

# **FROM CONCEPT TO REALITY**

**Advanced Technology and the Highway Maintenance Vehicle**

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By:

Duane Smith, P.E.  
Associate Director  
Center for Transportation Research & Education  
Iowa State University  
Ames, Iowa 50010  
Phone: 515-294-8103  
FAX: 515-294-0467  
[desmith@iastate.edu](mailto:desmith@iastate.edu)

**ABSTRACT:**

In 1995, the “snow belt” state departments of transportation’s in Iowa, Michigan, and Minnesota began a multi-phased project to define and develop the next generation highway maintenance vehicle. These states have a reputation for innovative highway maintenance management, operations, practices, and research. They formed the core research consortium. The Center for Transportation Research and Education (CTRE), an Iowa State University center, provided staff. The Federal Highway Administration and technology providers were added. One prototype vehicle was developed for each state. The incorporated technologies include:

Rockwell International’s Plow Master and Global Positions System (GPS)

Fossen Manufacturing’s Hydrofire Fuel Injection System

Roadware Corporation’s Norsemeter Friction Meter

Innovative Warning System’s fiber optic light system

Material application systems

Sprague Controls’, Inc. Roadwatch Warning system

Global Sensor Systems’, Inc. Search-Eye Sensor System

CTRE established the vehicle requirements using focus group sessions. The vehicles have been assembled and deployed to the states. The initial testing is completed; friction measuring devices have been compared; temperature sensors are calibrated; of GPS readings are verified and, data has been transferred for analysis and reporting. A vehicle user manual was distributed. Test plans for winter roadway friction and pavement temperature were initiated.

Questionnaires were developed for equipment performance. The next phase of development will include a cellular based data link; further evaluation of friction and temperature data; automated, on - board selection of chemicals and abrasives; and expanded technology applications.

Key words: Anti-icing, GPS, Pavement, Temperature

**INTRODUCTION:**

A universal challenge facing highway agencies 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 dictate 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, operations, practices, and research. The Center for Transportation Research and Education (CTRE), an Iowa State University center, provided support staff to the consortium. FHWA was added to the team and provided financial support, technical review, and opportunities to spread the word about this project. The 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. The advanced technologies that were integrated into the concept vehicles were:

Rockwell International's Plow Master and Global Positions System (GPS)

Fosseen Manufacturing's Hydrofire Fuel Injection System (power booster)

Roadware Corporation's Norsementer Friction Meter (friction meter)

Innovative Warning System's fiber optic light system

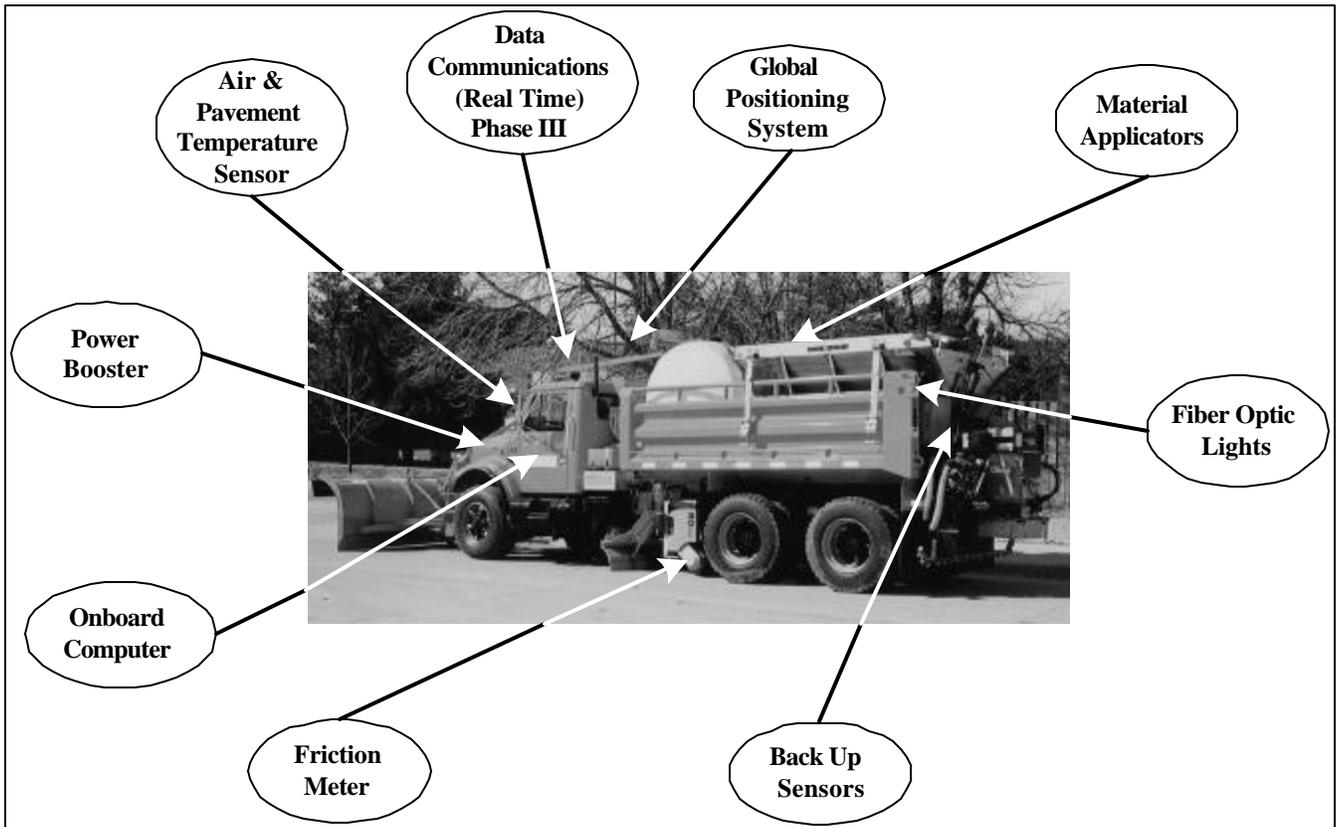
Material application systems

Sprague Controls', Inc. Roadwatch Warning System (temperature sensors)

Global Sensor Systems', Inc. Search-Eye Sensor System (back up sensors)

Figure 1 illustrates the typical installation of technology for all three of the prototype vehicles.

Of the many new technologies installed on these three prototype vehicles, this paper will describe only the pavement temperature sensing devices that are used in conjunction with global positioning systems (GPS). The paper then presents the reactions of the equipment operators who were exposed to the advanced technologies during winter storm conditions and concludes by looking at what is in the future for these concept vehicles.



**Figure 1 - Typical Technology Installation**

**PAVEMENT TEMPERATURE:**

According to the Transportation Research Board, “Demands on highway agencies for fast and effective deicing 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).

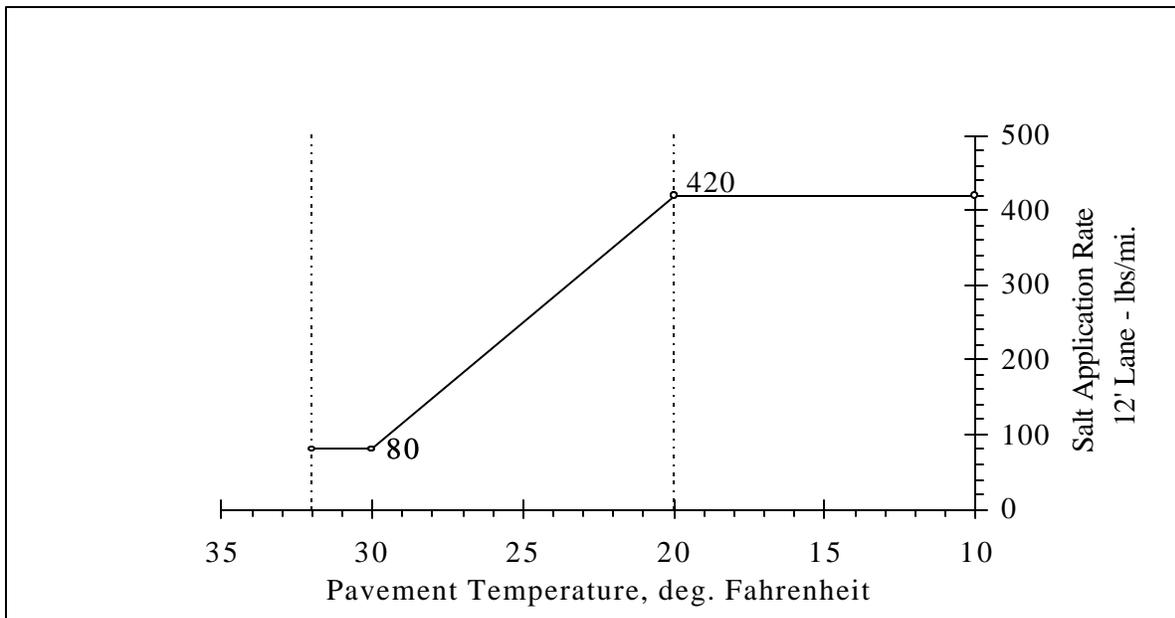
Pavement temperature is the controlling item in the effective treatment of highways during winter storms (2). Pavement temperature data may therefore be used to customize the rates of material application and the type of material utilized to match road conditions. CTRE research recommends selecting a 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 Transportation (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, to 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.

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

**Table 1 – Vermont Study, Melting Capacity of Salt**

The Vermont Study generated a graph correlating recommended salt application rates with pavement temperatures. See figure 2. The Vermont study identified an “economic salting range” which extends from 30° F down to 20° F. This is the temperature range where salt is most effective in melting ice. The Iowa DOT estimates that 75 to 80 percent of Iowa’s winter storms occur within this temperature range.



**Figure 2 - Vermont Recommended Application Rates**

All three prototype vehicles were equipped with the same pavement and air temperature sensors. The sensors have a road surface temperature range of  $-40^{\circ}$  to  $200^{\circ}$  F and an air temperature range of  $-40^{\circ}$  to  $120^{\circ}$  F. The sensors are accurate to within  $\pm 1\%$  of full-scale, or  $1^{\circ}$  F, whichever is greater. The recording response time is 1/10 second. The system is a passive infrared temperature indicator that uses infrared technology to read road surface energy and convert 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. See Figure 3.



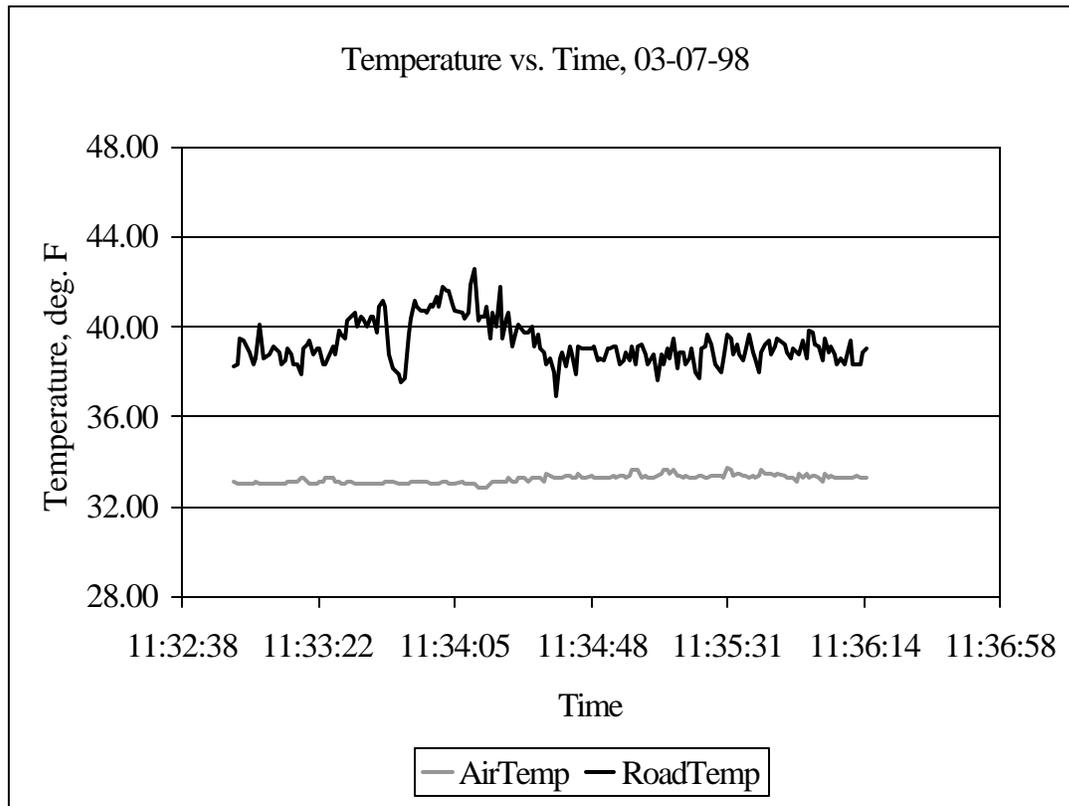
**Figure 3 – Typical Temperature Sensor Mounting**

To perform validity checks on temperature data, the following data were captured from the concept vehicles.

- Air temperature stamped with time and GPS location
- Pavement temperature stamped with time and GPS location

The vehicles recorded temperature data regularly and stored these data on the Rockwell PlowMaster. The data were 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 are referenced by GPS heading, or by time from when the maintenance run began. Figure 4 shows a typical temperature plot versus time.

Later on we will see the time reference converted to a milepost reference and illustrated in Figure 5.

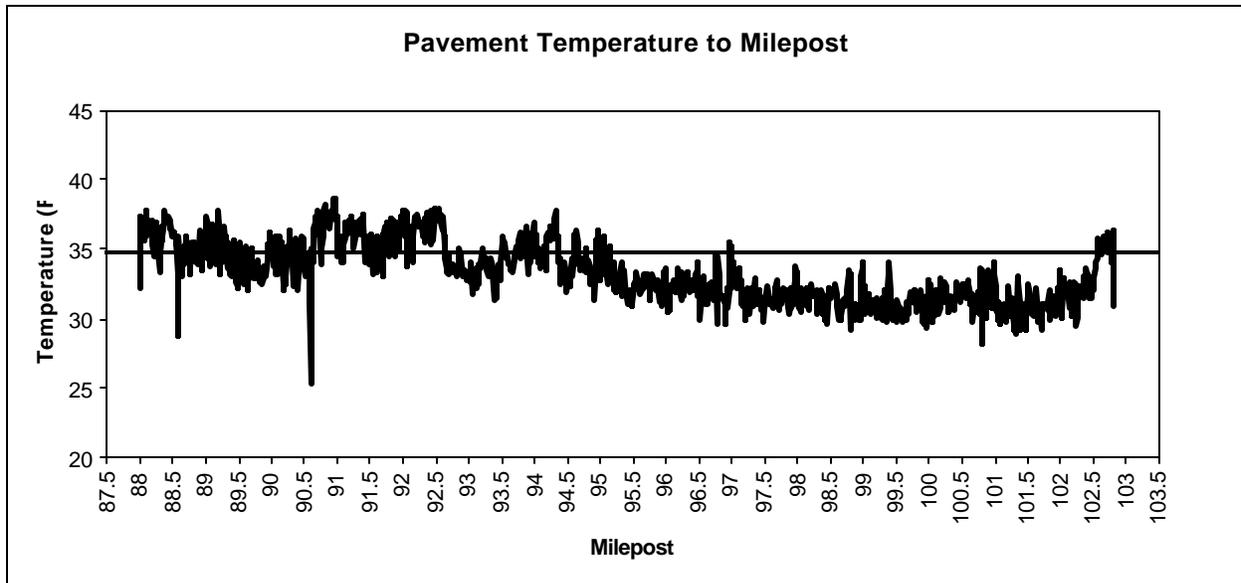


**Figure 4 - Temperature Plot Vs Time**

## **GLOBAL POSITIONING SYSTEM (GPS)**

GPS uses a constellation of 24 satellites that orbit the earth every 12 hours at an altitude of around 12,000 miles. They are arranged into 6 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 on the earth's surface. Each GPS receiver "listens" for the radio signal and calculates the elapsed time between radio signal transmission and its 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, and location of material applications, etc., there is a need to compare the vehicle GPS coordinates with baseline coordinate data supplied by the DOT. The concept vehicle established GPS locations of mileposts , 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 allowed the data coming from the concept vehicle to be reported by milepost. Figure 5 is an example plot of pavement temperature by milepost.



**Figure 5 - Temperature Plot Vs 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 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 CTRE recorded 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 with the vehicles, performance, and feedback from them was key in evaluating vehicle 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. Following are the questions that were asked, and a summary of the responses is provided with each question.

1. "What element of the new technology worked the best?" The operators appreciated the user-friendliness of the PlowMaster on-board computer. Equipment operators commented positively on the operation of the variable speed material applicators. With these applicators, the equipment operators can set a prescribed application rate at a given speed, and the material applicator compensates material application for changes in speed. One equipment operator termed the variable material applicator user 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.

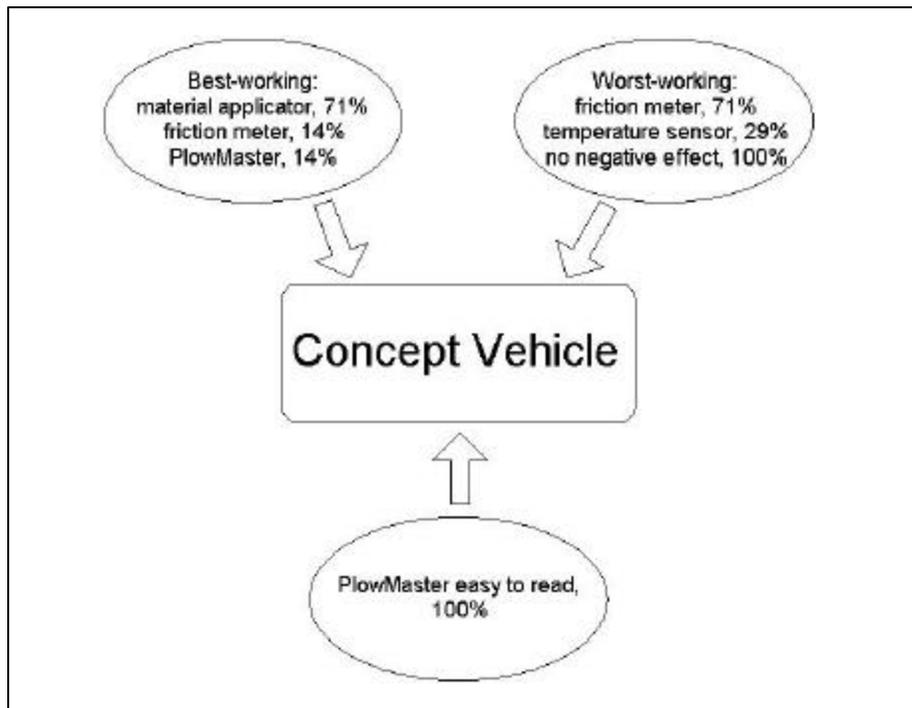
2. “What element of the new technology worked the worst? Did this relatively poor performance have any negative impact on the operation of the other vehicle components?” Equipment operators faced continuous challenges with both the temperature sensors and the friction meter. At one point, the Iowa DOT 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 with 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 by 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 with greater efficiency than 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. Figure 6 illustrates the responses CTRE received. The responses also indicate that the equipment operators are looking into the future and presenting input for modifications and refinements to be made.



**Figure 6 \_ Equipment Operators Responses**

**REQUIREMENTS FOR NEXT GENERATION PROTOTYPE VEHICLES:**

After the first prototype vehicles completed their assignments for the winter of 1997-1998, the experiences were reviewed and appropriate modifications and changes were detailed for the next generation prototype vehicle. A development schedule will be established for the modifications required and for incorporating the new technologies. The following technologies have been identified for integration with the concept vehicle.

**Differential GPS (DGPS)**

The 1997-1998 prototype vehicles used conventional GPS, which has potential location errors of 100-300 feet. DGPS provides greater location accuracy, with errors of 5 feet or less. DGPS provides a higher location accuracy that is important when identifying specific route locations requiring specialized treatment. Rockwell International, the provider of the conventional GPS units for the prototype maintenance vehicles, will retrofit the existing prototype vehicles with DGPS receivers. The DGPS applications on the prototype vehicles were adapted from agricultural applications. In addition, DGPS uses United States Coast Guard beacons, which means that the DOTs would not be responsible for maintaining the DGPS beacons.

**Collision Avoidance System**

Weather and driving conditions during winter maintenance activities is often less than ideal. Heavy snow, blowing snow, and fog sometimes reduce visibility to near zero. Stopped or stalled cars along the road present a danger for other drivers, including drivers of the maintenance vehicles. Sometimes snowplow-car accidents occur. Such collisions

are costly for everyone. In addition to collisions involving vehicles, the collision avoidance system could be set up to help the maintenance vehicle avoid guardrails and bridge wing posts. Using DGPS an inventory of guardrails and bridges could be established and logged, and used in conditions where visibility is poor. Consequently, a collision avoidance system on the maintenance vehicles is beneficial.

### **Cellular Phone Communications Link**

Presently, pavement and air temperature data and friction data are recorded by the PlowMaster on a PCMCIA card. The card is then removed from the PlowMaster for data downloading. Although this is a good way to record and transfer data, it is desirable to provide “real-time” information from the prototype vehicle to base stations (garages). Road and air temperature, friction values, DGPS location, etc., is valuable for decision making at the base station. A feasibility evaluation of using cellular phone communications for transmitting data from the vehicle to the base station is being completed.

The major expense for cellular communications is in the connect (20-40 seconds) and disconnect (20 seconds) time. This fact has led the research team to look at other communication links, namely the radio infrastructure at each DOT.

**Radio Communications Link**

Radio communications are a less expensive communication option when comparing to cellular phone. Each prototype truck would be equipped with a radio transmitter that sends data to the vehicle's base location using the existing DOT radio infrastructure.

**Mapping Packages**

Data collected from the prototype vehicle are initially displayed in tabular or spreadsheet format. A better method of displaying data is in graphic, or map, format. A "point and click" interface is envisioned that allows the user to click on a point on the map and obtain temperature, friction, and treatment material information for that point on the road.

**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 primarily because they were involved in the development of the requirements and throughout the development and implementation of the technologies. As a result of the operators cooperation and willingness to make the technologies a productive tool, the concept vehicle can measure pavement temperature, locate the vehicle position by GPS, and provide reports by milepost.

**ACKNOWLEDGEMENT**

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.

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## References

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