Concept Highway Maintenance Vehicle

Final Report: Phase Two

December 1998

Center for Transportation
Research and Education

Iowa State University

CTRE's mission is to develop and implement innovative methods, materials, and technologies for improving transportation efficiency, safety, and reliability, while improving the learning environment of students, faculty, and staff in transportation-related fields.

Concept Highway Maintenance Vehicle

Final Report: Phase Two

Principal Investigator

Duane E. Smith

Principal Contributors

Bill M. McCall

Dennis Kroeger

Research Assistants

Jeff Zogg

Tim Simodynes

Karen Giese

Center for Transportation Research and Education
Iowa State University Research Park
2625 N. Loop Drive, Suite 2100
Ames, IA 50010-8615
515-294-8103
515-294-0467 (fax)
www.ctre.iastate.edu/

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Minnesota Department of Transportation
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Federal Highway Administration

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Global Sensor Systems, Mississauga, Ontario, Canada
Innovative Warning Systems, Minneapolis, Minnesota
Monroe Truck Equipment, Monroe, Wisconsin
Navistar International Corporation, Fort Wayne, Indiana
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EXECUTIVE SUMMARY

This report documents Phase II activities of a potentially four-phase project. The goal of the project is to study the feasibility of using advanced technologies from other industries to improve the efficiency and safety of winter highway maintenance vehicle operations. State departments of transportation from Iowa, Minnesota, and Michigan initially formed the study consortium, and several private vendors have become project partners. The Center for Transportation Research and Education (CTRE) at Iowa State University is managing project tasks.

The primary goals for Phase II were to install selected technologies on three prototype winter maintenance vehicles, one in each of the consortium states, and to conduct proof of concept in advance of field evaluations planned for Phase III. Refer to Figure E-1 for a diagram of the study process, along with foundation statements.

PHASE II OBJECTIVES

A study team consisting of representatives from the consortium states, private partners, and CTRE directs study activities, and during Phase II the study team met regularly and participated in conference calls to oversee progress, monitor developments, and make joint decisions. Study team activities during Phase II are documented in Appendix A.

The study team developed the following objectives for Phase II:

- Install technologies, selected during Phase I focus group activities, on three snowplow trucks, integrating the subsystems into three working prototype winter maintenance vehicles, one in each consortium state.

- Conduct proof of concept for each of the technologies and for the data management process.

- Explore the comparison of data collected by sensor technologies to base data sources (part of proof of concept for several of the technologies).

- Document the cost of technologies implemented in Phase II.

- Solicit operator feedback about vehicle and technology performance.

- Integrate and format data collected by the add-on technologies for potential inclusion in DOT management systems.

Foundation Statements:

1. "The solutions must be selected and recommended based on a benefit/cost analysis and a reasonably short time to implementation".
2 " The application of solutions must be described in terms that related to improving ***service to customers*** **."**

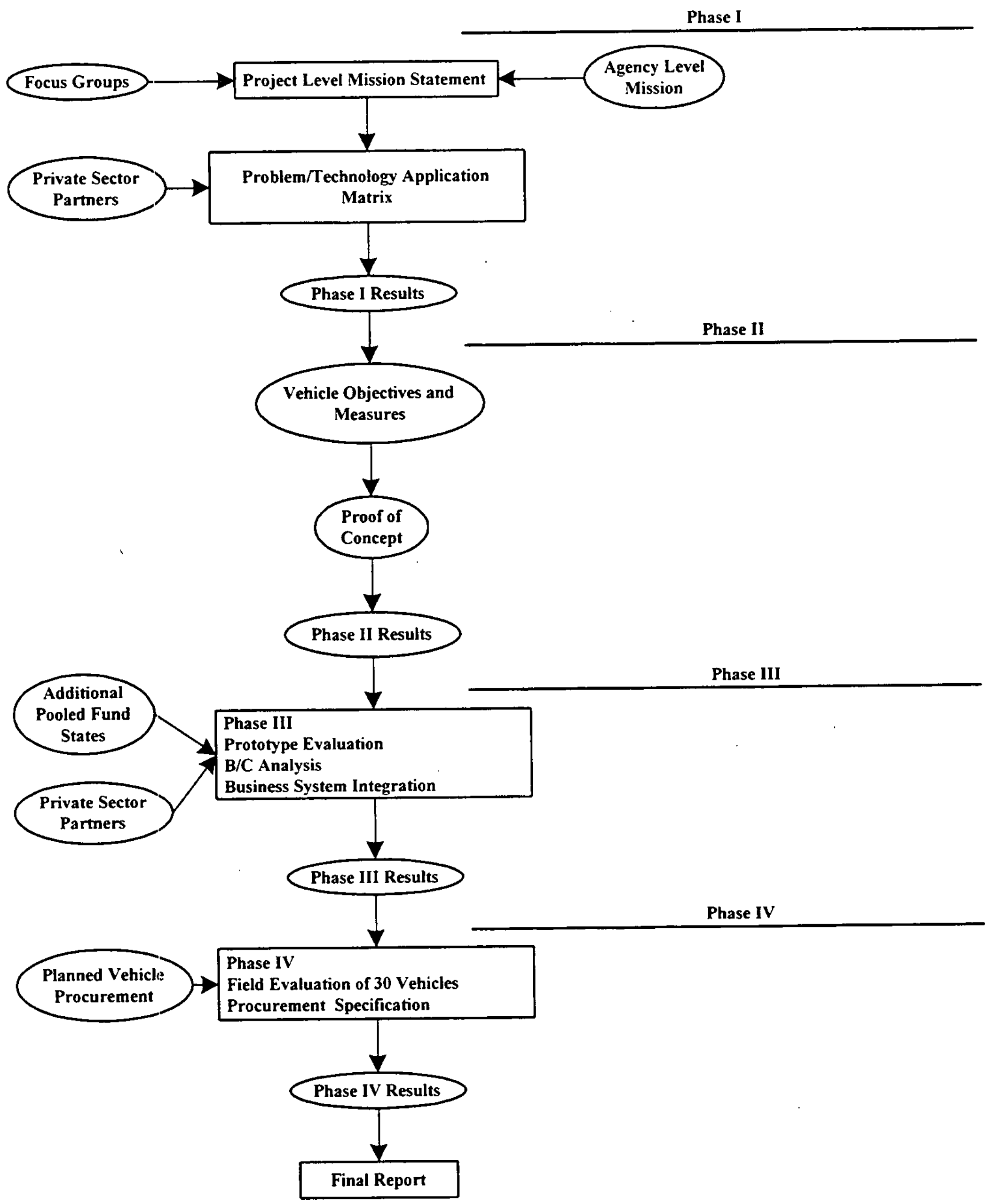


Figure E-1 Foundation statements and study process map

The study team approved a detailed Phase II work plan to guide CTRE's accomplishment of these objectives. Work plan tasks are outlined in Appendix B, along with references to sections of this report describing progress on and accomplishment of the tasks.

Objective 1: Install Technologies

The first objective of Phase II was to build three prototype winter maintenance vehicles by installing selected technologies on three basic state snowplow trucks. Many of the technologies, which were originally developed for applications in other industries, required special fabrication to fit on the trucks and operate effectively under harsh winter conditions. The friction meter offered the most significant installation challenges, and results were not entirely satisfactory. Iowa's installation interfered with full movement of the underbody blade; Minnesota's installation exposed the meter to excessive bouncing, as well as spray from the spreader; and Michigan installed its meter on a separate pickup-class truck. For the most part, however, the technologies were installed and operated on the prototype vehicles. Table E-1 points to the individual chapters in this report that discuss each technology in detail, including installation and proof of concept.

Table E-1 Technologies installed in Phase II

Technology Provider	Technology	Reference Name	Chapter Reference
DOT	Trucks, Plows, and Spreaders	Trucks, Plows, and Spreaders	5
Rockwell International	PlowMaster Computer	PlowMaster	6
Rockwell International	Global Positioning System	GPS	7
Roadware Corporation	Norsemeter ROAR Friction Meter	Friction Meter	8
Sprague Controls	Pavement/Air Temperature Sensors	Temperature Sensors	9
Fosseen Manufacturing	Engine Power Booster	Engine Booster	10
Innovative Warning Systems	High-Intensity Discharge Warning Lights	HID Lights	11
Global Sensor Systems	Reverse Obstacle Sensor	Reverse Obstacle Sensor	12

Objective 2: Conduct Proof of Concept

Proof of concept is simply a process that proves that an idea, or concept, is possible. Proving the possibility of deploying an advanced-technology winter maintenance vehicle required proving the feasibility of each add-on technology and of data management for the project as a whole. For each technology, then, CTRE first determined if the technology could be installed on the vehicle reasonably easily and then determined if the installed technology performed as expected and desired.

Table E-2 shows the results of the proof of concept activities. It lists the desired vehicle functions identified by focus groups in Phase I, the technology subsystems selected to fill those functions, whether the technology passed Phase II proof of concept, and modifications recommended for Phase III.

Table E-2 Proof of concept results

Function	Subsystem	Passed Proof of Concept	Modification for Phase III
Pavement Friction Condition	Friction Meter	Yes	Newer model
Ambient Conditions	Air and Pavement Temperature Sensor	Yes	None
Automatic Vehicle Location	Global Positioning System	Yes	DGPS
Apply Various Materials	Materials Applicators	Yes	Coordinate material applications with roadway conditions
Improve Vehicle Visibility	Fiber Optic Lights	Proof of concept not conducted	None
Provide Additional Horsepower during Periods of High Engine Demand	Power Booster	Yes	None
Rear Obstacle Alarm	Back-up Sensors	Proof of concept not conducted	None
Data Processing	Onboard Computer	Yes	Format data for reports
Data Communications (Real Time)	Cellular Data Communications	Proof of concept not conducted	Provide communication linkage to garages

The friction meter passed proof of concept under dry/wet road conditions but was not conducted under winter road conditions. Proof of concept for the fiber optic lights and back-up sensors was anecdotal only; methodical proof of concept will be conducted in Phase III along with evaluation of the systems. Real-time communications from the onboard computer to garages was not an objective in Phase II. Real-time cellular communications are planned for implementation in Phase III.

Objective 3: Compare Sensor Data with other Sources

Several of the add-on technologies on the prototype vehicles—GPS, air/pavement temperature sensors, friction meter—collect information about the environment, and it was important to proof of concept for those technologies to determine that the information they were collecting was reasonable. CTRE therefore compared data collected by the onboard sensors with known data.

Latitude/longitude readings collected by the onboard GPS at mileposts and compared to known milepost latitude/longitude references were found to be reasonably accurate. Air and pavement temperatures reported by the onboard sensors and compared to temperatures collected by other temperature sensors at the same time and location were found to be reasonable. Friction meter readings on dry/wet pavement were compared to friction data collected by ASTM E-274 equipment at the same time and location and found to be reasonable. Unfortunately, not enough friction data were collected under winter roadway conditions to determine that they were reasonable.

Objective 4: Document Cost of Technologies

CTRE documented the initial development costs for add-on technologies installed on the prototype vehicles, as well as for some technologies not implemented in Phase II. Potentially high development costs for the prototype vehicles were partially avoided by the state DOTs because private vendor partners provided technologies. Phase II installation and operations activities prompted some vendors to significantly modify their product (e.g., the friction meter), and these modifications may significantly reduce ultimate production costs.

Objective 5: Solicit Operator Input

As with many new ventures, successful implementation of the prototype maintenance vehicles depends on acceptance, even ownership, of the project by the people working with them every day: snowplow operators, mechanics, and supervisors. Therefore, operators, mechanics, and supervisors have been involved in this project from the beginning. They were central to Phase I focus group activities that determined the desirable functionalities for a high-technology maintenance vehicle. In Phase II telephone surveys, they provided feedback about their experiences with the prototype vehicles during 1997-1998 winter maintenance activities.

Each of the prototype vehicles was assigned to active duty and used for snow and ice control on roads in Michigan, Minnesota, or Iowa. The winter of 1997-1998 was unusual for its relatively few snow storms, but feedback regarding the vehicles' operations during those events was helpful. Generally, the operators' favorite feature was the automatic material spreaders. They found the onboard computer display easy to read and use and reported difficulties with the friction meters. Operator feedback is summarized in Figure E-2.

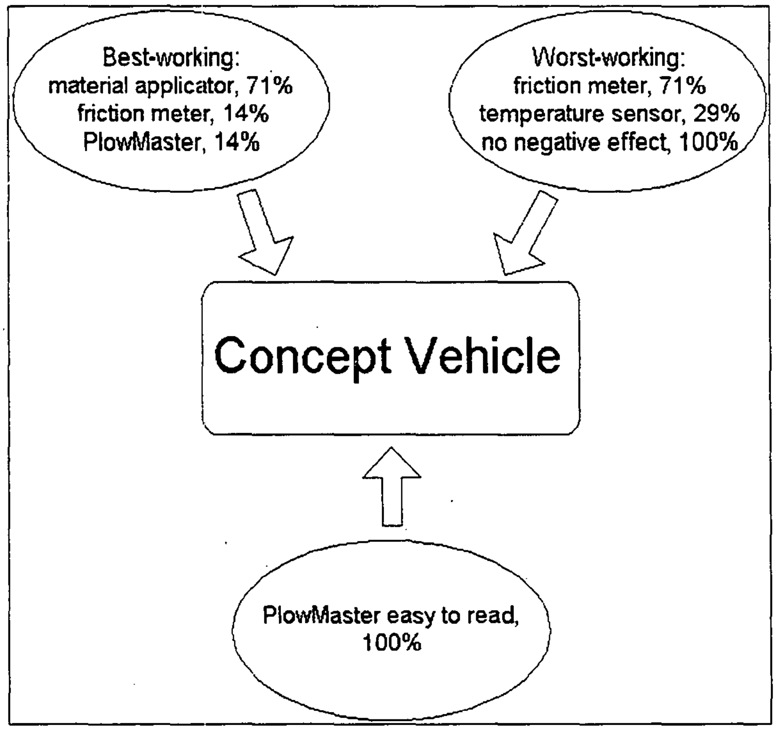


Figure E-2 Equipment operator feedback

Objective 6: Integrate and Format Data

The success of this project depends, in large part, on operators' and managers' ability to access data collected by the prototype vehicles' add-on technologies. Vehicle operators want immediate access to understandable environmental information (temperatures, friction, etc.) and information about the status of the technologies themselves (plow positions, engagement of power booster, etc.) to help them with their immediate maintenance operations. Managers want access to both kinds of information to support local and regional winter maintenance activities and to incorporate into various management systems.

During Phase II, data integration and management was conducted at two levels. First, the onboard computer collected data from the add-on technologies, formatted the data in common formats, interpreted data into understandable terms for the operator's in-cab display, and stored the data on removable Personal Computer Memory Card International Association (PCMCIA) cards for delivery to CTRE. Second, CTRE performed several data management activities related to proof of concept (e.g., compared the onboard data to data from known sources) and to the possible future integration of onboard data into state DOT management systems. These activities involved translating data into meaningful terms (e.g., GPS latitude/longitude to milepost, vehicle speed to distance traveled, etc.) and developing programs for organizing and plotting the data. These activities provide the foundation for real-time data communications planned for Phase III and, eventually, the possible incorporation of data into management systems.

CHAPTER 1: STUDY OVERVIEW

In 1995, the departments of transportation of three Snowbelt states, Iowa, Michigan, and Minnesota, formed a consortium to study the feasibility of applying advanced technologies, particularly technologies already used in other industries for other applications, to state DOT maintenance vehicles to improve their performance, efficiency, and safety. Interest was especially strong in applying technologies that would enhance maintenance vehicles' winter ice and snow control performance and simultaneously provide data and tools for managing winter maintenance activities.

Advanced technologies have the potential to improve winter roadway maintenance activities in a several ways. One improvement may be cost savings. For example, the Iowa Department of Transportation expends $60-70,000 per hour for snow and ice removal. If the use of advanced technologies reduces the amount of resources directed toward this effort by delaying the need to begin snow and ice removal for even one hour in each winter storm, there is a potential for large cost savings. The savings may offset the costs associated with the advanced technologies.

Another improvement may be the ability to provide management with more complete and detailed weather and road condition data to support maintenance management decisions. Many state departments of transportation are utilizing data recorded through roadway weather information systems (RWIS). These data include pavement, bridge deck, and sub-surface conditions, along with atmospheric condition data. However, although RWIS sensors provide accurate and timely data for specific locations, sensors are located several miles apart, and interpolation of recorded data between sites may not be accurate. If snowplow trucks are equipped with technology applications that measure and record data comparable with that collected by RWIS sensors, condition data may be collected over the trucks' network of roads and streets. The RWIS will provide data at RWIS sensor locations, and the moving snowplows will provide data for areas between those sensors, providing continuity of data all along a corridor or roadway section to help supervisors and equipment operators make better winter maintenance decisions and, ultimately, provide improved roadway conditions.

Finally, advanced technologies have the potential to improve communications with the traveling public, keeping travelers better informed of roadway and driving conditions. Winter driving can be a challenge, particularly during bad weather. Drivers struggle with slick roadway surfaces, poor visibility due to blowing and drifting snow, and traffic slowdowns. Today, there is not a complete system in place that measures these conditions and then shares descriptive information with the driving public. A snowplow equipped with technologies that record winter roadway friction values, pavement temperatures, visibility, and vehicle speed to improve maintenance operations can also provide descriptive information to the public in a credible, timely, and efficient format to help drivers make more informed trip decisions.

Cost savings, improved data, and improved communications are just three possible benefits of applying advanced technologies on winter maintenance vehicles. With these and other possible benefits in mind, the consortium initiated a three-phase study, which has now become a four-phase effort:

Phase I	Establish desired snow plow functionality
Phase II	Develop a prototype vehicle in each state and conduct proof of concept
Phase III	Conduct field evaluation of selected technologies
Phase IV	Conduct a fleet evaluation in each state

STUDY CONSORTIUM

The study is supported through a consortium of the Iowa, Michigan, and Minnesota departments of transportation, each of which has a reputation for embracing innovation in highway maintenance management, operations practices, and research; the Federal Highway Administration, which joined the consortium with the initiation of Phase II; and the Center for Transportation Research and Education (CTRE) at Iowa State University. CTRE is providing support staff to observe and document activities and coordinate study efforts.

A key element of the project has been the inclusion of private sector technology partners. Private partners were identified during Phase I activities and are now part of the consortium. In addition to the technologies they produce, these private partners have brought many assets to the project, including staff with specialized expertise, business connections, manufacturing facilities, and the potential to participate in funding and producing prototype and fleet vehicles in Phases II, III, and IV of the study. Consortium members include the following:

Public Agency Members
Iowa Department of Transportation
Michigan Department of Transportation
Minnesota Department of Transportation
Federal Highway Administration
Center for Transportation Research and Education

Private Sector Members
Boyer Ford; *Minneapolis, Minnesota*
Bristol Company; *Broomfield, Colorado*
Component Technology; *Des Moines, Iowa*
Federal Signal Corporation; *Tinley Park, Illinois*
Force America; *Burnsville, Minnesota*
Fosseen Manufacturing & Development Ltd.; *Radcliffe, Iowa*
Global Sensor Systems; *Mississauga, Ontario, Canada*
Innovative Warning Systems; *Minneapolis, Minnesota*
Monroe Truck Equipment; *Monroe, Wisconsin*
Navistar International Corp.; *Fort Wayne, Indiana*
O'Halloran International; *Des Moines, Iowa*

Roadware Corporation; *Paris, Ontario, Canada*
Rockwell International; *Cedar Rapids, Iowa*
Sprague Controls; *Canby, Oregon*
Tyler Ice (Tyler Industries); *Benson, Minnesota*
Wired Rite Systems; *Santa Rosa, California*

A study team manages the study. The team consists of representatives from each of the state DOTs, the Federal Highway Administration, CTRE, and private sector partners. Private sector representatives vary due to reassignment of duties or completion of tasks.

STUDY PHILOSOPHY

The foundational goals of the consortium were to select technologies that would, in a reasonably short time, improve functions as defined by the immediate customers (equipment operators, maintenance personnel, and decision makers), and have a reasonable cost-to-benefit ratio.

The study team developed direction for the study by developing mission statements, an approach to follow, and objectives to be achieved.

Agency-level Mission Statement

Provide a uniform, predictable level of service for winter driving while managing assets effectively.

Project-level Mission Statement

Develop a concept highway maintenance vehicle that will support equipment operators and fleet managers making more informed and cost effective decisions.

General Approach

Bring technology applications from other industries to the highway maintenance vehicle.

Study Objectives

The mission and approach statements led to the development of the following overall objectives for the four-phase study:

- Evaluate technology.
- Asses cost implications of technology applications.
- Develop benefit/cost analysis.
- Improve roadway safety for the driving public.

- Develop operator input and acceptance.
- Integrate data with DOT management systems.
- Develop "real time" data for storm management decisions.

Phase II Objectives

Specific objectives for Phase II include the following:

- Integrate selected technologies onto three prototype winter maintenance vehicles, one in each of the consortium states.
- Conduct proof of concept. This may include subjective observation of the technologies' performance as well as objective comparisons of sensor data with other source data.
- Document the cost of technologies provided in Phase II.
- Solicit operator input for the vehicle and technology performance.
- Integrate and format data on the vehicle for inclusion into DOT management systems.

STUDY APPROACH

As described above, a four-phase approach was developed for the project. Phase I included developing a description of the desired concept vehicle functions and securing the involvement of private sector partners. Phase II included fabricating three prototype maintenance vehicles with add-on technologies and conducting proof of concept. Phase III will include conducting field evaluation and benefit/cost analyses of the add-on technologies. Phase IV will include conducting a comprehensive field evaluation of a fleet of 10 vehicles in each of the consortium states.

The process map in Figure 1-1 illustrates the progression of the study from Phase I, when the desired functions of the specially-equipped vehicles were determined, to the vision of the Phase IV field evaluation on a fleet of similarly equipped vehicles in each state. The schedule for these phases is graphically presented in Figure 1-2.

Phase I: Establish Vehicle Requirements

The objective of Phase I was to identify the desired functionality of winter maintenance vehicles and to enlist private sector partners to join the consortium. This phase began with a review of literature related to winter highway maintenance activities. One hundred and five articles were collected pertaining to state-of-the-art equipment, technologies, and research on winter highway maintenance activities.

Foundation Statements:

1. "The solutions must be selected and recommended based on a benefit/cost analysis and a reasonably short time to implementation".
2 " The application of solutions must be described in terms that related to improving ***service to customers*** **."**

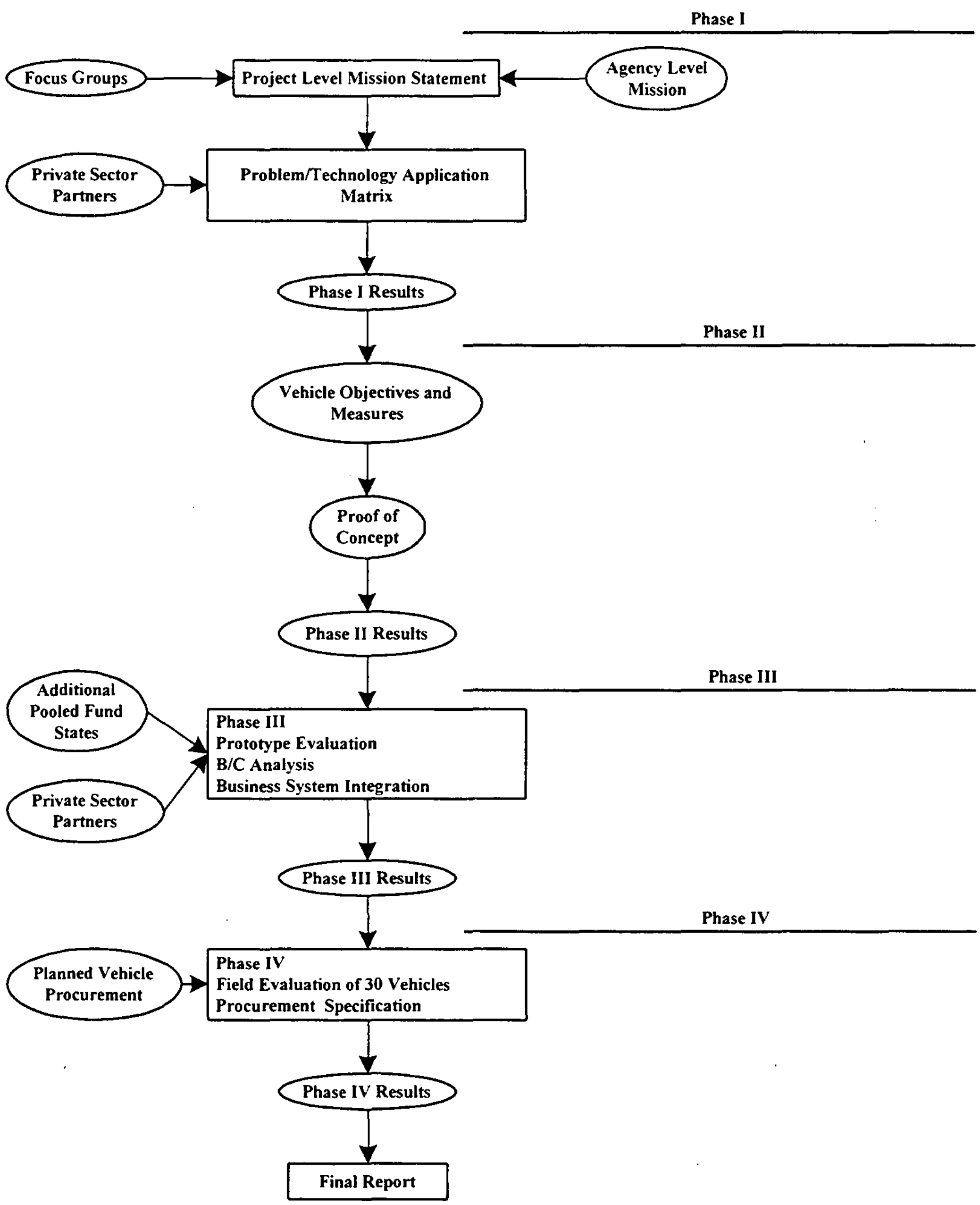


Figure 1-1 Study process map

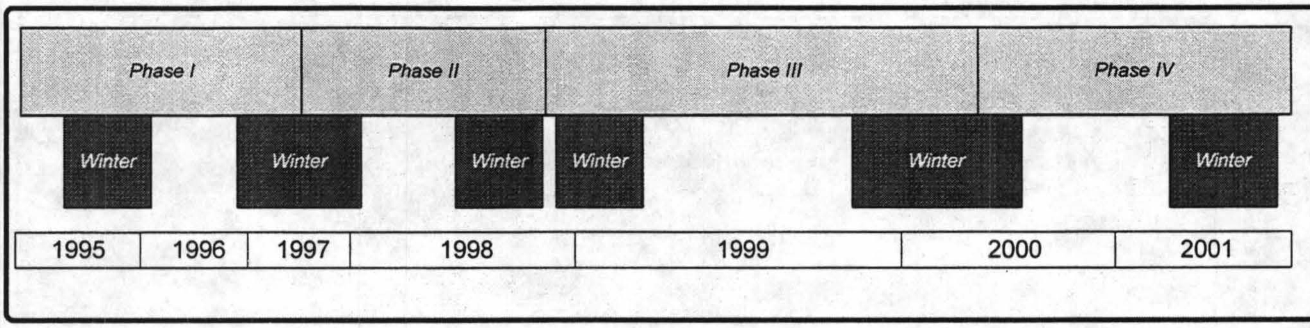


Figure 1-2 Four-phase time line

The ideal capabilities (or functionality) of a winter maintenance vehicle were identified through a total of five focus groups that met in the three states. Focus groups were comprised of the "customers" or end users of winter maintenance vehicles: equipment operators, mechanics, area supervisors, law enforcement, emergency responders, resident and central maintenance office engineers, and equipment managers. More than 600 ideas for vehicle functions were generated, organized into a list of 181 desired capabilities, and categorized into six major groups of functions:

- Administration
- Vehicle at Rest
- Infrastructure
- Pre-operations
- Roadway Systems Operations
- Post-operations

Ideas from the focus groups were prioritized, resulting in the following desired functionality for the three prototype vehicles:

1. Sense pavement surface (friction) condition.
2. Sense roadway surface and air (ambient) temperatures.
3. Record and download vehicle activities (vehicle location).
4. Provide adequate horsepower (improve engine performance).
5. Carry and distribute various types of materials.
6. Sense obstacles behind the vehicle (rear-obstacle alarm).
7. Provide removable salt/salt brine dispensing system.
8. Improve fuel economy.

Private sector equipment and technology providers were then introduced to the project and asked to join in the effort. The private partners listed on page 10 committed to providing equipment and expertise for the duration of the study. Although the overall goal was to implement equipment that would perform the functions identified in the focus groups, the technologies provided by vendors did not exactly match the desired functions in every case. For example, no technology was provided to "improve fuel economy," but fiber optic lights were provided to improve vehicle visibility in snow and fog. See Table 1-1 for a complete list of technologies selected for integration on the prototype vehicles during Phase II.

Phase I has been completed. A more detailed discussion of the work done in Phase I can be found in the report, Concept Highway Maintenance Vehicle, Final Report Phase One, dated April 1997. The report is available at CTRE and online at www.ctre.iastate.edu/projects/convehcl/.

Phase II: Develop Prototype Vehicles and Conduct Proof of Concept

The object of Phase II was to build three working prototype vehicles, one in each consortium state, integrating selected advanced technology subsystems; conduct proof of concept to demonstrate that the integrated technologies performed satisfactorily on the maintenance vehicles; and prepare for field evaluation of the prototype vehicles in Phase III. Manufacturers and system integrators worked with the study team to develop the prototype vehicles. Technology providers for some of the components varied from state to state, but, with the exception of the friction meter, the functions of the prototype vehicles were identical. (Michigan did not install the friction meter on its prototype vehicle; see chapter 8.) The study team selected technology for the winter of 1997-1998 and documented equipment names and model numbers, technology providers, and descriptions of the technology capabilities. Adjustments and modifications were made when the technologies were incorporated onto the prototype vehicles. CTRE documented these adjustments and modifications, along with the challenges involved with locating the technology components on the vehicles and during troubleshooting activities.

Table 1-1 lists the desired vehicle functions identified in Phase I, associated technology subsystems, and level of integration of the subsystems on the prototype vehicles during Phase II.

Table 1-1 Phase II level of integration of desired functionality on prototype vehicles

Function	Subsystem	Level of Integration
Measure Pavement Surface Condition	Friction Meter	Complete
Measure Ambient Conditions	Air /Pavement Temperature Sensors	Complete
Automatic Vehicle Location	Global Positioning System	Complete
Improve Engine Performance	Power Booster	Complete
Apply Various Materials	Materials Applicators	Partial
Improve Vehicle Visibility	Fiber Optic Lights	Complete
Rear Obstacle Alarm	Backup Sensors	Complete
Data Processing	Onboard Computer	Complete
Data Communications (Real Time)	Data Communications	Phase III installation

Proof of concept is simply a process of proving that an idea, or concept, is possible. The "concept" to be proved in this study is that advanced, existing technologies (e.g., air/pavement temperature sensor, global positioning system (GPS), onboard computer system) can be adapted for use on a snowplow vehicle. Figure 1-3 provides a simple schema of the relationship among the onboard technologies, or subsystems.

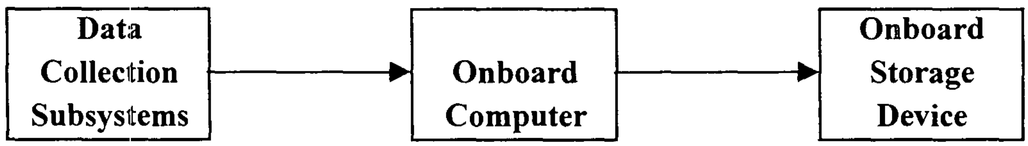


Figure 1-3 Phase II prototype vehicle system architecture

To conduct concept, the study team's goal was to run the add-on technologies while the prototype vehicles performed routine maintenance operations, and generally observe that the technologies functioned as expected. Proof of concept was conducted during winter operations in 1997-1998. For example, the temperature sensors collected data; the GPS collected location/time data; the onboard computer collected data, translated them to common formats, and stored them on removable PCMCIA cards; data were provided to vehicle drivers via a user friendly in-cab display; and, when CTRE converted and displayed the data, they appeared reasonable and suitable for incorporation into management systems. See Table 1-2.

Table 1-2 Proof of concept results

Function	**Subsystem**	**Passed Proof of Concept**	**Modification for Phase III**
Measure Pavement Surface Condition	Friction Meter	Yes	Newer model
Measure Ambient Conditions	Air and Pavement Temperature Sensors	Yes	None
Automatic Vehicle Location	Global Positioning System	Yes	DGPS
Improve Engine Performance	Power Booster	Yes	None
Apply Various Materials	Materials Applicators	Yes	Coordinate material applications with roadway conditions
Improve Vehicle Visibility	Fiber Optic Lights	Not conducted	None
Rear Obstacle Alarm	Backup Sensors	Not conducted	None
Data Processing	Onboard Computer	Yes	Format data for reports
Real-time Data Communications	Data Communications	Not conducted	Provide communications linkage to garages

A user manual was produced for the prototype maintenance vehicles, with documentation regarding operation and troubleshooting of the technological components. Each of the three state DOTs received a user manual specific to its vehicle, and a master manual is kept on file at CTRE.

A form was developed for DOT personnel to document problems, repairs, and maintenance on each prototype vehicle. Phone interviews were conducted with equipment operators to document equipment performance and user acceptance. Information from these interviews was entered into a database for analysis and comparison. As a result, the following desired functionality was identified for implementation in Phase III:

1. Provide additional weather data sources.
2. Provide a collision avoidance system.
3. Provide a differential global positioning system (DGPS).
4. Provide cellular telephone/radio communication linkage.
5. Trace roadway surface chemicals locally, regionally, and/or statewide.
6. Develop material distribution intelligence (using algorithms based on surface trace data, air/pavement temperatures, pavement friction, and weather forecast).
7. Display data on area-specific maps.

Phase III: Conduct Field Evaluation of Selected Technologies

The general objectives of Phase III will be to establish the specific vehicle functionality and related technology to be evaluated in this phase, conduct a benefit/cost analysis for each technology, estimate the time to implementation, conduct field evaluations, and produce data flow and decision process maps that integrate the concept vehicle functionality into management systems. Phase III will answer these questions:

- Which technologies will be implemented?
- What are the benefits/costs of each technology?
- What is the expected time to implementation?

Phase III tasks will include the following:

- Describe the vehicle and systems to be considered.
- Develop proof of concept for additional technologies and onboard intelligence.
- Develop a field evaluation plan for three prototype vehicles and conduct the evaluation.
- Obtain additional state partners (pooled fund).
- Obtain additional private sector partners.
- Develop a benefit/cost evaluation and conduct benefit/cost analysis.

- Develop a time-to-implementation projection.
- Develop data flow maps and suggest a method(s) to integrate the data with existing and planned state systems.
- Develop information flow process maps and suggest a method(s) to integrate the information with existing and planned management systems.

Phase IV. Conduct Fleet Evaluation in Each State

The objective of Phase IV is to conduct a field evaluation of 30 vehicles equipped with the functionality selected in Phase III and to develop a draft vehicle procurement specification. The evaluation will be based on the evaluation plan developed in Phase III. In Phase IV it is envisioned that a fleet of 10 vehicles in each consortium state will be equipped with the selected advanced technologies. Although equipping 10 vehicles implies a significant expense, the vehicles themselves will be standard design maintenance trucks that are part of each state's annual equipment program. Therefore, instead of purchasing vehicles only for a test, the vehicles will be available after testing for standard maintenance operations in the participating states. The only equipment costs directly attributable to this project, then, will be the costs of add-on technologies.

A VISION FOR THE FUTURE

The scope of this study is limited to several prioritized functionalities determined primarily in the Phase I focus groups. However, the proof of concept demonstrated in Phase II, the prototype vehicle evaluations in Phase III, and the fleet evaluations in Phase IV will establish a methodology for determining the feasibility and cost-effectiveness of incorporating additional advanced technologies on maintenance vehicles. Consider the possibilities:

- Automated chemical and abrasive distribution systems activated by measuring the conditions of the roadway surface.
- Automated data collection that interfaces with DOT management systems, including maintenance, pavement, bridge, and equipment management systems along with personnel and purchasing systems.
- Specific winter maintenance strategies for local conditions.
- Analysis of the applied chemicals and roadway conditions to ensure effectiveness.
- Heads-up displays for equipment operators so they don't have to look away from the road to see the gauges.
- Geographical information systems (GIS) integrated with GPS to map roadway condition data and other maintenance information.

- Collision avoidance systems that allow equipment operators to know when there is a stalled vehicle or other obstruction in the way while conducting snow and ice removal duties during inclement weather conditions.

- Systems that provide accurate and "real time" condition reports to the driving public.

These few examples illustrate the potential that exists when we look into other industries and look at other technology applications that can be imported into winter maintenance decision-making processes and public information systems.

CHAPTER 2: PHASE I SUMMARY

The objectives of Phase I were to identify the desired functionality of winter maintenance vehicles and enlist private sector partners to join the consortium. Work began with a review of literature related to winter highway maintenance activities.

LITERATURE SEARCH

The goal of the literature search was to identify subject materials related to state-of-the-art technologies and research results regarding snow and ice removal. The search was carefully organized and documented to facilitate ease of both presentation and retrieval of materials.

The search discovered several research activities in progress and many documents describing completed projects. The more important references are described in Table 2-1. The study team was interested in focusing on successful ventures and determining their potential application for this study. Many of the sources found were used to focus the scope of the project in the early stages, when direction for the study was being established. The least documented subject was economic evaluations of technology applications by either public or private entities.

The greatest value derived from the literature search was the identification of technologies already developed for applications other than highway maintenance that held promise for implementation on the concept highway maintenance vehicle.

Table 2-1 Selected literature

Ref. No.	Source	Subject
1	Roads and Bridges	International study tour sponsored by the FHWA brings both easy and complex solutions to domestic snow control problems.
2	NCHRP Research Results Digest	An NCHRP digest of the findings and recommendations of an international winter maintenance scanning tour conducted under the auspices of the FHWA's international programs and NCHRP Project 20-36, Highway Research and Technology - International Information Sharing.
10	TRB Maintenance Management Conference Proceedings 5	Automating maintenance scheduling and reporting including voice recognition software, pen based computers, bar-code scanners, and communication technologies.
25	Michigan Technology University	Explores new techniques of disbonding ice including pavement surface compositions, electromagnetic radiation, air and liquid jets, and acoustics waves.

TABLE 2-1 Selected literature (continued)

Ref. No.	Source	Subject
29	Washington DC University Trans. Centers	Enhance the value of data received by the maintenance foreman for making decisions regarding winter highway maintenance using a microcomputer-based decision support system (DSS).
32	WELS Research Corp.	Development of user-friendly, artificial intelligence-supported weather prediction software. Seeks to integrate historical and current local weather information.
47	Better Roads	A discussion of salting and anti-icing techniques including temperature-measuring devices attached to moving vehicles.
209	Better Roads	Cost reductions resulting from the Wisconsin Winter Weather System (WWWS) which allows for less use of salt by delaying applications until they are required for deicing activities.
233	South Dakota DOT	Snowplow light visibility and snow cloud reduction by using a variable angle snowplow.
242	Scranton Gillette Communications, Inc.	This report looks into how snow removal has moved from the mode of snow removal to that of prediction and prevention. There have been new developments in chemicals, equipment, and techniques, many of which are described.
247	Bundesministerium fur Wirtschafliche Angelegenheiten	New snowplow configurations that are hydraulically controlled for quick connect and disconnect features.
317	Stadden-K	This article discusses nationwide mobile messaging systems for trucking fleets. Mobile communications in trucks make drivers' lives easier, impress customers, and improve management efficiency.
342	Bristol Company	A press release for the SYN/CON FPS-1000-M Road Sensor that is truck mounted and displays the temperature of the liquid on the road and the freezing temperature of materials.
343	Traffic Technology International	An international review of road condition sensors, visibility sensors, thermal mapping, route optimization, pavement sensors, and variable message signs.
344	Traffic Technology International, Autumn 95	Pre-salting is effective where there is access to highly accurate road weather forecasts.
354	MNDOT	This paper discusses how reductions in roadway departure accidents can be achieved by integrating emerging sensing and control technologies into guidance control systems.
361	Finnish National Road Administration	This paper describes the principles of winter maintenance quality and road standards that the FinnRA has established.
363	Commonwealth of Pennsylvania, DOT	Field test performed in Pennsylvania of Tyler Ice's zero velocity spreader. Material savings and increased performance were documented.

DESIRED VEHICLE FUNCTIONALITY

A critical step in the early stages of this study was to develop and prioritize the desired winter maintenance vehicle functionality.

Process

The process used to identify and prioritize the functionality was similar to a one used by private industry to develop new products. The process, which focuses on the needs of the end users (and which is described thoroughly by L. P. Sullivan in the June 1986 issue of *Quality Progress)*, is called Quality Function Development (QFD). QFD requires defining the customers' desires, or "the voice of the customer." Once the customers' expectations have been defined, a prototype model is assembled, tested, evaluated, and modified to meet the customers' needs before production of the first manufactured models begins. By applying the QFD process, CTRE was able to identify the desired vehicle functionality using focus groups, affinity diagrams, and relations diagrams. For this project, the consumers are the people who work with maintenance vehicles as a part of their everyday jobs: maintenance equipment operators, mechanics, and maintenance supervisors. See Figure 2-1 for the three-step process CTRE utilized to capture the "voice of the customer."

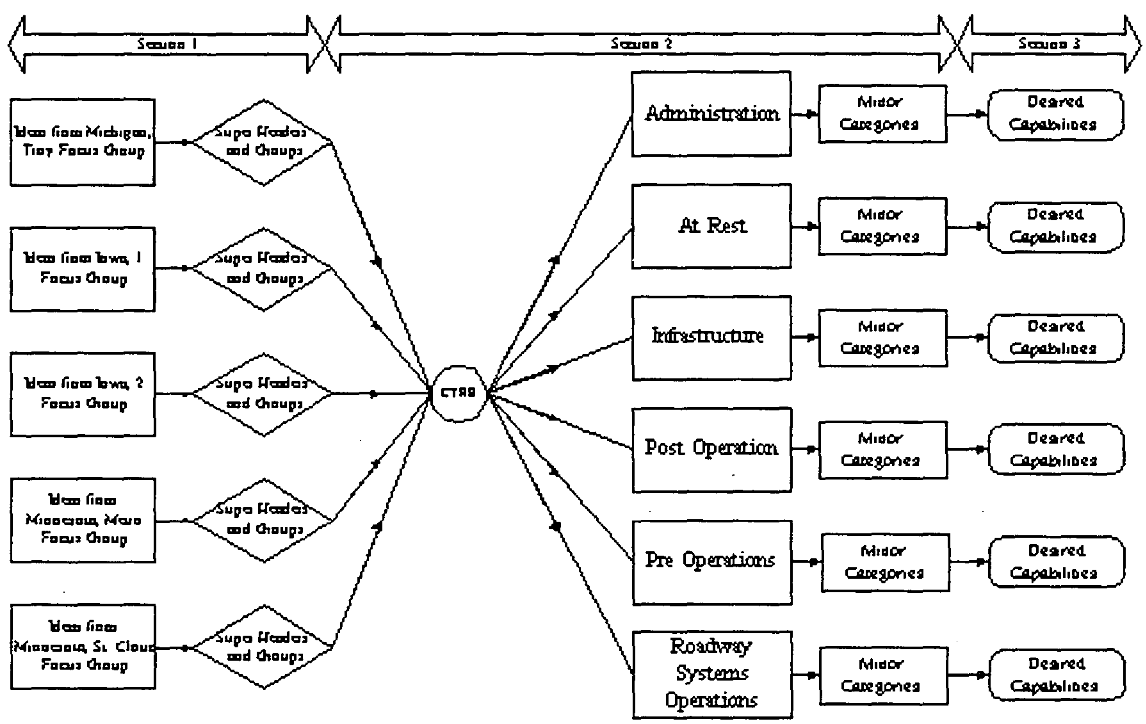


Figure 2-1 Three-step process flowchart

Focus Groups

To capture the "voice of the customer," CTRE conducted a total of five focus group activities in the three consortium states in the fall of 1995. The groups consisted of DOT equipment operators, mechanics, equipment specification writers, maintenance managers, and maintenance supervisors. In addition, representatives from other professions with an interest in winter highway maintenance activities, such as law enforcement personnel and emergency responders, participated.

Ideas generated by the focus groups were recorded in a format called an affinity diagram. After all ideas were generated, they were grouped into logical categories and labeled by the participants. A relations diagram was then used to determine relationships between categories. A relations diagram looks at cause and effect between categories and quantifies which of the categories exerts an influence on others, and which categories are influenced by others. Actions are most effective if they derive from categories that exert the most influence on other categories.

The relations diagram is an effective prioritizing tool. With a relations diagram, functions that exert the most influence are most effective and therefore have the highest priority for implementation. Using effectiveness as the criterion, then, all of the focus groups identified driver safety and snowplowing functions as the highest priorities. As a result of these activities, each partner state's DOT developed a prioritized list and a detailed description of the desired concept vehicle functionality.

Generally, the prioritized lists included the following functions:

1. Record and download vehicle activities.
2. Sense roadway friction conditions.
3. Sense roadway surface and air temperatures.
4. Improve fuel economy.
5. Carry multiple types of materials.
6. Distribute multiple types of materials.
7. Provide adequate horsepower for the vehicle.
8. Provide removable salt/salt brine dispensing system.
9. Sense obstacles behind the vehicle utilizing backing sensors/monitors.

PRIVATE SECTOR PARTNERS

To generate private sector interest and participation in the project, the study committee invited a large number of companies from various industries involved in snow and ice control to attend a workshop in Detroit, Michigan, in April 1996. Forty-nine industry representatives attended. The workshop began with an overview of the progress to date and a presentation of the results of the focus group activities. Then attendees participated in one of three discussion sessions—vehicle manufacturers, communication/technology providers, and equipment vendors—to define the technologies available for prototype evaluation in the participating states.

The workshop provided the consortium DOT maintenance engineers and research engineers an opportunity to meet with equipment providers and discuss the potential for advanced technologies on highway maintenance vehicles. The discussion sessions allowed private sector attendees to provide direction to the consortium DOTs. Furthermore, the technology and equipment providers were enticed by the opportunity to hear what the DOT equipment operators defined as improved vehicle and equipment capabilities, or functionality.

At the conclusion of the workshop, representatives from private organizations were given "partnership interest" forms asking them to indicate the level of participation that they could supply in terms of time, equipment, technology, and funding. Responding private sector partners were assigned to one of the state teams according to the technology and equipment they could provide, their geographical proximity, and their familiarity with each state's DOT. Figure 2-2 shows the 10 initial private sector partners grouped into state teams following receipt of partnership interest forms after the Detroit workshop.

Additional companies expressed interest in the project after the initial private sector assignments were made. These companies were asked to complete partnership interest forms, updated on the progress of the project, and invited to attend the next project workshop. Completing this step in the study assured the valuable backing of a variety of private sector partners.

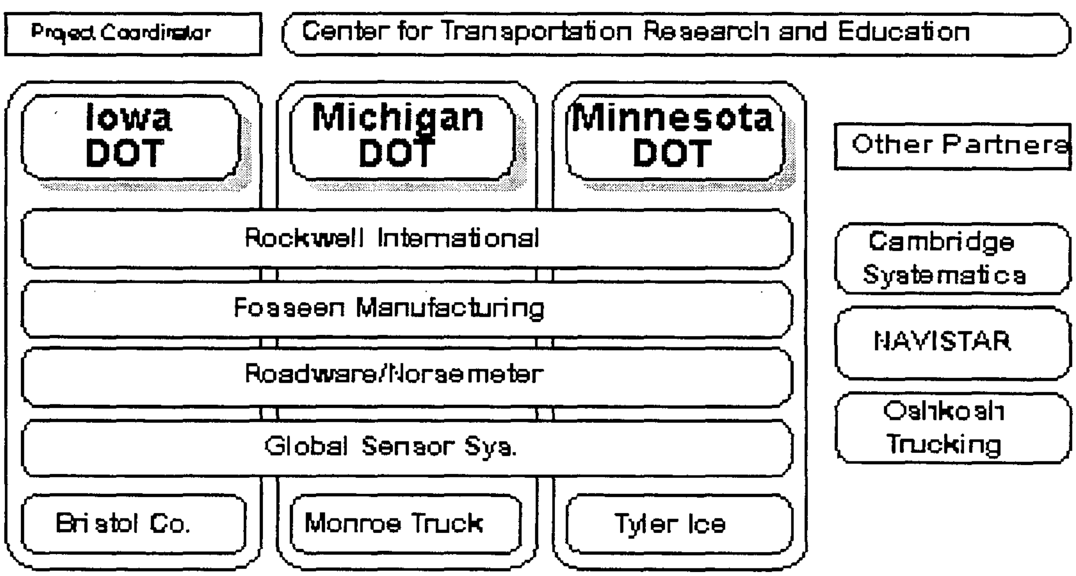


Figure 2-2 Initial prototype teams for winter 1996-1997

DETERMINING ACTUAL VEHICLE FUNCTIONALITY

In cooperation with private sector partners, the state DOT partners collaborated to define the systems, subsystems, and budget for the initial prototype vehicles—one in each state—to be developed. These decisions were based on the functionalities identified in the focus groups and the technologies available from participating vendors. Discussion and consensus-building during a July 1996 meeting in St. Paul, Minnesota, and subsequent conference calls assured participating private sector partners that the concept maintenance vehicle was worth the investment and convinced all partners to proceed with assembly of the prototype vehicles. At this point, the consortium members knew the equipment that would be on the vehicles, the technology that would be implemented, the funding available, and the extent of participation from private sector partners

PRODUCTION TIMELINES

An objective of the St. Paul meeting was to establish a reasonable timeline for assembly of the three prototype vehicles. Consideration was given to existing production schedules and commitments of manufacturers who were contributing resources to the project. For many of the technology providers, the time frame for planning and assembling the vehicles was their busiest time of the year. Private sector partners provided direction about product availability and valuable insight into industry practices and the commitments that could be formalized. The first prototype vehicles were scheduled to be fitted with new technology and equipment and ready for use by November 1996. The state DOTs were to make the vehicles available in August 1996.

PRODUCTION TEAM AND LOCATION

The production elements, associated costs, desired technology, and production timelines had been defined at this point. The consortium then designated two production teams for assembly of the vehicles. Iowa and Michigan were scheduled to have their plows and spreaders installed on their prototype vehicles at Monroe Trucking in Monroe, Wisconsin. Minnesota planned to have its assembly done at Tyler Ice in Benson, Minnesota, with whom it had cooperated on previous research projects. The steering committee conducted project meetings at each location and toured each of the facilities. Both Monroe Trucking and Tyler Ice were fully equipped to accomplish the equipment assembly and to overcome the unpredictability of installing prototype equipment.

TECHNICAL REPORT

A technical report was not written to document the feasibility of developing the prototype vehicles. Because the study team members (including private sector partners as they were added to the consortium) worked together during the entire process, they had continuous reassurance that selected technology elements could be provided and had been successfully proven in other applications. The time to assemble the vehicles for the winter of 1996–1997 was very short. Considering the coordination and assembly time required, the study team committed all its time to the assembly task. In later phases of the study, as technology applications were considered for winter 1997–1998 prototype vehicles, more emphasis was placed on assisting the needs of the vehicle operators. It would be important in Phase II that the feasibility of the vehicle and additional technology applications be carefully documented and the relationship of this project with the state DOTs' business plans be established before moving into Phase III prototype vehicle evaluation or Phase IV fleet evaluation in each of the participating states.

SUMMARY

Phase I began with a literature review of materials related to winter highway maintenance activities, including state-of-the-art equipment, technologies, and research related to winter highway maintenance activities.

By utilizing focus group activities in each state, the desired functionality of a winter maintenance vehicle was identified. Approximately 600 ideas were combined and organized into five categories, and a prioritized list of functions was developed.

Private sector equipment and technology providers were asked to join the project. Several private partners committed to providing equipment and expertise for Phase II, which included producing three prototype vehicles for the winter of 1996-1997 and conducting proof of concept during the winter of 1997-1998.

The specific equipment and technology to be included on the three prototype vehicles for the winter of 1996-1997 was determined in cooperation with the three DOTs and the private sector partners. Phase I concluded by establishing that assembling the three prototype vehicles would be beneficial to the project and the three state DOTs, and it was agreed to proceed to Phase II: assembly and proof of concept. Figure 2-3 shows the private sector participants' contributions to the prototype vehicles as modified for proof of concept.

A complete discussion of Phase I can be found in the report, Concept Highway Maintenance Vehicle, Final Report Phase One, dated April 1997.

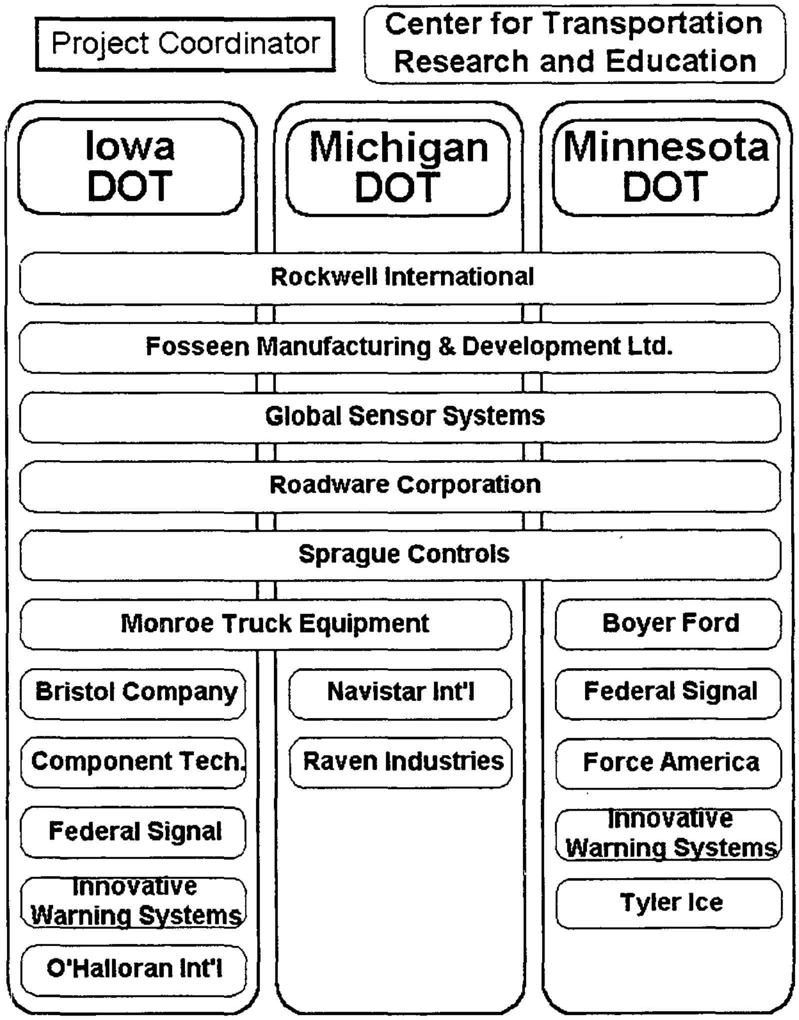


Figure 2-3 Relationship of the private sector participants to each concept vehicle at the end of Phase I

CHAPTER 3: PROOF OF CONCEPT

The primary objective of Phase II was to conduct "proof of concept." Proof of concept is simply a process that proves that an idea, or concept, is possible. The concept of this study is that advanced technologies, developed for other applications, can be adapted for use on snowplow vehicles to improve maintenance operations for operators and managers. The study team required proof of this basic concept before proceeding with full-scale field evaluation of the prototype vehicles in Phase III.

Proof of concept for the add-on technologies was conducted at two levels, installation and performance. Proof of concept for each add-on technology answered these questions:

- Can the technology be securely and relatively conveniently installed and operated on a winter maintenance vehicle?
- Once installed, does the technology perform as expected?

INSTALLATION

Installing some of the technologies on the prototype vehicles was straightforward. Installation of the high-intensity lights, for example, required little special fabrication. The lights proved sturdy and easily accessible for installation and maintenance.

Installation of other technologies, however, was more challenging. As described in Chapter 8, Minnesota and Iowa experimented with installing the ROAR friction meter in different locations. Iowa's installation resulted in interference with the underbody blade; Minnesota's installation resulted in excessive whipping and bouncing of the ROAR friction meter and subjection to salt and sand from the spreader. The ROAR friction meters on both prototype vehicles didn't stand up well to bumps and potholes and required special heavy-duty shock absorbers and other significant retrofitting. The ROAR friction meter would not fit on Michigan's prototype vehicle; the Michigan DOT installed it on a separate pick-up class truck.

Even these significant installation problems, however, did not disprove the concept of incorporating a friction meter on the prototype vehicles. Rather, they provided the impetus for Roadware Corporation to develop a newer, smaller, lighter, more rugged, and less expensive friction meter—the SALTAR, which is expected to be ready for installation and field evaluation in Phase III.

Installation procedures—including difficulties and successes—are discussed in detail in Chapters 5 through 11. The friction meter provided the greatest installation challenge of all the add-on technologies and in fact was not installed on Michigan's prototype vehicle. In general, however, as described in Chapters 5 through 11, Phase II activities proved the feasibility of incorporating and operating all the desired technologies on winter maintenance vehicles.

PERFORMANCE

Installing and operating the new technologies, however, is only half the proof. Once the technologies were on the vehicles, they had to perform as desired and expected. Again, determining that some of the add-on technologies worked as expected was fairly straightforward. For example, the backup sensors were observed to automatically apply the vehicle's brakes if the vehicles approached an object too closely while backing up, as expected. The PlowMaster display showed plow positions, temperature measurements, and other data collected from other onboard technologies, as expected.

Again, however, proving that some add-on technologies were performing as expected was more challenging. Primarily, these technologies included those that measured environmental conditions: the air/pavement temperature sensors, the friction meter, and the onboard global positioning system (GPS). To prove that these technologies were performing as expected or desired, it was not sufficient to determine that these technologies were collecting data; it was important to determine that they were collecting reasonable data.

For proof of concept, CTRE compared data collected by add-on technologies to known data to confirm that the data from the vehicle technologies were reasonable. For example, latitude and longitude data from the onboard GPS were translated to milepost locations and compared to known milepost and latitude/longitude data provided by the Iowa DOT (see Chapter 13). Data collected by the friction meters were graphed and the slopes compared to data collected by ASTM E-274 friction measuring devices (see Chapter 8). Air and pavement temperatures recorded by the temperature sensors were compared to temperature data provided by RWIS (see Chapter 9).

Performance of the various technologies—successes and difficulties—is discussed in detail in Chapters 5 through 11. Collecting enough winter-related data from vehicle sensors to compare to known data was a significant challenge, given the mildness of the 1997-1998 winter and CTRE's limited control over prototype vehicle operators' activities. Generally, however, as described in Chapters 5 through 11, Phase II proved that the add-on technologies could perform as expected during winter maintenance operations.

PROOF OF CONCEPT SUMMARIES

Table 3-1 lists the technologies installed on the prototype vehicles, the results of proof of concept for each technology, and suggested modifications. Proof of concept of real-time communications was not conducted during Phase II.

Table 3-1 Proof of concept results

Function and Chapter	Subsystem	Passed Proof of Concept	Modification for Phase III
Measure Pavement Surface Condition (8)	Friction Meter	Yes	Newer model
Measure Ambient Conditions (9)	Air and Pavement Temperature	Yes	None
Automatic Vehicle Location (7)	Global Positioning System	Yes	Implement DGPS
Improve Engine Performance (10)	Power Booster	Yes	None
Apply Various Materials (5)	Materials Applicators	Yes	Coordinate material applications with roadway conditions
Improve Vehicle Visibility (11)	Fiber Optic Lights	Not conducted	None
Rear Obstacle Alarm (12)	Backup Sensors	Not conducted	None
Data Processing (6)	Onboard Computer	Yes	Format data for reports
Data Communications (Real Time)	Data Communications	Not conducted	Provide communication linkage to garages

CHAPTER 4: INTRODUCTION TO TECHNOLOGIES

This chapter provides a general introduction to the technologies added to the prototype maintenance vehicles, assembly of the vehicles, and test drive and data capture routes during Phase II. Chapters 5 through 12 discuss specific technologies in detail.

BASIC PROTOTYPE VEHICLE CONFIGURATIONS

CTRE developed a matrix of technology providers, equipment names, model numbers, and versions for technologies selected for the winter of 1997-1998. Table 4-1 lists the general technologies and providers, along with common reference names used throughout these chapters and the specific chapter in which each technology is discussed. Table 4-2 lists the specific components assembled on the Iowa, Michigan, and Minnesota prototype vehicles for 1997-1998. Table 4-3 lists contact information for technology providers.

Two companies initially integrated the add-on components on the prototype vehicles. Monitor Truck Equipment, located in Monroe, Wisconsin, assembled the Iowa and Michigan vehicles. Tyler Ice, a division of Tyler Industries, located in Benson, Minnesota, assembled the Minnesota vehicle. Figure 4-1 shows the location of add-on technologies on Iowa's prototype vehicle.

As with any new or unique version of a product, the initial setup was subject to change. The prototype vehicles were the first of their kind in terms of advanced technology design and purpose. Some of the components, not originally designed for installation on a maintenance vehicle, posed unique challenges and required modified placement or other adjustments. As the vehicles were operated during Phase II, CTRE and DOT users identified additional modifications needed and made alterations.

CTRE solicited the DOTs, Monroe Truck Equipment, and Tyler Ice for detailed information concerning modifications made to the equipment and vehicles. Specific modifications are discussed in Chapters 5 through 11.

Table 4-1 Technology reference

Technology Provider	Technology	Reference Name	Chapter Reference
DOT	Trucks, Plows, and Spreaders	Trucks, Plows, and Spreaders	5
Rockwell International	PlowMaster Computer	PlowMaster	6
Rockwell International	Global Positioning System	GPS	7
Roadware Corporation	Norsemeter ROAR Friction Meter	Friction Meter	8
Sprague Controls	Pavement/Air Temperature Sensors	Temperature Sensors	9
Fosseen Manufacturing	Engine Power Booster	Engine Booster	10
Innovative Warning Systems	High-Intensity Discharge Warning Lights	HID Lights	11
Global Sensor Systems	Reverse Obstacle Sensor	Reverse Obstacle Sensor	12

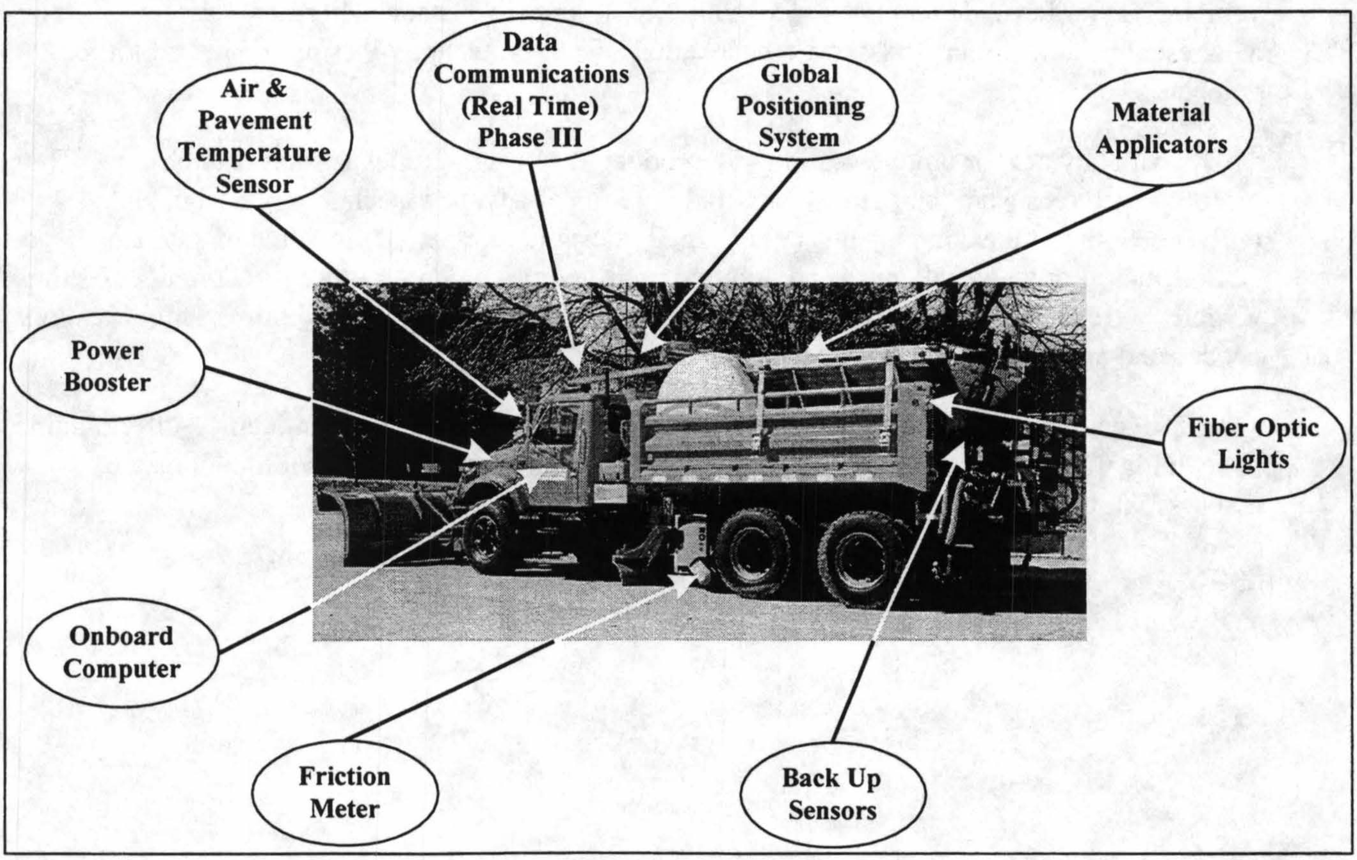


Figure 4-1 Iowa's prototype maintenance vehicle

Table 4-2 Concept vehicle technology and providers matrix

Technology	Iowa	Michigan	Minnesota
Truck	O'Halloran International International Navistar NAV 4900 (1996)	Navistar International Corporation International Navistar NAV 2574 (1996)	Boyer Ford Ford L9000 (1996)
Front Plow	Monroe Truck Equipment MTE MV-96-84-50-304-SS	Monroe Truck Equipment MTE DSM-120-86-48/304-MICH	Falls
Wing Plow	Monroe Truck Equipment MTE HDBW-11	Monroe Truck Equipment MTE RMJW-10	Minnesota
Underbody Plow (Scraper)	Monroe Truck Equipment MTE TS961B	Monroe Truck Equipment MTE 050-9012-0000-MICH	Root
GPS	Rockwell International GPS Antenna part number 013-1925-150	Rockwell International GPS Antenna part number 013-1925-150	Rockwell International GPS Antenna part number 013-1925-150
PlowMaster™	Rockwell International Rockwell Plowmaster™ #822-0972-004	Rockwell International Rockwell Plowmaster™ #822-0972-004	Rockwell International Rockwell Plowmaster™ #822-0972-004
Material Spreader	Monroe Truck Equipment Monroe Brute MSV	Monroe Truck Equipment Monroe Duz Mor	Tyler Industries Tyler V-Blend Dual Chamber Hopper
Material Spreader Controller	Bristol Company Bristol SYN/CON Controller Component Technology Spreadrite GL-400	Raven Industries Raven DCS 700 De-Ice Control System	Tyler Industries Quantum Controller and LDS-1000 Anti-Ice System
Engine Power Booster	Fosseen Manufacturing & Development Ltd. Hydrofire Power Booster (Custom Built)	Fosseen Manufacturing & Development Ltd. Hydrofire Power Booster (Custom Built)	Fosseen Manufacturing & Development Ltd. Hydrofire Power Booster (Custom Built)
Friction Meter	Roadware Corporation Norsemeter Roadway Analyzer and Recorder (ROAR) II	Roadware Corporation Norsemeter Roadway Analyzer and Recorder (ROAR) II	Roadware Corporation Norsemeter Roadway Analyzer and Recorder (ROAR) II
Pavement/Air Temperature	Sprague Controls RoadWatch Temperature Indicating System, RW1, 600 Series	Sprague Controls RoadWatch Temperature Indicating System, RW1, 600 Series	Sprague Controls RoadWatch Temperature Indicating System, RW1, 600 Series
Power System	Wired Rite Systems Integrated Power System	Wired Rite Systems Integrated Power System	Wired Rite Systems Integrated Power System
Reverse Obstacle Sensor	Global Sensor Systems Global Search-Eye Sensor System [Infrared] GS3000A	Global Sensor Systems Global Search-Eye Sensor System [Infrared] GS3000A	Global Sensor Systems Global Search-Eye Sensor System [Infrared] GS3000A
High-Intensity Warning Lights	Innovative Warning Systems/Federal Signal Corporation Spectra High-Intensity Discharge (HID) Fiber Optic Lighting System, HIDSYS-01	This option was not installed on the Michigan vehicle, it was a state option on whether to install it or not	Innovative Warning Systems/Federal Signal Corporation Spectra High-Intensity Discharge (HID) Fiber Optic Lighting System, HIDSYS-01

Table 4-3 Names, addresses, and phone numbers of private sector participants

Company	Contact Person	Voice	Fax	E-Mail
Boyer Ford 2623 Kennedy Street NE Minneapolis, MN 55413-2828	(N/A)	(612) 627-5543	(N/A)	(N/A)
Bristol Company 7140 West 117th Avenue Suite C-1 Broomfield, CO 80020-2978	Jack Doherty	(303) 665-7233	(303) 665-7252	(N/A)
Component Technology 1225 Illinois Street Des Moines, IA 50314-3189	Jim Bernardy	(800) 333-7411 (515) 244-7411	(515) 244-4204	(N/A)
Federal Signal Corporation 18606 81st Avenue Tinley Park, IL 60477-6257	(N/A)	(708) 633-4666	(N/A)	(N/A)
Fosseen Mfg. & Development 206 May Street, PO Box 10 Radcliffe, IA 50230-0010 www.netins.net/showcase/fmd/	Dick Evans	(515) 899-2115	(515) 899-2147	fosseenfmd@netins.net
Global Sensor Systems 400 Brunel Road Mississauga, Ontario Canada L4Z 2C2	Ray Glenn	(905) 507-0007	(905) 507-4177	(N/A)
Innovative Warning Systems 411 West 60th Street Minneapolis, MN 55419-2255	Dale Braddock, Jr.	(612) 861-3822	(612) 861-4230	(N/A)
Monroe Truck Equipment 1051 West 7th Street Monroe, WI 53566-9102	Norm LaValla	(800) 356-8134 (608) 329-8113	(608) 328-8390	(N/A)
Navistar International Corp. 2911 Meyer Road Fort Wayne, IN 46803-2926	(N/A)	(219) 461-1113	(N/A)	(N/A)
O'Halloran International 3311 Adventureland Drive Altoona, IA 50009-9593	Bob Kyser	(800) 800-6503 (515) 967-3300	(515) 967-0206	(N/A)
Raven Industries 205 East 6th Street Sioux Falls, SD 57102-0430 w3.iw.net/raven/	(N/A)	(605) 336-2750	(605) 335-0268	(N/A)
Roadware Corporation 147 East River Road Paris, Ontario Canada ON N3L 3T6 www.roadware.com/	Gil Boettcher	(800) 828-2726 (519) 442-2264	(519) 442-3680	gboettcher@roadware.com
Rockwell International 350 Collins Road NE Cedar Rapids, IA 52498 www.rockwell.com/	Scott Harry Greg Tomsic	(319) 295-5676 (319) 295-3743	(319) 295-0534 (319) 295-5420	sharry@cacd.rockwell.com gwtomsic@cacd.rockwell.com
Sprague Controls 1140 NW 3rd Avenue Canby, OR 97013-3441	Norman Petersen Glenda Westover	(800) 441-2048 (503) 263-3350	(503) 263-0532	npeterse@scioreg.echlin.com

Table 4-3 Names, addresses, and phone numbers of private sector participants (cont.)

Company	Contact Person	Voice	Fax	E-Mail
Tyler Ice PO Box 249 East Highway 12 Benson, MN 56215-0249 www.teamtyler.com/	Dave Gelhar	(800) 328-9128 (320) 843-3333	(320) 843-2467	(N/A)
Wired Rite Systems 5468 Skylane Boulevard Santa Rosa, CA 95403-1084 www.wiredrite.com/	Dave Rhodes Chuck Lamb	(800) 538-7483 (707) 545-7474	(800) 525-7483 (707) 545-7475	wiredrite@sonic.net
CTRE ISU Research Park 2625 N Loop Drive Suite 2100 Ames, IA 50010-8615 www.ctre.iastate.edu/	Duane Smith Jeff Zogg Karen Giese	(515) 294-8103	(515) 294-0467	desmith@iastate.edu karen@ctre.iastate.edu

A user manual containing documentation for operating and troubleshooting the advanced technologies was produced for the prototype vehicles. Each of the three consortium state DOTs received a user manual specific to its uniquely configured vehicle, and a master manual for all technologies used on the vehicles is on file at CTRE.

A form was developed for DOT personnel to document problems, repairs, and maintenance performed on each prototype vehicle. In addition, telephone interviews were conducted with vehicle operators to ascertain equipment performance. Information from the interviews was documented, providing a record of users' reactions. The results are provided in Chapter 15.

CTRE documented equipment performance during actual winter operating conditions during 1997-1998 and established modified system requirements for Phase III. Suggested modifications are discussed in Chapter 16.

PROTOTYPE VEHICLE ROUTES

The Iowa, Michigan, and Minnesota DOTs assigned their respective prototype vehicle to a specific maintenance route for the winter 1997-1998. Figures 4-2, 4-3, and 4-4 contain descriptions and maps of the vehicle routes in Iowa, Minnesota, and Michigan, respectively.

Iowa The route is on Interstate 35, between mileposts 87 and 102, or between the I-80/I-35/I-235 interchange on the northeast side of Des Moines to Iowa highway 210 interchange. This area is north of the Des Moines metropolitan area.

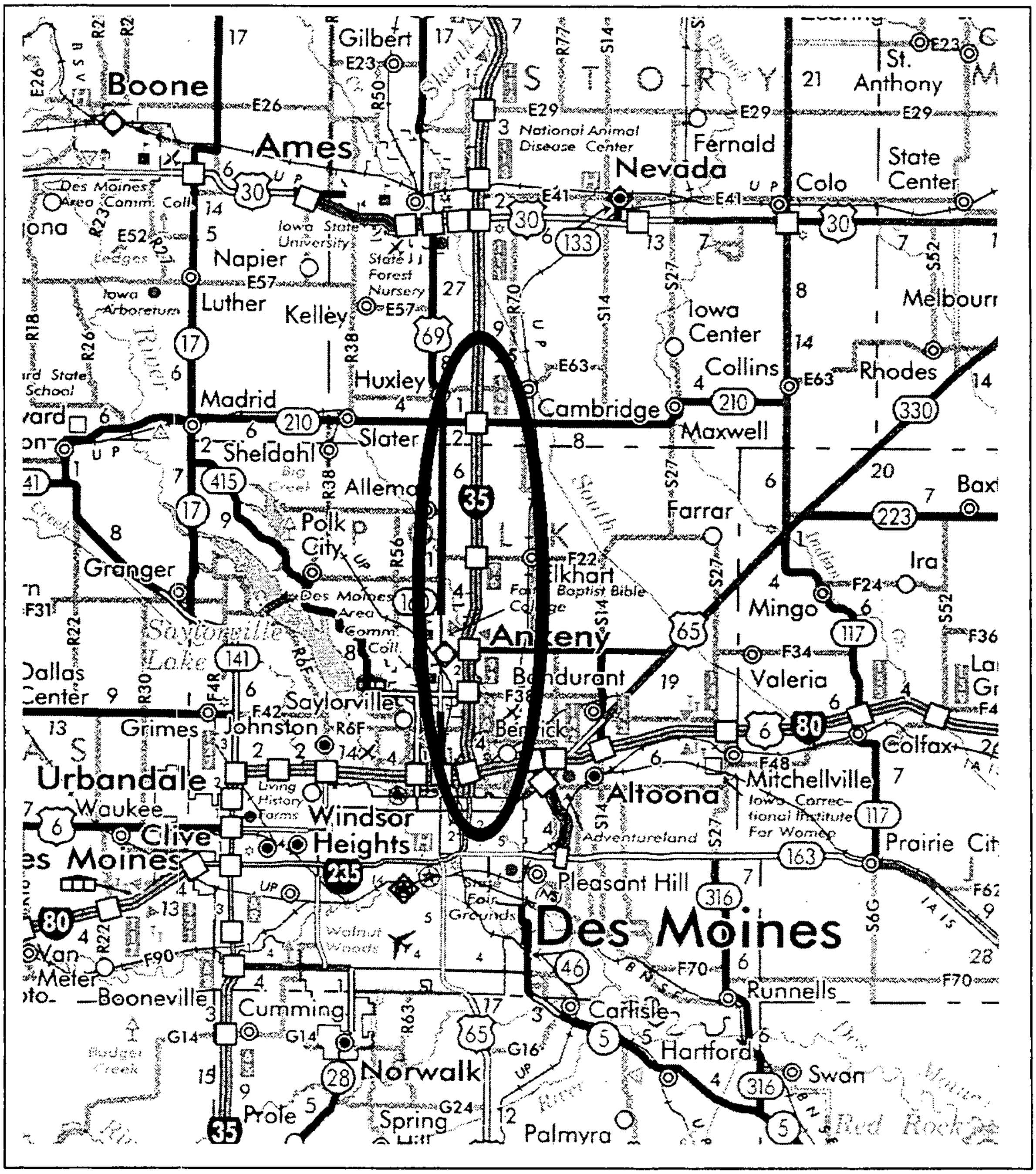


Figure 4-2 Iowa prototype vehicle route, winter 1997-1998

Minnesota The route is on US 169, between Belle Plâine (south end) and Minnesota highway 41 (north end). This area is on the southwest side of the Minneapolis-St. Paul metropolitan area.

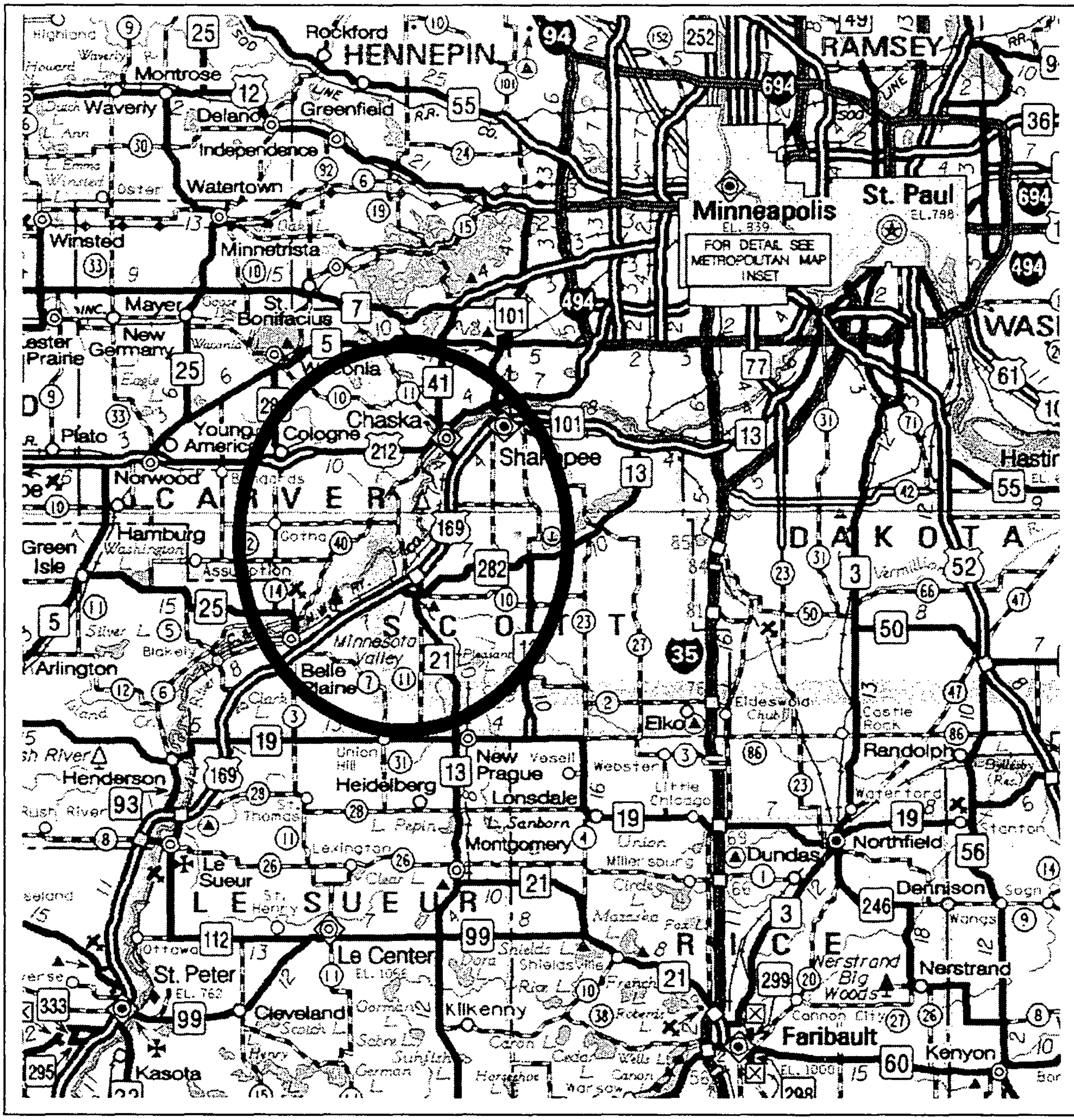


Figure 4-3 Minnesota prototype vehicle route, winter 1997-1998

Michigan The route is along US 131, between mileposts 160 (south end) and 173 (north end), or between a point 1 ½ miles north of Ashton to the Wexford-Osceola county line. This area is in the northwest Lower Peninsula, south of Cadillac. The friction meter is located near Lansing, which is in the south central portion of the Lower Peninsula.

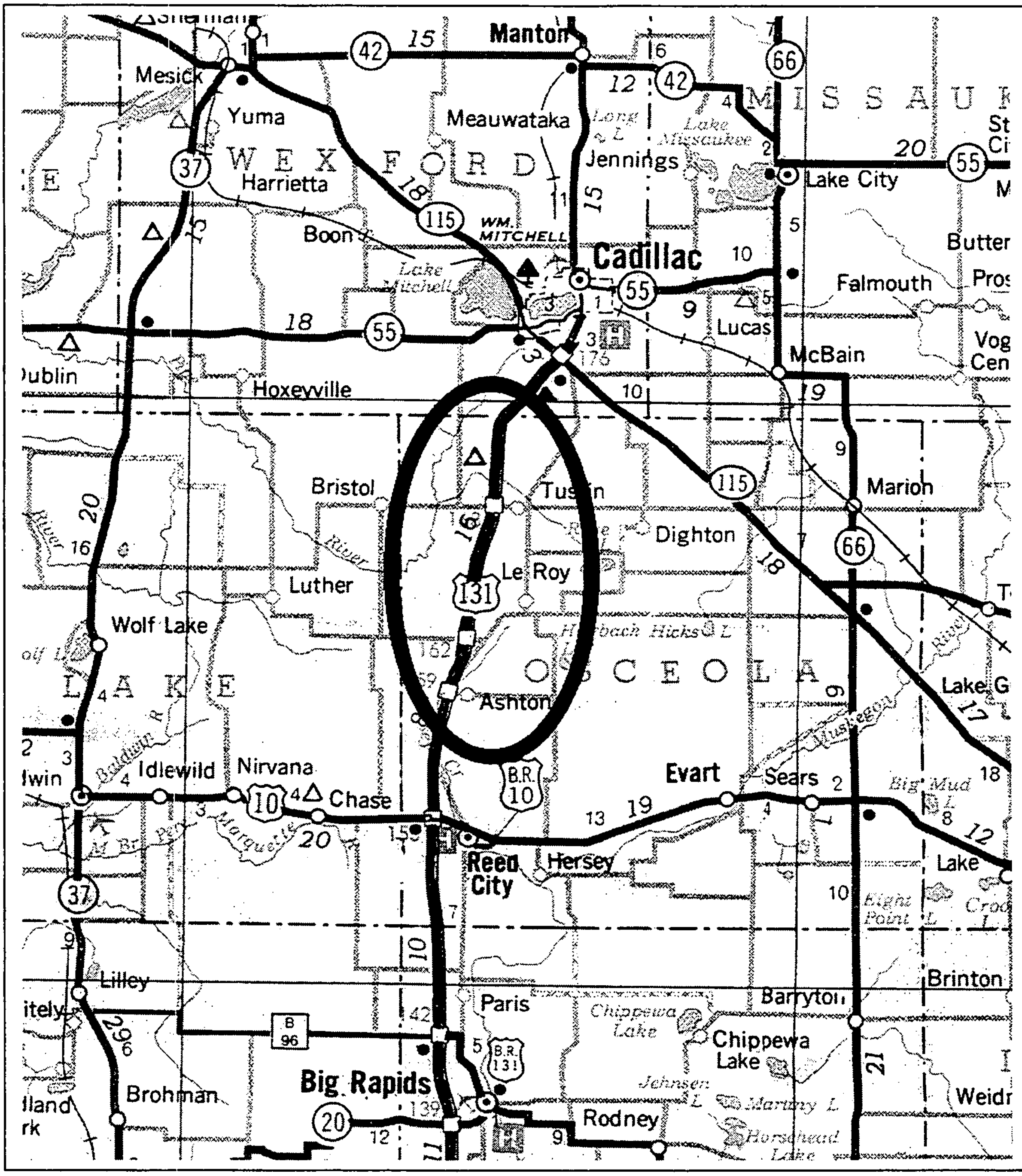


Figure 4-4 Michigan prototype vehicle route, winter 1997-1998

CHAPTER 5: TRUCKS, PLOWS, SPREADERS

Each DOT in the consortium states agreed to provide its own snow plow truck to be configured as a prototype winter maintenance vehicle for that state. Each basic vehicle provided by the states is a 50,000-pound gross vehicle weight (GVW) truck with tandem rear axles. Iowa's and Minnesota's trucks have dump bodies, while Michigan's truck has a chassis-mounted liquid tank and granular bin.

Equipment vendors equipped each prototype vehicle with three plows: a front plow, a side plow (wing), and an underbody plow (scraper). The front plow is capable of rotating side to side, with down pressure supplied by gravity. The wing plows are retractable and are mounted on the passenger side of the vehicles. Gravity supplies the wing plow's down pressure. The wing plow on the Iowa prototype vehicle is capable of raising to a benching height of 60 inches, and lowering for bench plowing. The underbody plows, or ice blades, allow the equipment operator to apply down pressure hydraulically, rotate the plow's angle from side to side (limited to right movement only on Iowa's vehicle due to the placement of the friction meter), and adjust its vertical angle forward and backward.

All three trucks are equipped with liquid tanks and granular V-box spreaders, and each is capable of performing anti-icing, prewetting, and deicing functions. Anti-icing refers to the application of material (e.g., salt brine, liquid calcium chloride, or calcium magnesium acetate) to the road surface early in a storm or during plowing operations to prevent the formation of a snow/ice-to-pavement bond. Prewetting refers to the application of a liquid to granular material, like salt, before or as the granular material is applied to the road surface. This accelerates the ice melting process and prevents salt from bouncing off the roadway surface. Deicing refers to the application of chemicals and abrasives on the road surface to remove snow, ice, or frost already bonded to the pavement. Equipment operators can use each spreader's "blast" mode feature to apply more chemicals and abrasives at locations that characteristically become icy. These locations include city street intersections, the ends of interstate highway exit ramps, or the bottoms of hills. The equipment operators use their own discretion with the blast mode.

OBJECTIVE

Conduct proof of concept for incorporating state-of-the-art plows, chemical/abrasive spreader systems, and in-cab controls and displays on snowplow trucks.

MEASUREMENT

Each state DOT in the consortium provides one snowplow truck. On each snowplow truck, three plows, a chemical and abrasive spreader system, and in-cab controls and displays are successfully installed, and they function as expected.

DISCUSSION

Each state provided a snowplow truck and plows on which add-on technologies were installed. Different private sector partners provided the material applicators for each of the three prototype vehicles, which were configured to meet the needs of each state. Because of the differences in trucks, the in-cab displays were also configured differently in each state's vehicle. Each prototype maintenance vehicle is therefore unique. Specific details are discussed in the sections of this chapter for each state's vehicle.

Iowa Prototype Vehicle

Truck

O'Halloran International, Incorporated, located in Altoona, Iowa, supplied Iowa's base truck, a 1996 International Navistar 4900, model number NAV 4900. Monroe Truck Equipment (Monroe), located in Monroe, Wisconsin, was the fabricator and installed the snow plows and the chemical and abrasive spreaders. Monroe also installed and conducted initial testing of Iowa's prototype vehicle's technological components.

Plows

Monroe supplied three plows and one spreader for Iowa's prototype vehicle. The front plow is an MTE MV-96-84-50-304-SS model. The wing plow is a heavy-duty benching wing with 11-foot moldboard and a benching height of 60 inches. The model number is MTE HDBW-11. The eight-foot moldboard underbody plow's (scraper) model number is MTE TS961B.

Iowa DOT mechanics encountered challenges when mounting the switches to determine plow positions. The initial hydraulic pressure switch installed in the hydraulic lines for the wing plow was unreliable, and mechanics replaced it with a magnetic proximity switch. The magnetic proximity switch, which senses when the wing plow is next to the cab ("plow up"), proved reliable. A second challenge was the underbody plow sensors. Initially, only one pressure switch was installed in the hydraulic line for one of the hydraulic cylinders. However, because two hydraulic cylinders are used to provide independent left- and right-down pressure, Iowa DOT mechanics later installed one pressure switch for each underbody plow hydraulic cylinder, solving the problem.

Two side-by-side underbody plow gauges were located in the prototype vehicle's cab, as show in Figure 5-1. The underbody plow gauges are the two on the right with black lettering against white backgrounds.

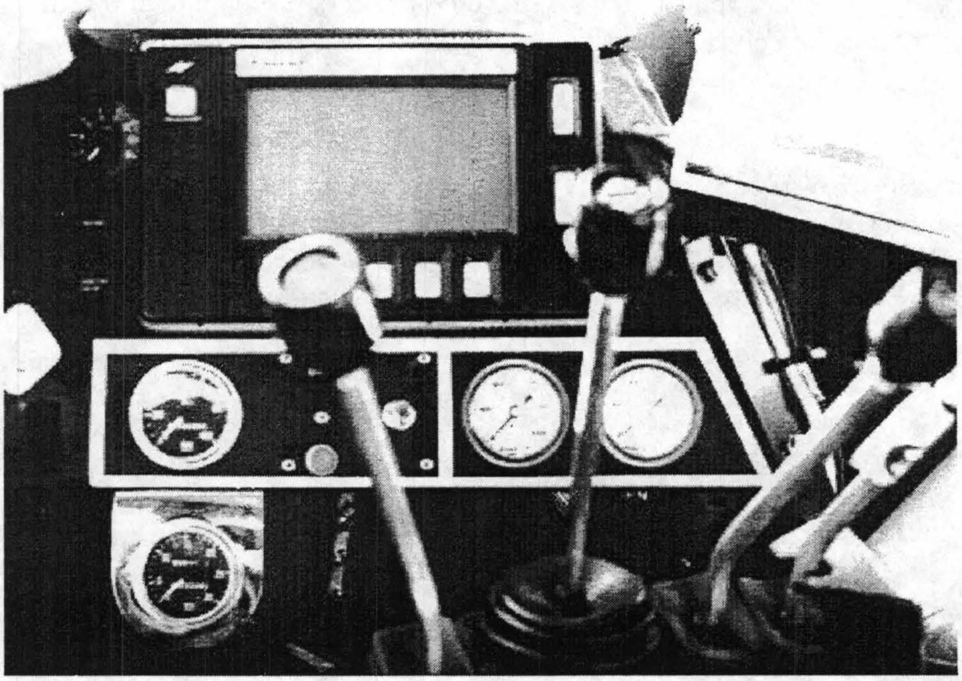


Figure 5-1 Gauges, Iowa vehicle

Spreader

The slip-in, single skid-mounted, 900-gallon liquid tank and 5.2 cubic yard Monroe Brute MSV heavy duty V-box spreader are located inside the Iowa prototype vehicle's dump box. The anti-icing and prewetting systems are controlled by the vehicle operator in the cab by a SYN/CON controller provided by Bristol Company. A Spreadrite controller provided by Component Technology dispenses granular materials.

Bristol Company, located in Broomfield, Colorado, supplied the SYN/CON onboard controller system in the cab for deicing and prewetting system control. This controller can store up to eight settings for liquid and granular material, each with six subsettings for prewetting material applications. These settings and subsettings allow for custom chemical and abrasive material applications that respond to level-of-service requirements and storm conditions.

Component Technology, located in Des Moines, Iowa, supplied the Spreadrite GL-400 modular spreader control system, which automatically adjusts material application rates to compensate for changing travel speeds. After a material application rate has been selected, the GL-400 uses a vehicle speed sensor to automatically adjust the feeder drive and maintain a uniform spread rate. This setup allows the equipment operator to concentrate on operating the vehicle safely, not on changing the material output rate. The GL-400 also has a manual mode option, which allows the equipment operator to manually control the material application rate, and a manual " blast" mode that overrides the selected material application rate for short time periods. The variable speed material applicators worked well; operators responding to CTRE's user survey appreciated the ease of vehicle operation made possible by the spreaders.

Inside the Cab

Through experimentation, Iowa DOT mechanics determined their optimum configuration for displays and controls in the prototype vehicle's cab. The first challenge was locating the PlowMaster and friction meter displays. They were first installed on a pedestal behind the driver's right elbow, where they were difficult for operators to view when they were driving the vehicle. See Figure 5-2.

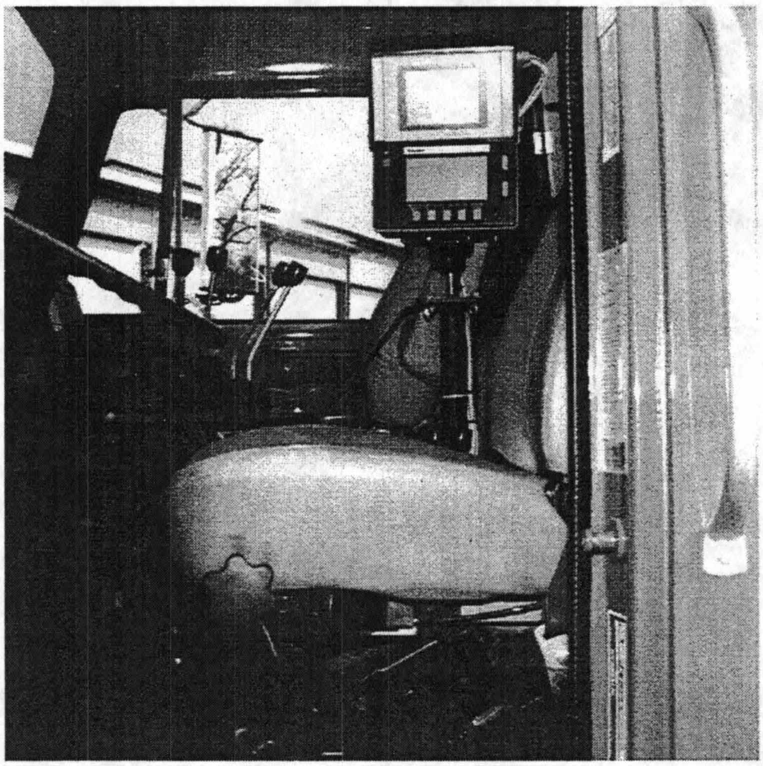


Figure 5-2 Initial placement of PlowMaster and friction meter displays, Iowa vehicle

To make the displays easier for the drivers to see, Iowa DOT mechanics mounted them in another location to the front and right of the driver, on the dash. However, this location blocked some of the controls and vents on the dash.

Iowa DOT mechanics next built a wrap-around dash extension of sheet metal to free up the dash and provide even easier accessibility to the PlowMaster and friction meter displays. See Figure 5-3. This final location was conceived by DOT mechanics after they observed a similar dashboard setup in over-the-road semis. DOT mechanics can easily remove and re-mount the dashboard extension because the original dashboard bolt holes are used.

The PlowMaster display is mounted behind the snowplow blade levers. (Eventually, friction meter information was incorporated into the PlowMaster display, and the friction meter display removed from the cab.) To the immediate left of the PlowMaster display are two gauges, the air filter restriction indicator (on top), and Sprague's temperature sensor system (on bottom).

Figure 5-3 Final placement of displays and technology gauges, Iowa vehicle

Immediately below the PlowMaster display is the control for the Fosseen engine booster system. The control area includes an alcohol pump pressure gauge and an on/off switch for the injection system. A green light indicates when the alcohol tank is empty. The gauge reads 15-20 psi (normally 17 psi) when the alcohol system is not injecting alcohol engine, and increases to 60 psi when the alcohol injection system is active.

To the immediate right of the alcohol injection system's control area are two hydraulic pressure gauges for the underbody plow. Since the underbody plow has independent left- and right-down pressure cylinders, two gauges are used. This configuration enables the equipment operator to observe the hydraulic pressure of each cylinder. Refer to Figure 5-4.

Iowa DOT mechanics also encountered challenges installing the friction meter computer. This computer was first located upright behind the passenger seat, which provided minimal legroom for the passenger. To overcome this, DOT mechanics removed the passenger seat's suspension base, built a custom-made cabinet/box suspension combination, and placed it underneath the passenger seat. The cabinet has a "drawer" for easy access to the computer unit.

Figure 5-4 Material applicator controls, Iowa vehicle

Michigan Prototype Vehicle

Truck

Navistar International Corporation, located in Fort Wayne, Indiana, supplied the Michigan snowplow truck. The truck is a 1996 International Navistar 2574, model number NAV 2574. Monroe functioned as the fabricator and provided initial installation of the prototype truck's technological components.

Plows

Monroe supplied all three plows for Michigan's prototype vehicle. The front plow is an MTE DSM-120-86-48/304-MICH model. The wing plow is a model MTE RMJW-10. The underbody plow's (scraper) model number is MTE 050-9012-0000-MICH.

Spreader

Michigan's vehicle has a 6.5 cubic yard Monroe Duz Mor chassis-mounted, self-unloading V-box with a spinner spreader and permanent 900-gallon liquid tank mounted in front of he V-box. The anti-icing and pre-wetting systems use a Raven de-ice system controller in the cab.

Raven Industries, Incorporated, located in Sioux Falls, South Dakota, supplied a DCS 700 de-ice system controller for the anti-icing and pre-wetting system. The DCS 700 consists of a computer-based control console, a speed sensor, two control valves, flow meter, granular rate sensor, and cable controls. The console mounts directly in the cab of the vehicle for operator use. The speed sensor is mounted on the vehicle. The motorized control valves, flow meter, and granular rate sensor are mounted to the vehicle framework. The equipment operator sets the target application rate for each product, and the DCS 700 uses the speed sensor to automatically maintain uniform material flow relative to vehicle speed and gear selection. A manual "blast" mode can be selected to allow the equipment operator to override the material application rate for short periods of time The DCS 700 also monitors distance and speed, and totals all materials spread, to help analyze material output amounts and rates. As in Iowa, the operators greatly appreciated the convenience of the speed-regulated material application system.

The first challenge involving the Michigan prototype maintenance vehicle was to find spray nozzles that would meet Michigan's standard procurement specifications—120 gallons per lane mile (for two lanes) at 60 mph, or 240 gallons per mile (gpm). Monroe's solution was a three-tiered system that activates three different booms per lane at various speeds and at the specification application rates. Raven Industries—Monroe's ground speed material applicator supplier—and Monroe developed a switching circuit to activate the system for the specified flow rates and associated vehicle speeds.

After the challenge involving material application rates was successfully met, another challenge arose—installing three-inch diameter pipes, hoses, fittings, and a liquid de-icer pump, to meet Michigan's standard procurement specifications for liquid material flow rates. The original 12-volt direct current ball valves selected by Monroe were replaced because of the room required to accommodate the hose barbs and the size of the components. Monroe selected an American National Standards Institute (ANSI) butterfly valve, which shortened the valve lengths and provided easier serviceability access. Monroe used stainless steel piping and welded elbows, flanges, and tees to complete the spray bar assemblies. This setup provided unrestricted liquid material flow and a smaller configuration.

Another challenge was meeting the Michigan DOT's performance specifications for the granular material spreader. A wider conveyor and relatively light Michigan DOT application rate specifications required a slow-moving conveyor. Monroe preferred a faster moving belt with a lower gate/door opening, which would allow the hydraulic components to perform better. Monroe provided an adapter opening to improve spreader performance, resulting in more uniform distribution of material within Michigan's specifications.

Inside the Cab

Through experimentation, Michigan DOT mechanics determined their optimum configuration for displays and controls in the prototype vehicle's cab. See Figure 5-5 for a picture of the Michigan prototype vehicle cab controls.

Figure 5-5 Michigan prototype vehicle cab controls

Minnesota Prototype Vehicle

Truck

Boyer Ford, located in Minneapolis, Minnesota, supplied Minnesota's base truck. The truck was a 1996 Ford L9000. Tyler Ice, a division of Tyler Industries, Incorporated, located in Benson, Minnesota, functioned as the fabricator for, and provided initial installation of, the prototype truck's technological components.

Plows

The Minnesota DOT purchased all three plows themselves and mounted them in-shop. The underbody plow on the Minnesota prototype vehicle is not capable of changing its vertical angle.

Spreaders

A slip-in Tyler V-blend, dual chamber V-box is located inside the dump body. It is a divided spreader box, allowing operators to distribute a ratio of two granular materials. In addition, the vehicle has a 900-gallon liquid tank.

The anti-icing, deicing, and prewetting functions are controlled in the cab using a Tyler Industries Quantum Controller, and a Tyler Industries LDS-1000 Anti-Ice System. These systems enable the equipment operator to specify and maintain predetermined material application rates. In addition, the Quantum Controller uses a speed sensor to automatically maintain uniform material flow relative to the vehicle speed and gear selection. A manual

" blast" mode can be selected to allow the equipment operator to override the material application rate for a short time. As in Iowa and Michigan, the operators appreciated the convenience of the semi-automated spreader system.

Inside the Cab

Tyler Ice's challenge with the Minnesota vehicle's cab controls was to find enough space for the extra displays and controls—anti-icing control and pressure gauges, the Tyler Quantum controller, the friction meter computer, and the hydraulic controls for the plows. To accommodate all the controls and make them easily accessible to operators, Tyler built a customized console-type mounting, with the controls wrapped around the driver's seat as shown in Figure 5-6. The computer for the friction meter was installed on the floor, in front of the engine cover, making for a crowded cab. Figure 5-7 shows the PlowMaster display, and Figure 5-8 shows material applicator readouts.

Figure 5-6 Cab controls, Minnesota vehicle

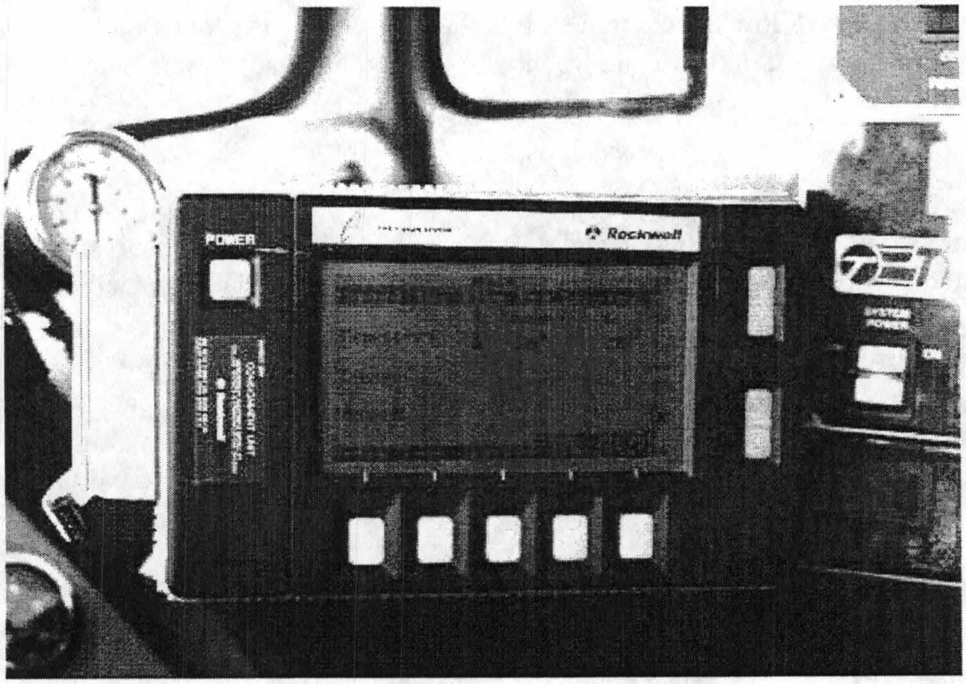


Figure 5-7 PlowMaster display, Minnesota vehicle

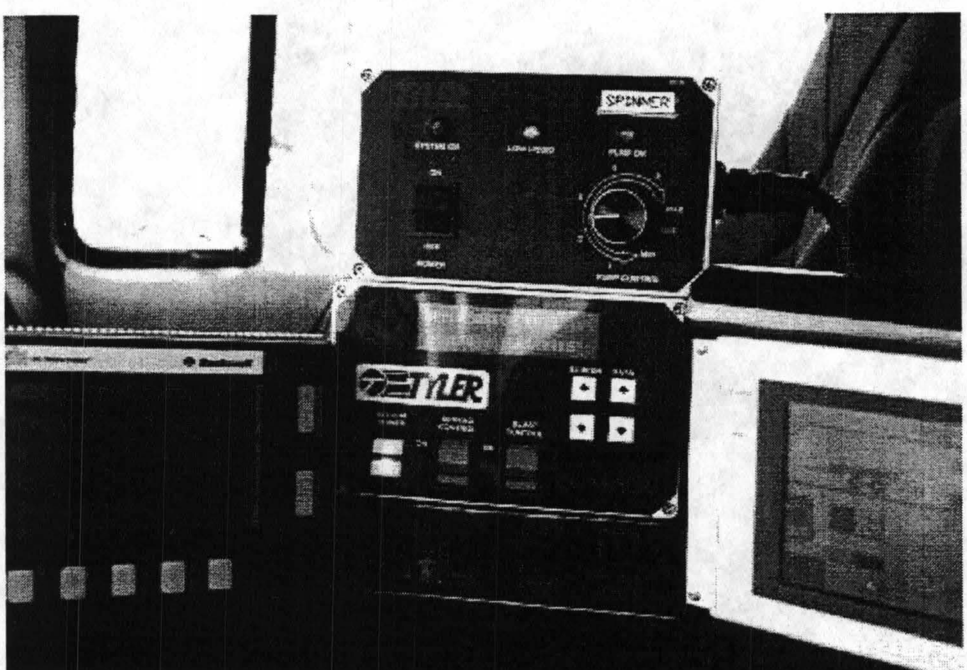


Figure 5-8 Material applicator controls, Minnesota vehicle

OBSERVATIONS

Proof of concept was successful for this stage of the project. Each state DOT in the consortium provided one snowplow truck equipped with plows, winter chemical and abrasive spreader systems, and in-cab displays and operator controls. Fabrication and installation activities during Phase II proved the feasibility of making a significant amount of technology and information available to the operator in the cab. Each vehicle is unique, but all three provide similar plowing and spreading capabilities. Generally, installation of all the PlowMaster display, operator controls, and gauges in the cabs made cab conditions quite crowded, but each state modified the in-cab installations to provide safe and efficient operating conditions for drivers. In Phase III, as more of the add-on systems are automated and coordinated through the PlowMaster (e.g., the material application systems), the in-cab configurations may be revised.

CHAPTER 6: PLOWMASTER

Many of the desired maintenance vehicle functions identified by the focus groups, as well as many of the desired improvements in maintenance management practices identified by the participating states, rely on the collection, delivery, and management of data about the maintenance vehicle's immediate environment, roadway conditions, and onboard systems. Rockwell International's PlowMaster mobile computer system (PlowMaster) is the centerpiece of the prototype maintenance vehicles, performing data integration and formatting functions critical to successful realization of the advanced-technology vehicle concept. Rockwell developed the PlowMaster from its own mobile computer system for transit applications. Installed onboard the vehicles, the PlowMaster collects data transmitted from vehicle sensors and other technologies, formats data in a common format, displays data in user-friendly formats for the operator in the cab, and stores data on a removable Personal Computer Memory Card International Association (PCMCIA) card for off-board data delivery. The PlowMaster has cellular and radio communications capabilities; the study team plans that, in future phases, the PlowMaster will perform off-board data communications via cellular, and perhaps eventually, radio communications.

The relationship between the PlowMaster and other technologies installed on the prototype maintenance vehicles for this study is shown in Figure 6-1. The primary components of the PlowMaster are a smart Mobile Data Terminal (MDT) and a Flexible Interface Adapter (FIA), shown in Figure 6-2.

This chapter discusses the main features of the PlowMaster, as well as installation, operations, and performance results during Phase II. See Appendix C for Rockwell's complete guide to the PlowMaster mobile computer system.

OBJECTIVE

Conduct proof of concept regarding incorporating a central, onboard, computerized data collection and management system on winter maintenance vehicles.

MEASUREMENT

The PlowMaster MDT and FIA are successfully installed on the prototype vehicles, and they operate as expected. Expected performance includes the following: Data from the subsystems (friction meter measurements, air/pavement temperatures, global positioning system (GPS) location and time, snow plow positions, power booster information, etc.) are collected by the onboard computer, formatted for user-friendly display on the in-cab terminal and for use in management systems, and stored on a removable PCMCIA card for off-board delivery. Data from the PCMCIA cards are found to be complete and formatted so that they can be manipulated for use in decision making and management processes. Equipment operators give a favorable report of information provided by, and the user friendliness of, the PlowMaster in-cab display.

DISCUSSION

The following sections discuss the components, installation and operations, and performance of the PlowMaster on the prototype winter maintenance vehicles.

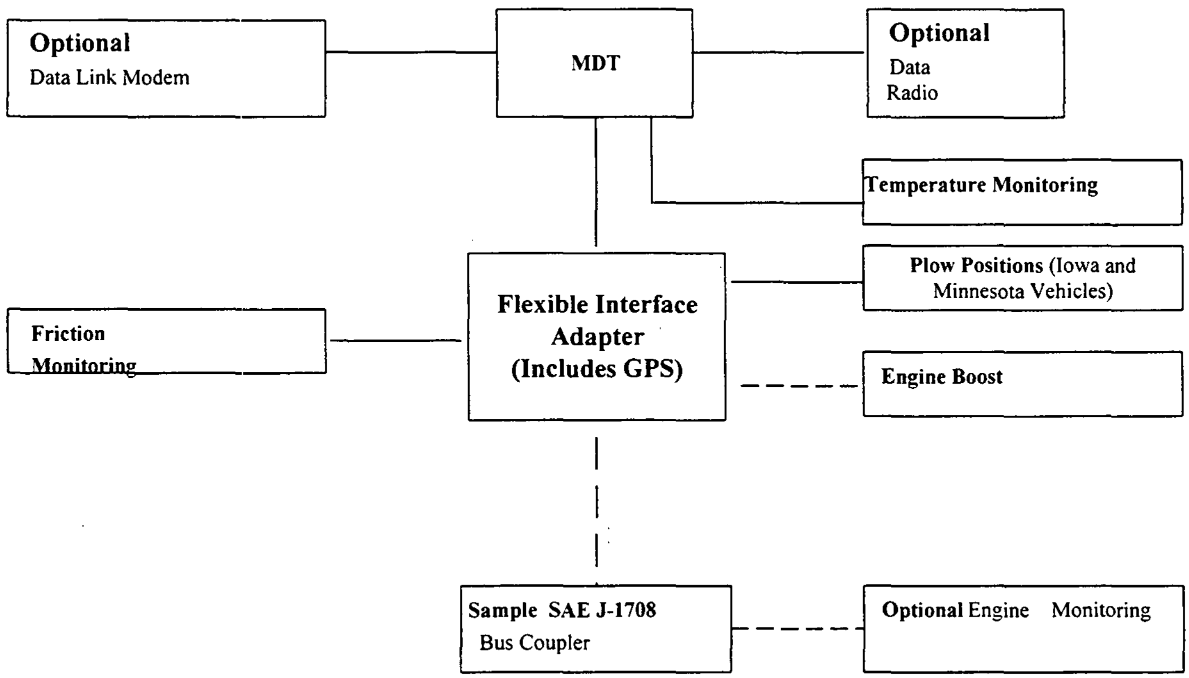


Figure 6-1 Interfaces between PlowMaster and other add-on technologies

PlowMaster Components and Installation

Table 6-1 lists PlowMaster components.

Table 6-1 Equipment supplied

Equipment Name	Vendor	Part No.
Mobile Data Terminal (MDT)	Rockwell Collins, Inc.	822-0972-004
Flexible Interface Adapter (FIA)	Rockwell Collins, Inc.	822-1125-002
FIA Terminal Adapter	Rockwell Collins, Inc.	988-5946-001
GPS Antenna (optional)	Rockwell Collins, Inc.	MA/COM pn AMP-C-114

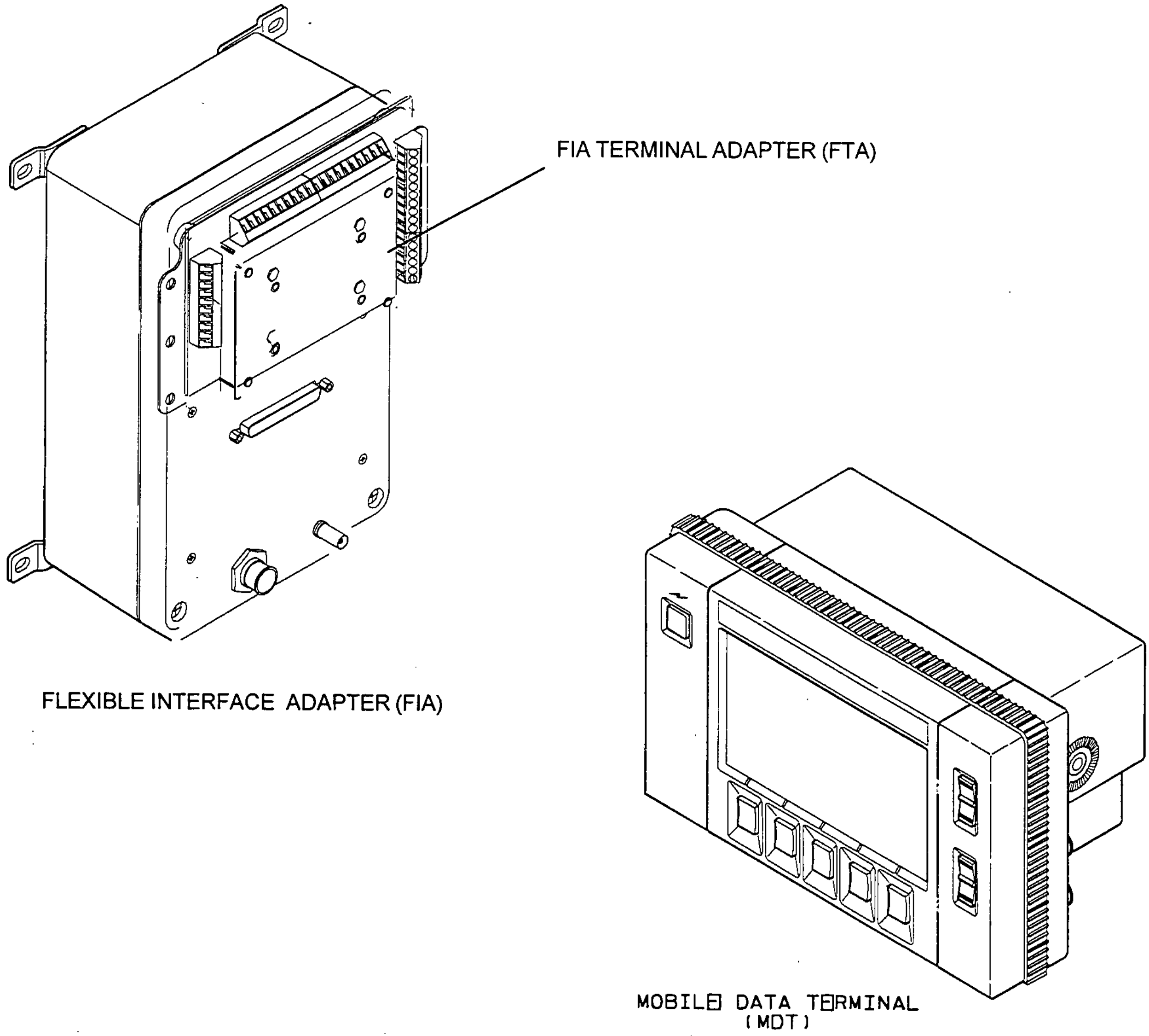


Figure 6-2 PlowMaster equipment

Flexible Interface Adapter

The FIA is the heart of the PlowMaster system. The FIA is a single, integrated unit containing an electrical interface to the MDT and other vehicle subsystems, a radio interface, and integral GPS receiver (engine). As shown in Figure 6-2, the FIA provides switching and control for numerous optional inputs and outputs. The GPS receiver within the FIA locates vehicles geographically as the vehicle travels on the roadway and then stamps, or codes, data collected from other systems with GPS location and time information. (The GPS antenna and receiver are discussed in detail as a separate technology in Chapter 7.)

Mobile Data Terminal

The MDT provides the human-machine interface and display in one rugged, compact package. The MDT connects to the FIA to provide all vehicle functions for the PlowMaster system. The MDT is mounted on a swivel base in the vehicle cab and is designed for maximum reliability and minimum operator workload. After experimenting with various locations for the MDT in the cab, each state installed its MDT in slightly different positions. Iowa constructed a wrap-around dash extension for the display, and Minnesota modified the swivel post mounting to a console-type mounting. The purpose of the modifications was to free as much space in the cab as possible. (See each state's in-cab configurations described in Chapter 5.)

The operator interface consists of a three-inch by six-inch, graphics-capable (128 x 240 pixel) monochromatic liquid crystal display (LCD) and 10 backlit switches for operator interaction with the system. The screen is readable in direct sunlight and is backlit for night operation. Controls are provided to vary the contrast and brightness of backlighting. The switches are used to access information by paging through information displayed on the screen.

The PlowMaster employs Intel® personal computer (PC)-based processor architecture and uses a real-time kernel to provide multitasking features. Access to vehicle systems outside of the MDT is provided by eight hardware interfaces. These interfaces include a portable PCMCIA interface, for downloading data, and an interface to the FIA. The MDT includes a Type II PC card. The PC card provides FLASH memory for the MDT and uses a 68-pin edge connector for electrical connection to the MDT. The PC card includes the PlowMaster software information. All information is stored on each PC card. This allows any vehicle to drive any route without changing the PC card.

GPS Antenna

Rockwell's optional GPS antenna was installed above the cab on the prototype vehicles during Phase II. (See a full discussion of GPS technology, including installation and performance, in Chapter 7.)

Operations: Data Collection, Formatting, and Storage

The PlowMaster collected data, or outputs, transmitted from other add-on technologies (GPS, friction meter, air/pavement temperature sensors, etc.), translated the data into a common format, and stored them on a removable PCMCIA card. These functions are illustrated in Figure 6-3. Translation was necessary because each technology had its own data format and reporting time sequence, and the formats were generally not compatible. The diagram in Figure 6-4 shows the data output of each add-on technology collected by the PlowMaster, along with the reformatted data output. Table 6-2 provides a brief definition of each data element.

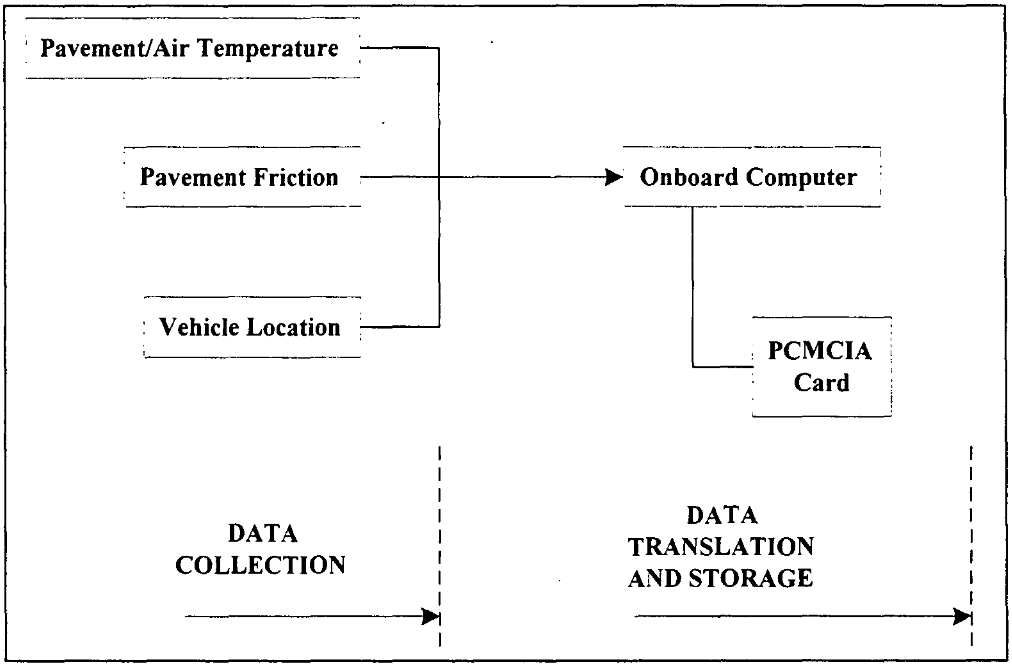


Figure 6-3 PlowMaster functions

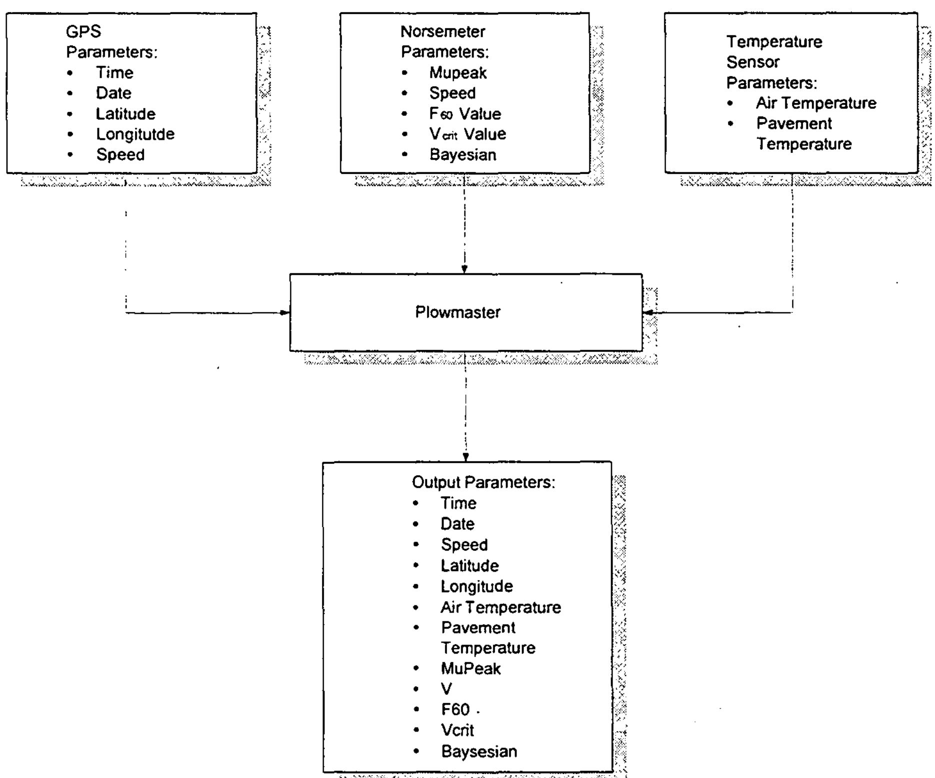


Figure 6-4 PlowMaster input/output parameters

Table 6-2 Sensor outputs

Parameter	Description
Time	Uniform Time Conversion (UTC)
Date	Date data was recorded
Latitude	GPS latitude location
Longitude	GPS longitude location
Speed	GPS speed of the vehicle in Km/h
Air Temperature	Temperature outside of the vehicle in degrees Fahrenheit
Pavement Temperature	Temperature of pavement in degrees Fahrenheit
μ_{peak}	Direct measured peak friction value
V	Slip speed, difference between the vehicle travelling speed and the tire rolling speed
C^2	Shape factor related to constant speed.
F_{60}	Measured peak friction value adjusted to a speed of 60 km/h
V_{crit}	Critical speed of vehicle at which slippage occurs
Bayesian	Statistically smoothed value for friction (averaged from several readings over a short period of time)

Tables 6-3, 6-4, and 6-5 are excerpts from data files, or sensor outputs, downloaded from the PlowMaster onboard computers, one data file for each of the prototype vehicles. The first five columns (UTC time, Lat, Lon, Heading, and GPS Speed) are GPS sensor outputs, i.e., the "GPS stamp." The next two columns (AirTemp and RoadTem) are temperature sensor outputs. The final six columns (Mu Peak, V, C2, F60, Vcrit, and Bayesian) are outputs from the friction meter sensors. Friction values recorded as "–1" indicate the sensor for that technology was not reporting at the time these data were recorded, which was early in the process verification effort. Friction values were successfully recorded at a later period in the Phase II study. . Generally, μ_{peak} is a measure of friction with a range of zero to one; the reading for μ_{peak} should therefore never be negative or more than one. PlowMaster multiplies the recorded μ_{peak} by 1,000 (to avoid fractions), creating an acceptable range for μ_{peak} up to 1,000. To obtain the actual μ_{peak} values, however, one would multiply the value shown in the table by 0.001. For example in Table 6-3, the first μ_{peak} value shown is 731. If one multiplies 731 by 0.001, the actual value for μ_{peak} is 0.731, (which is between 0 and 1). Some μ_{peak} values, however, were recorded above 1,000, indicating that the ROAR friction meter was not operating correctly.

Table 6-3 Onboard computer data file A041801.xls, Iowa vehicle, January 4, 1998

UTCTime	Lat	Lon	Heading	GpsSpeed	AirTemp	RoadTemp	MuPeak	V	C2	F60	Vcrit	Baysian
65666	41.6643169	-93.5763388	347.728	37.424	33.63	24.00	731	6647	-5871797	474	56977	717
65667	41.6644641	-93.5763818	347.613	37.446	33.63	24.00	731	6647	-5871797	474	56977	717
65668	41.6646108	-93.5764253	347.499	37.536	33.75	24.00	731	6647	-5871797	474	56977	717
65669	41.6647580	-93.5764689	347.499	37.446	33.75	24.00	731	6647	-5871797	474	56977	717
65670	41.6649047	-93.5765130	347.270	37.491	33.75	23.88	540	4068	-5871797	428	59138	670
65671	41.6650514	-93.5765560	347.671	37.312	33.75	24.63	540	4068	-5871797	428	59138	670
65672	41.6651975	-93.5765978	347.957	37.178	33.75	23.25	540	4068	-5871797	428	59138	670

Table 6-4 Onboard computer data file A141801.xls Michigan vehicle, January 14, 1998

UTCTime	Lat	Lon	Heading	GpsSpeed	AirTemp	RoadTemp	MuPeak	V	C2	F60	Vcrit	Baysian
219765	44.0059180	-85.5030835	192.170	10.133	31.25	23.88	-1	-1	-1	-1	-1	-1
219766	45.0059180	-84.5030835	193.170	11.133	32.25	24.88	-1	-1	-1	-1	-1	-1
219767	46.0059180	-83.5030835	194.170	12.133	33.25	25.88	-1	-1	-1	-1	-1	-1
219768	47.0059180	-82.5030835	195.170	13.133	34.25	26.88	-1	-1	-1	-1	-1	-1
219769	48.0059180	-81.5030835	196.170	14.133	35.25	27.88	-1	-1	-1	-1	-1	-1
219770	49.0059180	-80.5030835	197.170	15.133	36.25	28.88	-1	-1	-1	-1	-1	-1
219771	50.0059180	-79.5030835	198.170	16.133	37.25	29.88	-1	-1	-1	-1	-1	-1

Table 6-5 Onboard computer data file A13b701.xls Minnesota vehicle, February 5, 1998

UTCTime	Lat	Lon	Heading	GpsSpeed	AirTemp	RoadTemp	MuPeak	V	C2	F60	Vcrit	Baysian
417826	44.6563648	-93.6771439	242.934	42.233	26.38	19.00	680	-63	0	0	100	458
417827	44.6562875	-93.6773564	242.877	42.345	26.25	17.88	680	-63	0	0	100	458
417828	44.6562101	-93.6775690	242.934	42.256	26.25	17.63	680	-63	0	0	100	458
417829	44.6561339	-93.6777827	243.335	42.300	26.38	18.63	680	-63	0	0	100	458
417830	44.6560577	-93.6779964	243.564	42.323	26.38	17.00	680	-63	0	0	100	458
417831	44.6559821	-93.6782102	243.564	42.233	26.38	17.38	680	-63	0	0	100	458

Operations: MDT Display

In addition to collecting, translating, and storing data from other add-on technologies, the PlowMaster displayed these data in understandable formats for the vehicle operators on the MDT in-cab displays. Location data provided by the GPS were not displayed on the in-cab display; however, loss of GPS signals and information was highlighted on the MDT as an alert.

Rockwell programmed the display screens, or pages, for road maintenance operations, and the consortium states agreed which display screens to implement.. Because raw data collected by the vehicles' add-on technologies were not helpful to vehicle operators, the MDT display pages were refined during Phase II to provide information in user-friendly formats as described in this chapter. CTRE staff worked closely with equipment operators and Rockwell to fine-tune the in-cab displays, concentrating on developing easy-to-read menus and screens that presented information in convenient formats. For example, operators did not want to see friction values; they wanted to know whether roadway traction conditions were good, fair, or poor.

MDT Screen Setup

Vehicle operators access PlowMaster functions using two rocker switches and five function switches on the top right side of the MDT display, bottom right of the display, and along the bottom of the display. The switches and display screen are clearly shown in Figure 6-2. The top rocker switch selects an item on a page, and the bottom rocker switch changes the value of the selected item. Function switches across the bottom of the MDT for the main screens typically provide the following:

F1 – Setup
F2 – Temperature
F3 – Spreader
F4 – Traction
F5 – Plow status

For example, from the PlowMaster main page, pressing the function switch under the word "Temperature" (F2) changes the screen to the temperature page.

Operator Log In

Generally, before each data capture trip, vehicle operators must log in to, or initialize, the PlowMaster using the MDT toggle switches. The typical log-in procedure associates the operator with the assigned route to be driven and ensures the operator is authorized to access the vehicle. When the vehicle is started, the MDT prompts the operator to enter a driver identification number and the assigned route identification. Once the correct data are entered, the system automatically moves to the main page. If power is removed from the MDT after the driver is logged in and later restored, the MDT will return to the main page and automatically log in the operator to the same assigned route. However, if the run switch is turned off while the driver is logged in, the MDT logs off automatically.

If the vehicle system detects the vehicle has moved more than 1,000 feet prior to log-in completion, the operator is prompted by the MDT to complete the log-in procedure. After real-time communications have been implemented, if a vehicle continues to move more than 2,000 feet prior to operator log-in, the dispatcher/base station will be advised of a possible theft. When another operator assumes control of the vehicle, the initial operator must log out of the system and the new operator must enter the proper driver ID. The MDT maintains the previously entered route identification numbers.

Main Page

Figure 6-6 shows the MDT's main page.

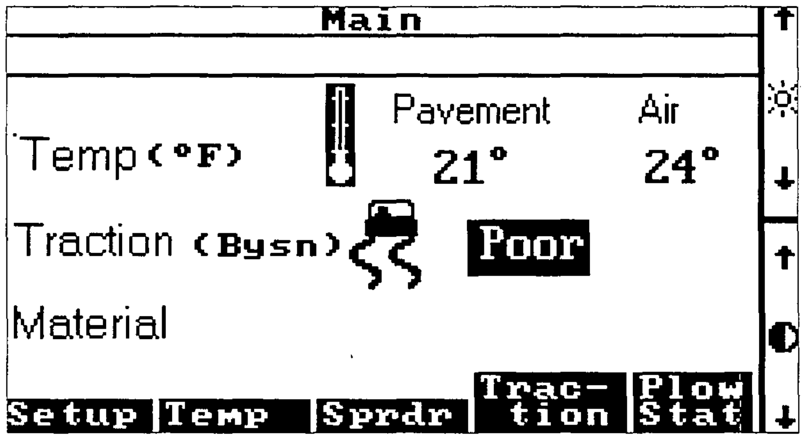


Figure 6-6 Typical main page

The main page of the PlowMaster displays current data collected through the operational sensors. When the light bulb and the half-blackened circle are displayed on the right side of the page, the top rocker switch on the right of the screen controls the brightness and the bottom rocker switch controls the contrast of the MDT display. The line under the title "Main" at the top of the page is called the advisory line. Advisories appearing on this line and the appropriate corresponding maintenance action are listed Table 6-6.

On the main page, both pavement and air temperatures are presented in degrees Fahrenheit. The thermometer icon to the left of the temperature indicators appears when a condition degrades to poor or falls below settings established by a supervisor as fair. The icon flashes to attract the attention of the vehicle operator and remains flashing for 45 seconds after first appearing.

The main page also displays road traction conditions. The conditions are calculated as friction coefficients, using data collected through the friction meter sensors. These coefficients are generally meaningless to operators, however, so Rockwell programmed the PlowMaster to translate the coefficients into good, fair, or poor, based on operator settings. When roadway surface traction conditions degrade to poor (i.e., fall below the setting established as fair), the slippery icon (Manual of Uniform Traffic Control Devices W8-5) to the left of the traction indicator, along with the word "Poor," appears on the screen. The icon flashes for 45 seconds.

The last row of data is reserved for identification of chemical materials used in road maintenance application. These data were not provided by the PlowMaster in Phase II.

Table 6-6 Maintenance advisory messages

Advisory	Maintenance Action Required
Log-in Required	None; operator must log in before beginning route
Insert Data Card	Ensure PCMCIA card is inserted into MDT
Data Card Full	Ensure empty PCMCIA card is inserted into MDT
Software Load Failed	MDT reprogramming was unsuccessful
Software Loaded, Resetting	None
Loading MDT Software	None
Check Receiver Connection	Check GPS receiver for secure connection
Check Diff Connection	Check GPS engine (receiver) for secure connection
Speed Too Slow for Logging	Increase vehicle speed
Check NorseMeter	Check Norsemeter for secure connection
Check RoadWatch Connection	Check Norsemeter for secure connection
Check Data Link	Check Norsemeter for secure connection
Data Card Load	None
Check GPS Antenna	Check GPS antenna for secure connection
Receiver Searching for Sats	None
Check Differential Source	None; suggest moving vehicle 400 feet
Poor Satellite Geometry	None; suggest moving vehicle 400 feet
Old Correction Data	None; suggest moving vehicle 400 feet
Receiver Position Degraded	None; suggest moving vehicle 400 feet
Receiver Position Obtained	None

Temperature Page

Pressing setup (F1) from the main page selects the maintenance page. This page was not intended to be operational during Phase II.

Pressing F2 from the main page accesses the temperature page. Refer to Figure 6-7.

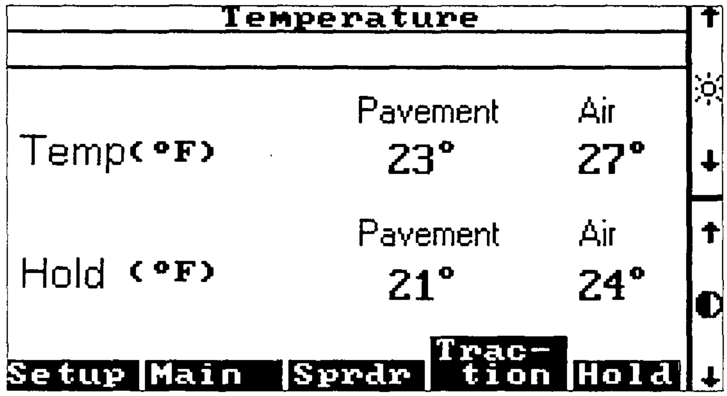


Figure 6-7 Temperature page

On the temperature page, notice the F2 switch now selects the main page. Pressing F2 from the temperature page returns the operator to the previous page, or main page.

The temperature page contains an advisory line (the line is blank in Figure 6-7) directly under the title of the page. For a listing of advisories, refer to Table 6-6.

Pavement and air temperatures are displayed in the top half of the screen. Had a trend been established from these changing values, an up or down pointing arrow indicator (↑) or (↓) would have appeared adjacent to the temperature readings indicating the direction of the trend. Temperature trends are established through the temperature setup display; see the next section.

The bottom half of the screen indicates the pavement and air temperatures when the operator pressed the Hold (F5) switch. The purpose of the hold function is to save a record of temperature readings at a specific time and location. At a later time or during a return run, the operator can compare current temperatures against temperatures held in hold.

From this screen, the operator may access the temperature setup page (F1), return to the main screen (F2), continue to the spreader page (F3) or traction page (F4), or press F5 to hold another set of pavement and air temperatures.

Temperature Setup Page

Pressing F1 from the temperature page accesses the temperature setup page. Refer to Figure 6-8.

The temperature setup page contains an advisory line directly under the title of the page, which is currently blank. For a listing of advisories, refer to Table 6-6.

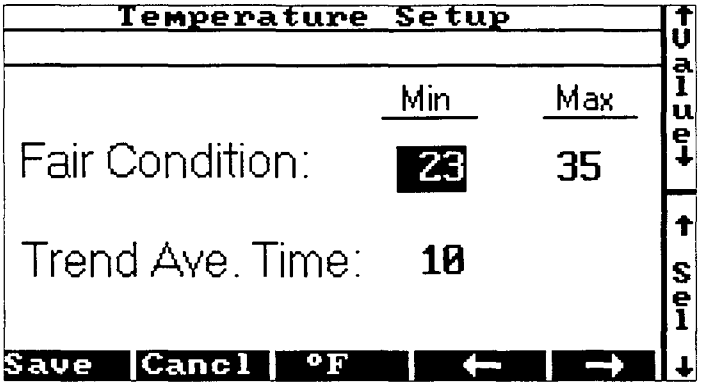


Figure 6-8 Temperature setup page

The top portion of the temperature setup page displays minimum and maximum temperature settings that define fair temperature conditions. The study team set the value for the fair condition during the June 24, 1997 meeting held in Cedar Rapids, at the Rockwell complex. Generally, the range for fair is from 32° F (below 32° F, the condition is poor) to 35° F; however, a 35° F temperature that is dropping quickly also changes to a poor temperature condition.

The bottom portion of the page displays the length of time, in seconds, for which PlowMaster will average temperatures to define trends. Pressing the bottom rocker switch moves the cursor between these two sections of the setup page. Pressing the top rocker switch increases or decreases the value selected. Switches F4 and F5 move the cursor left or right across the screen.

PlowMaster averages the temperatures recorded over the time set on this screen and compares the average with the previous average, then displays the arrow trend indicator on the temperature page to show if temperatures are generally rising or falling. When the temperature drops below the maximum fair condition, the advisory icon thermometer appears on the main page, indicating a fair to poor condition exists. When temperatures rise above the maximum fair condition, the advisory icon disappears, indicating a good condition exists.

Pressing F1 saves the information selected on this page and returns to the temperature page.

Pressing F2 cancels the information selected, reverting the system to previous information selected on this screen, and automatically returns to the temperature page.

Pressing F3 toggles between degrees Fahrenheit and Celsius.

Spreader Page

Pressing F3 from the main page accesses the spreader page. See Figure 6-9.

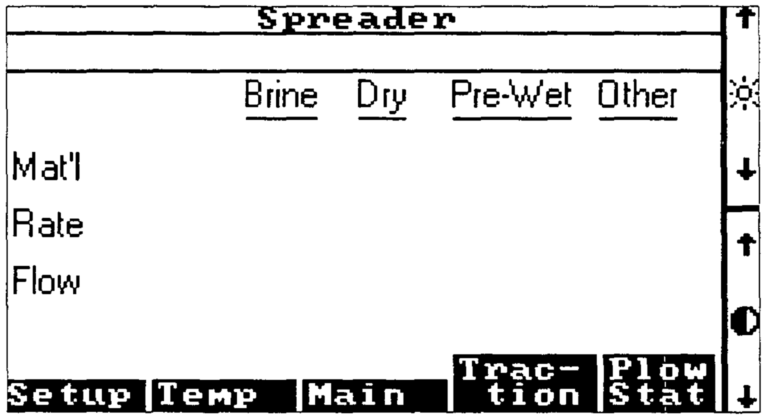


Figure 6-9 Spreader page

Although it was not implemented in Phase II, the spreader page can provide information about ice and snow control materials, their dispersal rate, and flow preparedness. These materials might include salt brine, dry and pre-wet chemicals, and a category designated for other agents used in road maintenance. Pages available from the spreader page are the spreader setup page (F1), temperature (F2), main (F3), traction (F4), and plow position status (F5).

Friction Monitor Page

Pressing F4 from the main page accesses the friction monitor page. Refer to Figure 6-10.

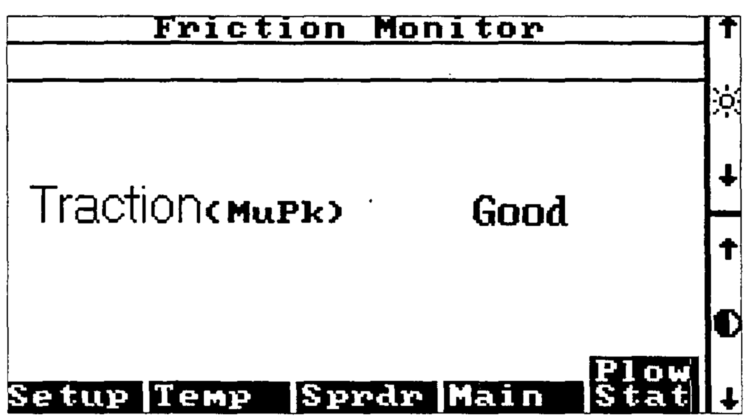


Figure 6-10 Friction monitor page

The friction monitor page contains an advisory line directly under the title of the page, currently blank. For a listing of advisories, refer to Table 6-6.

The friction monitor page displays road condition information based on the amount of traction the vehicle wheels have on the pavement. Traction is evaluated using a friction coefficient of μ_{peak}, F60, or Bayesian, which is selected from the friction meter setup page (F1); see the next section. The condition is evaluated in terms of good, fair, or poor. When the traction drops below the minimum fair condition, an advisory icon (Manual on Uniform Traffic Control Devices W8-5, "slippery when wet") appears on the main page, indicating a poor condition exists. When traction rises above the minimum fair condition, the advisory icon disappears indicating a fair condition exists and the friction monitor page displays a fair condition. Pages available from the friction monitor page are the friction meter setup (F1), temperature (F2), spreader (F3), main (F4), and plow position status (F5).

Friction Meter Setup Page

Pressing F1 from the friction monitor page accesses the friction meter setup page. Refer to Figure 6-11.

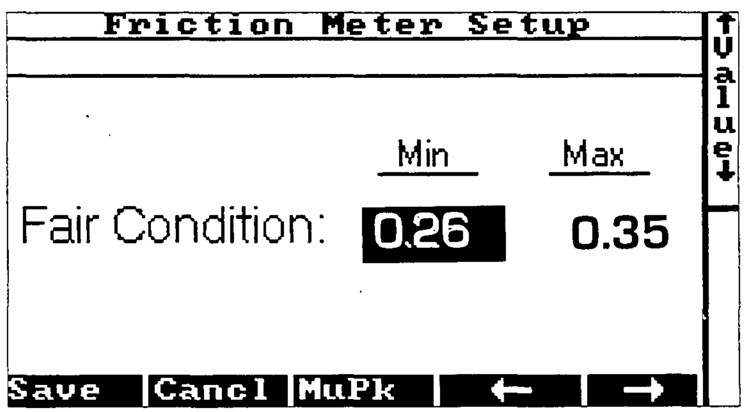


Figure 6-11 Friction meter setup page

The friction meter setup page contains an advisory line directly under the title of the page, currently blank. For a listing of the advisories, refer to Table 6-6.

Using data collected by the friction meter, PlowMaster stores friction conditions as a Bayesian, μ_{peak}, or F60 coefficient. μ_{peak} is the standard coefficient for friction. F60 is the result of the μ_{peak} coefficient at 60 kilometers per hour. The Bayesian coefficient is the calculation for friction based on a composite of averages represented as a nonlinear function. The friction setup page contains minimum and maximum coefficients of friction selected by the study team to define a fair traction condition.

At the June 24, 1997 meeting at Rockwell in Cedar Rapids, Iowa, the study team reviewed criteria used by traffic engineers to determine when wet pavement sections are slick enough to require posting special signs. The team set the default average μ_{peak} range for a fair traction condition at 0.26 – 0.35. If average μ_{peak} falls below .26, the display shows poor traction conditions; if average μ_{peak} is above .35, the display shows good traction conditions. It should be noted that this range of values for fair traction conditions applies to wet pavements, not to ice- or snow-covered pavements. During Phase III, the study team will consult the Federal Highway Administration's *Test and Evaluation Project No. 28: Anti-icing Technology, Field Evaluation Report* and other ongoing research across the country regarding winter roadway traction conditions and, based on their findings, will adjust the default fair traction range to reflect winter roadway conditions.

Pressing the top rocker switch increases or decreases the "fair" values selected. Switches F4 and F5 move the cursor left or right across the screen. Pressing F1 saves the information selected on this screen and returns to the friction monitor page. Pressing F2 cancels the information selected, reverting the system to previous information selected on this screen, and returns to the friction monitor page. Pressing F3 toggles between μ-peak, F60, or Baysian friction coefficients.

Plow Status Page

Pressing F5 from the main page accesses the plow status page. Refer to Figure 6-12.

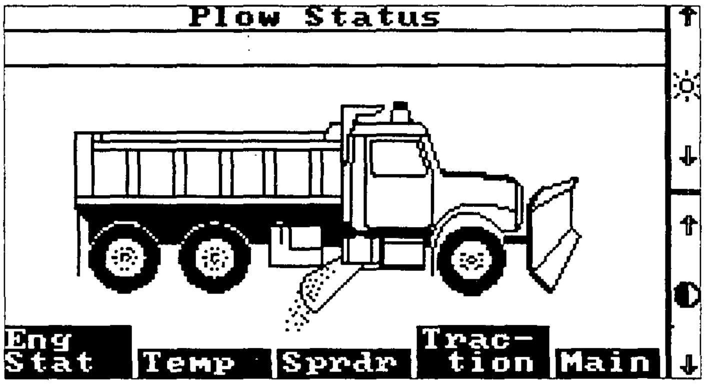


Figure 6-12 Plow status page

The plow status page contains an advisory line directly under the title of the page, currently blank. For a listing of advisories, refer to Table 6-6.

When visibility is poor, operators often cannot see if the plow blades are engaged. The plow status page gives the operator a quick graphical representation of the three plows (front, carriage, and wing) in service and activated. Active plows appear on the screen; unengaged plows do not appear on the screen. In Figure 6-12, the front and carriage plows are active. In Figure 6-13, all three plows are active (front, carriage, and wing). Pages available from the plow status page are the engine status page (F1), temperature (F2), spreader (F3), traction (F4), and main page (F5).

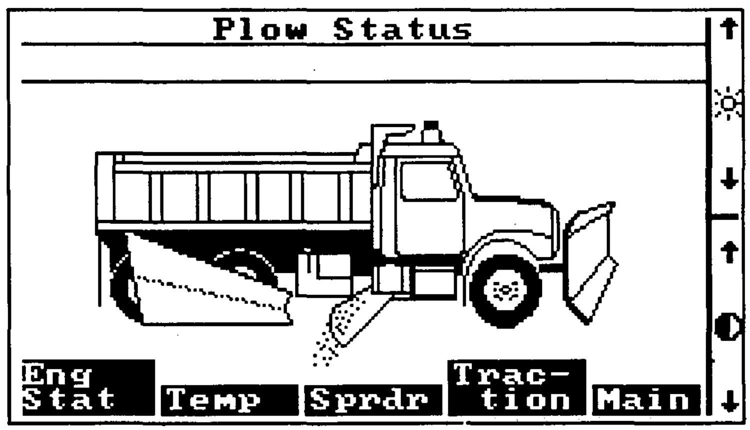


Figure 6-13 Full plow status page

Engine Status Page

Pressing F1 on the plow status page in Figures 6-9 or 6-10 accesses the engine status page. Refer to Figure 6-14.

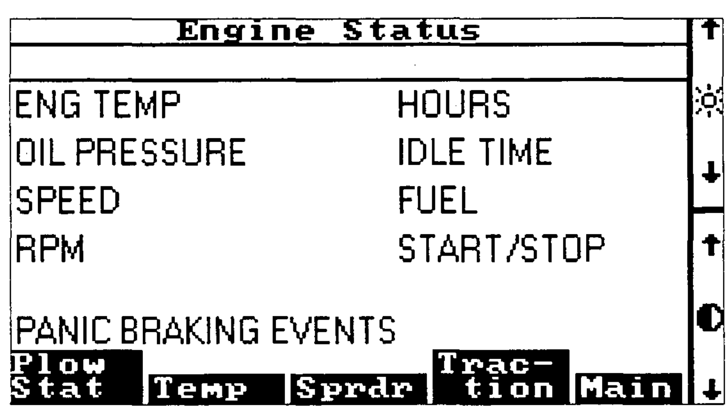


Figure 6-14 Engine status page

The engine status page, which was not implemented in Phase II, can provide information about engine maintenance and current data indicating engine performance: engine temperature, oil pressure, speed, revolutions per minute, hours of operation, idle time of operation, fuel level, and number of starts and stops. Engine status functionality, with software apparatus and sensor interface, is currently under development. Pages available from the engine status page are the plow status page (F1), temperature (F2), spreader (F3), traction (F4), and main (F5).

Log-Out Procedures

At the end of the shift, the operator logs off the MDT. To log off, the operator repeatedly presses a function switch until F2 displays LOG OUT. The operator presses F2, and the screen returns to the log-in page. The values for driver ID, and route designation remain. A new driver on the route needs to change only the driver ID.

When the vehicle is shut off, the MDT remains on for a length of time determined by supervisor dispatch. This allows the operator to log off the MDT after the vehicle is shut off. It also prevents loss of MDT data in case of a temporary shutdown on the road and allows dispatch to communicate with the MDT after the end of a road maintenance run.

If the vehicle is off long enough while en route for the MDT to shut itself off, the route designation and driver ID, odometer readings, disabled mechanical alarms, etc., are lost. The driver ID and route must be reentered when the vehicle is started.

Performance

Based on data downloaded from the PlowMaster computers and collected at CTRE, the PlowMaster successfully collected outputs from other add-on technologies on the prototype vehicles, translated them into a common format, and stored them on PCMCIA cards. Missing or inaccurate data were generally traced to operator error or sensor malfunction rather than to problems with PlowMaster performance.

The PCMCIA card was generally an effective method for delivering data to CTRE. However, the only significant system malfunction traced to a PlowMaster computer program involved a failure to download data to the card. Data could not be downloaded because, during the data capture trip, the vehicle operator had shut down the system before logging out. Rockwell developed a software solution that allows the operator to log off the MDT after the vehicle has been shut down.

Because of the time lag between recording the sensor outputs on the Rockwell onboard computer and delivering data to CTRE, the PCMCIA card is not the most effective method of data transfer for supporting decision-making processes. In fact, lack of timely data after 1997-1998 winter storms made it impossible for CTRE to prove the concept that winter friction data can be collected by friction-measuring devices on a maintenance vehicle. See Chapter 8 for details. To be truly effective for roadway maintenance decision making, data must be analyzed in "real time," that is, as data are collected by the sensors. The study team is investigating the feasibility of using cellular data links and, eventually, existing DOT radio networks for real-time data communications in Phase III. PlowMaster will also provide the interface for real-time communications.

Based on feedback from vehicle operators, described more fully in Chapter 15, the in-cab displays, as modified by Rockwell for road maintenance operations, were easy to view and use without distracting the operators from their driving and maintenance tasks. The information presented on the displays was user friendly.

OBSERVATIONS

Proof of concept was successful; the Plowmaster supplied by Rockwell was successfully installed and worked as expected, proving that a central, onboard data collection and management system is possible on winter maintenance vehicles. Data were collected from the sensors, recorded, translated into common formats, and displayed on the MDT. Operators generally found the displays easy to read and operate.

In Phase II, data collected by vehicle sensors were stored on the MDT's removable PCMCIA card for transfer to CTRE. The study team's plan for Phase III is to implement real-time cellular communications as an interim step toward radio data communications. The MDT provides an RS232 interface to the in-circuit switched cellular mode of the MP205/210 modems. In Phase III, the modems will provide communications over an AMPS cellular network offering up to 14,400 bits per second (bps) using CCITT group V.32bis specifications. Practical limitations of the cellular network typically limit the maximum data rate to 9,600 bps.

With real-time data communications, the following trip events will trigger data transmission by the PlowMaster once every mile or every two minutes, whichever occurs first. If none of these events occurs, data transmission is every 10 minutes or five miles, whichever comes first.

- Friction degrading from good, to fair, to poor
- Temperature degrading from good, to fair, to poor
- Direction change greater than 45 degrees

Cellular data link information collected in the PlowMaster database and transferred during an event operation will include the following minimum, maximum, and average values:

- Bayesian friction
- F60 friction
- μ_{peak}
- Air temperature
- Pavement temperature

If costs are feasible, a digital data communications link may be activated via the DOT statewide radio network during Phase IV, fleet evaluation. At that time, the vehicle's mobile radio, mobile antenna, and handset will be implemented with the PlowMaster for data communications. When equipped with digital data communications capabilities, the PlowMaster will support 4,800- to 9,600 bits per second (bps) data transfer. The radio is typically configured with one channel for voice communication and one channel for data communication. The FIA will switch the radio between voice and data channels as required.

CHAPTER 7: GLOBAL POSITIONING SYSTEM (GPS)

To be useful in management systems, data collected by the prototype vehicles' sensors must be spatially referenced; that is, the data must be correlated to specific locations on the earth's surface along the vehicles' routes where the data are collected. Global positioning system (GPS) technology is a worldwide, precision navigation and location tool that uses three-dimensional positioning capabilities to identify spatial references. It is based on triangulation of radio signals from a constellation of 24 satellites orbiting the earth. A local GPS location system receives radio signals from a satellite, calculates the signal's travel time from the satellite to the GPS antenna, and then translates the travel time into distance between the satellite and the GPS antenna. To determine a specific location (for example, the location of a prototype maintenance vehicle) using GPS, an onboard GPS receiver would simultaneously calculate the distance of at least three satellites (synchronized by atomic clocks in the satellites), triangulate the three distances to find their common location on the earth, and record the location in latitude and longitude, along with the GPS time the signals were received.

In Phase II, Rockwell International, Cedar Rapids, Iowa, provided GPS on the prototype vehicles for spatially referencing data collected by the vehicle sensors. Rockwell adapted GPS product lines originally developed for military, transit, agricultural, and commercial vehicle GPS to suit highway maintenance applications.

OBJECTIVE

Conduct proof of concept regarding incorporating GPS technology on winter maintenance vehicles to correlate data collected by other add-on technologies and stored on the PlowMaster with realistic location coordinates, GPS time, and GPS speed.

MEASUREMENT

The GPS antenna will be successfully installed on the prototype vehicle, and the GPS works as expected. Sensor output data (air and pavement temperatures, friction meter readings, etc.) stored on the PlowMaster's removable PCMCIA card have a GPS location stamp (latitude/longitude coordinates) comparing favorably to other GPS latitude/longitude coordinates for the same locations, and a GPS time stamp. Output data also include GPS speed data.

DISCUSSION

Installation

GPS requires a special antenna to receive radio signals from the GPS satellites, and a receiver (engine) to translate the signals into location information. During Phase II, the GPS on the prototype vehicles consisted of (1) an antenna mounted above each prototype vehicle's cab and (2) a receiver (engine) and GPS software located in the PlowMaster's Flexible Interface Adapter in the cab. (The GPS antenna part number is 013-1925-150, and the GPS antenna cable part number is 989-2383-111.)

In areas where full GPS satellite visibility may not always be available, such as urban canyon environments, the PlowMaster system can revert to navigation based on the vehicle's odometer if equipped for this function, using dead-reckoning algorithms and auxiliary sensors. However, the prototype vehicles were not so equipped in Phase II; if conditions temporarily prevented the PlowMaster from acquiring GPS information (location and time) during Phase II, the loss of GPS signals and information was highlighted on the in-cab display as an advisory message.

Installation of the GPS antenna/receiver systems was easily accomplished. The GPS antennae were installed above the cabs without difficulty and posed no significant maintenance problems. The receiver is incorporated in the PlowMaster unit; see Chapter 3 for descriptions of in-cab configurations of the PlowMaster units in the three prototype vehicles. Incorporating the various in-cab technologies made the cabs quite crowded, and the states experimented with various arrangements. In the spring of 1998, Michigan's GPS failed, and Rockwell ultimately replaced the GPS unit on Michigan's prototype vehicle. No difficulties were experienced after the unit was replaced.

Performance

During Phase II data capture runs, each prototype vehicle's GPS recorded the location of the vehicle in latitude and longitude every five seconds and sent the location data, along with the GPS time and GPS heading and speed, to the onboard PlowMaster computer processor for recording. Each recording thus provided a GPS location and time stamp that accompanied data being simultaneously collected by vehicle sensors and recorded on the PlowMaster.

GPS time was recorded in Uniform Time Conversion (UTC) time, which is the number of seconds past midnight Sunday at the International Dateline. GPS time synchronized the PlowMaster system with friction and temperature sensor systems. The GPS location information was recorded in latitude and longitude and used to determine heading and speed with respect to the vehicle's prescribed route.

It was important in Phase II to prove that GPS could perform satisfactorily on the prototype vehicles. To confirm that Rockwell's GPS was collecting reasonable data, CTRE compared latitude and longitude data collected at mileposts by the onboard GPS system to known latitude and longitude values for those mileposts supplied by the Iowa DOT. The comparison showed that the two sets of values are not significantly different, confirming that GPS performs as expected and desired on the winter maintenance vehicles.

OBSERVATIONS

Proof of concept was successful; the GPS supplied by Rockwell worked as expected, proving that location information can be collected by technology on winter maintenance vehicles. The systems were easily installed and required little or no maintenance. Milepost comparisons illustrated that the accuracy of location information was within the tolerances expected. GPS is an accurate method of relating prototype vehicles' sensor outputs spatially for analysis and comparison.

For greater location accuracy in Phase III, Rockwell plans to retrofit the prototype vehicles' GPS with differential GPS (DGPS). With DGPS, a local area DGPS base receiver receives signals from satellites and adds a correction factor. The differential corrections provide location data accurate within 16 feet.

CHAPTER 8: FRICTION METER

Pavement surface friction is a critical factor in keeping moving vehicles under control. The study team recognized the benefits of incorporating a friction-measuring device on the prototype vehicles to help operators make decisions about applying materials to keep surface friction at a safe level. A friction testing device and procedure used by most states to measure warm pavement friction values—the ASTM E-274 skid trailer—is not used in the winter because it requires a spray of water in front of the tire, which is not feasible when temperatures are below freezing. However, one manufacturer of friction measuring devices, Norsemeter AS of Oslo, Norway, and its agent Roadware Corporation of Paris, Ontario, Canada, agreed to participate in the study and provide three Roadway Analyzer and Recorder (ROAR) friction meters for testing on the prototype winter maintenance vehicles.

The ROAR friction meter has been tested successfully on airport runways as part of a multiyear winter friction project sponsored by NASA, FAA, and Transport Canada. The units are also being used by several Scandinavian road authorities to test highway conditions, with the goal of establishing monitoring systems that can be used to advise the public of winter road conditions. In 1995, the Minnesota DOT conducted tests in the Minneapolis area using a ROAR prototype, and the results indicated that such devices held promise for determining the friction condition of snow-, ice-, and slush-covered pavements.

Installing and operating the ROAR meters on the prototype vehicles provided some installation and operational challenges. This chapter discusses the ROAR meter, installation procedures, operations and test sites, data analysis, and lessons learned during Phase II.

OBJECTIVE

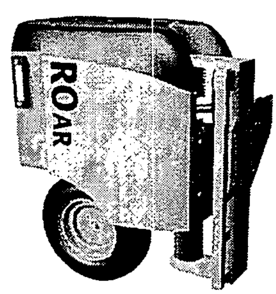
Conduct proof of concept regarding incorporating friction-measuring devices on winter maintenance vehicles to measure pavement surface friction.

MEASUREMENT

The ROAR friction meter is installed on prototype maintenance vehicle. Expected performance includes the following: First, friction data collected by the prototype vehicle under controlled wet/dry conditions are reasonable when compared favorably with data collected by a ROAR friction meter on a Roadway trailer and by ASTM E-274 (American Society of Testing and Materials) skid trailers; that is, when the data are plotted, they have similar slopes. Second, friction data collected by the prototype vehicle during normal winter maintenance operations are reasonable.

DISCUSSION

The ROAR friction meter basic unit employs a hydraulic mechanism to apply a braking force to an ASTM E-1551 test tire with a 400 mm (15.75 in) diameter pneumatic tire that rides on the roadway. The ROAR consists of the basic friction measuring unit, two electronics enclosures, and an operator panel. The exterior measurements are approximately 36 inches high by 18 inches wide by 31 inches long. The basic unit has a total weight of approximately 330 pounds, including brackets and other mounting hardware. The ROAR friction analyzer is controlled by electronics in a weatherproof master control enclosure. A second enclosure containing an IBM compatible computer is installed in the operator cab. A color LCD operator panel is also mounted in the cab. During Phase II, the ROAR operating functions were incorporated into the PlowMaster display, and the ROAR display panel removed from the cabs.) The equipment operates at travel speeds from 10 to 130 kilometers per hour. ROAR measures friction when the road surface is bare and dry, as well as when it is contaminated by water, snow, slush, or ice. From a winter road maintenance perspective, contaminated road surfaces are the primary interest, and ROAR is specifically designed to operate reliably under harsh winter conditions.



During operation, the hydraulic flow is metered to cycle between free-rolling and locked wheel at preselected intervals. During Phase II, the cycle time was usually set at two- or four-second intervals. In calibrating the friction meter, the three state DOTs simulated the skid number (SN) of the ASTM test standard E-274 using the International Friction Index (IFI) standard ASTM E-1960.

Figure 8-1 ROAR Friction Meter

The ROAR friction meter has two substantially different measuring modes. In Continuous Friction Measurement Equipment (CFME) mode, the tire is slipped at a constant percentage of the forward speed. In this measuring mode, the friction meter supersedes the old fixed slip measuring devices by offering the equipment operator the option of setting the constant slip ratio of the measuring wheel to any percentage between five percent and 100 percent. The setting most commonly used is around 18 percent.

The second measuring mode, variable slip mode (% slip), is becoming the new industry standard. According to Norsemeter, friction outputs in the variable slip mode agree with outputs from decelerometer measuring devices on winter contaminated roads, providing consistent comparisons between the ROAR friction meter and other more conventional friction measuring devices such as the ASTM E-274 trailer. In the variable slip mode, the ROAR meter measures the friction of the road surface by computer controlled braking of the test wheel from free-rolling to fully locked, while constantly monitoring the braking friction force that the road surface exerts against the test wheel. The test wheel is hydraulically braked under computer control over a 0.5-second interval. During this time several hundred friction readings are recorded and various parameters such as peak friction are calculated. The wheel is then given time to come back up to full vehicle speed before starting another measurement. The time interval for each measurement cycle is set by the operator and in this test was typically two to four seconds between readings. At 30 miles per hour, a vehicle travels 44 feet per second. This results in a friction measurement over an 11-foot portion of an 88-foot segment when the test cycle time is set at two-second intervals. (Refer to Appendix E for additional details.) The friction meter provides measures of friction for clean and bare road surfaces, as well as for surfaces contaminated by water, snow, slush, abrasives, or ice.

During winter maintenance operations, road authorities typically use the variable slip mode, and this was the mode used during Phase II proof of concept for the friction meter.

Installation

Normally, for summer friction measurements, the ROAR friction meter is mounted on a trailer equipped with a water tank and metering system. The friction meter's design also allows mounting on the back of a one-ton pickup truck or other large vehicle when water is not necessary or desirable, as in winter operations. The study team was aware that successfully mounting the friction meter on a snowplow might be challenging because of tight space restrictions and the harsh environment it would encounter.

As expected, one of the first obstacles to installation was finding a suitable space in which to mount the ROAR device. It measures 36 inches tall by 18 inches wide by 31 inches long, and weighs approximately 330 pounds. In addition, it requires seven inches of vertical clearance to raise and lower the unit.

On Iowa's vehicle, the ROAR friction meter was installed in front of the left dual rear wheels, just behind the underbody plow. This location restricted the underbody plow to one angle (to the right; interference problems would occur if the underbody blade were angled to the left). While not wholly desirable, this location was considered acceptable for proof of concept in Iowa. Iowa's ROAR unit experienced two malfunctions. In one case, the axle on the test tire wheel broke. Heavy damage to the tire itself indicated the wheel hit a pothole or other obstruction when the wheel was locked in the down position, putting excessive strain on the axle shaft and sheering it off internally. A new axle was installed and no further problems with it were noted. The other malfunction was traced to a ROAR computer program. Data could not be removed from the computer's main memory because the operators inadvertently shut off the computer system before completing a normal shutdown procedure. A software fix was developed by Norsemeter and installed by Roadware to avoid this problem in the future. (The same situation was discovered in the other ROAR systems, and Roadware installed the software fixes.)

On Minnesota's vehicle, the ROAR friction meter was installed behind the right dual rear wheels because Minnesota DOT did not want to limit the use of the underbody blade, especially for clearing left lanes of multilane highways. However, this location caused mounting problems. Special brackets were fabricated by Tyler (the technology integrator) to mount the ROAR friction meter's computer relay control between the frame rails of the vehicle. After the initial testing in September 1997, Minnesota DOT mechanics redesigned the mounting bracket because it was cracked and twisted, reinforcing the lower arm of the mount and straightening it to allow the ROAR unit to raise and lower properly. Minnesota DOT also moved the box mounted in the frame rails to the rear of the prototype truck because of its previous relative inaccessibility during repairs. Because of its location at the rear of the vehicle, the ROAR unit installed on the Minnesota DOT's prototype vehicle was subjected to salt and sand dispensed from the center-mounted spreader spinner. A metal plate on the discharge chute was installed to reduce the amount of material actually hitting the unit. However, the swirling air behind the truck still caused some material to hit the ROAR unit. A much more critical problem was the serious whipping and bouncing to which the ROAR unit was subjected at the back of the truck, resulting in several belt failures caused by a bent measuring wheel axle. In one case, the actuator to raise and lower the unit broke a mounting lug. Investigation showed this was also caused by the violent bouncing motion of the ROAR unit at the back of the truck. To correct this problem, Norsemeter designed and shipped a heavy-duty hydraulic damper (shock absorber) assembly that each of the three DOTs installed on their ROAR friction meters. The shock absorber eliminated the bouncing, and no failures were encountered after installation of the shock absorbers.

The Michigan prototype vehicle had no room either in front of or behind the real dual wheels. After lengthy discussions, the Michigan ROAR meter was mounted on a separate pickup-class truck that had been used to tow an E-274 skid trailer for summer friction operations. This produced an excellent environment, and no difficulties were encountered with the installation or operation of Michigan's ROAR unit. However, because it was mounted on a separate vehicle, the ROAR unit could not be interfaced with the Rockwell PlowMaster.

While not officially a part of this study, a fourth ROAR friction meter was mounted Minnesota DOT on a snowplow in the Duluth, Minnesota, district on a 50,000-pound GVW snowplow without an underbody blade. The installation and operation of this unit went smoothly, and it was used for part of a Federal Highway Administration comparison of winter friction devices, independent of this study.

After much effort in all three states, then, the friction meter was securely and relatively satisfactorily installed only on Iowa's prototype vehicle, passing the installation proof of concept. Even after significant fabrication, Minnesota's friction meter installation was only marginally satisfactory on the prototype vehicle, although it was completely satisfactory on the Duluth vehicle without an underbody blade. In Minnesota, therefore, installation feasibility was only marginally proved. A friction-measuring device was not installed on Michigan's prototype vehicle. Electronic connection between the friction meter and the onboard PlowMaster was proved feasible in Iowa and Minnesota.

See Figures 8-2 and 8-3 for the Iowa vehicle friction meter location.

Figure 8-2 Friction meter, Iowa prototype vehicle

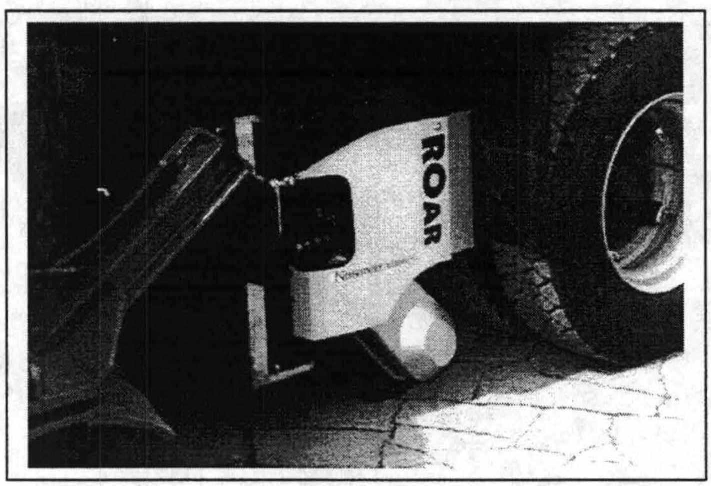


Figure 8-3 Friction meter, Iowa prototype vehicle

Operations

Roadware representatives conducted training sessions for operators of all four ROAR units. While these training sessions were adequate, the operators' skill levels deteriorated during the course of Phase II, causing some operator errors in operating and recording friction data during winter storms. This was judged to be a result of the fact that the ROAR friction meter is designed to be operated by more highly trained technicians accustomed to working with complex testing systems. This conclusion was borne out by the fact that the Michigan DOT operator, who was normally assigned to operate the ASTM E-274 skid trailer, had fewer operator errors and no operating difficulties.

Performance under Dry/Wet Conditions

Dr. James Wambold at CDRM, Inc., suggested that the data collected by the onboard friction meters could be proved reasonable (i.e., proof of concept for friction meter performance) by comparing the data to an industry standard. The following sections discuss the calculation of friction coefficients and the correlation of collected data to ASTM E-274 skid trailer base data.

Friction Coefficients

When measuring friction, the critical value is μ_{peak} or the point at which slipping will occur. Equation 1 demonstrates how μ_{peak} is obtained, based on the Rado friction model. See Appendix D for a complete description of the Rado model included in *A Primer on Modern Runway Surface Friction Measurement.*[1]

$$\mu(S) = \mu_{max}(S) \bullet e^{-[\ln(S \div S_{max}) \div C]^2}$$

where μ = friction number
$\mu_{max} = \mu_{peak}$
S_{max} = critical slip (slip speed at which μ_{peak} occurs), also called S_{crit}
S = slip speed (% slip times vehicle speed)
C = shape factor
V = vehicle speed

The variable slip measuring cycle can be applied repeatedly in a pulsing measuring manner, so as to determine the friction equation for surface segments from 3 to 30 meters in length depending on the traveling speed of the measuring device. When a segment is not sufficiently homogeneous for the quality of the curve fitting, the measurement will be discarded manually.

The friction meter reads several values of μ, C, S, and S_{max} over a short period of time and obtains the μ_{peak} value shown in the sensor output. As shown in Figure 8-4, the factor *C* mainly affects the shape of the curve. A low value of *C* produces a curve with a steep slope (a large speed gradient); whereas, the larger C is, the less speed dependent. The uppermost value on the curve is the μ_{peak} value. The slope of the curve beyond the μ_{peak} value depends on the macro texture of the pavement (C^2); i.e., a flatter slope beyond the peak represents a more acceptable pavement friction value.

[1] Norsemeter AS *A Primer on Modern Runway Surface Friction Measurement* Courtesy Publication 2, Chapter 3, page 8. Rud Norway 1996

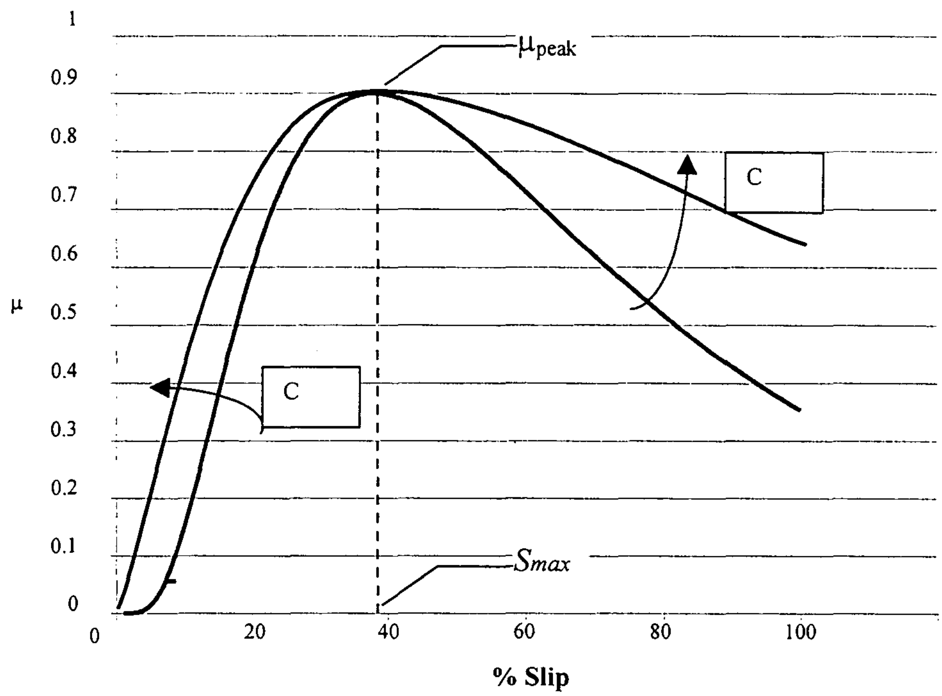


Figure 8-4 Rado Model friction print

Correlation Testing

To check the reasonableness of data collected by the ROAR friction meters on the prototype vehicles, data collected by the ROAR friction meters were compared to ASTM E-274 skid trailer base values, the U.S. industry standard for pavement friction measurements. If plotted data collected by ROAR friction meters (on the prototype vehicles and on Roadware's trailer) have a similar slope to base data collected by the ASTM E-274 trailer, the ROAR data should be reasonable. Testing to correlate the data was completed on September 18, 1997. A test track in St. Cloud, Minnesota, which could be flooded and contained no other traffic, was used. The track had four sections of pavement with average mean texture depth as shown in Table 8-1. Additional track condition information is given in Appendix E.

Table 8-1 Texture of St. Cloud, MN, test track, September 18, 1997

Track Site	Speed Gradient (kilometers/hour)	Mean Texture Depth (MTD)
1	74	.75
2	16.17	.24
3	46.33	.51
4	182.18	1.71

The St. Cloud tests were conducted under both dry and wet pavement conditions at speeds of 20, 30, 40, and 50 mph. The test devices used in this data collection session were the Iowa prototype vehicle equipped with a Roadware ROAR friction meter, the Minnesota prototype vehicle equipped with a ROAR friction meter, a Roadware ROAR friction meter trailer, the Iowa ASTM E-274 skid trailer, and the Minnesota ASTM E-274 skid trailer. Michigan did not participate. The ASTM E-274 skid trailers and Roadware's trailer recorded friction data while the Iowa and Minnesota prototype vehicles followed directly behind and recorded friction data with the ROAR friction meters. During the St. Cloud tests, the ASTM E-274 trailers traveled at a designated speed, water was dispersed on the pavement at a specified depth ahead of the tire, and the braking system systematically locked the test tire while the resulting friction force between the tire and the pavement was recorded. A water truck was used to disperse water directly ahead of the prototype vehicles.

ASTM E-274 skid trailers utilize the ASTM E-274 Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire. The E-274 trailer traveled at a designated speed, water was dispersed on the pavement at a specified depth ahead of the tire, and the braking system systematically locked the test tire while the resulting friction force between the tire and pavement was recorded. See Figure 8-5 for a list of ASTM E-274 test parameters.

K.J. Law ASTM E-274 Skid Trailer

K.J. Law Input/Output Parameters:

- Time
- Date
- Distance
- mpeak
- Speed
- Air Temperature

Figure 8-5 ASTM E-274 parameters

During the St. Cloud data collection sessions, the following data were recorded: skid number (SN) from ASTM E-274, % slip, μ_{peak} friction value, speed of trailer, air temperature, time, and date. Data collected by the ROAR meters on Iowa's and Minnesota's prototype vehicles and on the Roadware trailer, and by the ASTM E-274 skid trailers, were examined by Dr. Wambold to determine the difference of values reported by the ROAR devices on the prototype vehicles, the significance of those differences, and whether the ROAR devices pass proof of concept. For each friction meter in each data run, the % slip at the peak (*Smax*), was plotted at the corresponding vehicle speeds. As shown in Figure 8-6, data collected by the Roadware ROAR skid trailer instrument and the ROAR friction meter on Minnesota's prototype vehicle had similar slopes; data collected by the Iowa prototype vehicle's ROAR friction meter had a flatter slope and showed a different trend.

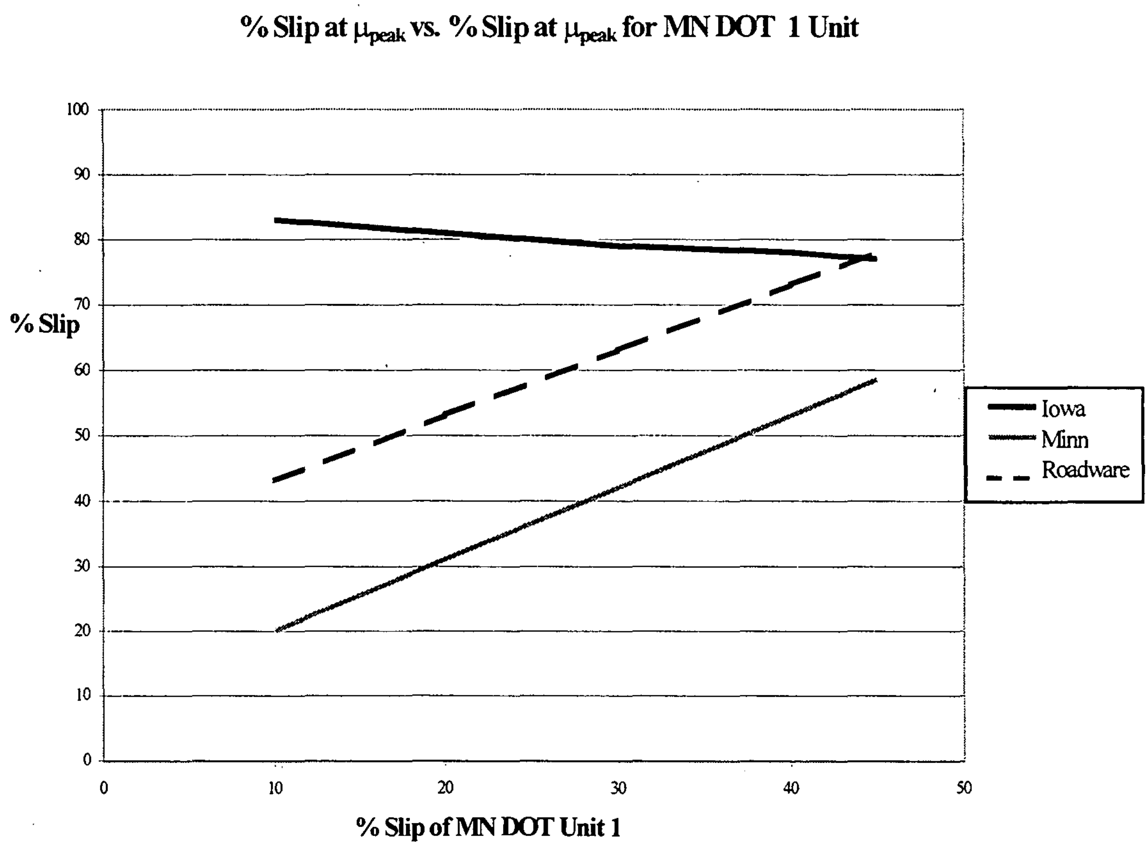


Figure 8-6 Friction trends from data comparison, St. Cloud, Minnesota, September 18, 1997. Figure is courtesy of Dr. James Wambold.

Dr. Wambold found no significant factor contributing to Iowa's skewed data from September 18, 1997. A Roadware representative, however, examined Iowa's raw data and determined that during the test, the Iowa operator had not followed the correct start/stop sequence during the St. Cloud tests, and the data records for the various runs could not be correctly interpreted. A software fix was developed by Norsemeter and installed by Roadware to avoid this operator error in the future.

After the software was installed, additional tests were then conducted with the Iowa prototype vehicle on April 16, 1998, in Iowa. During these tests, the vehicle was equipped with a temporary water dispensing system that directed water in front of the tire. Since only a wet surface was required for testing, the amount of water applied was not calibrated. At higher speeds (50 mph), the test tire chirped frequently, indicating that not enough water was being dispensed for the higher speeds. A larger hose could be used in future testing to ensure that the pavement was wetted properly at higher speeds.

Three test sites were used for the April 16 testing, and runs were repeated at several speeds. These sites were selected from several in the Ames, Iowa, area and were selected to represent different pavement surfaces: old portland cement concrete, new asphalt concrete, and old asphalt concrete. See Appendix F for a map and descriptions of these test site locations, as well as test notes and data.

For each data collection run, the % slip at μ_{peak} was plotted at corresponding vehicle speeds. In Figure 8-7, data from the tests runs (% slip versus vehicle speed) are plotted, showing a slope similar to that derived from data collected by the Minnesota vehicle and the Roadware trailer in St. Cloud on September 18, 1997.

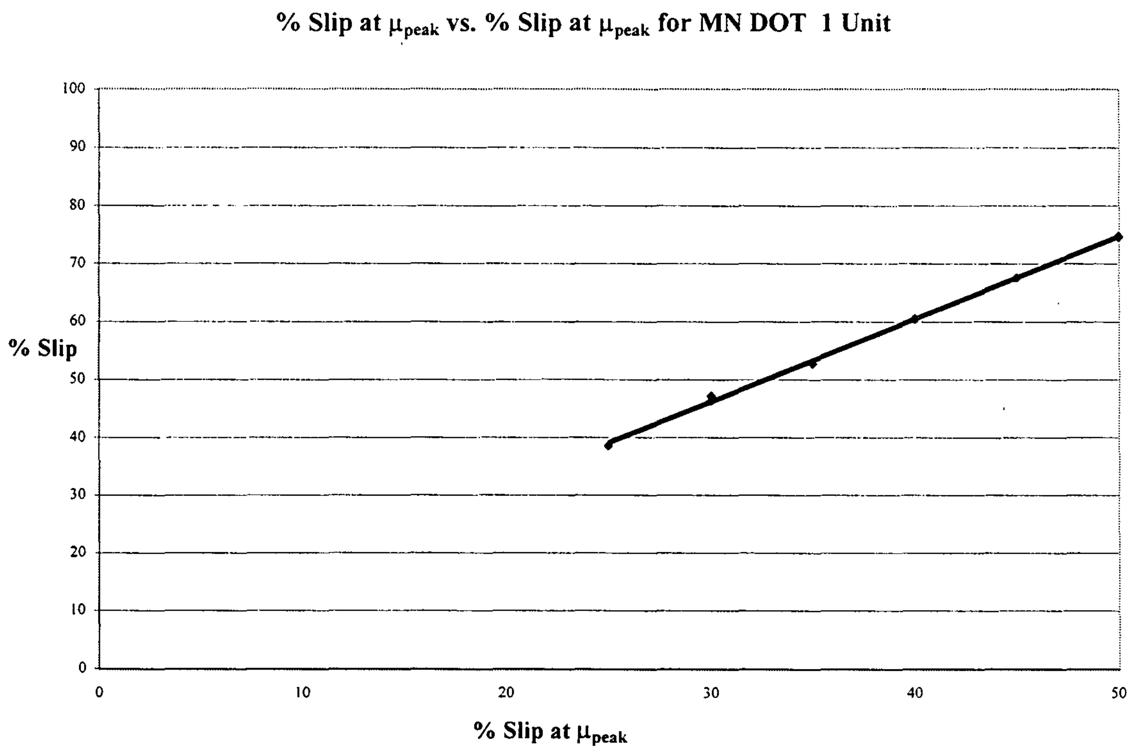


Figure 8-7 Additional Iowa testing results, April 16, 1998

In Figure 8-8, Iowa's April 16, 1998 data slope is superimposed on September 18, 1997 data slope from the Minnesota and Roadware friction meters to show the similarity in slopes. Therefore, the concept is proven that a maintenance vehicle equipped with a friction measuring device can collect reasonable friction data during dry or wet conditions.

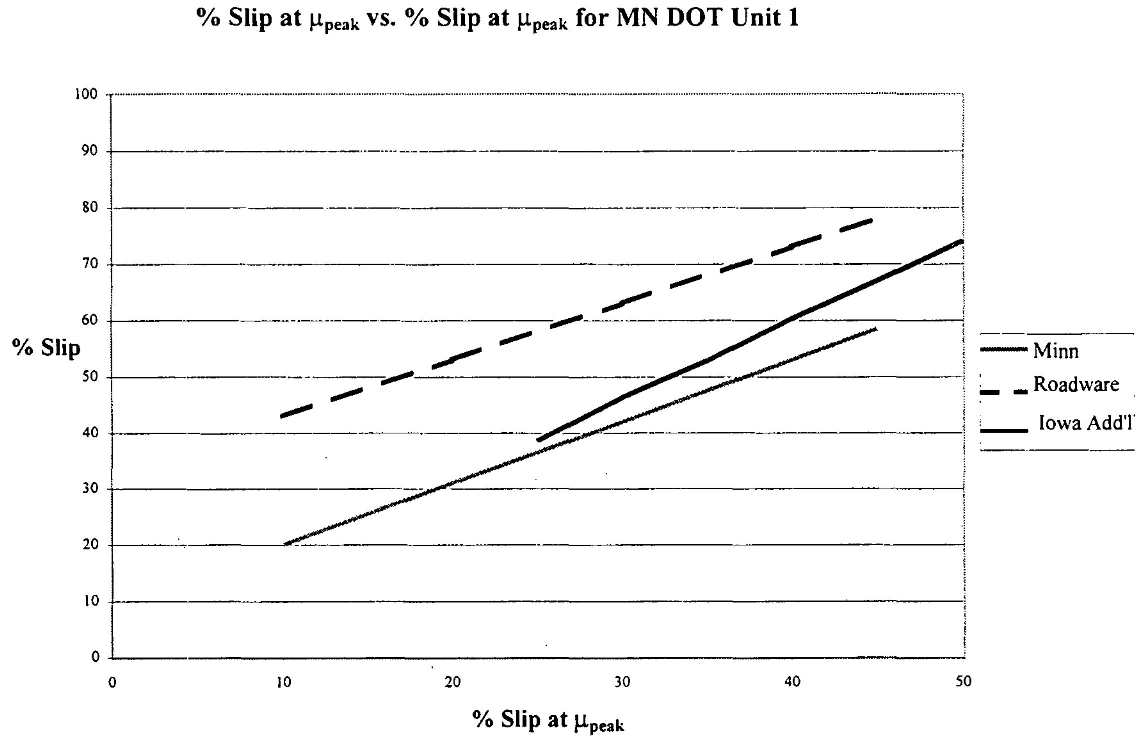


Figure 8-8 Comparison of Iowa's additional test results from April 16, 1998, with trendlines from Minnesota DOT and Roadware data collected on September 18, 1997, courtesy of Dr. James Wambold

As a final step in the proof of concept, the peak measurements and F60 of the Norsemeter Friction Units are compared to the peak and skid number (SN) values measured with a K.J. Law E274 Unit. Figure 8-9 illustrates the comparisons of the peak value and Figure 8-10 illustrates the comparison of F60 to SN. All of the data are from the September 18, 1997 tests. The Iowa ROAR unit μ_{peak} are compared to the μ_{peak} of the Law units. Dr. James Wambold analyzed these data. He found that the Roadware and Minnesota Law units compared favorably. He further found that while the Iowa μ_{peak} values do not unconditionally agree to the others, the data still sufficiently correlate. Therefore, the concept is proven that a maintenance vehicle equipped with a friction measuring device can collect reasonable friction data during dry or wet conditions.

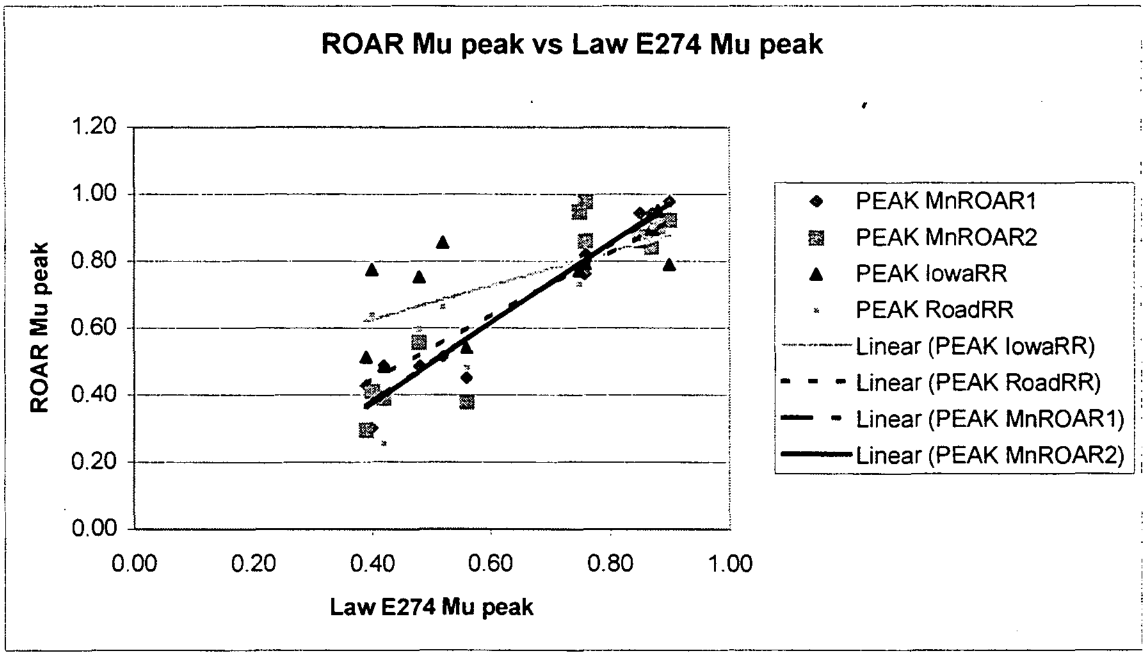


Figure 8-9 Comparison of Mu Peak measured by the various Norsemeter units versus the Mu Peak measured by a K.J. Law Unit at the September 18, 1997 tests. Figure is courtesy of Dr. James Wambold.

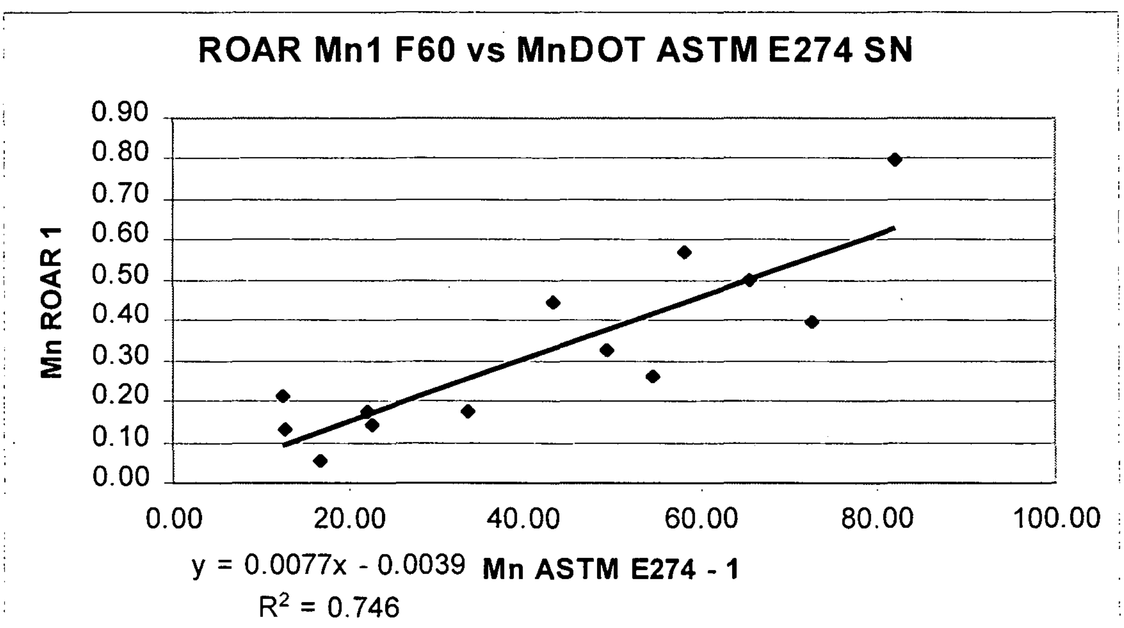


Figure 8-10. Comparison of F60 measured by the various Norsemeter versus the Skid Number (SN) measured by a K.J. Law E274 unit at the September 18,1997 tests. Figure is courtesy of Dr. James Wambold.

Performance under Winter Conditions

With assurance that, under dry or wet pavement conditions, Iowa's and Minnesota's friction meters were recording and reporting reasonable data, the study team wanted to begin collecting friction values representing a variety of winter conditions to prove the concept under winter conditions. Additional friction data would be important not only to this study but also for another research project in Minnesota. (See Appendix G for the work plan for Test and Evaluation of Friction Measuring Devices for Winter maintenance Activities.) Therefore, CTRE collected some winter data and laid the foundation for full-scale data collection and evaluation in Phase III.

First, the data collection plan in Figure 8-11, based on Minnesota's work plan for the above-named project, was approved by the study team and distributed to the partner states. Significant time was devoted by CTRE staff to developing data conversion macros, as discussed in Chapter 13. These macros provided the tools to quickly translate data collected by the onboard sensors into common formats (e.g., translate latitude/longitude to milepost location, GPS time to Central Standard Time, etc.) and to plot data sets and subsets, including friction data.

Unfortunately, few data sets were collected during the winter of 1997-1998. The weather was atypically warm, with few snow events. Another significant problem was that the collection process was not tightly controlled. Some data sets forwarded to CTRE included incomplete or clearly unreasonable readings that were traced to operator errors. Data were generally received several days or even weeks after they were collected, making it virtually impossible to correlate data collected under similar conditions or, if appropriate, to notify operators their equipment was malfunctioning.

Delays in receiving data were a direct result of the fact that the primary mission of the snowplow operators was snow and ice control; data collection and transfer were secondary. All the operators were genuinely cooperative and enthusiastic; however, they were not under the direct control of the principal investigator. As a result, tight coordination was not possible, and not enough friction data were collected during winter maintenance operations to prove the concept.

OBSERVATIONS

Proof of concept for friction measuring devices on winter maintenance vehicles was only moderately successful. Installation was successful in Iowa and moderately successful in Minnesota; the ROAR meter was not installed on Michigan's prototype vehicle. Performance (the collection of reasonable data) was successful on dry/wet conditions in Minnesota and Iowa but could not be proven for winter conditions due to lack of data.

The ROAR friction meter is a good device for testing and analysis by trained technicians but is less well suited for direct use on snowplows. The following observations do not imply any criticism of the ROAR friction meter but are offered as suggested improvements for future friction devices that might be directly mounted on snowplows.

Size

In order to fit a wide range of truck configurations the friction-measuring device must be smaller. Some difficulty was encountered in accommodating the onboard electronics and control boxes. Reducing the size of these components will allow more flexibility in installing the friction units. Reducing the size may also reduce the cost, which is important for widespread use on maintenance fleets. Norsemeter has recognized this factor and is designing a new friction device—SALTAR—that is engineered specifically for mounting on a snowplow. It is smaller, more rugged, and much less expensive than the ROAR unit.

Data Output

The ROAR unit was designed for detailed analysis of road surfaces and produces a wide variety of parameters. However, displaying all of this information is not necessary and can be confusing to drivers/operators. A simple display indicating levels of service (such as that in the PlowMaster display) is more appropriate. In the new SALTAR design, Norsemeter is developing new software that will be display a limited number of parameters and will be easier to set up and operate. This is also expected to reduce operator errors and training requirements.

Durability

The environment associated with snowplows is extremely harsh and demanding. Friction devices must be designed to withstand the abuse they will receive and still function reliably. Maintenance requirements must be simple and require little attention. Test tires, which are consumable items, must be inexpensive and easy to replace. Expensive ASTM specification tires may not be required for this operational application. Norsemeter has taken note of this requirement and is incorporating ruggedness as a primary design objective in the new SALTAR design.

Procedures

An important lesson learned was the need for tighter control of data collection and processing. The original plan did not anticipate the difficulties of receiving and processing data in a timely fashion, resulting in a loss of control over the quality of data. Future pooled-fund study phases will incorporate tighter controls to ensure data quality can be monitored closely. Problems caused by operator error will be addressed with new software provided by Norsemeter to make it easier to set up and operate the friction meter.

SUMMARY

The DOTs participating in the project continue to feel that friction is an important condition to measure and monitor via the advanced technology snowplow vehicles. Cooperation with industry is an absolute necessity to identify the needs and requirements of the winter maintenance community. Experiments such as that conducted in Phase II with the Norsemeter friction meter are important as much for what did not work as for what did.

WINTER FRICTION TEST PLAN
1997 - 1998

The testing will be conducted to establish the repeatability and reliability of the Norsemeter friction device. The test will also be used to determine the optimal vehicle speed and frequency of measurements. This test plan is considered necessary to get data from which basic statistics can be obtained. The data will also be used to in the *Test and Evaluation of Friction Measuring Devices for Winter Maintenance Applications* being conducted by the Minnesota Department of Transportation.

The data will be collected during normal winter maintenance activities.

Maintenance Related Testing

*Use predetermined and fixed routes for all tests
*Test runs are to be performed when there is:
  *No danger from the slippery surface
  *Weather forecasts predict good conditions
*Sufficient personnel will be available
*Test routes to include roads when salted and when not salted
*Test route to include weather stations
*Measure at normal truck speed in normal traffic
*Make one data file per route completed

Tests:

1.One test on bare pavement for each section
This is to be done with the ASTM E-274 and the Norsemeter at pavement temperatures below 25 degrees
2.One test one or two hours before weather conditions require maintenance
3.One test every time maintenance is performed - one each run
4.One test 4 - 8 hours after maintenance is completed
Note: Be sure that no maintenance was performed or that conditions changed
The purpose is to evaluate the maintenance effectiveness

Conditions:

1.Wet and dry snow
2.Hard pack snow
3.Wet ice = when pavement temperature is between 32 degrees and 25 degrees
4.Dry ice = when pavement temperature is below 25 degrees
5.Slush

Figure 8-11 Winter 1997-1998 data collection plan, based on the work plan for Test and Evaluation of Friction Measuring Devices for Winter Maintenance Activities

CHAPTER 9: TEMPERATURE SENSORS

Pavement temperature is the critical measurement for applying chemicals and abrasives in snow and ice control operations. The pavement surface is where chemical reactions occur as salt or other chemicals are applied to melt ice or snow pack, and pavement temperature greatly influences those reactions. Real-time pavement temperature data can therefore help snowplow operators make efficient decisions about the kind and amount of material to spread on the pavement. Air temperature is only secondarily important. Depending on other atmospheric conditions (e.g., the amount of sunlight, wind, humidity, etc.), air temperatures may forecast changes in pavement temperature.

In Phase II, the study team's goal was to observe if pavement and air temperature sensors, similar to other environmental sensors used in agricultural applications, could be installed on winter maintenance vehicles and provide real-time data to vehicle operators to help them continually refine their maintenance operations. In later phases, the study team plans to carry this concept a step farther. The onboard temperature sensors will provide input directly to other logic systems on the maintenance vehicles, which will react to changing temperature values with programmed responses. For example, the temperature sensors will provide real-time pavement temperatures to the material spreader system. If pavement temperatures fall below freezing (32° F), the chemical and abrasive spreader system will select the materials and application rates appropriate for the recorded temperature and automatically dispense the materials. For this kind of interoperability to be effective, the air and pavement temperature sensors will require a very high degree of reliability and accuracy. In Phase II, therefore, it was critical to determine that the temperature sensors were collecting reasonable data. A controlled field evaluation of temperature sensor performance will be conducted in Phase III.

Sprague Controls, Incorporated, of Canby, Oregon, provided a Sprague RoadWatch Temperature Indicating System (RoadWatch) , RW1, 600 Series, for each of the three prototype maintenance vehicles to monitor pavement surface and air temperatures.

OBJECTIVE

Conduct proof of concept regarding using sensors on a winter maintenance vehicle to automatically collect air and pavement temperature data.

MEASUREMENT

The RoadWatch system is successfully installed on the prototype vehicles and operates as expected; that is, the RoadWatch system collects reasonable air and pavement temperatures.

DISCUSSION

RoadWatch is a passive infrared temperature indicator that uses infrared technology to translate surface energy into a temperature reading. For road surface temperatures, an infrared sensor absorbs heat energy from the road surface through a small lens on the bottom of the sensor, converts that energy into an electrical signal, sends the signal to a processor in the vehicle cab, and converts the electrical signal to a temperature display. The process is similar to a light meter in a camera that absorbs light energy and converts it to an electrical signal; the pavement surface temperature sensor absorbs heat energy and converts it to an electrical signal.

The RoadWatch temperature indicating system consists of the infrared sensors, the in-cab processor and display, and a shielded cable connecting the sensors to the display. The in-cab display shows the air temperature (at the top of the display) and the road surface temperature (at the bottom of the display). The display also has a small beeper and a warning light that are activated when either temperature cools to 35° F. The infrared sensors were mounted without difficulty on the driver's side-view mirror as shown in Figure 9-1. The two-inch digital gauge is mounted in the vehicle cab. The road surface temperature range is -40° to +200° F, and the air temperature range is -40° to +120° F. Its manufacture-stated accuracy is plus or minus one percent of full scale, or 1° F. The response time is 1/10 second. The RoadWatch pavement and air temperature readings are collected on the Rockwell PlowMaster system.

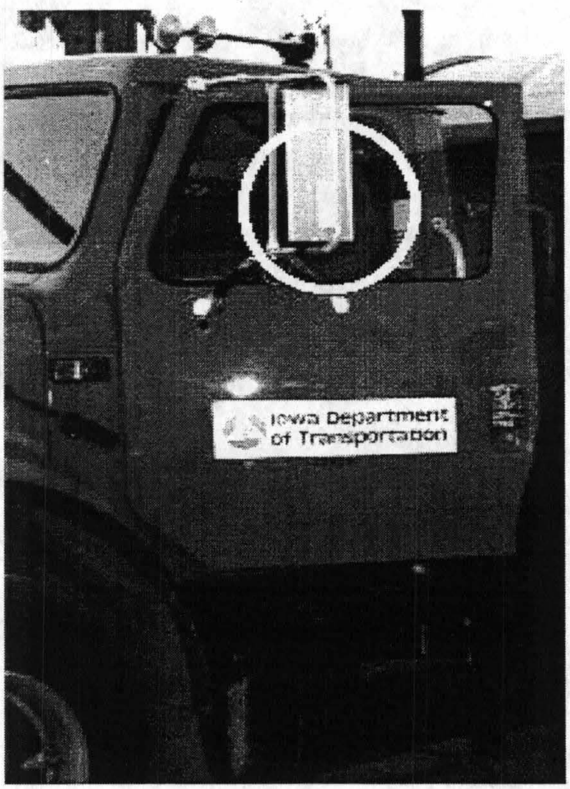


Figure 9-1 RoadWatch, Iowa prototype vehicle

Comparing Sensor Data to RWIS Data

The nearest Roadway Weather Information Systems (RWIS) site to the Iowa route is located on I-235 near downtown Des Moines, on the Des Moines River bridge. This RWIS site is approximately eight miles from the closest point on the route and represents a very different environment from the route. Therefore, comparing the temperature data collected by the concept vehicle on the test route to the data collected at the RWIS site located eight miles from the route is not appropriate.

Temperature Sensor Test and Evaluation Done by Other Investigators

Braun Intertec Corporation, Portland, Oregon, an independent testing and engineering consulting firm, issued report 05-047-1007 reporting results of project EARX-97-0270. The report provides results of a comparative performance test conducted with Control Products 996A and a Sprague RoadWatch surface temperature monitoring system. Report 05-047-1007 is included in Appendix H. The results of this evaluation point out that the RoadWatch temperature sensor is capable of collecting road and air temperature.

Observations Made by Iowa Maintenance Area Supervisiors

Proof of concept for the RoadWatch on Iowa's prototype vehicle has been conducted regularly since the sensors were installed. The vehicle is stationed at the Des Moines North shop. Lance Starbuck, Iowa DOT Des Moines North Area Supervisor, and Charles Pickett, Iowa DOT Des Moines West Area Supervisor, have observed readings taken by the RoadWatch sensor. Both supervisors were asked about the roadway temperature sensors and their correlation with RWIS and other pavement temperature sensing devices they use.

To more fully understand this new technology and build his and his operators' confidence in its reliability for use in snow and ice control operations, Lance Starbuck regularly monitored the temperature sensors' accuracy. He followed Iowa's prototype vehicle during snow removal operations and compared its RoadWatch readings with readings from the Control Products temperature sensors mounted on his pickup. Mr. Starbuck found the RoadWatch sensor to be within 1° F of the Control Products sensor.

Charles Pickett has checked both RoadWatch and Control Products sensors mounted on his pickup at two RWIS sites in his maintenance area. Mr. Pickett found that the RoadWatch sensor temperature readings typically run 2° F colder than RWIS, and readings from the Control Products sensor runs about 1° F colder than RWIS.

Because of its satisfaction with the Sprague RoadWatch, in the past year the Iowa DOT has installed about 100 RoadWatch sensors on a variety of snowplow and supervisor trucks.

OBSERVATIONS

Proof of concept was successful. The RoadWatch sensors were successfully installed on the prototype maintenance vehicles and, based on temperature sensor testing and evaluation performed by other investigators and observations made by Iowa DOT maintenance area supervisors, the sensors collected reasonable data.

CHAPTER 10: POWER BOOSTER

During Phase I focus group activities, equipment operators expressed a desire for more horsepower during certain operating situations; e.g., plowing snow while going uphill, entering traffic with a full load, changing lanes, and accelerating to travel speeds in high traffic conditions. The transit industry had already been using a power booster system to increase engine horsepower during peak demand periods. Fosseen Manufacturing's engine booster, the DriverMax/Hydrofire system, had successfully been installed on transit buses in Des Moines and Cedar Rapids, Iowa, and was the candidate for this study.

OBJECTIVE

Conduct proof of concept regarding implementing an engine power booster to increase the horsepower of a winter maintenance vehicle during peak engine demand periods.

MEASUREMENT

The Hydrofire system is successfully installed on the prototype vehicles and operates as expected; that is, wheel horsepower is higher on the prototype vehicle when the power booster system is engaged.

DISCUSSION

Fosseen Manufacturing & Development Ltd. (Fosseen), located in Radcliffe, Iowa, supplied a custom-built "Hydrous-Ethanol Hydrofire Injection System and Power Booster" for each prototype vehicle. The Hydrofire fuel injection system consists of an electronic control unit (DriverMax) in the cab; an auxiliary fuel tank mounted on the outside of the vehicle; and a pump to inject fuel from the auxiliary tank into the engine's airstream intake, along with related plumbing and exhaust treatment devices, under the vehicle's hood. The auxiliary tank contains Hydrofire Fluid, a water-alcohol-lubricant blend fuel. Hydrofire is pre-mixed and provided by Fosseen. DriverMax, the electronic fuel controller, has pre-set values that determine when the engine needs more power and then engages turbo boost pressure to automatically inject the Hydrofire.

The injection of hydrous-ethanol results in a cleaner running engine with a longer engine life. Increased engine performance, longer life, decreased nitrogen oxide emissions, particulate matter reduction, and savings of petroleum fuels are among the benefits of the Hydrofire injection system. During tests conducted by Fosseen Manufacturing and Five Seasons Transit in Cedar Rapids, Iowa, the hydrous-ethanol was injected into a diesel engine under heavy load conditions.

The approximate dimensions of the DriverMax control box are six inches by two inches by four inches. Iowa DOT mechanics encountered challenges with the capacity and the location of the alcohol tank for Fosseen's Hydrofire engine booster system. The Iowa prototype vehicle first arrived from the fabricator with an eight-gallon alcohol tank, mounted on the driver's side behind the cab. Due to the relatively small capacity of this tank and high rate of fuel consumption, Iowa DOT mechanics replaced the eight-gallon tank with a 30-gallon tank. They selected the 30-gallon tank not only because of its higher capacity but also because it could easily be installed in a new location—on the passenger side, beneath the cab. Iowa DOT mechanics built a custom shield to protect the container and its contents from the heat of the exhaust system, running within six inches of the tank.

Michigan DOT mechanics moved the engine power booster system to a more protected and convenient location on top of the diesel fuel tank and plans to install a larger power booster fuel tank at a later date. In addition, a ladder was installed on the side of the liquid tank to make it easier and safer to fill. The Michigan and Minnesota vehicles have eight-gallon tanks.

Figure 10-1 shows the location of the power booster fuel tank installed Iowa's prototype vehicle.

Figure 10-1 Alcohol tank, Iowa prototype vehicle

The engine power booster on Iowa's prototype vehicle was first tested in Des Moines, Iowa, on June 23 and 24, 1997. The vehicle was placed on a dynomometer and tested three times, first without any alteration to the vehicle, second with the installation of the supplemental injectors and manifold but using only diesel fuel, and finally with the new Hydrofire parts and alcohol-based fuel additive. The tests with the with new Hydrofire system resulted not only in an increase in engine horsepower but also in a drop in exhaust gas temperature.

Fosseen next examined the effects of the engine power booster on wheel horsepower using dynomometer tests on all three prototype vehicles. Iowa's (230-horsepower Navistar 466 engine) was tested on July 22, 1997; Minnesota's (230-horsepower Cat 3176B engine) was tested on October 7,1997; and Michigan's (300-horsepower Cummins L10 engine) was tested on November 1, 1997. The tests of all vehicles indicated a boost in wheel horsepower by about 20 horsepower, and a decrease in exhaust temperatures by 50 to 75° F. Refer to Figures 10-2, 10-3, and 10-4 for graphs of test results for the Iowa, Minnesota, and Michigan prototype trucks, respectively. Correspondence with data files from the three Fosseen tests is included in Appendix H.

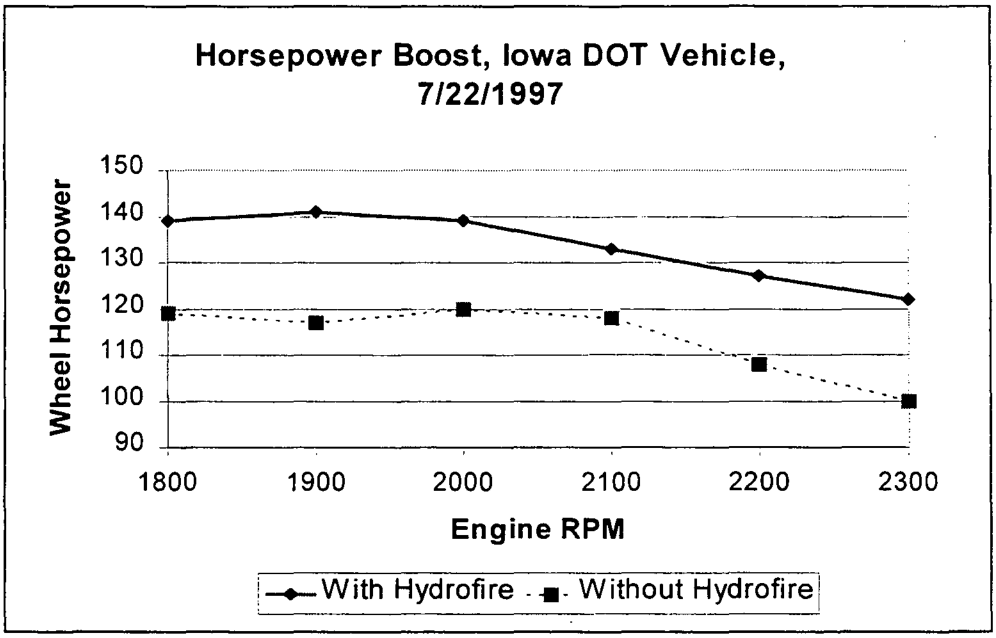


Figure 10-2 Horsepower boost, Iowa DOT vehicle, July 22, 1997

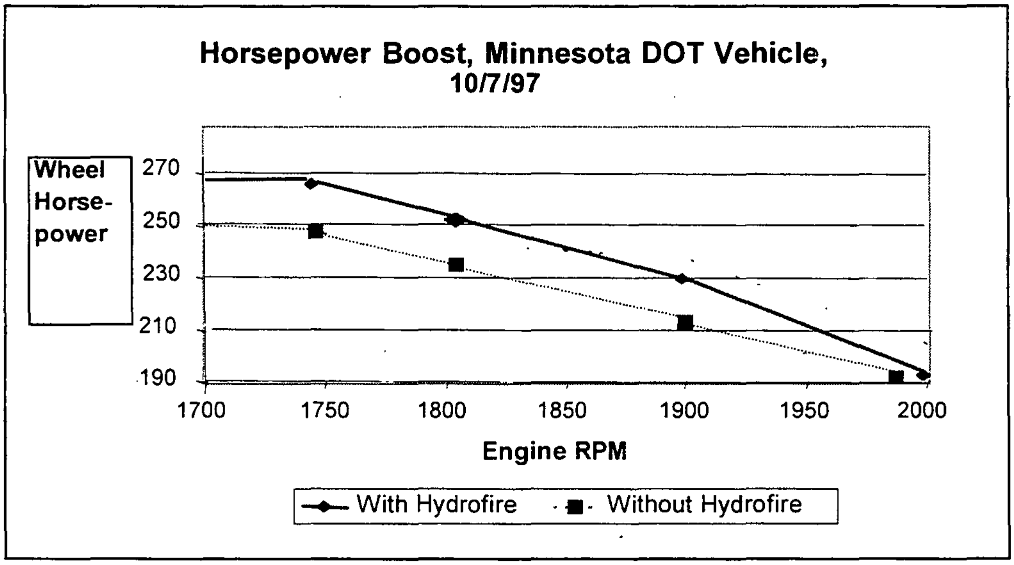


Figure 10-3 Horsepower boost, Minnesota DOT vehicle, October 7, 1997

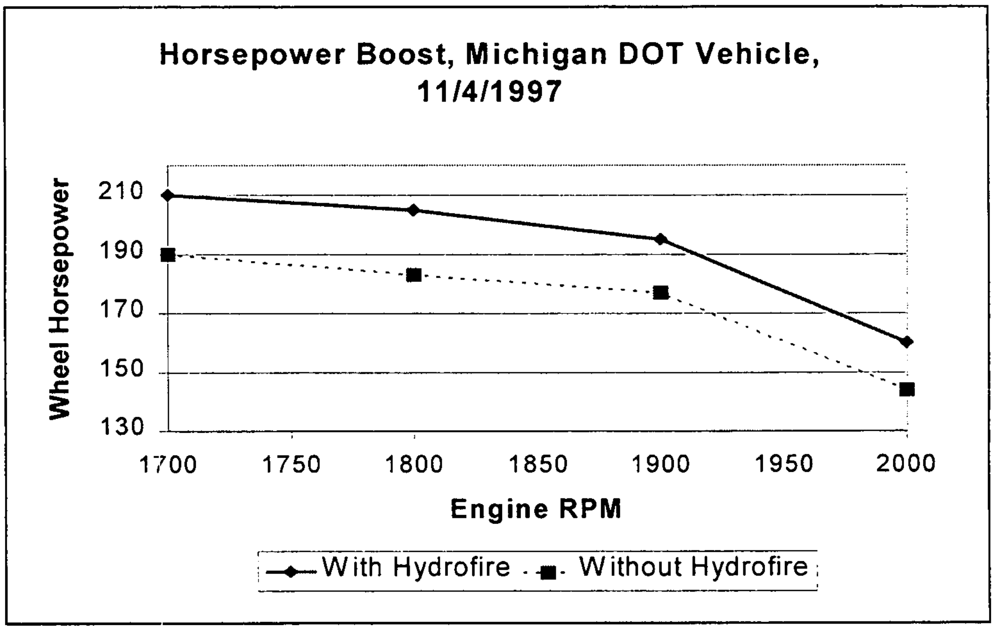


Figure 10-4 Horsepower Boost, Michigan DOT Vehicle, November 4, 1997

On Minnesota's vehicle, the extra wheel horsepower provided by the Hydrofire system fell as engine RPMs approached 2000. The greater manifold pressure of this particular engine works against the injection pressure of the additive, particularly at the highest RPMs. Fosseen reports that the injection pressure can be increased for this and similar engines to provide continuing wheel horsepower increases at high RPMs.

OBSERVATIONS

Proof of concept was successful. The power boosters were successfully installed on all three prototype vehicles, and wheel horsepower measured higher when the power booster system was active on all three vehicles.

CHAPTER 11: LIGHTING (VEHICLE CONSPICUITY)

During Phase I focus group activities, equipment operators in all three consortium states expressed concern about snowplows being visible when weather conditions are poor. Fiber optic lighting systems have the potential to improve visibility of the vehicles. Innovative Warning Systems provided a fiber optic lighting system to supplement existing strobe lights and revolving beacons on the Iowa and Minnesota prototype vehicles.

OBJECTIVE

Conduct proof of concept regarding use of high-intensity lighting systems to improve snowplow visibility.

MEASUREMENT

High-intensity lights are successfully installed on the prototype vehicles and perform as expected; that is, they provide vehicle visibility superior to conventional rotating beacons.

DISCUSSION

Innovative Warning Systems, located in Minneapolis, Minnesota, supplied the Innovative Warning Systems Spectra High-Intensity Discharge (HID) fiber optic lightning system, HIDSYS-01, for the Iowa and Minnesota prototype vehicles. See Figure 11-1 for a rear view of Iowa's prototype vehicle showing the fiber optic lights.

Figure 11-1 Fiber optic light system (circled), Iowa prototype vehicle

The Spectra Distributed Light system projects light instead of reflecting it, directing all of the light energy where it is required. The Spectra system also uses color contrasting, which creates a powerful attention-getting flash effect by changing colors instead of flashing the lights on and off. Spectra can produce numerous color or combination of color patterns.

The heart of the Spectra Distributed Light System is the light engine, which utilizes a high intensity discharge (HID) short-arc lamp. The light engine's 60-watt lamp is resistant to shock and vibration failure because it has no filament. This lamp has 10 times the life and uses less than one-third the energy of four halogen lamps. It may replace the typical revolving warning light. The Spectra system also has a rapid-start and instant-restart technology to ensure a warning signal is always available when needed.

Light from the light engine is transmitted through "light pipes"—flexible, plastic optical fibers that conduct the light produced by the light engine to its ultimate destination. Light pipes can diverge and distribute light in any direction and at any intensity, allowing a single high-intensity lamp to replace multiple halogen lamps, thus dramatically lowering current draw.

The light pipes are connected to light converters, which take light from the light pipes and project it outwardly in any desired direction and intensity. Light converters have a variety of designs and can be mounted in spaces that do not accommodate larger conventional lights.

Iowa DOT mechanics encountered challenges with Innovative Warning Systems' High Intensity Discharge (HID) Fiber Optic Lighting System. It was installed by Iowa DOT personnel. The light engine in the prototype vehicle's cab was the first component to cause challenges. It seemed very sensitive to mounting orientation, mounting location, and the routing of the fiber-optic cables.

According to Iowa DOT mechanics, most of the challenges with the HID lighting system stemmed from the system's fiber-optic cables. The most troublesome challenge involved the intrusion of moisture into the cables' lining, causing the light to reflect along the cable improperly, or not at all. The moisture entered between the cable's inner lining and the fiber optic strands. Through experimentation, Iowa DOT mechanics discovered an improvement in light transmission when they cut the fiber-optic cables to make them shorter. There is a limit to the extent that the fiber optic cables may be shortened, namely a length long enough to permit continued operation, free movement, and deployment of the prototype truck's components when the lighting system is still in use.

The HID light on top of the prototype vehicle is mounted to the U-bracket on which the conventional rotating yellow beacons are mounted.

To solve the two rear HID light challenges involving (1) moisture intrusion and (2) precise aim and positioning required with the HID lights, Iowa DOT mechanics mounted the rear HID light upside down (to eliminate the water intrusion) and onto a ball and socket joint to provide proper positioning. This ball and socket joint enabled Iowa DOT mechanics to easily tilt and aim the rear HID light up, down, left, and right. The ball and socket joint was originally conceived by the Minnesota DOT on their prototype vehicle. See Figures 11-2 and 11-3 for pictures of these ball-and-socket jointed lights.

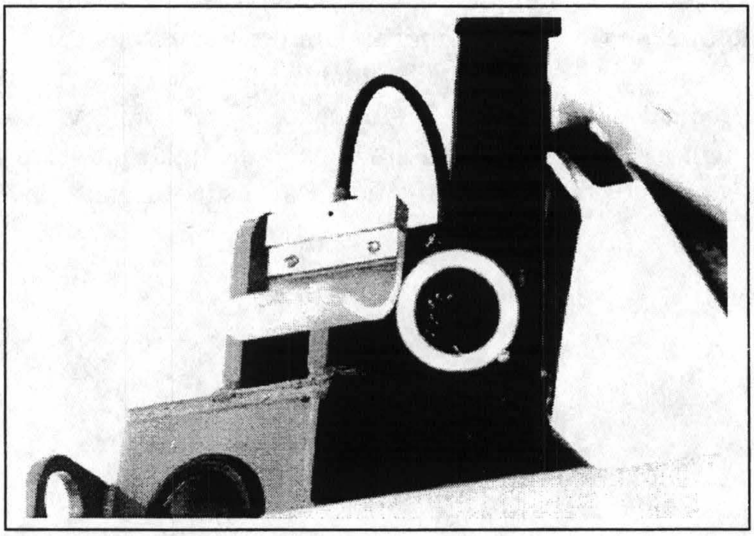


Figure 11-2 Left ball-and-socket joint (circled), HID lighting system, Iowa vehicle

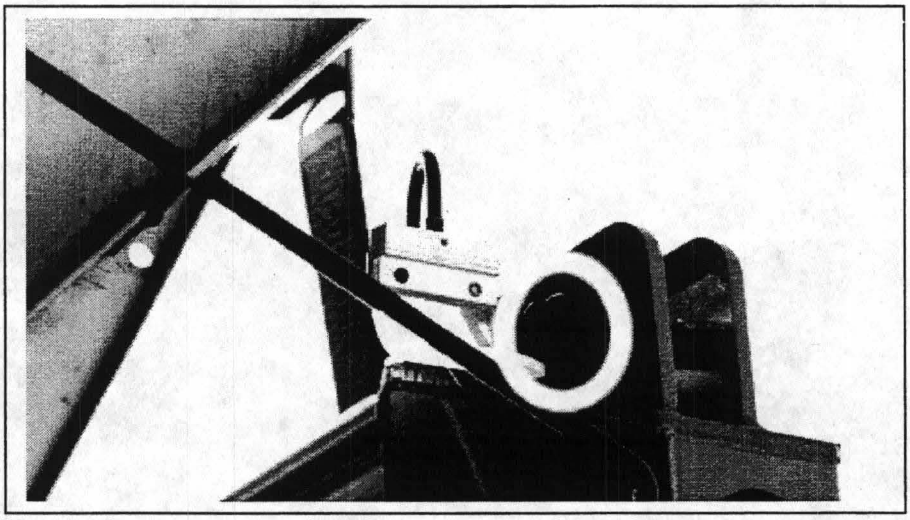


Figure 11-3 Right ball-and-socket joint (circled), HID lighting system, Iowa vehicle

Minnesota DOT mechanics extended a fiber optic cable along the top of the wing plow. They removed the black casing, exposing the clear tubing. This provided illumination along the blade, making it more visible to motorists during dark or adverse weather conditions. The result is a glowing tube on top of the wing plow. Conventional lights could not be used for this purpose because the extreme vibrations broke their filaments. Iowa used the same installation procedure along the top of the wing plow.

OBSERVATION

Installation of the HID lighting was successful on Iowa's and Minnesota's prototype vehicles after modifications to prevent moisture infiltration. Michigan did not install this system. Proof of conduct was not formally conducted on the lights' performance. CTRE received only anecdotal evidence about performance; observations were primarily based on weather and light conditions. Some users thought the lights provided superior visibility of the vehicle to conventional rotating beacons in fog and snow, but others did not.

CHAPTER 12: BACKUP VEHICLE STOP SENSORS

During Phase I focus group activities, equipment operators expressed an interest in technology that could detect objects behind their snowplows and help prevent accidents when they are backing up. The particular situation they described was when they need to turn around on a divided highway and can't negotiate the entire turn with one movement because of the snowplow's long wheelbase and large turning circle. As a result, they can't always make a complete turn without stopping and backing up, and during the turning process other vehicles can pull in behind the snowplow into the operator's blind spot without the operator' knowledge. If the driver backs up to complete the turn, a collision is likely.

Global System's Search-Eye Sensor System is used by many industrial and commercial fleets and on some school bus fleets. When the vehicle is in reverse and Global's sensors detect an obstacle behind the vehicle, the brakes are automatically applied.

OBJECTIVE

Conduct proof of concept regarding implemention of an automatic sensor/braking system on winter maintenance vehicles to prevent collisions with vehicles or other obstacles when the maintenance vehicles are backing up.

MEASUREMENT

The Search-Eye system is successfully installed on the prototype vehicles and performs as expected; that is, when an obstacle is behind the prototype vehicle, the sensor automatically prevents the vehicle from backing up by applying the brakes.

DISCUSSION

Global Sensor Systems, Incorporated, located in Mississauga, Ontario, provided its Search-Eye Sensor System for all three prototype vehicles. The sensor system detects the presence of objects behind the prototype vehicles when reverse gear is engaged, and automatically applies the brakes.

Global's system consists of sensors mounted on the rear of the vehicle and wired into the braking system. Placing the gearshift lever in reverse turns on the system. If an object is detected while backing up, the brakes are applied automatically, and an audible "Sonalert" and large red light on the cab control box warn the driver. Moving the gearshift to any other position turns the system off.

The normal Search-Eye installation requires two sensors on the back of the vehicle. On a snowplow vehicle, however, the sensors "saw" the salt/sand chute protruding from the rear of the vehicle as a separate object. It was necessary to install a third sensor to compensate for the chute's interference with the other sensors' cones of vision. See Figure 12-1 for the location of the reverse obstacle sensors on the rear of Iowa's prototype vehicle.

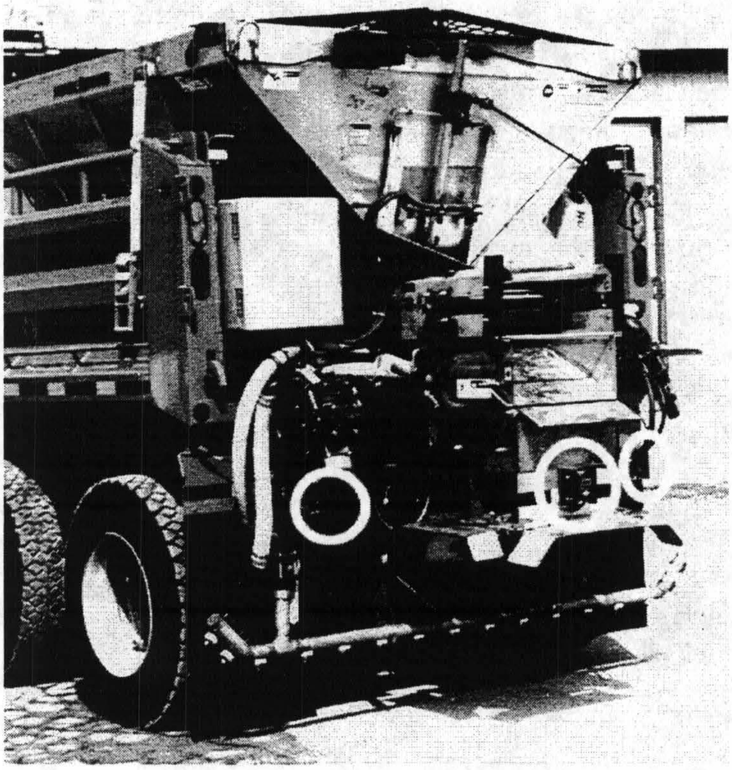


Figure 12-1 Location of reverse obstacle sensors (circled), Iowa vehicle

The Search-Eye Sensor System can be used with either hydraulic brakes or air brakes. The units have a manual override switch that permits the operator to disable the automatic braking system when the need arises, such as when backing up to a loading dock. The audible beeping sound will continue until the manual override switch is reset. The systems that are supplied for vehicles equipped with hydraulic brakes consist of two rear-mounted sensors, a heavy-duty plunger-type solenoid, and a transceiver. The heavy-duty air brake system consists of three rear-mounted sensors, one electrically operated air relay valve, and a transceiver.

OBSERVATION

The backup sensor system was successfully installed; however, proof of concept was not conducted on their performance. Anecdotal evidence indicates the sensor system worked as expected; the prototype vehicles automatically stopped when they were backing up and approaching obstacles. Field evaluations in Phase III may indicate that, with this or similar technology on winter maintenance vehicles, operators could experience a decrease in backing accidents involving vehicles in poor visibility situations, and there could be a lower accident-related maintenance repair cost.

CHAPTER 13: DATA MANAGEMENT

Proof of concept for many of the prototype vehicles' add-on technologies involved comparing, organizing, and otherwise working with data collected by systems on the vehicles. As described in Chapter 6, Rockwell's PlowMaster was critical to this process. Data outputs from vehicle sensors and other technologies were collected on the PlowMaster, which formatted the various data outputs in a common format and stored the data on PCMCIA cards for delivery to CTRE. Figure 13-1 demonstrates the data flow during Phase II.

As data outputs were delivered from the state DOTs via PCMCIA cards, CTRE staff invested significant effort in developing procedures for organizing, translating, and manipulating the data. In Phase II, these efforts were critical for determining if data being collected by the add-on technologies were reasonable and if the systems appeared to be working as expected; that is, the data were critical to proof of concept. In the future, these Phase II development efforts will provide the basis for statistical analyses and reporting to be conducted during the Phase III field evaluations, as well as a foundation for developing data formats that will make the data accessible to DOTs' management systems.

This chapter briefly discusses CTRE's process for managing data downloaded from the PCMCIA cards.

OBJECTIVE

Conduct proof of concept regarding formatting and organization of data collected by technologies on winter maintenance vehicles to support proof of concept of the various add-on technologies and to provide a foundation for future use of data collected by the vehicles in maintenance decision making and in DOT management systems.

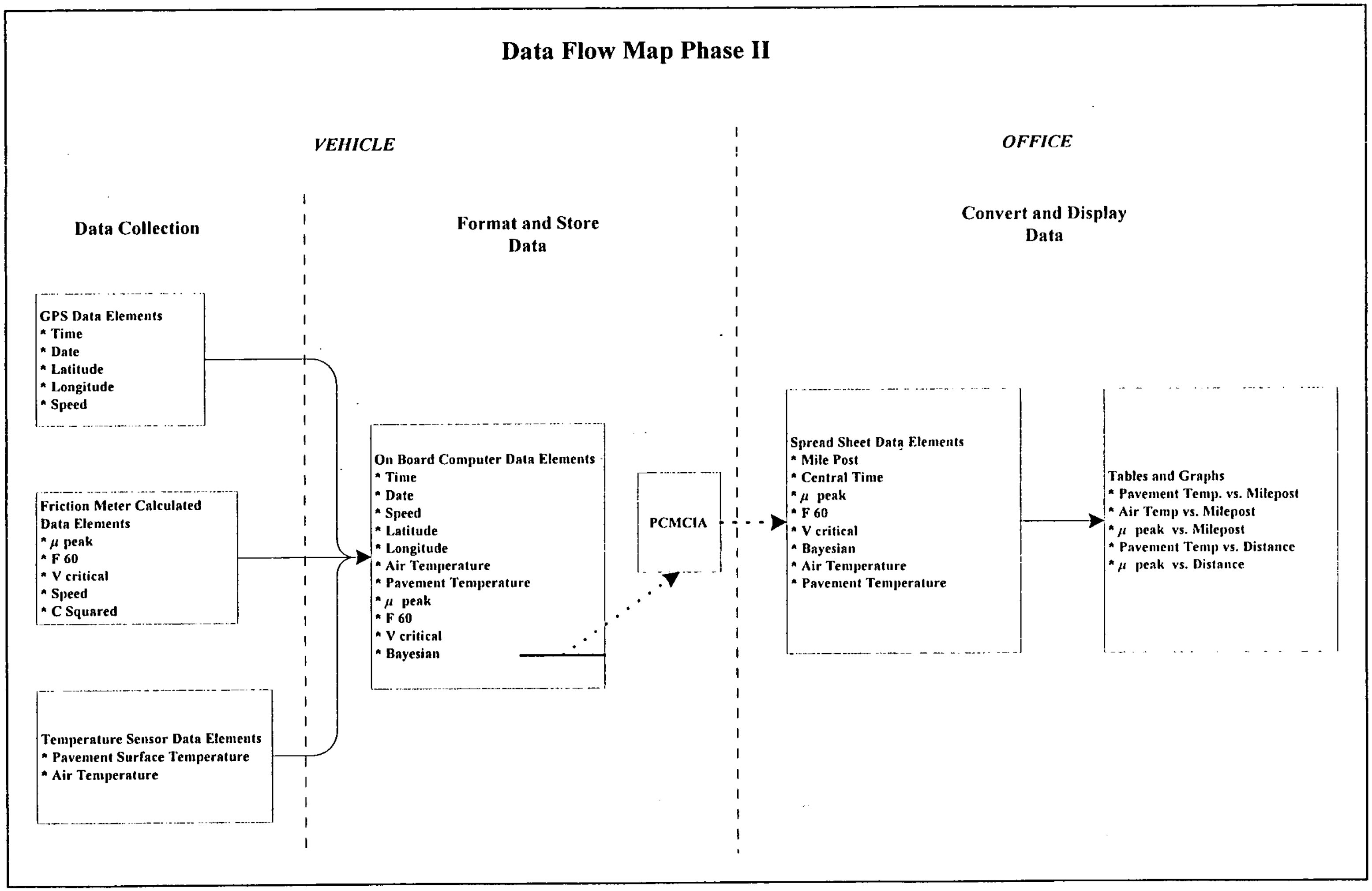
MEASUREMENT

Raw data downloaded from PlowMaster PCMCIA cards are converted to more understandable terms: GPS latitude and longitude to mileposts, GPS time to Central Standard Time, GPS speed to distance traveled by the vehicle. After conversion, data are plotted in graphs using various parameters.

DISCUSSION

In Phase II, data collected by the prototype vehicles' onboard technologies were stored on PCMCIA cards and delivered to CTRE via one of three avenues, at the convenience of the individual states:

Figure 13-1 Phase II data flow chart



1. CTRE staff went to the vehicle location, collected the PCMCIA card, and returned with the card to CTRE where they downloaded the data, cleared the card, and mailed it back to the originating location.

2. Local maintenance personnel removed the PCMCIA card from the PlowMaster and transmitted the card via overnight mail to CTRE. CTRE downloaded the data, cleared the card, and mailed it back to the originating location.

3. Local maintenance personnel removed the PCMCIA card from the PlowMaster, downloaded the data, and transmitted the data via electronic mail to CTRE.

Data downloaded at CTRE from the PCMCIA cards were imported into Microsoft Excel 7.0 for translation and organization. All files were organized at CTRE by state, technology, and date and stored permanently on zip disks along with a detailed directory structure. They are available for distribution on request.

The raw data sets from the PCMCIA cards contained thousands of data points, which CTRE filtered down to sets containing only necessary data points collected by correctly operating equipment. Raw GPS time and location data downloaded from the PlowMasters were not referenced in terms that were meaningful to most DOT staff or the study team, and CTRE converted these data to commonly understood terms for easier analysis. Also, distance data were not provided on the PlowMaster data sets; CTRE therefore computed distances and added distance data points to the data sets.

A macro program was written in Visual Basic to simplify and accelerate the tedious process of converting location and time data, computing distance traveled by the vehicles in each data capture run, and plotting graphs in Microsoft Excel; the complete macro code is included in Appendix I. For each data set collected and filtered in the winter of 1997-1998, all parameters were plotted against each other and reviewed for discrepancies, trends, etc. The macro will greatly facilitate data management during Phase III evaluation.

Raw Data from PlowMaster

All three prototype vehicles recorded sensor outputs during the winter of 1997-1998 and transferred the results to CTRE, for a total of 35 data files. On data capture trips, the Rockwell onboard computers recorded sensor outputs every ¼ second. Data runs lasted from five minutes to two hours, generating data files containing thousands of data points, often more than 10,000.

Table 13-1 lists the names of the files in the file directory, using the following naming convention:

- The " A" indicates the file is from the onboard computer.

- The first two digits indicate the calendar date when the file was created.

- The next one or two digits indicate the digit(s) of the current month.

- The next digit indicates the last digit of the year.
- The last two digits indicate the number of this file, in relation to other ones recorded the same day.

For example, using the file A141801.xls from Minnesota:

- The " A" means this file is from the onboard computer.
- The first two digits, 14, indicates the calendar date of the day when the file was created (the 14th).
- The next digit, 1, indicates the month is January.
- The next digit, 8, indicates the last digit of the year, 1998.
- The last two digits, 01, indicates this file was the first to be recorded for this date.

The naming convention was the same for data files from all three prototype vehicles.

Tables 13-2 , 13-3, and 13-4 are excerpts of data sets (onboard sensor outputs) received on the PCMCIA cards by CTRE, one data set from each of the prototype vehicles.

- The first five columns (UTC Time, Lat, Lon, Heading, and GPS Speed) are GPS outputs (i.e., the GPS stamp).
- The next two columns (air temp and road temp) are temperature sensor outputs.
- The Mu Peak values are outputs from the friction meter sensors. (Readings of –1 indicate the sensor was not reporting when these data were recorded.)

Table 13-1 File directory, winter 1997-1998

State	Date	File Name
Iowa	01/04/98	A041801.xls
	01/05/98	A041802.xls
	01/12/98	A121801.xls
	01/14/98	A141802.xls
	01/21/98	A201801.xls
		A211801.xls
	01/22/98	A221801.xls
	03/02/98	A023801.xls
	03/07/98	A073801.xls
	03/08/98	A083801.xls
		A083802.xls
		A083803.xls
		A083804.xls
	03/09/98	A093801.xls
Michigan	01/08/98	Nm.xls
	01/14/98	A141801.xls
	02/24/98	A242801.xls
	03/04/98	A043801.xls
	03/06/98	A063801.xls
		A063802.xls
	03/09/98	A0681026.xls
		A0681058.xls
		A093801.xls
		A093802.xls
Minnesota	11/13/97	A13b701.xls
	11/14/97	A13b702.xls
		A14b701.xls
	11/15/97	A15b701.xls
		A15b702.xls
		A15b703.xls
	12/30/97	A30c701.xls
	12/31/97	A31c701.xls
	02/05/98	A052801.xls
	03/23/98	A233801.xls
	04/01/98	A014801.xls
		A014802.xls

Table 13-2 Sample data from onboard computer data file A041801.xls, Iowa vehicle, January 4, 1998

UTC Time	Lat	Lon	Heading	GPS Speed	Air Temp	Road Temp	μ Peak (as x 1,000)
65668	41.6646108	-93.5764253	347.499	37.536	33.75	24.00	731
65669	41.667580	-93.5764689	347.499	37.446	33.75	24.00	731
65670	41.6649047	-93.5765130	347.270	37.491	33.75	23.88	540
65671	41.665014	-93.5765560	347.671	37.312	33.75	24.63	540
65672	41.6651975	-93.5765978	347.957	37.178	33.75	23.25	540
65673	41.6653425	-93.5766385	348.129	36.842	33.63	23.88	540

Table 13-3 Sample data from onboard computer data file A141801.xls Michigan vehicle, January 14, 1998*

UTC Time	Lat	Lon	Heading	GPS Speed	Air Temp	Road Temp	μ Peak (as x 1,000)
219765	44.0059180	-85.5030835	192.170	10.133	31.25	23.88	-1
219766	44.0058916	-85.5030910	192.055	5.816	31.25	23.75	-1
219767	44.0058796	-85.5030944	192.285	2.684	31.25	24.00	-1
221816	44.1674611	-85.4381147	317.416	6.331	31.13	24.63	-1
221817	44.1674731	-85.4381342	314.325	3.982	31.00	25.13	-1
221818	44.1674777	-85.4381457	302.293	1.767	31.00	25.38	-1

*Friction sensors were not reporting and did not record μ_{peak} values.

Table 13-4 Sample data from onboard computer data file A13b701.xls Minnesota vehicle, February 5, 1998

UTC Time	Lat	Lon	Heading	GPS Speed	Air Temp	Road Temp	μ Peak (as x 1,000)
417826	44.6563648	-93.6771439	242.934	42.233	26.38	19.00	680
417827	44.6562875	-93.6773564	242.877	42.345	26.25	17.88	680
417828	44.6562101	-93.6775690	242.934	42.256	26.25	18.63	680
417829	44.6561339	-93.6777827	243.335	42.300	26.38	17.00	680
417831	44.6559821	-93.6782102	243.564	42.233	26.38	17.38	680
417832	44.6559065	-93.6784244	243.564	42.412	26.38	17.75	680

Data Filtering

Data delivered to CTRE on PCMCIA cards included several data points related to friction that were superfluous to the project's data management goals or simply incorrect. For example, F60 friction values are the equivalent of μ_{peak} (mu-peak) when vehicles travel at 60 km/hr on dry pavement. Because data required for proof of concept of the ROAR friction meter included only those collected under winter conditions (wet, snow, and ice), the F60 values are not needed for purposes of this project.

Generally, μ_{peak} is a measure of friction with a range of zero to one; the reading for μ_{peak} should therefore never be negative or more than one. PlowMaster multiplies the recorded μ_{peak} by 1,000 (to avoid fractions), creating an acceptable range for μ_{peak} up to 1,000. Some μ_{peak} values, however, were recorded above 1,000, indicating that the ROAR friction meter was not operating correctly.

Finally, some data sets included friction data points with values of zero or –1. According to Rockwell, zero indicated that the ROAR friction meter was turned on but not able to record friction because the ROAR device was not touching the roadway surface. The –1 indicated that the ROAR friction meter was not turned on or not working.

To provide realistic and manageable data sets for graphing and other data reduction purposes, CTRE created data sets that filtered out the following information:

- Friction values of 0 or -1

- μ_{peak} readings outside the range of 0-1,000

All original data sets containing all data points are stored at CTRE.

Conversion to Central Standard Time

The Rockwell onboard computer recorded time in Uniform Time Conversion (UTC) time, which is the number of seconds past midnight Sunday at the International Dateline. UTC time therefore needed to be converted to days, hours, minutes, and seconds in Central Standard Time. This was a fairly straightforward conversion using Equations 2 through 5.

$$Day = \frac{UTC\ \text{sec}}{86{,}400\ \text{sec}/day} \qquad [2]$$

$$Hour = \left(\frac{UTC\ \text{sec}}{86{,}400\ \text{sec}/_{day}} - Day\right) \times \left(24\ {}^{hrs}/_{day}\right) - 6\ hr \qquad [3]$$

$$Minute = \left(\frac{UTC\ \text{sec}}{60\ \text{sec}/_{\text{min}}}\right) - \left(Hour \times 60\ {}^{\text{min}}/_{hr}\right) - \left(Day \times 1440\ {}^{\text{min}}/_{day}\right) - \left(6\ hr \times 60\ {}^{\text{min}}/_{hr}\right) \qquad [4]$$

$$Second = UTC\ \text{sec} - \left(Day \times 86{,}400\ {}^{\text{sec}}/_{day}\right) - \left(Hour \times 3600\ {}^{\text{sec}}/_{hr}\right) - \left(6\ hr \times 3600\ {}^{\text{sec}}/_{hr}\right) \qquad [5]$$

where
UTC = Uniform Time Conversion
6 hr = Time difference between International Dateline Time and Central Standard Time
86,400 = Number of seconds per day
3,600 = Number of seconds per hour

Computing Distance Traveled

A data point desired by CTRE but not recorded by any of the on-board technologies to the PlowMaster was distance traveled by the prototype vehicle. CTRE therefore calculated the distance, using GPS speed and UTC time elapsed, as shown in Equation 6:

$$\text{Dist, ft} = \frac{\text{Speed}\ {}^{\text{mi}}/_{\text{hr}} \times \text{Time, sec} \times 5{,}280\ {}^{\text{ft}}/_{\text{mi}}}{3{,}600\ {}^{\text{sec}}/_{\text{hr}}} \qquad [6]$$

where
Speed = Speed of the Vehicle in miles per hour
Distance = Distance Vehicle Traveled in feet
Time = Time Elapsed between Readings in seconds

Conversion to Milepost

The GPS vehicle location is recorded in latitude and longitude coordinates, and there is no commonly used reference point for these coordinates. DOT maintenance personnel wanted to know where their vehicles were in relation to mileposts on their routes, so a conversion from GPS distance to milepost was completed along the vehicle routes.

With the GPS transponder collecting location (latitude/longitude) data, the prototype vehicles were driven their assigned routes and stopped for approximately five seconds at each milepost. CTRE graphed these data runs and documented locations where vehicle speed was zero. CTRE recorded the latitude and longitude values where the vehicle speeds were zero and established the correlation for milepost locations. (Minnesota did not complete this exercise but instead provided CTRE with milepost latitude and longitude values.) Figure 13-2 shows sample data, using the Iowa vehicle, of the speed run for establishing this correlation.

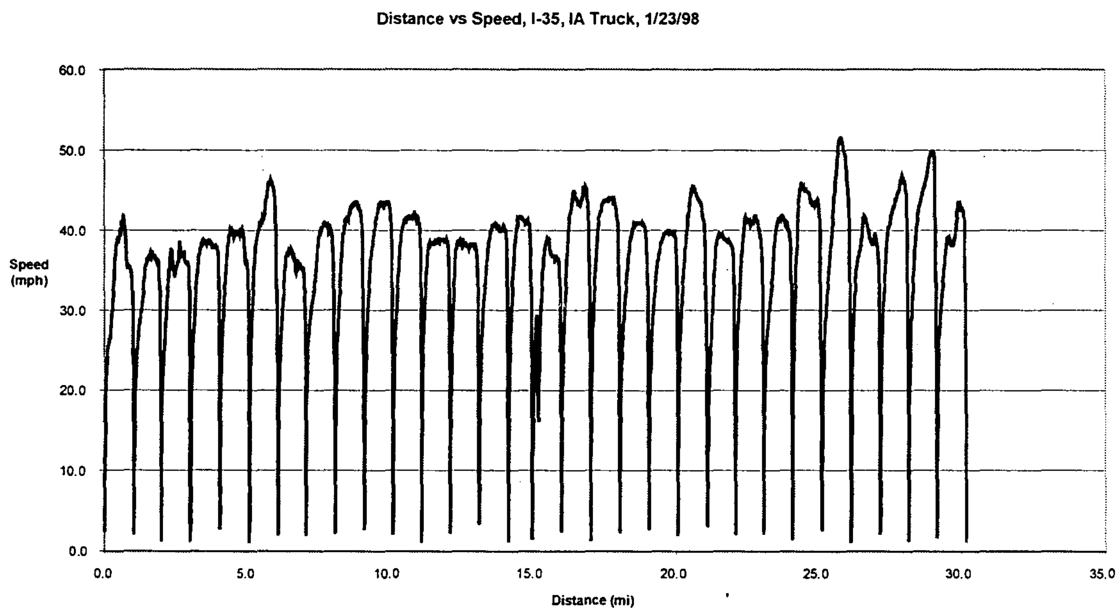


Figure 13-2 GPS speed versus distance, Iowa truck, January 23, 1998

Equation 7 was then used for the conversion from latitude and longitude to milepost along the Iowa vehicle's route:

$$\text{milepost} = 88.0 + (x - 41.66480) / (41.86635 - 41.66480)\,(102 - 88) \qquad [7]$$

where "x" is the latitude in degrees

Equation 7 applies to mileposts 87.5 to 104 along I-35 in Iowa. A similar equation was developed for Minnesota and for Michigan to convert GPS latitude and longitude to milepost.

After converting GPS location data, users could look at sensor output reports and relate them to known milepost locations, allowing CTRE and the DOTs to observe trends in sensor outputs, erroneous data points, or equipment malfunctions and relate them to milepost locations. CTRE then plotted various sensor outputs from the Rockwell onboard computers, using milepost as the y-axis.

Figures 13-3 through 13-6 demonstrate some of the ways in which parameters were plotted. These figures represent sample data collected for proof of concept; data anomalies were not closely examined during Phase II.

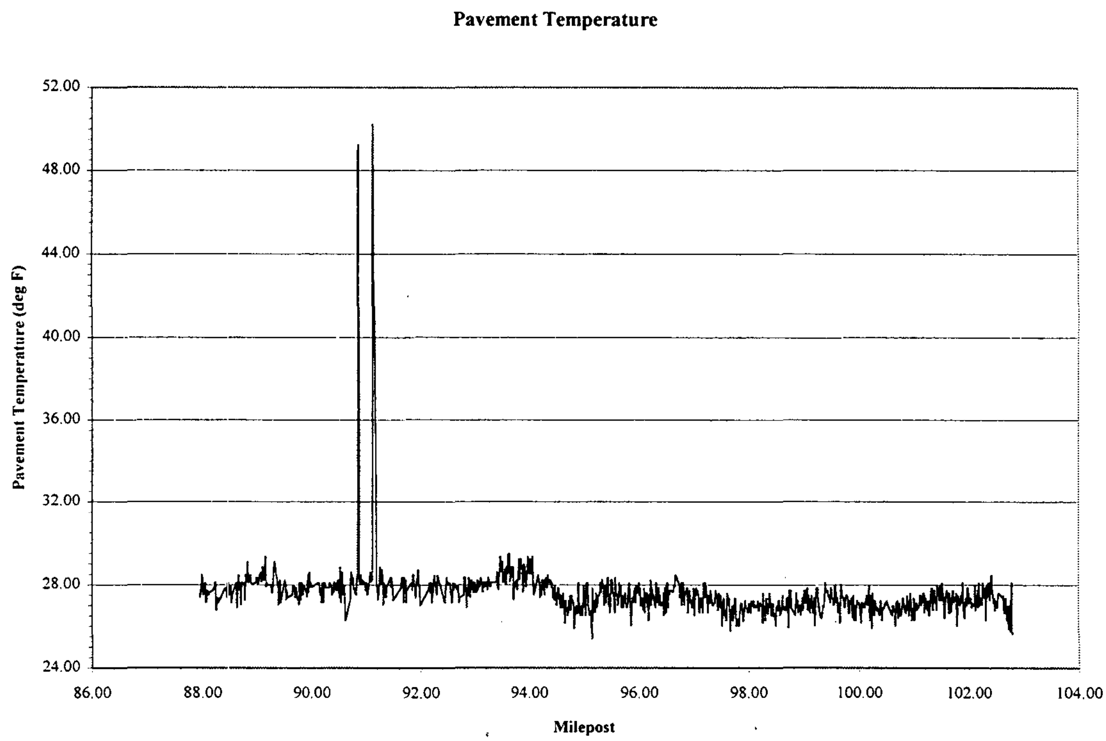


Figure 13-3 Pavement temperature versus milepost, Iowa vehicle, January 4, 1998

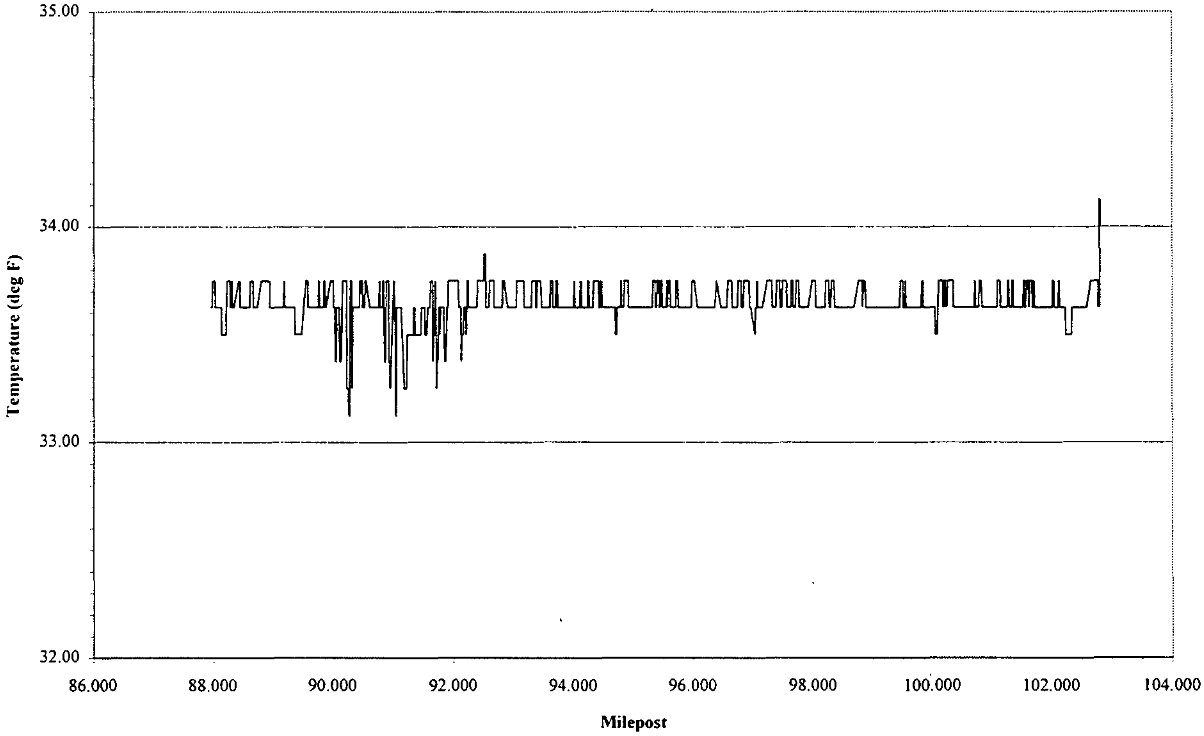


Figure 13-4 Air temperature versus milepost, Iowa vehicle, January 4, 1998

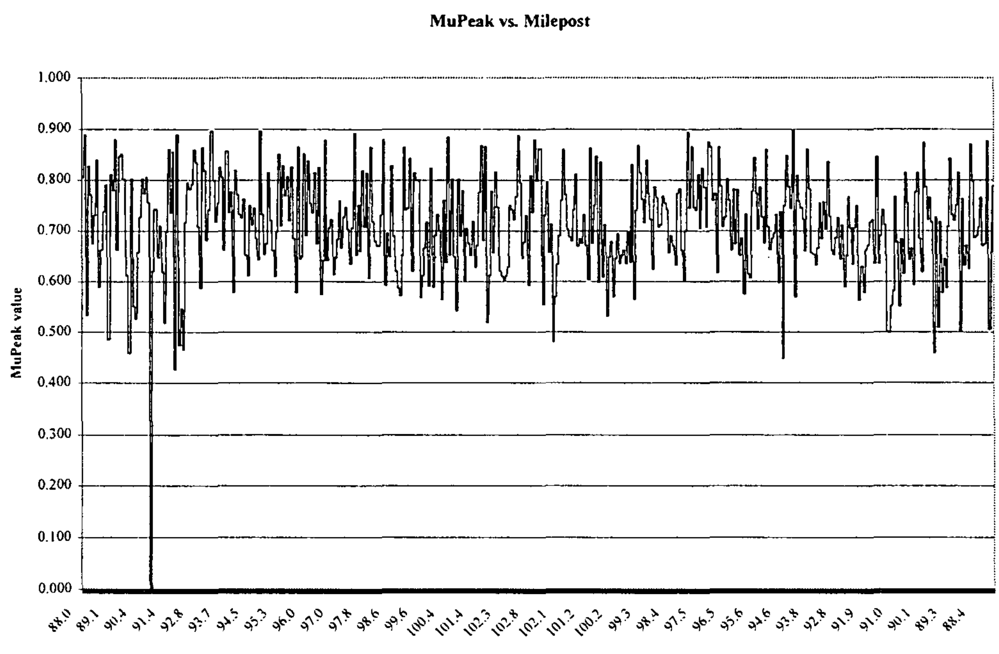


Figure 13-5 μ_{peak} versus milepost, Iowa vehicle, January 4, 1998

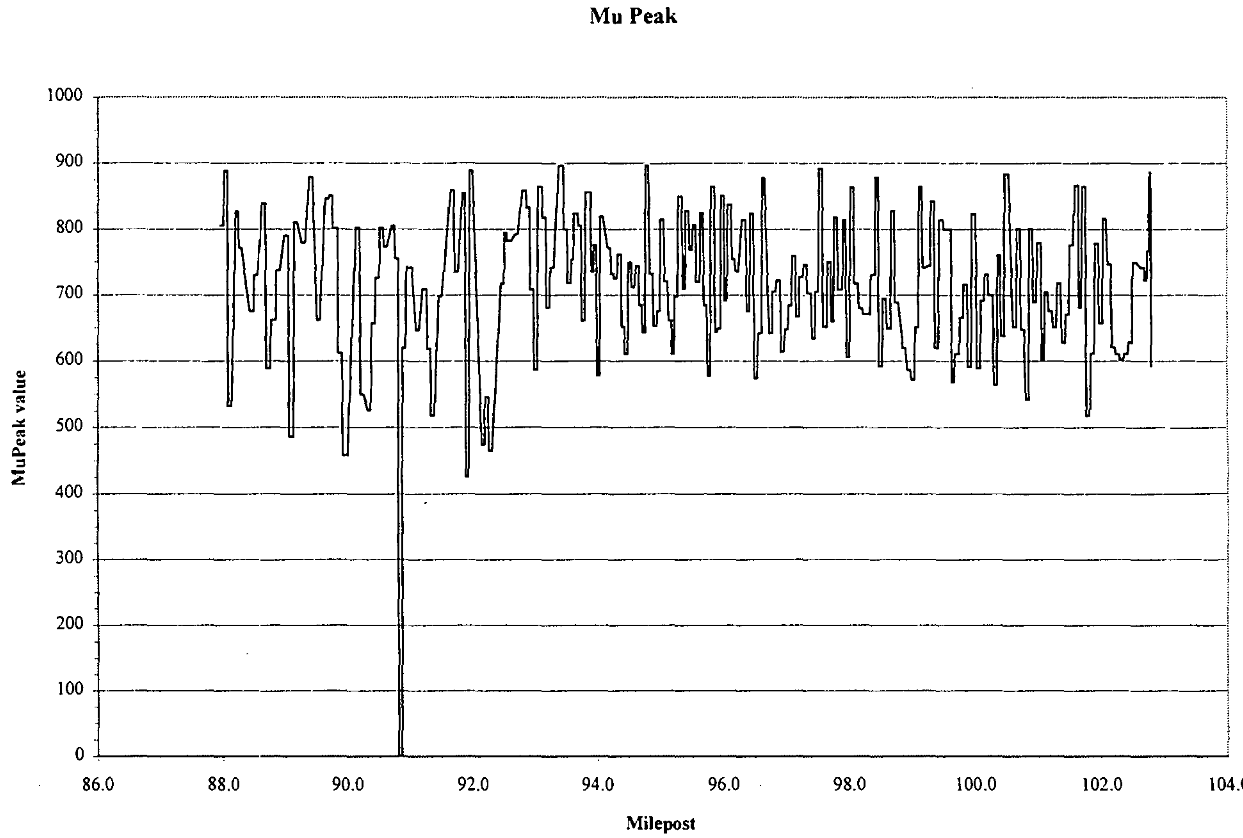


Figure 13-6 μ_{peak} versus distance Minnesota vehicle, February 5, 1998

OBSERVATIONS

Proof of concept regarding formatting and organizing data collected by technologies on the prototype vehicles was successful. Data were successfully downloaded from PCMCIA cards, filtered as necessary, translated into user-friendly terms, and plotted to find trends, erroneous data, and system malfunctions. Data files were stored in DOT format for use with decision-making tools like management systems.

Phase II data management activities demonstrated that data collected on winter maintenance vehicles can be translated into meaningful and useable data. The activities also helped identify problems with data collected by the onboard technologies so that adjustments could be made and proof of concept successfully accomplished for the technologies. The development activities for data management accomplished during Phase II will greatly facilitate data management processes in future phases.

CHAPTER 14: COST IMPLICATIONS OF PAVEMENT TEMPERATURE SENSORS

Many highway agencies and state departments of transportation (DOTs) are facing staff cutbacks even as the public expects agencies to improve the level of service on roadways and increase their sensitivity to the environment. Advanced technologies on winter maintenance vehicles have the potential not only to improve roadway conditions but also to provide economic and environmental benefits to both the state DOTs and highway users, including reduced use of winter chemicals and abrasives, equipment, and labor.

Benefit/cost analyses of specific technologies implemented on the prototype maintenance vehicles will be conducted during Phase III. This chapter merely introduces some general cost implications of these technologies. First, development costs are listed for technologies selected for implementation. Then, using a salt application curve and a scenario-based decision-making process, potential savings in ice and snow control materials and other assets are estimated for particular scenarios. These potential savings derive from the implementation of one advanced technology: pavement temperature sensors. Pavement temperature is a major factor for material application on highways during winter storms. When advanced technologies provide accurate pavement temperature data, maintenance staff can more accurately determine appropriate materials to apply and rates and timing of application. Other assets to be considered in cost savings for winter maintenance operations are labor and equipment.

INITIAL COST OF TECHNOLOGY

The technologies selected for the prototype maintenance vehicles are listed in Table 14-1, along with their costs, technology providers, and implementation schedule. These are development costs for the prototype vehicles shared by the technology providers and study sponsors, not ultimate production costs. Detailed information concerning the initial prototype providers, budget, and schedule can be found in the Phase I report, Concept Highway Maintenance Vehicle, Final report Phase One, dated April 1997.

TABLE 14-1 Initial prototype providers, budget, and schedule

Item	Technology Provider	Provider Contribution	Project Contribution	Schedule
IOWA TEAM (Ames)				
50,000 GVW Truck, Plows, Box	Iowa DOT			10/01/96
Trip Master/AVL System	Rockwell			--
Two-way Communication	Rockwell			--
Material Application	Bristol	$12,500	$12,500	09/01/96
Incremental Power	Fosseen	1,500	Fuel	09/15/96
Friction Meter	Norsemeter	45,000	20,000	01/01/97
Surface Temp. Sensor	SXI	500		10/01/96
Vehicle Weight Sensor	SXI	1,500		10/01/96
	Sub Total:	$61,000	$32,500	
MICHIGAN TEAM (Cadillac)				
50,000 GVW Truck, Plows, Box	Michigan DOT			10/01/96
Fleet Advisor	Eaton	$25,000		09/01/96
AVL System/Communications	Eaton			09/01/96
Material Application	Monroe	8,000		09/01/96
Incremental Power	Fosseen	1,500	Fuel	09/15/96
Friction Meter	Norsemeter	45,000	20,000	01/01/97
Surface Temp. Sensor	SXI	500		10/01/96
Vehicle Weight Sensor	SXI	1,500		10/01/96
	Sub Total:	$81,500	$20,000	
MINNESOTA TEAM (St. Cloud)				
50,000 GVW Truck, Plows, Box	Minnesota DOT			08/15/96
Data Logger	SXI	$25,000		10/01/96
AVL System	Tyler Ice	42,000		09/15/96
Two-way Communication	SXI			10/01/96
Material Application	Tyler Ice			09/15/96
Incremental Power	Fosseen	1,500	Fuel	09/15/96
Friction Meter	Norsemeter	65,000		01/01/97
Surface Temp. Sensor	SXI			10/01/96
Vehicle Weight Sensor	SXI			10/01/96
Air Foil	Monroe			09/01/96
	Sub Total:	$133,500	$0	
	Project Totals:	$276,000	$52,500	

Note: Vehicle weight sensors and air foil technologies were not used on the prototype vehicles but are included here because this table, established in Phase I, documents all potential technology costs.

EFFECTIVE USE OF CHEMICALS AND ABRASIVES

Iowa DOT 1996 budget figures for snow and ice removal indicate that, statewide, material costs average $35,000 per hour, labor costs average $19,000 per hour, and equipment costs average $16,000 per hour, for a total average snow removal cost of $65,000 per hour for the state of Iowa. If the amount of chemicals and abrasives used for snow and ice control can be reduced while maintaining the level of service for roadway users, potentially large savings can be realized. As stated earlier, pavement temperature data control decisions about the type and amount of snow and ice control materials applied to the roadway.

Objective

Illustrate the potential reduction in winter chemical and abrasive usage when advanced technologies are used. The pavement temperature sensor is used as the example.

Measurement

Calculate cost savings or losses if the known pavement temperature is used to determine the salt application rate.

Discussion

During the winter of 1993-1994, the Vermont Agency of Transportation (VAT) conducted a study that correlated pavement temperature information to the melting capacity of salt. The results of the VAT work has application to this study and in actual winter maintenance activities. Table 14-2 shows the relationship between pavement temperature and pound of ice melted per pound of salt. When pavement temperature falls and the rate of salt application remains constant, less ice melts.

Table 14-2 Melting capacity of salt

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

The Vermont study, Smart Salting: A Winter Maintenance Strategy, recommended that maintenance crews do two things:

1. Determine pavement temperature before and during a storm through the use of infrared thermometers mounted on vehicles.

2. Utilize salt application rates based on the relationship between pavement temperature, melting capacity of salt, and the thickness of ice or snow on the pavement.

The study generated a graph, or curve, correlating recommended salt application rates with pavement temperatures. Figure 14-1 shows that salt quantities should increase as pavement temperature decreases. The salt quantities shown in the figure are expressed in pounds per lane mile (pplm), a unit commonly used to express salt application rates. An economic temperature range for salting activities was identified from 30° F to 20° F. The Iowa DOT estimates that 75 to 80 percent of Iowa's winter storms occur when pavement temperatures are above 20° F. The study team decided that states would not apply less than 100 pound of salt per 12-foot lane mile.

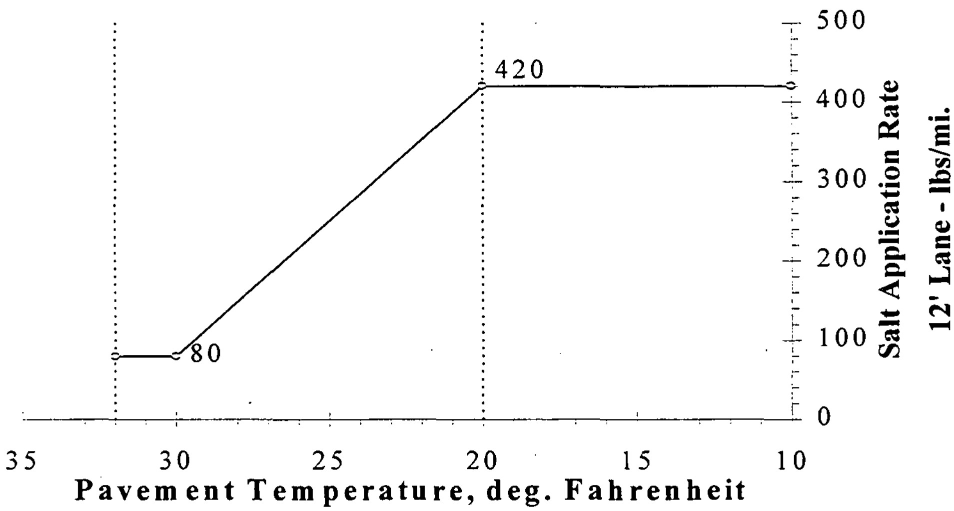


Figure 14-1 Vermont study recommended salt application rate curve

To estimate potential savings in salt usage based on more accurate knowledge of exact pavement temperatures in Iowa, the Vermont curve is applied to current practice in Iowa (i.e., using temperatures from the Roadway Weather Information System, or RWIS) and to recommended practice (i.e., using pavement temperatures all along the roadway as reported by sensors on a moving maintenance vehicle), and material usage is computed in each case.

Figure 14-2 shows a hypothetical pavement temperature plot (thermal trace) that illustrates differences in pavement temperature along a roadway segment as reported by a temperature sensor on a prototype vehicle. (A hypothetical plot is used because actual temperature data were collected by the prototype vehicles only during a non-winter period.)

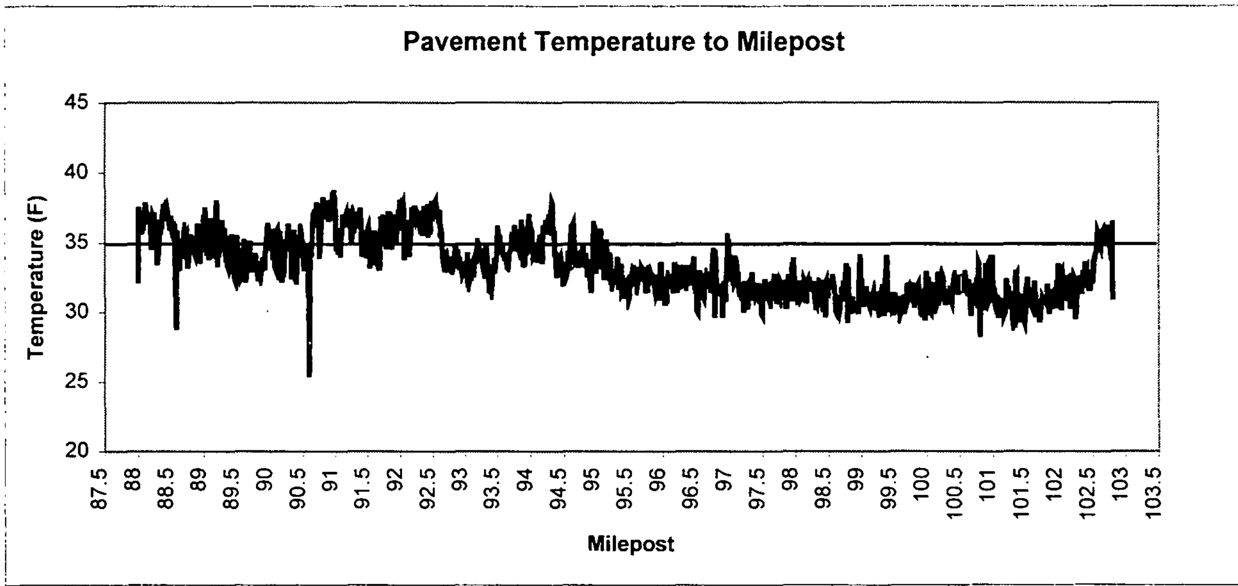


Figure 14-2 Pavement temperature vs milepost

In Figure 14-2, the average pavement temperature is 34° F, but the thermal trace indicates that spot freezing could be occurring on the highway at mileposts 88.5 and 90.5 and at various locations from milepost 95.0 to 103.0.

If the maintenance supervisor in this situation were relying on temperatures from an RWIS, the supervisor would have access only to temperatures reported from the location of the RWIS sensors, or 34° F. If a precipitation event were occurring, the supervisor might decide not to treat the pavement to prevent freezing. However, most supervisors know their areas well enough to understand that a 34° F RWIS pavement temperature means that some highway spots are well below freezing and require some type of chemical treatment to maintain a non-slippery surface. The response of supervisors to this situation would vary; generally, they would treat the entire roadway but with differing amounts of chemical.

If a supervisor decided to treat the entire roadway based on the coldest spots, an application rate of 250 pounds of salt per 12-foot lane-mile would be recommended by the Vermont study. This rate would require 3,750 pounds of salt for the 15-mile run for just one lane. If the supervisor decided to use less than 250 pounds per lane mile, there would be some spot-freezing, resulting in needless exposure for motorists and the DOT. However, if supervisors had access to temperatures all along the roadway, such as those in the temperature trace in Figure 14-2, they could finetune material application rates. Using the thermal trace to adjust the spreader rate according to Vermont's salt application rate curve in Figure 14-1, the supervisor would apply an average of only 600 to 700 pounds of salt for the same 15-mile, one-lane run.

The challenge of tailoring salt application to ever-changing pavement temperatures is more than most supervisors or equipment operators can handle—unless their truck is equipped with pavement temperature sensing that is integrated with intelligent material application technology. The savings in materials that would result from the application of this advanced technology is obvious: fewer budget dollars to do the job right, less negative impact on the environment, and an increase in winter driving level of service.

When pavement temperature data become available in "real time" and maintenance vehicles have the capability to automatically adjust material application rates based on real-time pavement temperatures, savings such as those described above may be realized. Pavement temperatures, as shown in Figure 14-2, will be integrated with the distribution curve shown in Figure 14-1, and material cost savings will be maximized.

OBSERVATIONS

Knowledge of pavement temperature provides an opportunity to reduce the amount of salt applied during winter maintenance operations. The reduction translates to cost savings. Pavement sensor devices on winter maintenance vehicles can realize maintenance budget savings if the use of such devices results in less salt applied to roadways. In addition, automatically adjusting material applications based on pavement temperatures has the potential to provide drier, safer highways for the traveling public, resulting in improved mobility and fewer accidents during winter weather event, as well as more environmentally friendly maintenance operations.

CONCLUSION

The use of advanced technologies like pavement temperature sensors potentially reduces resources used in winter maintenance operations. By using pavement temperature data to determine salt application rate, less salt may be applied, resulting in cost savings.

Potential savings do need to be compared to the cost of acquiring, installing, and maintaining the technologies. The development costs provided at the beginning of this chapter are not production model costs and should be used cautiously for cost analyses. However, it appears that using pavement temperature to determine salt application rates would provide a cost benefit even if the sensors do not go down in price during production.

In Phase III, a more comprehensive benefit/cost analysis for selected technologies will be conducted.

CHAPTER 15: OPERATOR INPUT AND ACCEPTANCE

The success of any new venture depends on its acceptance by the end users. This is particularly true when new equipment or technologies are introduced to maintenance workers and equipment operators. If vehicle operators and mechanics are not supportive, there are sure to be implementation problems. Early in this project, the consortium members recognized the importance of end-user involvement and support and placed winter maintenance staff and snowplow operators at the center of the Phase I focus group activities. Many of the technologies added to the prototype maintenance vehicles are thus a direct result of end-user input about desired vehicle functionality.

The winter of 1997-1998 was an important observation period for the prototype vehicles, and end users were again centrally involved. The prototype vehicles were assigned to active duty, and they provided snow and ice control on roads in Michigan, Minnesota, and Iowa. Equipment operators and mechanics had first-hand experience with the prototype vehicles' performance, and their feedback was critical to evaluating the vehicles' performance during Phase II activities.

OBJECTIVE

Develop end-user input and acceptance.

MEASUREMENT

Record questionnaire responses from equipment operators and mechanics in the three consortium states.

DISCUSSION

Understanding that reporting procedures that require minimal effort will benefit everyone involved in the study, CTRE did not want to burden equipment operators and mechanics with lengthy, time-consuming documentation. CTRE's goal was to develop questions that made sense and were easy to respond to and would therefore have a high response rate. Two questionnaires were developed. The first was used by CTRE staff to guide personal telephone interviews with prototype vehicle operators. The second was an equipment performance log sheet, which could be completed by either the vehicle operators or mechanics. CTRE sent the log sheets, along with sample operator questionnaires, to each of the three state DOTs and the maintenance garages where the prototype maintenance vehicles were located, with instructions about completing the log sheets and responding to the telephone interviews.

Operator Interviews

After winter storms, CTRE conducted telephone interviews with prototype vehicle operators using questions approved by the study team. A key question was whether the add-on technology made the vehicle operator's workload easier or if it added to the equipment operator's job. Of course, if the technology made the job more difficult, it would not be successful when implemented on a larger scale.

As they conducted telephone interviews with prototype vehicles operators, CTRE staff recorded operator responses on the form shown in Figure 15-1.

PROTOTYPE VEHICLE PERFORMANCE RECORD

Please answer each of the following questions.

Date:

Time of your shift:

What piece of equipment on the prototype truck worked the best?

What piece of equipment on the prototype truck worked the worst? Did this have any negative impact on your operation of the prototype truck?

Was the PlowMaster display easy to read while you were driving?

How did the added technology on the prototype vehicle affect your comfort and attention to the road, as compared to a conventional maintenance truck?

Any other problems you had with the truck while driving it?

What suggestions for improvement do you have?

Initials:

Figure 15-1 Sample equipment performance evaluation questionnaire

The questionnaire's sections and their intended meanings are as follows:

Date

The date of the shift.

Time of shift

The beginning and ending times of the shift.

What piece of equipment on the prototype truck worked the best?

The element on the prototype vehicle that performed the best during the vehicle's run. CTRE wanted to identify those components that worked well for the operators.

What piece of equipment on the prototype truck worked the worst? Did this have any negative impact on your operation of the prototype truck?

The element on the prototype vehicle that performed the worst during the vehicle's run. CTRE wanted to determine if poor performance had a negative impact on vehicle operation compared to the operation of a standard winter maintenance truck.

Was the PlowMaster display easy to read while you were driving?

For the best performance, the PlowMaster display must be easy to read while the prototype truck operator is driving. If the screen is too dim or too bright, for example, the brightness feature should be corrected. Good visibility is especially important for the PlowMaster screen due to its central function on the truck.

Any other problems you had with the truck while driving it?

CTRE wanted to know of any other problems were encountered with the prototype vehicle while the operator was driving it. Other problems might include equipment failures, or other problems with equipment.

What suggestions for improvement do you have?

CTRE was especially interested in suggestions for improvement of the prototype trucks. Since the truck operators use these trucks the most, they would have valuable insight.

Some of the more common answers to these questions follow:

1. What element of the new technology worked the best?

Equipment operators commented positively on the operation of the variable speed material applicators. With these tools, the equipment operators were able to 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 interface valuable and friendly.

In addition, the operators appreciated the user-friendliness of the PlowMaster computer.

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 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 a piece of equipment malfunctioned or failed, that particular piece 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 the same level of service at which they operated conventional snow plows. This fact was considered important by CTRE, as it showed that operating the advanced technology vehicle provided no more demand on equipment operators than operating unmodified vehicles.

3. Was the PlowMaster display easy to read while you were driving?

Equipment operators reported the screen dimness and brightness feature of the PlowMaster display was relatively easy to use while they were driving the vehicle. 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)—then the display was difficult to read. Polarized sunglasses may help correct this problem.

The PlowMaster screens were designed in a logical and easy-to-follow manner. Equipment operators reported being able to quickly call up information regarding the various elements reported by the PlowMaster computer.

On a related note, the equipment operators reported more problems reading the friction meter display, mostly because of the lack of a brightness or dimness feature. Norsemeter is working on this problem.

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 added technology helped them focus more of their attention on the road, especially when the equipment was functioning properly. The added technology took more tasks out of the hands of the equipment operators, allowing them to focus their attention where it was needed (for instance, on the road).

5. Any other problems you had with the truck while driving it?

Equipment operators from Iowa reported the material applicator control should be placed in a better location because its present location requires them to stop whenever they desire to change the material applicator's settings.

6. What suggestions for improvement do you have?

Again, Iowa equipment operators suggested changing the placement of the material applicator controls so that operators could reach the controls more easily while the truck was moving.

Vehicle Performance Log Sheet

The second questionnaire was a log sheet for vehicle operators and/or mechanics to record problems with, or repairs or maintenance on, the prototype vehicles. Keeping accurate records for each vehicle allowed DOT maintenance personnel to notice any patterns involving problems, repairs, or maintenance, and allowed CTRE to keep comparable records from state to state.

After internal testing and modifications of the log sheet's layout, CTRE asked maintenance personnel at the Iowa, Michigan, and Minnesota DOTs to use the log sheets to record the performance of their respective prototype vehicles. These logs included information on equipment outages and repairs or modifications made. The main sections of the log sheet are shown in Figure 15-2.

PROTOTYPE VEHICLE EQUIPMENT RECORD

Date	Equipment	P=Problem • R=Repair • M=Maintenance	Start Date	End Date	#Days*	Initials

* Note: Minimum duration for an entry is ½ day.

Figure 15-2 Sample equipment performance log sheet

The log sheet's sections and their intended meanings were as follows:

Date

The date of the entry. This particular information can be referenced by later activity on the same equipment.

Equipment

The name of the equipment, such as "friction meter," "lighting system," or "pavement temperature sensor."

P=Problem • R=Repair • M=Maintenance

Maintenance personnel can denote problems by "P", repairs by "R", and maintenance and modifications by "M". Problems consist of electrical shorts, fuse blow-outs, or general equipment failure. Repairs consist of solutions to the problems. Maintenance or modifications consist of relocations of equipment, replacements, etc.

Start Date

The date the problem, repair, or maintenance, began.

End Date

The date when the problem, repair, or maintenance, ended. In the case of problems, "End Date" is the date on which the problem was diagnosed and repairs were started.

#Days

Duration of the problem, repair, or maintenance. Minimum duration for an entry is ½ day.

Initials

The initials of the person making the entry. If necessary, CTRE could contact the person to ask questions or clarifications regarding a problem, repair, or maintenance.

OBSERVATIONS

The winter of 1997-1998 was unusual in that there were relatively few snow events in the three consortium states, and the prototype vehicles were not tested as rigorously as they may be in future years. Given that limitation, however, equipment operators provided an overall positive and enthusiastic response to the advanced technologies on the prototype vehicles.

Observations from Operator Interviews

One major theme in operator responses was that the operators required additional time to become acclimated to the new technology. This was not unlike their previous experiences using a new piece of equipment and was not considered a negative. After becoming familiar with the new technology, equipment operators were able to function with relative ease and indicated efficiencies higher than experience with conventional snow plows.

Figure 15-3 summarizes equipment operator responses and how they viewed the concept vehicle. Sample records from CTRE interviews with operators are included in Appendix J.

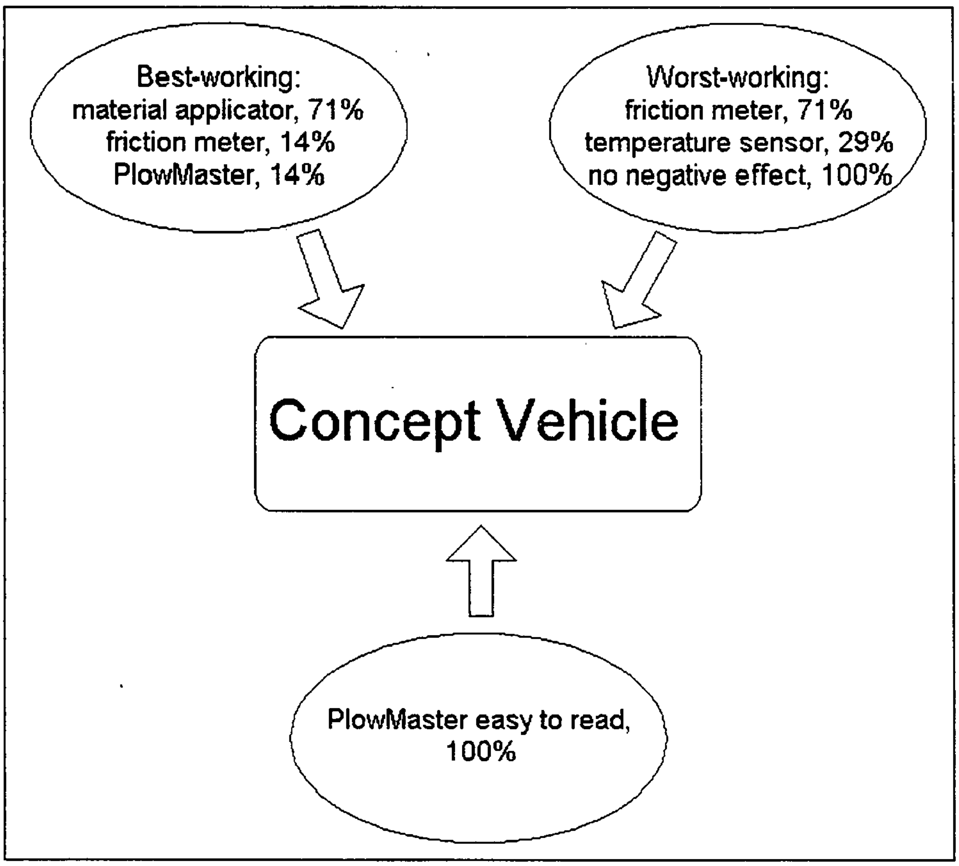


Figure 15-3 Equipment operators' response

Observations from Equipment Performance Log Sheets

No log sheet reports were returned to CTRE. Through other contacts with the state DOTs, CTRE learned about various equipment modifications, malfunctions, or other problems as documented in the technology chapters of this report. The lack of completed log sheets did not reflect a lack of interest in the project by operators and mechanics but rather their focus on their primary mission of snow and ice control.

CHAPTER 16: NEW AND DEVELOPING TECHNOLOGIES

As this project has progressed, the study team members have expressed significant interest in investigating additional technologies for the prototype maintenance vehicles during the course of the study. The following examples illustrate the variety of opportunities for enhancing the technological capabilities of the vehicles, some of which may be implemented during Phase III.

TECHNOLOGIES CONSIDERED FOR PHASE III

Differential GPS

To determine vehicle location, the 1997-1998 prototype vehicles used conventional GPS, which has a potential range of error of 100 to 300 feet. Differential GPS (DGPS) offers much higher accuracy, with a potential range of error of only 2 to 5 meters. Real-time DGPS reports would provide highly accurate location information for the maintenance vehicles, which is especially important for identifying specific locations along the highway that require custom treatments (bridge approaches, culverts, etc). The existing onboard computers provided by Rockwell International already have DGPS receivers installed, and during Phase III DGPS will be used to determine vehicle location.

Chemical Sensor

A chemical sensor may be added to the prototype vehicles. The sensor would function like the chemical dilution sensor in RWIS, measuring the electrical conductivity between two points on the roadway and using the conductivity to estimate the amount of chemical present on the roadway surface. With such a sensor on their maintenance vehicles, operators would know the amount of chemical remaining on the roadway since the last maintenance pass, allowing them to make better-informed decisions about applying additional chemicals and abrasives.

Data Averaging

During Phase II, the PlowMaster recorded data concerning pavement temperature, air temperature, friction values, etc., as the respective sensors collected these data. In future phases, to improve the detection of trends and to remove unnatural "noise" from the data, some data may need to be averaged or smoothed. Specifications concerning how much averaging to perform and when to perform it need to be developed by the study team and CTRE.

Mapping Packages

During Phase II, data downloaded from the prototype vehicle were displayed in tabular, or spreadsheet, format. The study team desires to display data in graphic, or map, format for easier interpretation, eventually providing a "point and click" user interface. With such an interface, users can click on a point on the map and obtain a display of sensor output information associated with that point on the road. Several computerized commercial mapping packages are available and are being evaluated for implementation during Phase III.

Cellular Telephone Communications Link

During Phase II, friction sensor outputs, pavement and air temperature sensor outputs, and GPS stamps were recorded on each prototype vehicle's PlowMaster and delivered to CTRE on PCMCIA cards. Although the cards transmit data satisfactorily, the study team is interested in pursuing avenues for providing "real-time" data to centralized locations to facilitate the decision-making process. CTRE is investigating two possible means for real-time data transmission, including cellular communications and radio communications.

Cellular communication is being used for data transfer in other applications, and its application on the prototype vehicles would be a step toward using a DOT radio system for data transmission (see the discussion of radio communications below). Cost is the biggest concern about using cellular connections on large-scale applications. Most of the expense involved in cellular communications is in the connect time (20-40 seconds) and disconnect time (20 seconds). Since cellular charges are billed in "round minutes," there is an incentive to keep the minutes to a minimum by having fewer call-ups. Fewer call-ups reduces the real-time value of data transmitted. However, for systems evaluation in Phase III on the three prototype vehicles, cellular communications links will be affordable and the real-time data transmissions adequate.

Each central office will be connected to and will forward data to a network server via a leased telephone line. Because other technologies may eventually be used to collect and transmit other data from the maintenance vehicles (see Chapter 17 on integrating additional data with DOT management systems), a special querying software application will be selected to query the resulting network database of outputs collected from many base stations. From the network server, weather data will be linked to the RWIS communication system for relay to weather forecasters; other data would eventually be linked to other management systems as appropriate.

TECHNOLOGIES BEING CONSIDERED BEYOND PHASE III

Radio Communications Link

Radio communications is less expensive than cellular for large-scale applications of real-time data transmission. Rockwell International has developed radio communications technology that can easily be adapted for use with the prototype maintenance vehicles. Each vehicle would have a radio receiver/ transmitter to transmit data to a base or repeater site. Ideally, the radio communications would be interfaced or "piggybacked" with the DOT's existing radio links and communications system but would remain separate in the event of radio communications system failure.

A frequency range of 800 to 900 megahertz (MHz) is recommended because of overpopulation on lower-end frequencies. Rockwell's chip technology would be used to transmit data, which presently are transmitted at around 4,800 baud.

Each maintenance vehicle would transmit data in real-time via radio to a base station, which may be located at a DOT maintenance garage. In the event the maintenance vehicle is out of range of a base station, sensor outputs would be stored until the maintenance vehicle is within range, then transmitted via a data "burst." The number of base stations required in each state for statewide real-time communications would be determined using modeling software at Rockwell. Statewide radio coverage in Iowa, for example, would probably require six or seven base stations.

As with cellular communications between maintenance vehicles and base stations, each base station would be connected to a network server that would collect data from all base stations for query and use with various management systems.

A radio transmitter and receiver presently costs about $500 to $800 per vehicle, depending on desired transmission frequencies and radio communications features. Each radio base repeater unit costs about $6,000 to $8,000, and the computer to interface with the repeater costs about $3,000. Thus each repeater installation would cost around $10,000, for a total of $60,000 to $70,000 for six or seven repeater stations in the state of Iowa.

Collision Avoidance System

When winter maintenance vehicles are on the road, weather and driving conditions are often less than ideal. Blowing snow and heavy fog can reduce visibility to near zero, making stopped or stalled cars in or along the roadway a danger for maintenance equipment operators. To reduce maintenance vehicle collisions with stalled vehicles and other obstacles that might be in the roadway, CTRE suggests including a collision avoidance system on the prototype maintenance vehicles.

By incorporating a geographical information systems (GIS) based inventory of DPGS-established locations of guardrails, bridges, roadway medians, and other roadside features, the collision avoidance system could also help reduce maintenance vehicle collisions with these features. The system would alert drivers when they get dangerously close to a roadside feature and, eventually, display roadside features on the in-cab monitor as the vehicle travels down the roadway.

Additional Weather Data

Researchers in the FORETELL and FORETELL PLUS weather research project are interested in obtaining fine-scale weather observations for use in mesoscale weather forecasting models with FORETELL and the National Weather Service. The prototype maintenance vehicles may be a part of this fine-scale network of weather information. FORETELL researchers are interested in the pavement and temperature data already provided by the prototype vehicles and in relative humidity and wind speed and direction information that could be provided through additional add-on technologies.

If the study team directs it to do so, CTRE will pursue the possibility of placing relative humidity and wind speed and direction sensors on the prototype vehicles. Due to the movement of the vehicles, however, collecting wind speed and direction data may be a challenge. These instruments may require input data about the truck's speed and heading to compensate for the movement of the truck.

CHAPTER 17: DATA INTEGRATION WITH DOT MANAGEMENT SYSTEMS

In Phases I and II, the study team relied primarily on a "bottom-up" approach to product development, which starts with the needs of the immediate end users. Equipment operators, mechanics, managers, and maintenance supervisors identified the desired functionality of winter maintenance vehicles and, together with technology providers, the study team fulfilled those functions by incorporating off-the-shelf technologies on prototype vehicles. To maximize the value of this study, however, a "top-down" approach to product development is also required. In a top-down approach, the needs of management drive product development. During proof of concept for Phase II, CTRE used a top-down approach to consider possibilities for integrating data collected by the vehicles into state management systems. During Phase II, progress was made in defining both a data architecture compatible with DOT systems, as well as logical data transfer points from the vehicle to other business processes. This task required input from top DOT management personnel. The eventual integration of maintenance vehicle data into DOT management systems will ultimately depend on each state DOT's approval and budget allocation.

OBJECTIVE

Begin to develop systems and procedures that, in future phases, will allow data collected by the prototype maintenance vehicles to be integrated with DOT management systems.

MEASUREMENT

Format and content of data collected by the prototype vehicles are compatible with DOT management systems and are used in the management process.

DISCUSSION

The success of the maintenance vehicle research project depends on having a management system(s) in place to receive data collected by vehicle sensors or otherwise generated by the vehicles and to direct these data to appropriate management systems within the appropriate state DOTs. The best formula for success would be an iterative process of increasingly refined bottoms-up equipment/technology development that is compatible with a top-down system design and architecture development. This iterative process will assure that advanced technology implementations similar to the prototype maintenance vehicles will be deployed and integrated into the business process of the state DOTs.

Top-down Approach Implementation

The steps to consider for the prototype vehicles in each state include the following:

1. Develop high-level description of state highway agency business processes, including management systems, using data flow diagrams. Correlate the prototype maintenance vehicle requirements established by the focus groups to the state's business/management system activities.
2. Develop a preliminary technical and physical architecture that addresses the vehicle, electronic equipment data capture capabilities, communication linkages from the vehicle to receiving locations, storage and retrieval of data, and management systems/reporting requirements. The architecture must also allow for interfacing with existing maintenance management systems (MMS).
3. Develop a logical data model that provides guidance for establishing a database for data from the prototype maintenance vehicle (eventually, from the vehicle fleet). This model could be based on a more detailed data flow diagram, entity-relationship diagrams, or an object-oriented analysis technique. Of importance here is the incorporation of real-time data.
4. Develop a preliminary design document for the state vehicle(s). The design should consider data that are recorded and then displayed to the equipment operator in the vehicle cab and/or forwarded to the database. Consider the input and output panels and screens inside the vehicle and analyze the safety and human factors. Finally, address the equipment interface opportunities and the communication system that could be utilized.

When the study advances to Phase IV, in which a fleet of 10 advanced technology maintenance vehicles will operate in each state, each of the above steps needs to be revisited and redefined. The data requirements will be set, but the reporting protocols may need to be redefined. The communication linkages will need to incorporate additional features such as vehicle-to-vehicle communications, bandwidth requirements, and integration into the existing communication configuration. There will most likely be a desire to interface with local officials and other government agencies to coordinate emergency response operations or to provide Intelligent Transportation System (ITS) information to the public.

Management Systems Interface

Several management systems currently exist in each of the state DOTs to provide management information to maintenance managers at all levels in the organization. These management systems generally include maintenance (MMS), payroll, equipment, purchasing and inventory, transportation inventory database, structures, and maintenance programs developed at the central office and at field locations. The basic systems that the prototype vehicles may eventually interface with are the MMS, payroll, and equipment.

The MMS is the primary system used by maintenance managers to obtain, establish, and adhere to their work programs; monitor the effectiveness of operations; and control expenditures to live within their budgets. Managers are also provided with data necessary to monitor and control the overall maintenance effort and to analyze performance against maintenance standards. A properly developed MMS is a closed circuit containing seven primary management functions: planning, budgeting, allocating, scheduling, performing, reporting, and evaluating. In addition, an MMS has common data sources and links to other systems, such as equipment, utility systems, and financial reporting/accounting systems.

An MMS addresses requirements in four areas:

1. System requirements—major tasks that need to be performed in the system. These tasks are organized by seven management functions: planning, budgeting, allocating, scheduling, performing, reporting, and evaluating. In addition, miscellaneous requirements are established by maintenance managers.

2. Interface requirements—lists the various systems that currently exist or are planned that should interface with the MMS. The type of information that passes between the various systems and the MMS is also defined.

3. Operational requirements—provides the features that should be included in the computer operations to ensure the system is easy to use and provides the proper information to users.

4. Support requirements—identifies the actions that must be taken to ensure successful implementation and ongoing operations once the system is installed.

Concept Vehicle Interface

The maintenance concept vehicles will have the opportunity to provide data to many of the management systems discussed and can be a primary data collector for the MMS. The vehicles can perform these data collection tasks while completing maintenance activities assigned by maintenance managers. The data can be available much more quickly than with conventional management systems and in many cases can be available in "real time." Some of the data collection potentials are discussed below as they relate to the various management systems previously mentioned. To perform these functions, the maintenance vehicles may need to be fitted with some additional equipment and software.

- Maintenance Management System (MMS) -- the data available from the concept vehicle that can be provided to the MMS include: vehicle utilization and equipment repairs, personnel information including labor hours and work elements accomplished, material and quantity usage, update base inventory database for work elements completed (i.e. completing an asphalt overlay), and work performed on bridge surfaces.
- Payroll—the data available from the concept vehicle, by location, that can be provided to the payroll system include labor hours worked, work elements accomplished, and overtime hours utilized.
- Equipment Management—the data available from the concept vehicle, by location, that can be provided to the equipment management system include vehicle hours, vehicle utilization, down time, equipment repairs, and work elements accomplished.

- Purchasing and Inventory—the data available from the concept vehicle, by location, that can be provided to the purchasing and inventory system include materials consumed and stockpile inventory.
- Transportation Inventory—the data available from the concept vehicle, by location, that can be provided to transportation inventory databases include work completed (such as an asphalt overlay) and inventory data collection of roadway features.
- Pavement Management—the data available from the concept vehicle, by location, that can be provided to the pavement management system would include: data relating to maintenance functions performed such as crack and joint sealing, edge rutting, shoulder slurry applications, traffic line painting, and other pavement related tasks.
- Structures Management—the data available from the concept vehicle, by location, that can be provided to the structures management system would include: inventory of guardrail etc., work tasks and related costs for work performed on the surface, and inventory of surface conditions.
- Public Information—the data available from the concept vehicle, by location, that can be provided to the public information system would include: roadway surface conditions, level of service reporting, weather conditions, and winter chemical and abrasive usage.

OBSERVATION

As demonstrated by proof of concept activities in Phase II, winter maintenance vehicles can function as mobile data collection platforms. If all maintenance vehicles are similarly equipped, they have the potential to input data as a fleet into management systems, providing automated, real-time data collection for many DOT management systems.

List of appendices

(appendices collected under separate cover)