driving?" The PlowMaster screens required some learning but the operators admitted they experienced similar situations whenever they received a new piece of equipment. Equipment operators reported the screen dimness and brightness feature of the Rockwell PlowMaster display was relatively easy to read. During the day the operators would brighten the screen, and during the evening the operators would dim the screen. The only reported problem of reading the PlowMaster display was in direct sunlight (from the Minnesota DOT). The screens were designed to be logical and easy-to-follow. Equipment operators reported being able to quickly call up information reported by the PlowMaster computer.
4. "How did the added technology on the prototype vehicle affect your comfort and attention to the road, as compared with conventional maintenance trucks? Was the added technology a detriment or enhancement to the attention you could give the road?" The equipment operators reported the advanced technology helped them focus more of their attention on the road, especially when the equipment was functioning properly. The technology took tasks out of the hands of the equipment operators and allowed them to focus their attention where it was needed. Of key importance was the statement made from equipment operators at all three state DOTs concerning the periods when the equipment malfunctioned. The operators reported that during these periods they were able to operate the truck without a loss in productivity when comparing to conventional DOT snowplows. This fact states that the prototype trucks can function the same as conventional snow plows if there is a failure in the advanced technologies. After the initial time used to become familiar with the new technology, equipment operators were able to use the technology with relative ease, and efficiency higher than that with conventional snowplows.
5. "Any other problems you had with the truck while driving it?" Equipment operators from Iowa reported the present location of the material applicator requires them to stop the vehicle whenever they change the material applicator's settings.
6. "What suggestions for improvement do you have?" Iowa equipment operators suggested changing the placement of the material applicator controls and allow the operator to change the settings while the truck was moving.

All of the responses to these questions were positive and supportive. They also indicate that the equipment operators are looking into the future and presenting input for modifications and refinements to be made.

CONCLUSION

The acceptance of new technology applications by equipment operators, and others whose jobs are related to the highway maintenance vehicle, is critical to its success. The equipment operators embraced the new technologies and the basic reason was due to being involved in the development of the requirements and being involved throughout the development and implementation of the technologies. As a result of their acceptance, the concept vehicle can measure pavement temperature, locate the vehicle position by GPS, and provide reports by milepost.

ACKNOWLEDGMENT

The author wishes to thank the people at the Iowa, Michigan, and Minnesota DOTs who worked so hard to make this project a success. Without their full support the concept maintenance vehicle project would not be as successful as we see it today. The private sector partners were invaluable for providing the technologies, assembling them on the vehicles and then providing support during the initial stages of the project.

REFERENCES

1. Transportation Research Board. Highway Deicing, Comparing Salt and Calcium Magnesium Acetate. *Special Report #235*. Transportation Research Board, National Research Council, Washington D.C., 1991.
2. Boselly, S. E. III. Benefit-Cost Assessment of the Utility of Road Weather Information Systems for Snow and Ice Control. *Transportation Research Record No. 1352*, Transportation Research Board, National Research Council, Washington D.C., 1992.
3. Vermont Agency of Transportation. *Smart Salting: A Winter Maintenance Strategy*. Maintenance Division, Vermont Agency of Transportation, 1995.