Highway Maintenance Concept Vehicle

Final Report: Phase Four

June 2002

Center for Transportation
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Iowa State University

HIGHWAY MAINTENANCE CONCEPT VEHICLE
FINAL REPORT: PHASE FOUR

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CHAPTER 1: INTRODUCTION

This report documents Phase IV of the Highway Maintenance Concept Vehicle (HMCV) project, a pooled fund study sponsored by the Departments of Transportation of Iowa, Pennsylvania, and Wisconsin. This report provides the background, including a brief history of the earlier phases of the project, a systems overview, and descriptions of the research conducted in Phase IV. Finally, the report provides conclusions and recommendations for future research.

Background

The goal of the Highway Maintenance Concept Vehicle Pooled Fund Study is to provide travelers with the level of service defined by policy during the winter season at the least cost to taxpayers. This goal is to be accomplished by using information regarding actual road conditions to facilitate and adjust snow and ice control activities.

The approach used in this study was to bring technology applications from other industries to the highway maintenance vehicle. This approach is evolutionary in that as emerging technologies and applications are found to be acceptable to the pooled fund states and as they appear that to have potential for supporting the study goals they become candidates for our research.

The objective of Phase IV is to: Conduct limited deployment of selected technologies from Phase III by equipping a vehicle with proven advanced technologies and creating a mobile test laboratory for collecting road weather data.

The research quickly pointed out that investments in winter storm maintenance assets must be based on benefit/cost analysis and related to improving level of service. For example, Iowa has estimated the average cost of fighting a winter storm to be about $60,000 to $70,000 per hour typically. The maintenance concept vehicle will have advanced technology equipment capable of applying precisely the correct amount of material, accurately tailored to the existing and predicted pavement conditions. Hence, a state using advanced technology could expect to have a noticeable impact on the average time taken to establish the winter driving service level.
If the concept vehicle and data produced by the vehicle are used to support decision-making leading to reducing material usage and the average time by one hour, a reasonable benefit/cost will result. Data from the friction meter can be used to monitor and adjust snow and ice control activities and inform travelers of pavement surface conditions. Therefore, final selection of successfully performing technologies will be based on the foundation statements and criteria developed by the study team.

The Consortium

Phase IV brought new partners into this research and study team was established to provide technical guidance to the Center for Transportation Research and Education (CTRE) during the study. Study team membership includes the following:

- The designated chairperson of the study team is Leland D. Smithson, Research Management Division of the Iowa Department of Transportation.

- Three “snowbelt” state departments of transportation (DOTs) - Iowa, Wisconsin, and Pennsylvania formed a consortium to define and develop the next generation highway maintenance vehicle. Each of these DOTs has reputations for embracing innovation in highway maintenance management, maintenance operations practices, and research. CTRE provided project management and products stated in the Phase IV work plan. A key element of this project was the inclusion of private sector partners and other public sector members into the consortium. Private sector partners brought many assets to the project, including staff with specialized expertise, business connections, manufacturing facilities, and the potential to participate in the funding and production of both prototype and fleet vehicles.

The Phase IV consortium membership includes the following:

Membership

Iowa Department of Transportation
Wisconsin Department of Transportation
Pennsylvania Department of Transportation
Center for Transportation Research and Education, Iowa State University

Other Public Sector Partners

Federal Highway Administration

Private Sector Partners

AreoTech Telub, Ostersund, Sweden
Component Technology, Des Moines, Iowa
IDA Corp, Fargo, North Dakota
Monroe Truck Equipment, Monroe, Wisconsin
Navistar International Corporation, Fort Wayne, Indiana
Norsemeter AS, Oslo, Norway
O’Halloran International, Des Moines, Iowa
Raven Industries, Sioux Falls, South Dakota
Sprague Controls, Canby, Oregon
Wired Rite Systems,

The following discussion summarizes the work leading to Phase IV.

Phase I

The objective of Phase I was to develop the concept vehicle’s functionality and to enlist private sector partners to provide the functionality. This phase began with a literature review of materials related to winter highway maintenance activities. One hundred five articles were collected which pertained to state-of-the-art equipment, technologies, and research related to winter highway maintenance activities.

The ideal capabilities of a winter maintenance vehicle were identified through focus group activities. Five focus groups were formed. The focus groups included representation from equipment operators and managers, mechanics, resident and central maintenance office engineers, area supervisors, and law enforcement emergency responders. Focus group meetings were held in the three consortium states generating more than 600 ideas, which were later combined and organized into a list of 181 desired capabilities for the highway maintenance concept vehicle. These ideas were then organized and placed into six major categories for analysis. These major categories were developed with the purpose of breaking the activities of the maintenance vehicle into logical sequences. The six major vehicle requirement categories were

- Administration
- At Rest
- Infrastructure
- Pre Operations
- Roadway Systems Operations
- Post Operations

The final prototype design for the three prototype vehicles provided the following desired capabilities that resulted from the focus group activities.

- Sense roadway friction conditions
- Sense roadway surface temperatures
- Record and download vehicle activities
- Improve fuel economy
- Provide adequate horsepower for the vehicle
- Carry and Distribute multiple types of materials
- Provide removable salt/salt brine dispensing system
- Provide back-up sensors/monitors

Private sector equipment and technology providers were introduced to the study and asked to join in the effort. These private partners committed to providing equipment and expertise for the duration of the study. 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.

Phase II

The objectives of Phase II were to build three prototype concept vehicles, integrating the subsystems into a working system; conduct proof of concept; and prepare for field evaluations of three prototype vehicles in Phase III. During this phase, manufacturers, system integrators, CTRE, and the study team developed one prototype concept vehicle in each of the three consortium states. The study team selected technology for the winter of 1997–1998 by detailing precise equipment names and model numbers, the technology provider, and descriptions of the technology capabilities.

Adjustments and modifications required for incorporation of technology into the prototype vehicles were also documented. As the prototype vehicles were tested and inspected, better locations for some of the technology were realized, and CTRE documented these changes. Challenges also arose regarding location of technological components and troubleshooting the equipment.

Four equipment manuals were produced for the prototype maintenance vehicle. Each manual contains documentation regarding operation and troubleshooting of the technological components of the prototype vehicle. Each of the three state DOTs received an equipment manual for its prototype vehicle, and a “master” manual is kept on file at CTRE.
Proof of concept was conducted for each of the functional areas integrated into the prototype vehicle. Proof of concept for Phase II is defined as conducting “end-to-end” processing, observing the success of the “end to end” processing, and observing if the data are reasonable. Proof of concept is not a rigorous statistically valid field test. For example, processing verification includes stimulating the sensor to provide an output, reading and storing the output on the onboard storage device, and determining if the data are reasonable.

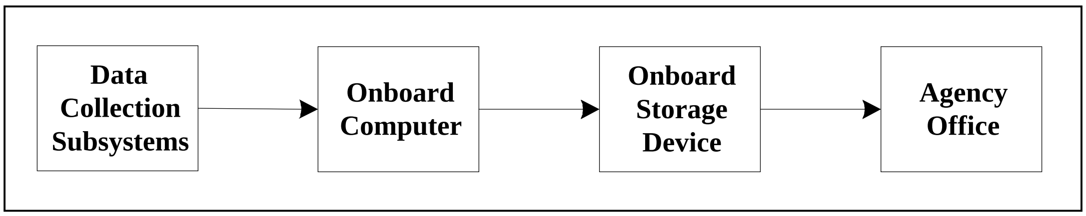

Figure 1: Phase II Prototype Concept Vehicle System Architecture

A data collection and observation plan was developed to conduct proof of concept while operating the prototype vehicles during the winter of 1997–1998. The objective of the plan was to assure the study team that the subsystems were successfully integrated and the prototype system was providing reasonable data. Computer software packages (Microsoft Excel, Microsoft Access, and Microsoft Word) were used in the data analysis and observations. Data from Rockwell’s PlowMaster unit was saved on Personal Computer Memory Card International Association (PCMCIA) data cards by the state DOTs and then forwarded to CTRE for analysis. Plans were developed to correlate the prototype data with base data and to document the performance of the subsystems.

CTRE researchers developed a process to document equipment performance during actual winter operating conditions for 1997–1998. 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 the prototype vehicle operators to ascertain equipment performance. Information from these interviews was entered into a database for comprehensive analysis and comparison. The interviews and documentation of equipment performance led to guidelines for the desired equipment capabilities for the Phase III prototype vehicle.

CTRE researchers also solicited information from vendors regarding new and developing technology and evaluated the appropriateness of the respective technologies for potential incorporation into the Phase III prototype maintenance vehicle. Technologies to be considered for the Phase III concept vehicle are identified in Figure 2, Phase II Prototype Concept Vehicle Design.

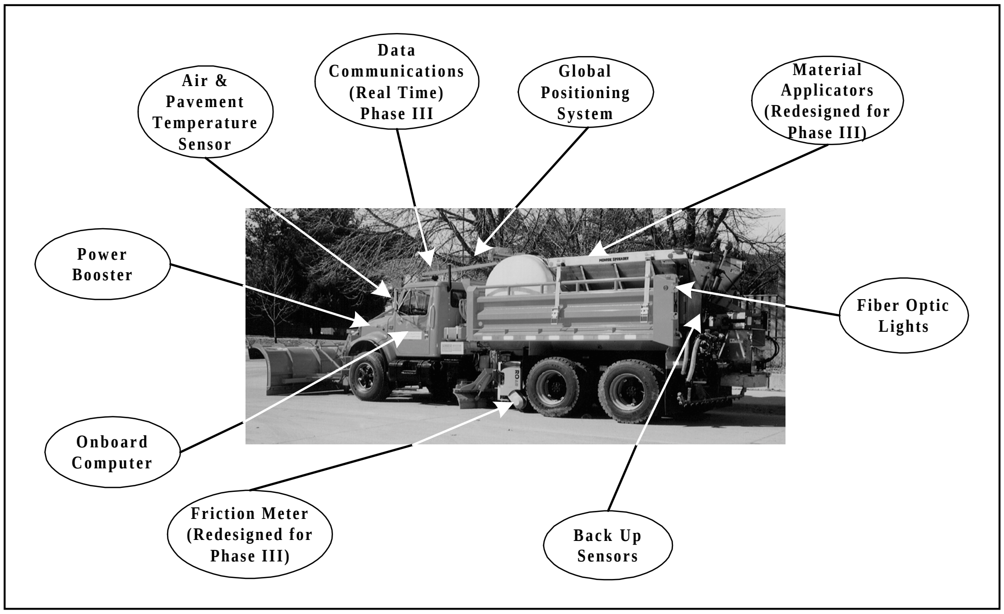

Figure 2: Phase II Prototype Concept Vehicle Design

Phase III

The general objectives of Phase III were to establish the functionality and technology to be implemented at this time, estimate the time to implementation, conduct field evaluation, and produce data flow and decision process maps to integrate the concept vehicle functionality into management systems.

The HMCV conducted field evaluations of the technology, particularly the friction meter, by testing it at National Aeronautics and Space Administration (NASA) facilities in Wallops Island, Virginia, and North Bay Ontario. The results of the field tests are included in the Phase III report. Overall, the friction–measuring device called SALTAR demonstrated that the principle of continuously measuring friction and transferring those data to the vehicle management system was sound. The friction meter, however, was not totally successful, and problems had to be addressed. The friction meter that was installed on the Minnesota DOT vehicle did not perform up to expectations. The installation proved to be challenging and once it was installed, the data received were shown to be unreliable. A failure analysis of the unit showed that after a period of time, corrosion seeped into the gearbox and damaged the assembly. Other aspects of Phase III were successful. The rear obstacle sensor (not included in Phase IV), pavement temperature sensor, and lighting proved their reliability.

Also, a baseline was established for a benefit-cost analysis of the technologies. The benefit-cost analysis is based on comparing the resources necessary to achieve the target road surface condition in a given maintenance area. An analysis was not conducted because not all the technology was deployed on the vehicles. Once the concept vehicle is fully equipped, the onboard vehicle systems will include pavement temperature, automatic vehicle location, and automated materials distribution subsystems. These systems will be taken into account for the benefit-cost analysis.

CTRE also created and maintains a web site that includes the study results. Furthermore, the web site includes articles about the HMCV and links to other appropriate sites. The URL for the HMCV web site is http://www.ctre.iastate.edu/conceptv/.

Phase IV

Researchers at CTRE, as well as our partners at Iowa DOT, Wisconsin DOT, and Pennsylvania DOT, have long considered the benefits of advanced technology to enhance winter maintenance activities. The HMCV demonstrates near term benefits of the technologies for winter maintenance operations. A goal of the project is to assist the snowplow operator to perform his or her operations safely and efficiently. A second goal is to demonstrate the applications of the technologies for winter maintenance operations. An underlying theme for this project is to use relatively low cost commercially available components, so that the partners may readily adopt them.

Phase IV builds on work accomplished in previous phases and supports the maintenance management system. Phase IV has two major strands, technical and financial. The outcome of Phase IV is a clear path to technology implementation, operation, and maintenance based on business case analyses.

The Phase IV goal of the HMCV is to examine and test newly emerging technologies that have potential for improving the level of service defined by policy during the winter season, at the least cost to taxpayers. To support achieving the goal, this scope of work is divided into these basic work activities:

- Conduct project management
- Develop and integrate the materials distribution intelligence function
- Develop and integrate the decision support system
- Test newly emerging technologies
- Determine the usefulness of the advanced technology systems installed on trucks assigned to the Iowa DOT
- Prepare a final report

The HMCV research team consists of CTRE and the Iowa DOT Research Management Division. Iowa DOT is the lead organization on the study, providing the vehicle, operators, and equipment. The departments of transportation from Wisconsin and Pennsylvania also provided support for this phase of the research. Wisconsin DOT is working on a similar project with their maintenance operations and is supporting these efforts to gain further knowledge in this area.

Both Wisconsin DOT and Pennsylvania DOT provided access to their departments and operations so that we may gather valuable information on snow removal operations.

The Phase IV HMCV provides significant improvements over the previous phases of the project. The friction meter has been redesigned to be smaller, more durable, and less costly. The vehicle is equipped with a FRENSOR freezing point detection system. The vehicle is now equipped with an automated vehicle location system (AVL) to provide position data. Other improvements include an RDS dump body, dual side mounted 120 gallon pre-wetting tanks, a 900-gallon stainless steel anti-icing tank, and high-intensity discharge plow lights.

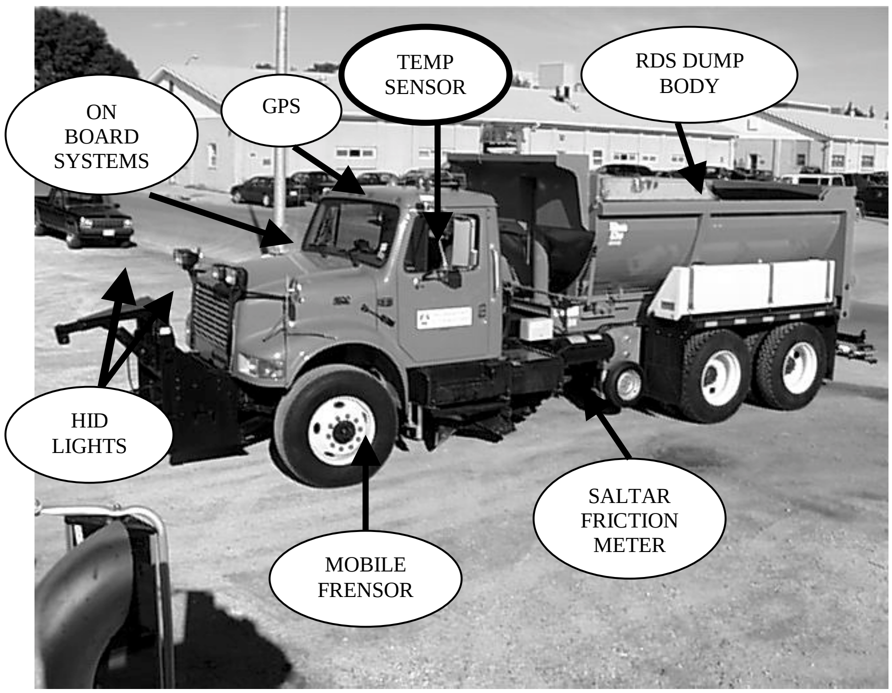

Figure 3: Phase IV Highway Maintenance Concept Vehicle

This second generation HMCV has now been through two winters of operations. Data were collected during both winters and are incorporated in this report.

Project Overview

The goal of the HMCV is to determine the feasibility of integrating location data (GPS/AVL), friction readings, surface freeze point information, and road surface weather conditions (air and pavement temperature) with a chemical application system. The HMCV uses a combination of commercial-off-the-shelf (COTS) systems along with prototype devices. The COTS systems consist of the IDA Trakit systems for AVL, the Raven DCS 710 spreader controls, the Raven AMS 200 Data Management Console, and the Sprague air and pavement temperature sensor. The prototype devices include the SALTAR friction meter, developed by Norsemeter and the FRENSOR freezing point detection system, developed by AeroTech-Telub of Ostersund, Sweden. All of these devices combined provided a mobile data-gathering platform to enhance winter maintenance operations.

Costs

Some of the equipment used in this research was provided to the study, some had to be purchased, and some was included in the cost of upgrading the snowplow that was done during the normal course of the vehicle replacement schedule at Iowa DOT. The chart below lists the costs of the equipment, along with the vendors that supplied those equipment items.

Table 1: Cost of HMCV

Equipment Item	**Cost**	**Vendor**
Chassis – International	$65,500	Monroe Snow & Ice Control
RDS Dump Box	5,500	Same
Front Plow	4,000	Same
Sander/Salter	2,600	Same
Underbody Blade	6,600	Same
On board pre-wetting	2,500	Same
Anti Icing Spray Bar System	14,000	Same
DCS 710 Ground Speed Controller	8,000	Raven Industries
Added Features for HMCV		
Surface Temp. Sensor	800	Sprague
AMS 200 Data Management	2,500	Raven Industries
Trakit AVL*	4,663	IDA Corp
DGPS Antennae	1,400	Communications Systems International
HID Plow Lights	1,100	Speaker
Frensor Mobile Freeze Point Detection	Provided**	AeroTech-Telub
Total	**$119,163**	

*The Trakit AVL costs are hardware and software only. The HMCV incurred additional charges for testing and development of the communications system that are explained in Chapter 4.

**The Mobile Frensor was provided by AeroTech-Telub for the field tests that were conducted. If purchased, the cost of the Mobile Frensor is approximately $10,500.00 USD.

The addition of the various advanced technology applications can add $20,000–$30,000 to a regular snowplow. If the automation processes are successful, however, work reductions may be achieved. For example, fewer applications of chemicals are needed on a section of roadway. A detailed investigation is needed regarding equipment amortization, labor costs, the amount of chemicals used, and level of service gained. Consequently, any projections for a benefit-cost ratio would be preliminary at this time.

Test Area

The HMCV was field tested on an area of Interstate 35 near Des Moines, Iowa, during the winters of 2000–2001 and 2001–2002. The vehicle also conducted field tests of the SALTAR friction meter at Wallops Island Virginia and North Bay Ontario during the National Aeronautics and Space Administration (NASA) Friction Workshops.

The area of the data collection runs from Guthrie Avenue in Des Moines, north to milepost 97, north of Ankeny, Iowa, a stretch of 14 miles of Interstate 35. This is the assigned route of the snowplow, dispatched from the Des Moines North Garage in Iowa DOT's fleet. This route is rather unremarkable in it topography; there are no steep hills or deep valleys on this route or any extensive shady areas. Thus, during a snow event with high winds, there can be significant amounts of drifting across the roadway. Also, there is a significant amount of commuter traffic that occurs between Ankeny and Des Moines. This area of I–35 carries about 52,500 vehicles daily.

The data that were collected during the field tests near Des Moines were collected during the snowplow's normal operations. The map below shows the test area, with the section of I–35 highlighted.

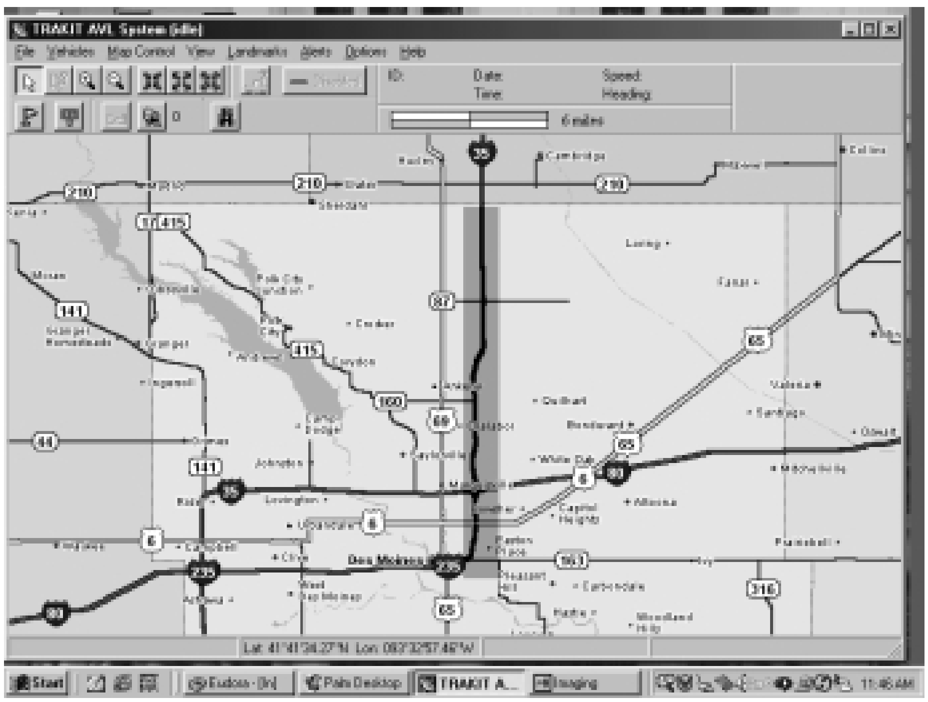

Figure 4: Map of Data Collection Area

Phase IV Report Overview

The remainder of this report provides the details of the HMCV systems and testing.
The report describes the progress made in the areas of field testing the SALTAR friction meter, the Frensor freeze point detection, the integration of the systems, and the communications linkages that were made.

Chapter 2 provides the detailed overview of the HMCV project architecture in relation to the National ITS Architecture. The Turbo Architecture Software was used to make this project architecture.

Chapter 3 provides detailed information for the field-testing of the SALTAR friction meter and the successes and failures encountered during this process.

Chapter 4 describes the bench testing and field-testing of the Frensor freezing point detection system.

Chapter 5 describes the communication setup used by the HMCV and the bench testing of the AVL prior to deploying it on the vehicle.

Chapter 6 describes the software architecture used in the HMCV. The architecture is based on a set of processes that communicate through a shared database process.

Chapter 7 provides conclusions, lessons learned, and recommendations for future research. Appendices are provided to include detailed documentation of software, hardware, and other information useful in this project.

CHAPTER 2: PHASE IV SYSTEM ARCHITECTURE

Introduction

When the Highway Maintenance Concept Vehicle project began in 1995, the focus was to determine what maintenance operators needed in the future and to determine if that vehicle could be built. The most difficult job for maintenance operations is snow and ice control, so the project focused its efforts in this area.

The universal challenge facing highway agencies today is to simultaneously increase productivity, quality, and environmental sensitivity. These challenges are of major importance to three–quarters of state DOTs, who must face the hazards of winter as they strive to provide uninterrupted mobility to the traveling public. Snow and ice control during winter storms includes highly complex tasks and long, stress filled hours for equipment operators and their supervisors. Continued reductions in staff dictate that a single equipment operator must be able to drive snowplow trucks and manage all of its ancillary equipment, whereas in the past there were two operators. These staff reductions come at a time when the traveling public requires greater mobility and an increased level of service for winter driving. Therefore the Highway Maintenance Concept Vehicle project was undertaken as a means to re-engineer highway maintenance vehicles so that they would include the latest available technologies, and to better suit the needs of the operator and the highway agencies.

Over the past five years, we have seen how snow and ice control operations have benefited greatly from the improvements in technologies such as automatic vehicle location (AVL), on–board computer systems, pavement sensing devices, multiple materials distribution systems, increase horsepower, increased vehicle conspicuity, automated activity reporting, and friction–measuring devices. These technologies have been installed and field–tested on the HMCV.
All of these technologies passed a proof of concept test and are ready for further field implementation. For example, the engine power booster proved that hydrous–ethanol could boost power in full acceleration needs. The case for a stronger engine was made and heard by the engine specification staff, and the Iowa DOT increased the horsepower requirements on later models of snowplow trucks. Fiber optic lights are now being installed on trucks used by Minnesota DOT.

Other states are following suit and are experimenting with various configurations on outlining the truck and plow. Many states are adapting AVL in their maintenance fleets as their budgets permit. The Ames Maintenance Area installed 18 AVL units in its operations. The Iowa DOT is using about 200 temperature-sensing devices. The Wisconsin DOT has purchased about 500 temperature sensors for the vehicles it uses for winter maintenance. The information obtained from these types of technologies can be integrated to better manage snow and ice control operations. For example, the 18 trucks in the Ames area, coupled with GPS, can generate a “thermal trace,” showing pavement and air temperatures at specific locations. This information is transmitted to the shop to enable supervisors to make more informed decisions for snow and ice control. The use of these technologies by different entities also demonstrated a need for integrating the information obtained from these various sources of data.

Also, the technologies being applied today have advanced considerably from the beginning of the project in 1995.

In Phase IV of the HMCV project, progress continued in integrating the communications systems onboard the vehicle to the desk side applications. The figures below depict the planned integration of these systems. It is envisioned that projects such as the Highway Maintenance Concept Vehicle Project can be applied to the National ITS Architecture. The following diagram, based on the National ITS Architecture, describes at a high level, how the study team sees the HMCV incorporating the National ITS Architecture. (This description was envisioned prior to the release of the Maintenance and Construction Operations Center in the National ITS Architecture document.)

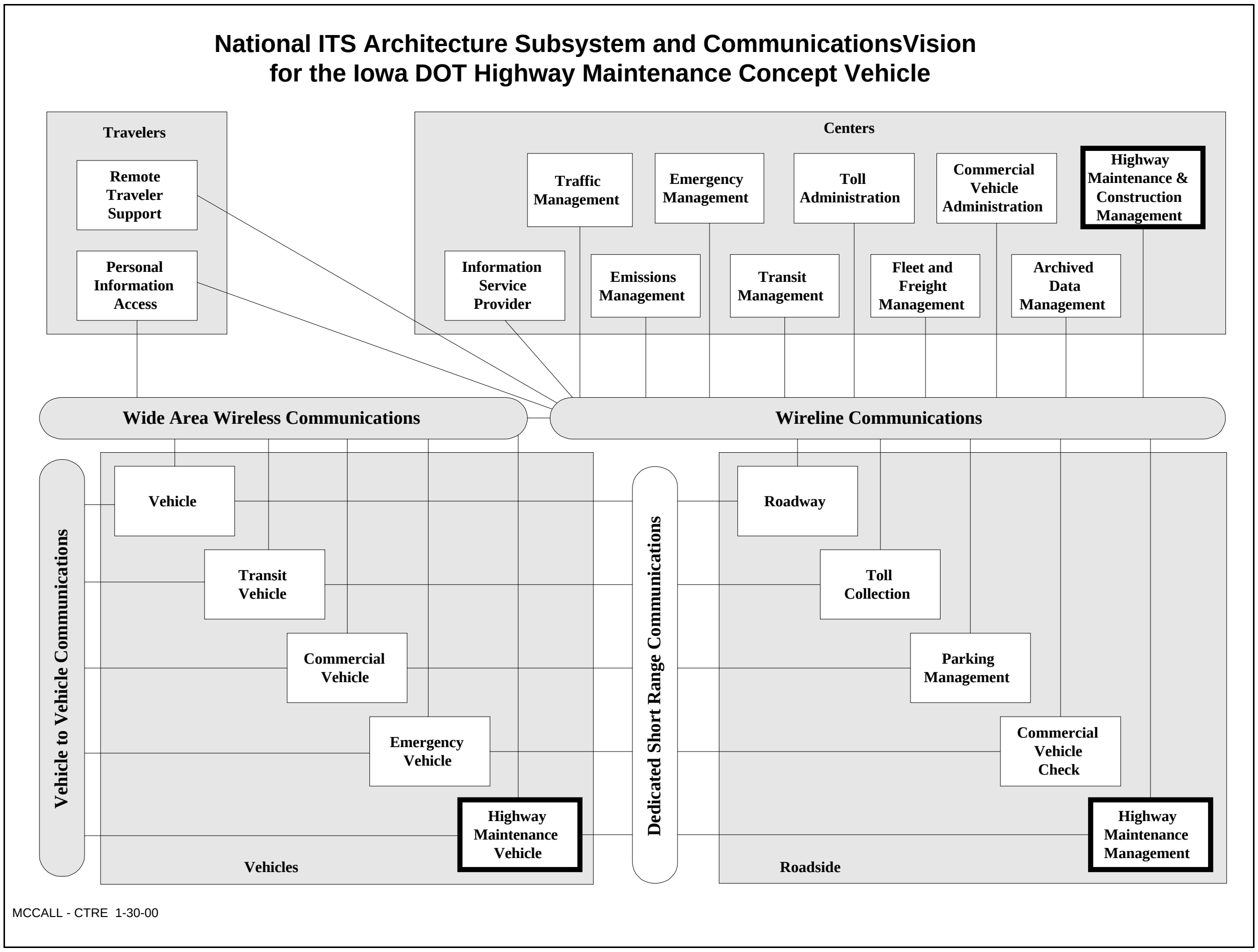

Figure 5: National ITS Architecture with HMCV Vision

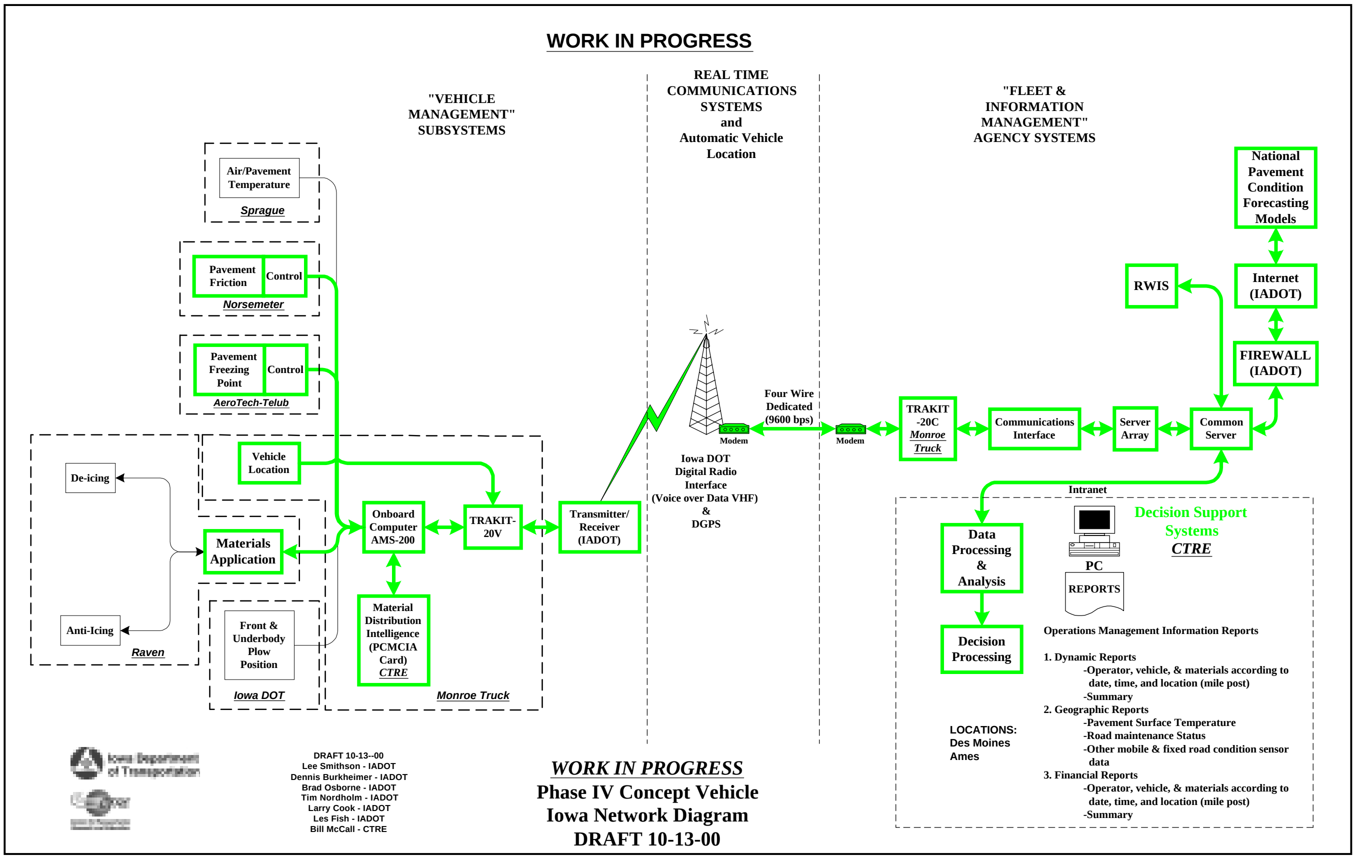

Figure 6: Iowa Concept Vehicle Network Diagram

The Iowa Concept Vehicle Network Diagram describes the data communications from the roadside to the desk side and establishes a maintenance decision support system. The highlighted areas show new paths for integration opportunities to enable the decision support system (DSS). In this diagram the network shows sensor input (air and pavement temperature, pavement freezing point, pavement friction indicators, vehicle location, and materials application rates) from the truck delivered over the radio to the network and eventually to a maintenance decision support system. The diagram also envisions the integration into the DSS of additional information such as road weather information systems (RWIS) data, national weather system (NWS) forecasts and national weather models, such as Foretell.

One of the critical steps in this project is the development of a HMCV "project architecture." A project architecture describes the "big picture" for ITS deployment in terms of individual components (i.e., subsystems) that will perform the functions necessary to deliver the desired services. The architecture provides a "road map" for system development. It describes what is to be deployed, but not how those systems are to be deployed. A project architecture defines how components and subsystems will interface with each other, the functions to be performed by those subsystems, and the data flows among subsystems.

Using the Turbo Architecture software, we developed a project architecture for the HMCV project based on the National ITS Architecture, developed by the United States Department of Transportation (U.S. DOT). This process provides a structured approach to developing an ITS Architecture for the HMCV that is based on addressing the project needs and is consistent with the National ITS Architecture. This chapter highlights the critical components of the HMCV Project Architecture, including its subsystems, market packages, data flow, and suggested recommended standards.

Identification of ITS User Services

User services have been selected based on discussions with the area maintenance operators and focus groups that were held during earlier phases of the project. The user services are listed because if these services were successfully implemented, they would directly address the needs expressed by the focus groups and maintenance operators. The architecture describes a long-term view, so not all needs expressed are met by the HMCV project at this time. However, we included these services to aid in our planning efforts. For this reason, it is important to include even those services that are not seen as viable for implementation, or are deemed highly applicable in the short term. While this process focuses on the immediate area, it can be replicated for any project.

For describing the HMCV Architecture, the Turbo Architecture Software was used.

User Services Mapped for HMCV

User services have been selected based on local needs and problems associate with winter maintenance. A mapping process was used to associate user services with local needs and problems identified through the surveys sent to the maintenance garages. The user services are listed here and discuss the needs as voiced by the maintenance supervisors that we spoke to

Table 2 presents the user services identified by HMCV. The user services are grouped by similar function into general categories or “bundles.” The services reflect the need to obtain weather and road condition information and disseminate that information to the traveling public. Also, maintenance supervisors require reliable forecasting information to plan their snow and ice control strategies.

Table 2: HMCV User Services

HMCV User Services	
User Service Bundle	**User Services**
Travel and Transportation Management	• Pre-trip Travel Information • Enroute Information • Route Guidance • Traveler Services Information • Traffic Control • Incident Management
Emergency Management	• Emergency Notification and Personal Security • Emergency Vehicle Management
Information Management	• Archived Data Function

Identification of ITS Market Packages

Earlier in the project, focus groups identified needs that the various project stakeholders wished addressed. The information from these focus groups was used to help identify market packages for use in the project architecture. The use of market packages is a concept introduced in the National ITS Architecture. Market packages are defined as a collection of equipment capabilities that satisfy a market (stakeholder) need and are likely to be deployed as a group. Another way to think of market packages is as groupings of functions that are needed to deliver user services. Table 3 lists the market packages that are applicable to the Highway Maintenance Concept Vehicle project focusing on the vehicle to roadway connections.

Table 3: HMCV Market Packages

Market Packages Applicable to HMCV	
Market Package Category	**Market Packages**
Advanced Traffic Management Systems (ATMS)	• Network Surveillance • Probe Surveillance • Traffic Information Dissemination • Regional Traffic Control • Incident Management System • Road Weather Information System
Advanced Traveler Information Systems (ATIS)	• Broadcast Traveler Information • Interactive Traveler Information • ISP Route Guidance • Integrated Transportation Management/Route Guidance
Advanced Vehicle Safety Systems (AVSS)	• Vehicle Safety Monitoring • Driver Safety Monitoring
Archived Data Management System	• Government Reporting Systems Support • ITS Data Repository • On-Line Analysis and Mining • Traffic and Roadside Data Archival • Virtual Data Warehouse Services
Emergency Management (EM)	• Emergency Response • Emergency Routing

Subsystems and Equipment Packages

Following the identification of the market packages, we identified the equipment packages to go along with them. The equipment packages often reside in several different subsystems within the architecture framework and may be operated by different stakeholders.

To understand and analyze these potential deployment variations, the defined market packages must be broken down to their constituent elements. The portion of the market package capabilities that are allocated to each subsystem are segregated and defined as “equipment packages” to support this additional resolution. An equipment package represents equipment (or software) that is likely to be purchased by an end-user to achieve a desired capability.
The results of the exercise identifying the HMCV list of subsystems (SS) and equipment packages (EP) are summarized in Table 4.

Table 4: HMCV Plan Subsystems (SS) and Equipment Packages (EP)

Subsystems	Equipment Packages
EMERGENCY MANAGEMENT (SS)	Emergency Response Management (EP) Emergency Vehicle Routing and Communications (EP)
HIGHWAY MAINTENANCE CONCEPT VEHICLE (EMERGENCY VEHICLE) (SS)	On-board EV Incident Management Communicator (EP)
INFORMATION SERVICE PROVIDER (SS)	Interactive Infrastructure Info (EP) Basic Information Broadcast (EP) Infrastructure Provided Route Guidance (EP) EM Route Plan Information Dissemination (EP)
REMOTE TRAVELER SUPPORT (SS)	Remote Basic Information Broadcast (EP) Remote Interactive Information Reception (EP)
ROADWAY SUBSYSTEM (SS)	Roadway Basic Surveillance (EP) Roadway Freeway Control (EP) Roadway Incident Detection (EP) Roadway Traffic Information Dissemination (EP)
TRAFFIC MANAGEMENT (SS)	Collect Traffic Surveillance (EP) Traffic Maintenance (EP) TMC Incident Detection (EP) TMC Traffic Information Dissemination (EP) TMC Incident Dispatch Coordination/Communication (EP) TMC Road Weather Monitoring (EP)
VEHICLE SUBSYSTEM (SS)	Vehicle Route Guidance (EP) Driver Visibility Improvement System (EP)
ARCHIVED DATA MANAGEMENT (SS)	Government Reporting Systems Support (EP) ITS Data Repository (EP) On-Line Analysis and Mining (EP) Traffic and Roadside Data Archival Virtual Data Warehouse Services (EP)

Functional Architecture

A functional architecture "...defines the functions (e.g., gather traffic information or request a route) that must be performed to implement a given user service, the physical entities or subsystems where these functions reside (e.g., the roadside or the vehicle), the interfaces/information flows between the physical subsystems, and the communication requirements for the information flows (e.g., wire line or wireless). In addition, it identifies and specifies the requirements for the standards needed to support national and regional interoperability, as well as product standards needed to support economy of scale considerations in deployment." (National ITS Architecture v.3.0, USDOT) The functional architecture provides a framework for delivering the selected market packages by identifying the major components of the system, referred to as subsystems, and how these subsystems relate to each other, including what data will be communicated between subsystems.

The HMCV Functional Architecture is developed from a physical and logical perspective. The physical layer will describe a technical and institutional layer. The technical architecture coordinates overall system operation by defining interfaces between equipment and systems that may be deployed by different organizational or operating agencies throughout Iowa. The institutional architecture represents the organizations, services, working arrangements, and jurisdictional structure that support the technical layer of the Iowa DOT statewide architecture.

Physical Architecture

The physical architecture provides agencies with a physical representation (though not a detailed design) of the important ITS interfaces and major system components. It provides a high-level structure around the processes and data flows defined in the logical architecture. The principal elements in the physical architecture are the 19 subsystems and architecture flows that connect these subsystems and terminators into an overall structure. A physical architecture takes the processes identified in the logical architecture and assigns them to subsystems. In addition, the data flows (also from the logical architecture) are grouped together into architecture flows. These architecture flows and their communication requirements define the interfaces required between subsystems, which form the basis for much of the ongoing standards work in the ITS program. Figure 3 on the following page, depicts the systems and subsystems distributed along with the primary communications media (wire line, wireless, DSRC) identified. This diagram is frequently referred to as the "sausage diagram" within the National ITS Architecture due to the shape of the communication components. This diagram has been modified to reflect the subsystems that are part of the HMCV project.

The document demonstrates the need for coordination and sharing of data and resources among the various transportation providers in the statewide area. The architecture presents a centralized approach to winter maintenance management in the area. This does not dictate the need for a large physical building for a traffic management center; rather, it highlights the need for sharing the resources, data, and some physical hardware. For example, the urban area TMCs will need to coordinate with other organizations such as Iowa DOT, and other cities and counties in Iowa, for implementing some parts of this architecture. Those organizations that perform traffic management functions will participate in this regional concept by sharing data (and potentially physical location and some control) between urban area TMCs and other transportation infrastructure elements.

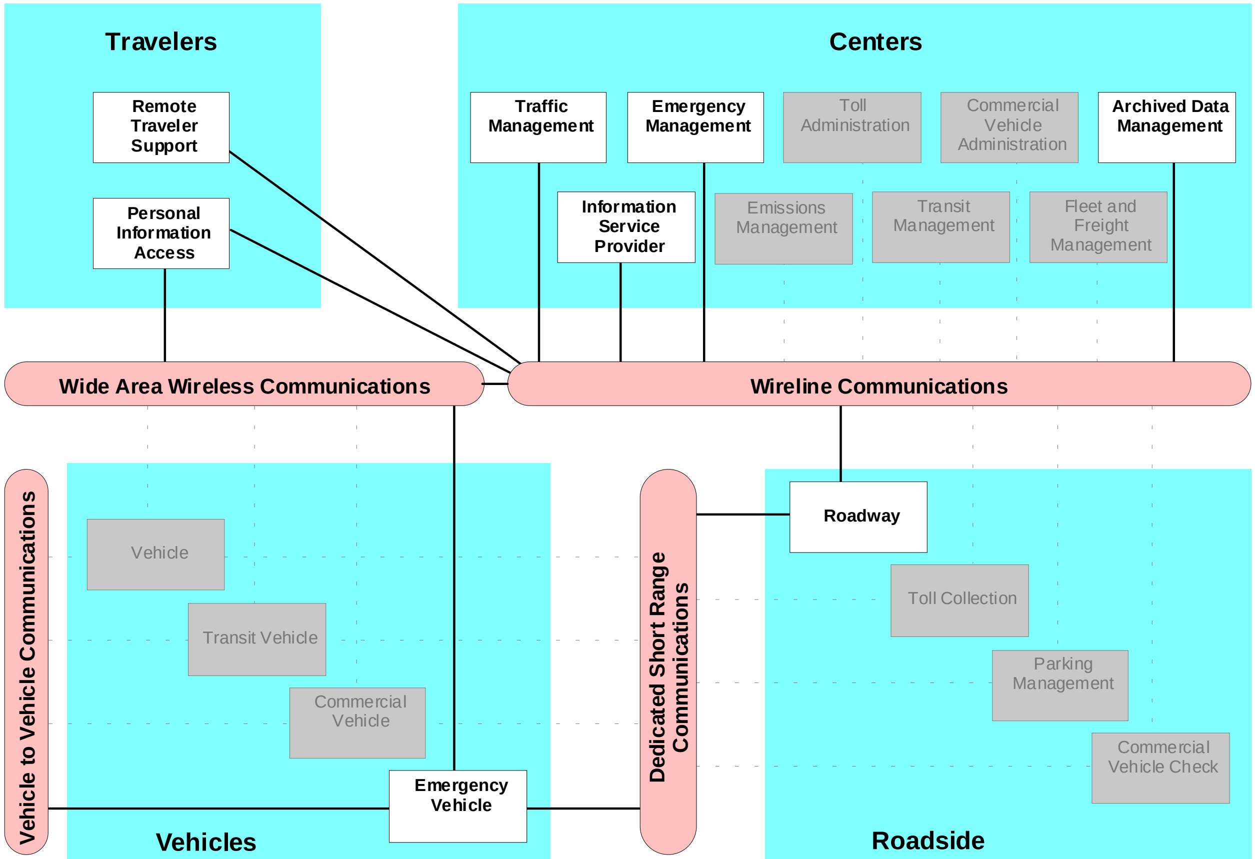

Figure 7: HMCV Physical Architecture

Description of Subsystems

The following sections describe the individual subsystems included in the architecture.

Traffic Management Center

Presently, there are no physical TMC Centers. However, the architecture plans for the functions of TMC to be included in the Iowa DOT.

> Iowa DOT: Manages functions that deal with the statewide traffic control, interagency coordination, and planning functions. This function also provides standards compliance oversight and enforcement for public and private ITS activities. The Iowa DOT would analyze, coordinate and disseminate the information collected from the HMCV to make its management decisions.

> HMCV: Consists of functions that deal with collection of raw and/or processed data and fusing these data to enhance the information made available to the user. Currently, this

system collects road condition and surface conditions (e.g., air, pavement temperature, road friction measurements, and chemical freezing point). In the future, the information will be processed and sent to the FORETELL system. Information can include road condition, presence or absence of friction, whether the road has been treated or plowed, etc. to assist in winter maintenance decision support and traveler decision-making.

Emergency Management Center

This system consists of functions that deal with emergency response to traffic, incidents, weather, mayday functions, and emergency routing functions.

Includes coordination with the traffic management area for incident detection/notification/verification and the use of AVL technologies for location of emergency vehicles for dispatching and tracking purposes, and emergency routing, in this case the HMCV. The HMCV would be able to detect hazardous conditions on the roadway and forward the information to the DOT Management Center.

State Highway Patrol/Police Agency: Interacts with the emergency management subsystem to assist in emergencies, road closures, re-routing, etc.

Independent Service Provider Center

This system deals with the functions necessary to disseminate information to travelers by processing information and adding value-added data.

Foretell: the Iowa DOT is leading this project. It is designed to implement a commercially viable, self-sustaining integrated intelligent weather and transportation system. Foretell is designed to increase safety, security and mobility, and will lead to improved Iowa DOT maintenance and operational efficiencies.

Private ISP - In the future, a private ISP may be interested in providing information to the traveling public in the Iowa area. Information can include incidents, route guidance, weather information, etc.

Archived Data Management Center

This subsystem consists of planning, data archiving, and data management activities.

Iowa DOT: Manages the ITS planning and data management activities for the state. This includes data collection, archiving, and possibly data sharing to other agencies regionally and locally.

The Center for Transportation Research and Education (CTRE): CTRE is the focal point for transportation at Iowa State University. CTRE performs transportation research for public and private agencies; manages its own education program for students; and conducts local, regional and national transportation services and continuing education programs.

Traveler Subsystems

The development and deployment of traveler information systems is a prime area for private sector involvement. While the public sector is well equipped for the development and management of the infrastructure (roadways, traffic management, etc.), the private sector is well suited for the development of products to use the information collected by the public sector and provide that to the traveling public. The architecture focuses on four major areas within the traveler information systems as follows:

> Interactive Traveler Information (Web Page, Personal Route Guidance): These involve the user requesting information through a device/system. Iowa DOT currently has a web page and this system can be enhanced to include route guidance, pre-trip and en route travel information. These systems can be remote units like in-vehicle systems or hand-held personal computers. These systems can also perform route guidance functions.
>
> Broadcast Traveler Information (Automated Telephone, RWIS, Pagers): These systems provide traveler information through a broadcast mechanism where there is no interaction between the user and the broadcast system. This could include providing information to road weather information systems, pagers, automated telephone systems, etc. The information broadcast is real-time and supports en route driver information.
>
> Media Reports: Included separately, the interfaces with the media include electronic interfaces such as those described above as well as interfaces with the print media in Iowa. Though not real-time, the print media can provide a valuable source of information dissemination to the general public about known traffic and travel conditions. This can be of particular benefit in the dissemination of traffic information about planned events (road construction or special events).
>
> Policy decisions by the Iowa DOT statewide partners will determine their role in providing traveler information services. Philosophically, the Iowa DOT partners, in cooperation with the other state and local agencies, must decide whether the provision of traveler information is to be left up to the private sector or if the public sector will provide this information as a public service. The architecture will support either approach.
>
> Data Transmission Network (DTN) Weather Information: This is a system that delivers information via satellite to rest areas and is available through subscriptions.
> Automatic Weather Observation System (AWOS): This system is managed by the Iowa DOT Office of Transportation Data and collects weather information from 32 airports around Iowa. Data are available from an interactive web site, found at www.DOTweatherview.com.

Vehicle Subsystems

Because the HMCV operates in inclement weather and hazardous conditions, the vehicle subsystems include linkages to other emergency vehicles in the event of an incident. The linkages are listed here:

Emergency Vehicles: Includes functions that deal with regular and HAZMAT incident response and clearance, emergency routing, Mayday support, signal preemption/prioritization and interacting with the infrastructure for advanced automatic vehicle operation.

Highway Maintenance Vehicle System: Includes functions that communicate with the maintenance vehicle, which collects weather data for traveler information applications, maintenance fleets, and for the application of road treatment material.

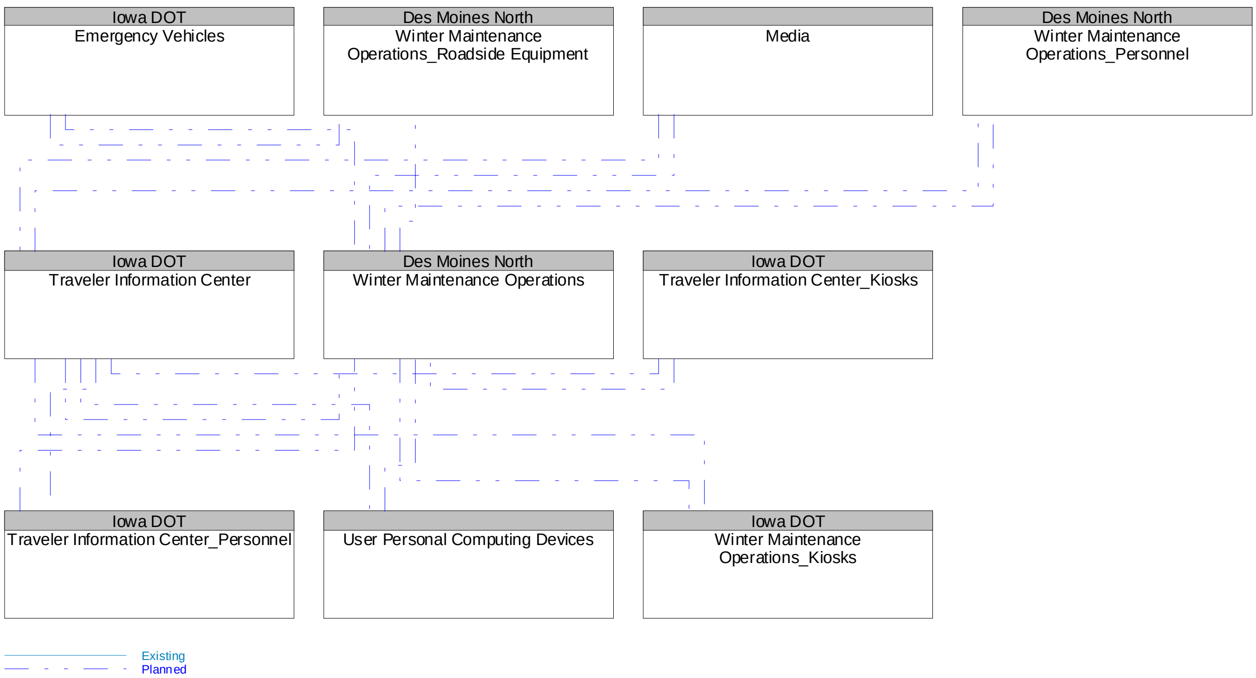

Figure 8: HMCV Planned Interconnects

Interconnections/Data Flows

The planned data flows for this architecture are shown in Figure 8.

Des Moines North Shop: The first depository of sensor information from the vehicle. The data include surveillance and communications from the hardware installed to provide operational coverage of the freeways using the HMCV as probe.

Winter Maintenance Operations: Part of roadside traffic information dissemination and includes the physical infrastructure in place on the freeway and arterials for disseminating traffic information through changeable message signs controlled remotely by various agencies.

Media: The roadside traffic information dissemination includes having a physical infrastructure in place for disseminating traffic information through specific channels. Once the media have the road conditions and weather information, they can broadcast, or narrowcast, them out to the traveling public.

Maintenance/Emergency Vehicle Sensors: The HMCV conducts road and weather surveillance and includes communications and hardware installed to provide weather conditions of the freeways through pavement and weather sensors, environmental sensor detectors.

Logical Architecture

This section describes the logical architecture developed for the HMCV. This depiction of the architecture represents the study team's approach to managing the intelligence and, specifically, the communications between the roadside and desk side. The logical architecture presented in Figure 9 was adapted from the National ITS Architecture, data flow diagram (DFD), using the Turbo Architecture software.

The diagram depicts the functional areas integrated with the Iowa DOT and how the data flow from one area to another.

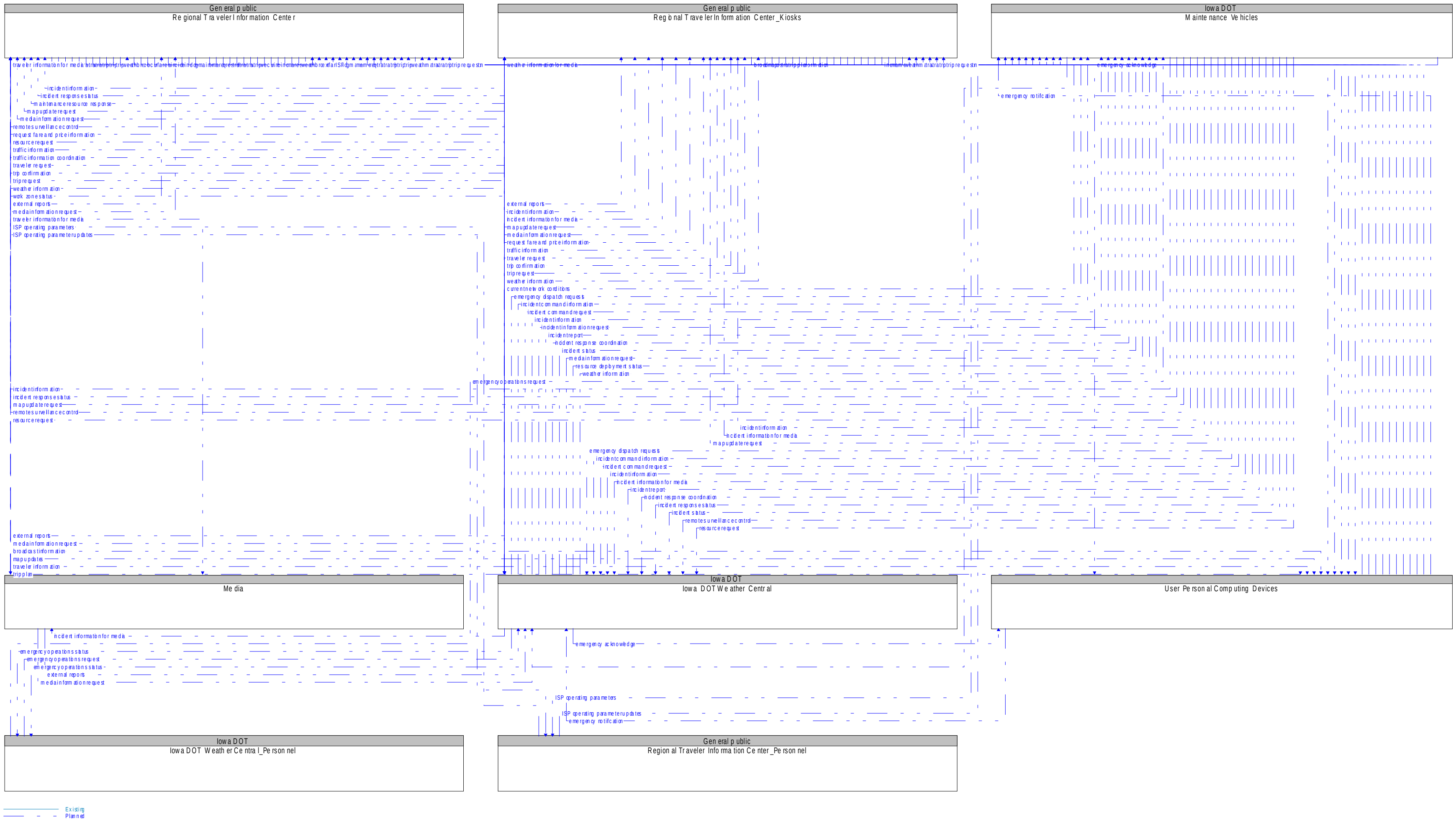

Figure 9: HMCV Planned Data Flow, Logical Architecture

Note: Please contact Dennis Kroeger, CTRE, at kroeger@iastate.edu, 515-296-0910, for a larger printout of this data flow.

Recommended Standards

Standards can be thought of as the glue that pulls the various pieces of the architecture together. The logical architecture presents a functional view of the ITS user services. It defines the functions or processes that are required to perform the selected ITS user services, and the information or data flows that need to be exchanged between these functions. The physical architecture partitions the functions defined by the logical architecture into systems and subsystems. In order to accomplish the functions outlined in the logical architecture, some communication must take place between the elements of the physical architecture. Standards define how these communications take place.

The process used to identify and prioritize the communications standards is similar to that of developing the physical architecture. The table below identifies the key standards supporting the HMCV.

Table 5: Key Standards Supporting HMCV

Standard Name	Standard Title
ITE-9601-1	ATMS Data Dictionary (TMDD) - Section 1&2 (Links/Nodes/Events) (TM 1.01)
ITE-9604-1	Message Set for External TMC Communication (MS/ETMCC) (TM 2.01)
TCIP-CC	TCIP - Control Center Objects
TCIP-OB	TCIP – On-board Objects
TCIP-TM	TCIP – Traffic Management Objects
P1512	Standard for Common Incident Management Message Set (IMMS) for use by EMCs
J2354	Advanced Traveler Information System (ATIS) Message Set
J2355	ITS Data Bus Reference Architecture Information Report
NTCIP 1204	Object Definitions for Environmental Sensor Stations & Roadside Weather Information System
NTCIP 2202	Internet (TCP/IP and UDP/IP) Transport Profile
NTCIP 1301	Message Set for Weather Reports – NTCIP

HMCV Project Architecture

Finally, the winter maintenance functions demonstrated by the HMCV project are compatible with the National ITS Architecture approach. The HMCV can provide critical weather and road condition data to weather forecast models such as Foretell. The architecture presented here provides a "road map" for further deployment of additional vehicles. It is envisioned that more advanced technology maintenance vehicles will be deployed that will serve as mobile data platforms using NTCIP standards to provide real-time data, such as, air and pavement temperatures, wind speed, pavement condition data, etc., to maintenance operations centers to assist in their operational decision making. The information can then be forwarded to a traffic control center for further dissemination, providing for the continued progressive deployment of weather and road condition information throughout the area.

CHAPTER 3: FIELD FRICTION TESTS

As with earlier phases of the project, during the winter of 2001–2002 friction measurements were taken to determine the reliability, durability, and applicability of the SALTAR friction meter to snow and ice control operations. This method of measuring friction during snow and ice control operations was designed to also assist the operator in determining the presence of friction on the roadway and whether chemicals are to be applied during these operations.

SALTAR

The SALTAR pavement friction device is a slip friction-measuring device mounted on the highway maintenance concept vehicle. The SALTAR friction meter is a device designed to measure friction on winter-contaminated surfaces and based on the measurements classify the winter contaminants and or surface in five levels. Fundamentally the SALTAR unit is a small, durable frame equipped with an electronic brake and a measurement tire with pneumatics to hold the tire in place. The brake is controlled by an advanced software and electronic control system to simulate car-braking action and measure the generated friction coefficient between a measuring wheel and the surface.

Figure 10: SALTAR Mounted on Snowplow

Theory of Operation

The measuring wheel together with the holding bracket can be retracted or lowered by means of a pneumatic mechanism that also provides the controlled and calibrated load for the measurement tire. For measuring, it is lowered on to the surface with a predetermined and controlled vertical load by means of two pneumatic cylinders that are part of the frame and holding bracket of SALTAR. As the host vehicle moves on the measured surface, the electronic brake periodically applies braking action to the measuring wheel in order to measure the effective braking power.

The measuring wheel is mechanically geared to the high precision and durable electronic brake. The device measures the effective braking power during a braking cycle, where the wheel is restricted from freely rolling to locked position. The measurement is based on the principle of measuring the time necessary to speed up the measurement wheel from locked position to freely rolling. The complex and sophisticated control software computes the necessary parameter from the acquired physical parameters measured during the braking cycle and calculates the effective braking power. As extra equipment a data link can be installed. This link can transmit the measuring results to a PC, either in a remote location by radio or directly to a portable PC in the driver's cab, for storage, presentation, or further processing.

Sensor Design

To brake the measurement wheel from freely rolling to a locked stage in a very short period of time and then release in an ABS braking style the SALTAR system is equipped with a fast and strong electronically controlled brake. The brake unit is a SEW BM30 electronic brake with a BSG electronic rectifier and control unit. The brake has a 600 Nm maximum braking torque and can be operated by standard 24V power. The brake unit is enclosed in cast iron casing and can be used under any weather conditions.

The SALTAR measuring system has a separate pneumatic system, fitted in the rear of the assembly. The pneumatic system is designed for two different host vehicle environments. One is for trucks and utility vehicles with their own auxiliary air supply, and one is for vehicles with no usable air system.

1. The system can be connected directly to the air supply system of trucks. SALTAR has an automatic air pressure regulator and can be connected without any prior modifications to most trucks. This system consists of a pressure accumulator, regulating system, valves, and piping.
2. The system designed for vehicles with no air supply is a stand-alone design. This system consists of an electrically driven pump, a pressure accumulator, regulating system, valves and piping. The system is a self-contained unit. Power to the pneumatic system is supplied by the electric system of the base car.

The SALTAR computer system is of type SALTAR Mk I Computer system, specifically designed for the SALTAR Friction Tester. It consists of two basic units:

- Central computer
- Operator panel and user interface

The central computer is an industrial high performance computer that can be operated under extremely harsh conditions. The small size and the rugged design of the compartment makes it fit to be mounted nearly anywhere on the host vehicle. The computer unit is connected to the measurement sensors located in the brake and measuring wheel assembly by two wires supplying the power to the brake and to the sensors and carrying the control and measurement signals. The SALATAR Mk I computer is based on the state of the art industry leader micro-controller AMD

AM186EM controller processor and a fully fledged Real Time Kernel. The schematic layout of the controller can be seen in Figure 11.

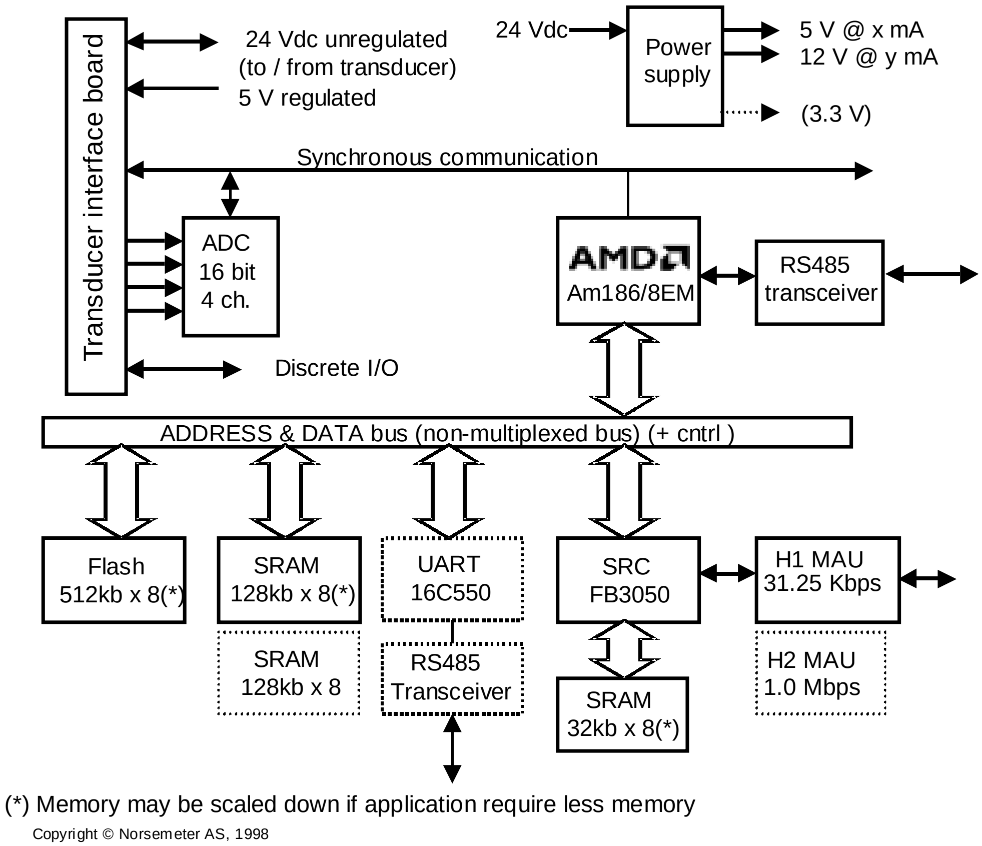

Figure 11: Schematic of SALTAR Mk I Computer

A keyboard operates the computer system with a display for operator guidance. The keyboard operator panel is a palm size "remote control" unit of the measurement system that also displays the measurement results in real time. The control buttons, indicators, and light emitting diodes (LED) are arranged to give the operator maximum flexibility and easy observation. Because of the small size the operator panel can be placed anywhere in the host vehicle driver's cabin. The Mk I computer system is easy to calibrate. Calibration is done automatically via a laptop computer and a standard RS232 communications port. The keyboard is detachable and can be moved. The system is easy to maintain and is made up of only three easily replaceable units. It has a built-in self-test function. The Mk I Computer System is fitted with a data link interface for transfer of measurement values to a PC for storing/presentation. The data-link can be connected to a radio link modem, or a link to a portable PC in the vehicle. Figure 12 is the schematic of the operator panel. Figure 13 shows the panel mounted in the vehicle cab.

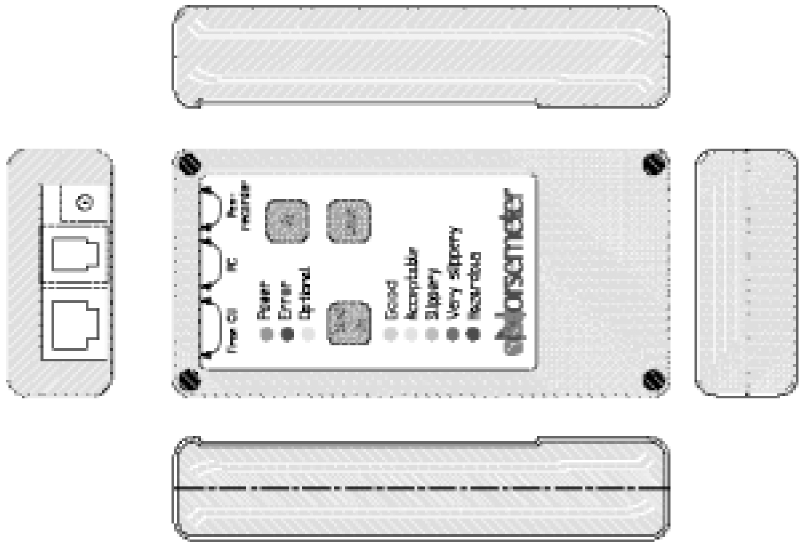

Figure 12: Operator Panel and User Interface

Figure 13: Operator Panel Installed in Truck

The panel mounted in the truck indicates the presence of friction on the roadway by the LEDs.

Field Tests

The SALTAR friction-measuring device was field tested during Phase IV. The SALTAR however, was not as successful as the other vehicle subsystems tests. During the winter of 2000–2001, some friction readings were obtained, but not enough to be statistically significant. During winter operations, the device was damaged, and the unit had to be rebuilt. The underbody blade struck a curb, then pushed back into the side of the truck and struck the SALTAR. A lesson learned from this experience would be to add more distance between the friction-measuring device and the underbody blade. By the time repairs were completed, the winter season was over. However, additional friction readings were obtained during the 2001–2002 winter season.

The roadway used for the field tests was a segment of Interstate 35 between Ames and Des Moines. The segment is the area that snowplow is regularly assigned to operate on. The surface area is a normal concrete roadway. During the field tests, friction measurements were taken on both the northbound and southbound lanes of this section of I-35. A road weather information station (RWIS) sensor located near highway mile marker 95 on I-35 collected atmospheric conditions. Along with friction measurements, the following atmospheric data were recorded: air temperature, road surface temperature, relative humidity, wind speed and direction.

The segment of I-35 is approximately 14 miles long (see Figure 14). The route runs from Guthrie Avenue in Des Moines, traverses through Ankeny, Iowa, continues north to mile marker 97. There is also a rest area just north of Ankeny. The average daily traffic between Ankeny and Des Moines is 52,500 vehicles.

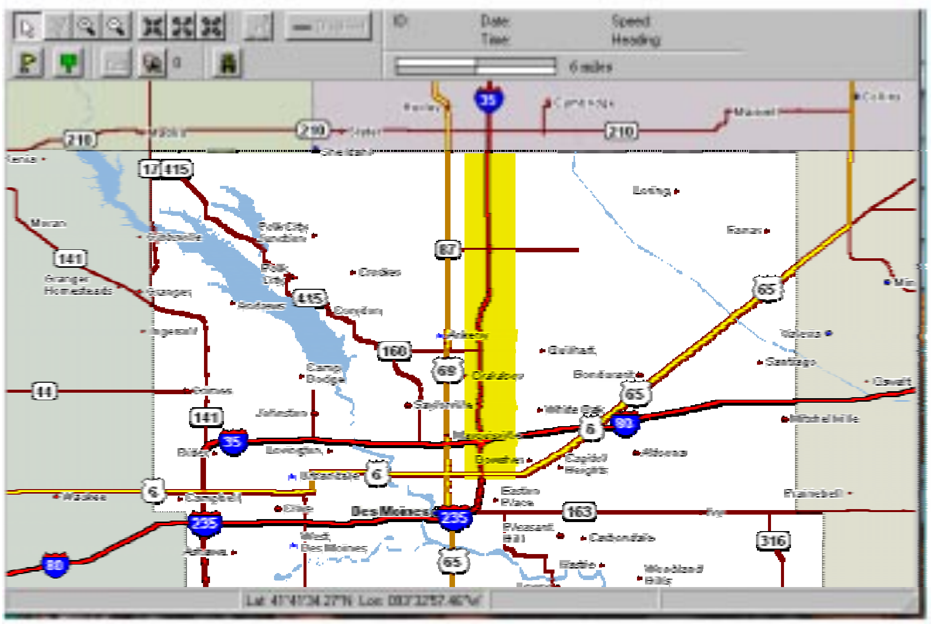

Figure 14: Map of Data Collection Area

Test Procedures

The investigation of winter pavement friction attempted to reflect more actual conditions during maintenance operations. The conditions were tested using the SALTAR mounted on a snowplow during the winter of 2001–2002.

The SALTAR is mounted on the snowplow vehicle just behind the underbody blade and in the driver's side-wheel track of the snowplow. The vehicle traveled on its normal maintenance route when the friction readings were taken.

The SALTAR is mounted on the snowplow vehicle just behind the underbody blade and in the driver's side-wheel track of the snowplow. The vehicle traveled on its normal maintenance route when the friction readings were taken.
The SALTAR was redesigned to record friction levels in five categories rather than specific numeral indicators. The categories are listed in Table 6.

Table 6: Friction Level Indicators

Friction Levels		**Color Level Indicator** (as seen on Operator Panel)
Hazardous	Mu < 0.15	Red
Very Slippery	0.15 < Mu < 0.25	Yellow
Slippery	0.25 < Mu < 0.4	Amber
Acceptable	0.4 < Mu <0.5	Orange
Good	0.5 < Mu	Green

The SALTAR determines friction on the roadway by measuring the braking action on the wheel and the decreasing rotational wheel speed from rolling to a stopped position. The torque on the wheel action is then measured and converted to a friction coefficient by the device’s computer. The measurements are then sent to the device’s controller where the friction level is displayed on the LED output. The friction levels are recorded on the AMS 200 onboard computer for later downloading and analysis.

Winter 2001–2002 in Iowa was unusually mild, so the number of friction readings taken was less than in previous years. The graphs below are samples of data that were collected on January 31 and February 1 of 2002.

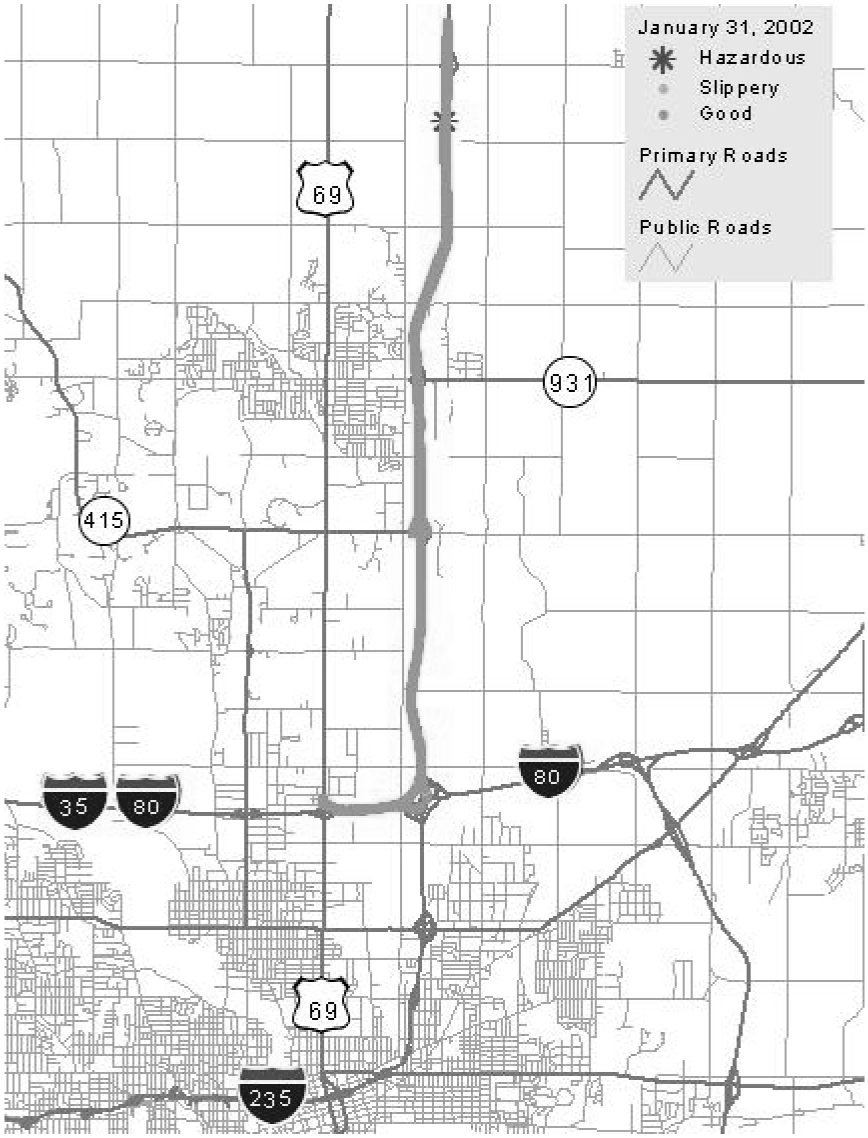

Figure 15: Sample Friction Measurements taken January 31, 2002

Figure 15, above, shows friction data collected with the SALTAR friction–measuring device mounted on the HMCV, on the plow route on I-35. These readings were taken after the roadway had been plowed and treated with chemicals. The crews had been out since 12:01 AM plowing and applying chemicals to road surfaces. Intense application of salt and brine ended about 7:00 AM. These friction readings, taken between 9:00 AM and 12:00 M indicate "good" friction levels following treatment. At the time of these measurements light snow was falling and the HMCV was engaged in clearing any drifting snow on the roadway, as the wind was out of the southwest at 17 mph. Both air and pavement temperatures recorded between 27° F and 30° F during the data collection period. On the north end of the route, the map shows an area reading "hazardous". There was drifting snow occurring where this reading was taken. The area was plowed and showed good friction readings on the following pass.

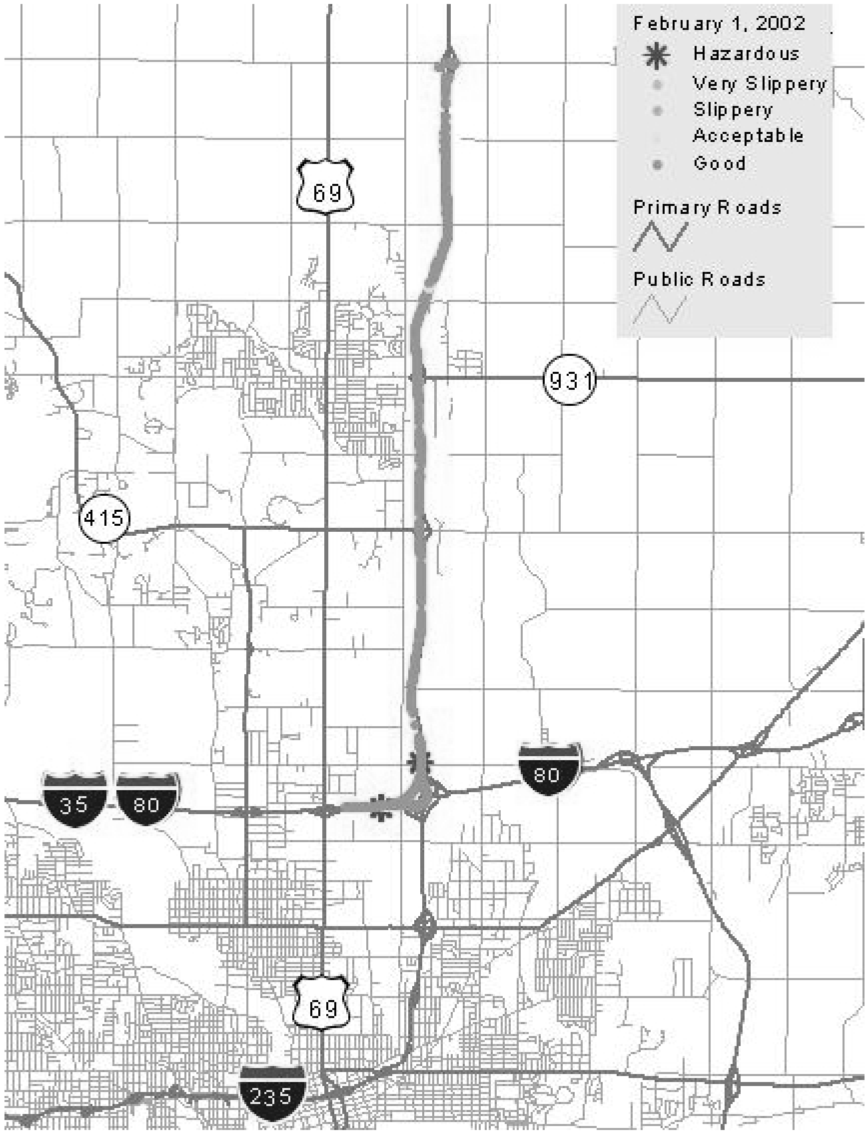

Figure 16: Sample Friction Measurements taken on February 1, 2002

Figure 16 shows friction measurements taken on I-35 February 1, 2002. The readings indicate friction levels the "good" category. There was precipitation overnight in the form of wet snow that ended approximately 5:00 AM. The crew pretreated the roads with salt brine prior to the morning rush hour. The snowplow was engaged in cleanup activity on this day, clearing any drifting snow. The road pavement temperature during the time that these readings were taken ranged from 28° F to 30° F. The air temperature ranged from 28° F to 29° F. These friction readings were taken between 9:00 AM and 12:00 PM following plowing and chemical treatment. There were two areas shown here that indicate "hazardous" friction level. These "hazardous" areas were shoulders and ramps that had patches of ice and hard packed snow that required additional treatment. Following the plowing and brine application, these shoulder areas showed "good" friction level.

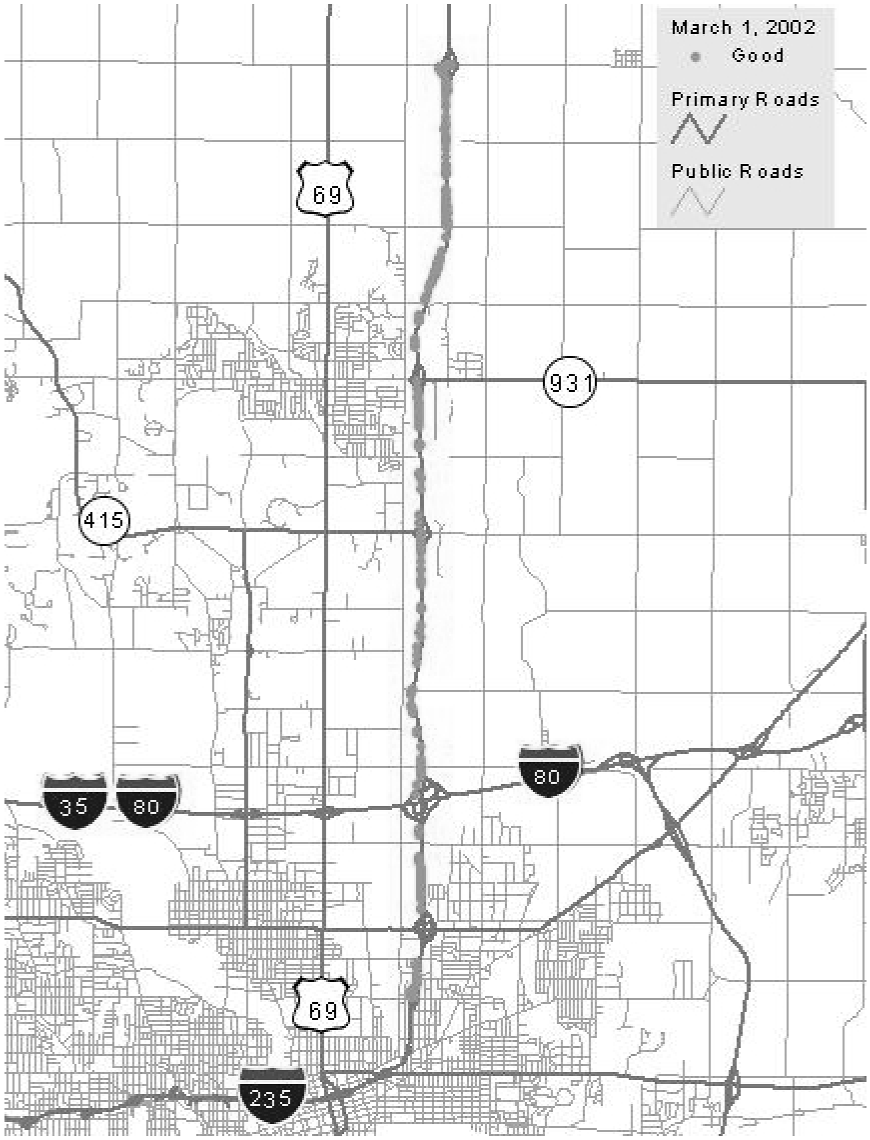

Figure 17: Sample Friction Measurements taken March 1, 2002

Figure 17, above, shows data collected on the snowplow route on I-35 on the afternoon of March 1, 2002. Snow started falling about 6:00 AM. These readings were taken after the roadway had been treated with chemicals. The air temperature was recorded at 24° F and the pavement temperature was recorded at 25° F during this data collection period. These readings, taken between 5:00 PM and 7:30 PM indicate "good" friction levels following treatment. The crews had been out since 7:00 AM plowing and applying chemicals to road surfaces. Intense application of salt and brine ended about 3:00 PM. At the time of these measurements light snow was falling and the HMCV was engaged in clearing drifting snow on the roadway, as the wind was out of the southwest at 22 mph.

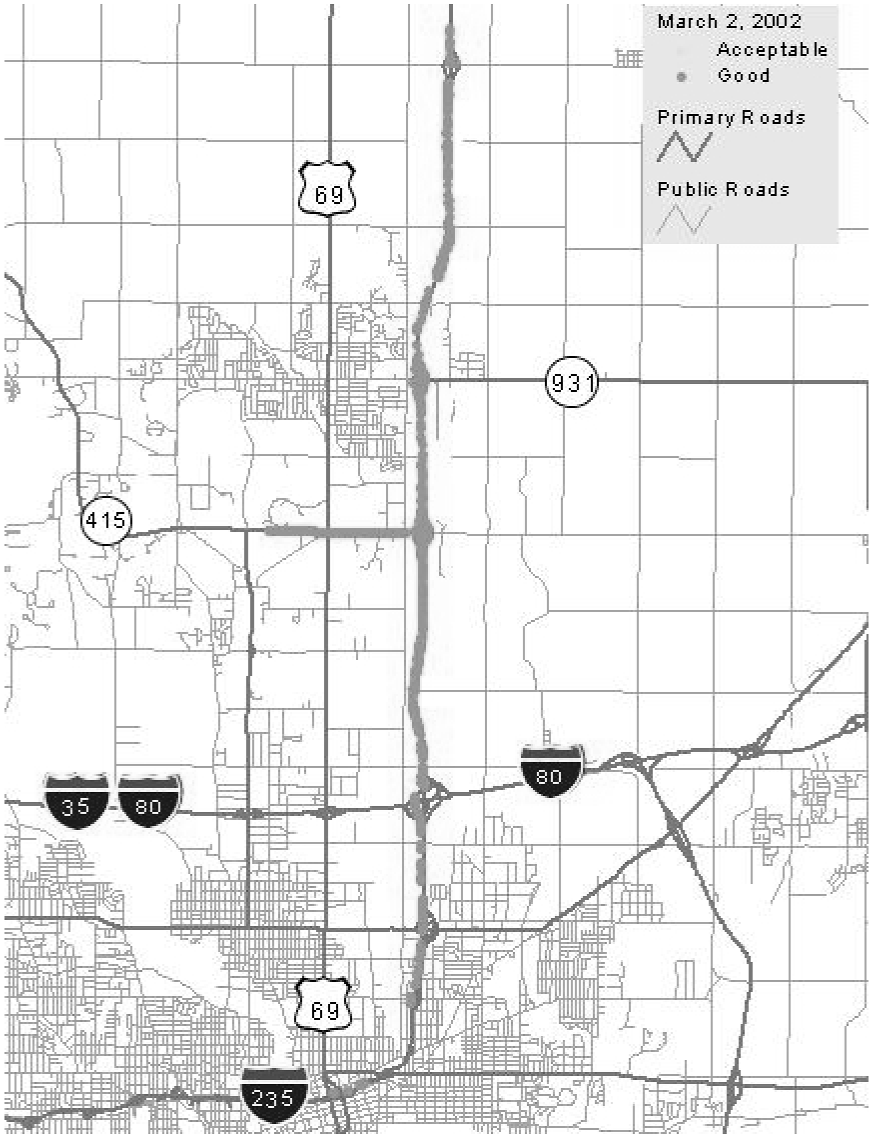

Figure 18: Sample Peak Friction Measurements taken March 2, 2002

Figure 18 shows the friction readings taken from I-35 on March 2, 2002.These readings were taken between 11:30 AM and 4:30 PM. The road pavement temperature during the time that these readings were taken ranged from 13° F to 20° F. The air temperature ranged from 15° F to 19° F. Brine was applied about 9:00 AM. The snowfall started out with light flurries, but its intensity increased as the day progressed. The plows were assigned to keep the roads open from possible drifting across the roadways, as winds were gusting to about 20 mph. The storm ceased about 4:00 PM, with a total of approximately three inches of accumulation.

The graph indicates that following treatment; there is generally acceptable friction on the roadway.

Another means of analyzing the effectiveness of measuring friction and treating roads is to compare the road surface conditions before and after treatment. Table 7 shows the changes in friction values on dry pavement, at 9:40 AM, following the chemical applications during a storm event on January 31, 2002. Again the area near the RWIS station was used to collect the data.

From the raw data collected, and using the Rado Friction Model, we can calculate μ to determine the friction readings.

Table 7 shows friction levels as they were measured near MM 95 on northbound I-35. Prior to these measurements, the crews had been out the previous night, treating the roadways in anticipation of the storm event. The measurements were taken on the morning of January 31, 2002. The chemical applications held the friction at the 40 gallons per lane mile rate.

Table 7: Friction Values in Winter Conditions, NB I35 Near MM 95, 01/31/2002

Time of Day	Chemical Application Rate	Friction Value	Air Temperature (F)	Pavement Temperature (F)	Rel. Hum
09:40	(first run)	0.57	26.3	28.8	96.0%
10:49	40 gal/ln mi	0.52	26.5	29.7	97.0%
11:51	40 gal/ln mi	0.56	26.6	30.7	97.0%

Table 8 shows friction readings taken in the same area on the next day. The snow removal crews remained on duty through the night clearing and treating the roadways. Due to the light snow that kept falling throughout the morning, additional materials were applied. These readings were taken later that morning.

Table 8: Friction Values in Winter Conditions NB I35 Near MM 95 02/01/2002

Time of Day	Chemical Application Rate	Friction Value	Air Temperature (F)	Pavement Temperature (F)	Rel. Hum
08:56	(first run)	0.64	11.3	16.4	82%
09:48	40 gal/ln mi	0.70	13.2	21.0	79%
10:43	40 gal/ln mi	0.72	16.7	27.9	74%

The information in Table 8 indicates that the chemical applications maintain friction levels on the roadway surface.

Previous Field Testing

As was discussed in detail in the Phase III report, in May of 1999, the study team took the Highway Maintenance Concept Vehicle, mounted with the SALTAR unit, to Wallops Island, Virginia, to participate in a NASA-sponsored friction-testing workshop. The purpose of these tests was to collect data from the SALTAR, and then compare those data to an industry standard. The reasonableness of the data (goodness of fit test) collected by the SALTAR was then compared to several other friction measuring devices, including the ASTM E-274 skid trailer, the industry standard for pavement friction measurements. The SALTAR tests at Wallops Island, Virginia were conducted under the supervision of Dr. James C. Wambold, of CDRM, Inc., State College, Pennsylvania. Dr. Wambold assisted the concept vehicle project earlier in Phase II. Dr. Wambold holds a Ph.D. in mechanical engineering and is Professor Emeritus of Mechanical Engineering at Pennsylvania State University. Presently, he is president of CDRM, Inc., an engineering consulting firm.

Dr. Wambold provided the following analysis of the friction measurement tests at the Wallops Flight Center. As the workshop was held in May, the tests were conducted on wet pavement, as opposed to snow and ice conditions. The wet pavement still provided vital data for the SALTAR friction-measuring device.

These tests were to evaluate, from comparative data, the effect of surface type on wet friction levels, collected on grooved and smooth concrete and asphalt surfaces. Through these tests, the HMCV team hoped to obtain a better understanding of the SALTAR's performance under adverse weather conditions and acquiring friction measurements.

Investigation into the SALTAR showed that the computation done by Norsemeter should be somewhat speed sensitive; however, it was designed for speeds of plow and salt trucks and indeed at the 50 kph (32 mph) speed the SALTAR measured in the middle of the range of the rest of the devices. Furthermore, when the SALTAR results are plotted versus the E274 trailer at 30 km/h, both devices measure approximately the same friction values. Thus, it would be expected that at low speeds the SALTAR should give friction measurements within its design range. The results of the SALTAR tests on wet pavement are graphically displayed in Figure 19. The trend line was added to the trend between the SALTAR measurements and the ASTM E-274 skid trailer.

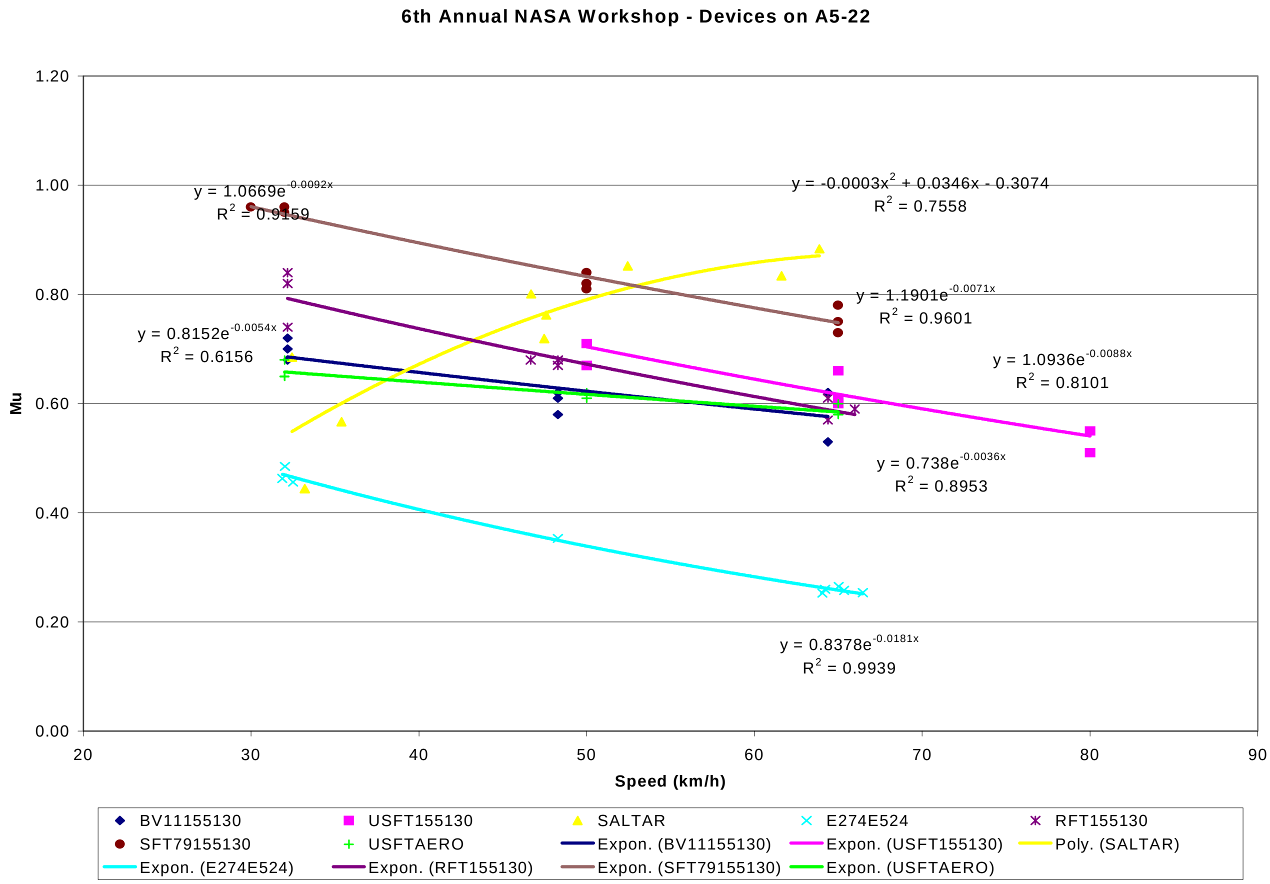

Figure 19: Results from Wallops Island Test

In these series of tests the SALTAR trend line shows an effect of friction increasing as speed increases. As the investigation showed, this increase in friction was due to inconsistent water film thickness between the tire and the road surface. Thus, the water film thickness decreased as the speed of the vehicle increased, creating more friction between the tire and the pavement surface. The other friction measuring devices indicated a decrease in friction as speed increased. Accordingly, the tests showed that the SALTAR does consistently measure friction; however, more testing was needed to specifically determine if the speed of the vehicle also played a factor in the "reverse" trend line. Figure 19 shows a comparison of the SALTAR test results to the other friction measuring devices participating in the tests at the Wallops Facility.

Field-Testing SALTAR at North Bay, Ontario

Because the Highway Maintenance Concept Vehicle study team needed to test the SALTAR in a winter environment, under controlled conditions, the HMCV study team participated in the Joint Winter Runway Friction Program in North Bay, Ontario, in January 2000.

North Bay Test Results

The SALTAR unit, mounted on the HMCV, was tested along with nine other ground friction–measuring devices during the Joint Winter Runway Friction Measurement Program.

Preliminary analysis revealed that the SALTAR was sensitive to extreme cold temperatures. When the pneumatic system was exposed to cold temperatures for a period of time, there was a delay in the lowering of the wheel to the road surface and holding the wheel on the surface. Once this delay was discovered, the down pressure was adjusted. Subsequent tests were run after the wheel was lowered and set in place for two minutes. The SALTAR performed as expected following these adjustments.

The testing at North Bay concluded that the SALTAR unit, while it shows promise, needs additional improvement in order to perform as expected in the harsh conditions that it is subject to in winter maintenance operations. Furthermore, it does appear that from the road test made after the down pressure load was increased that the system worked much better.

Conclusions and Recommendations

The SALTAR friction meter has been field tested in both controlled testing environments and in actual winter conditions operating on a snowplow through two winters. These tests have shown that the SALTAR is still very much a prototype device. However, it can establish friction levels, and it shows promise in measuring road friction under winter conditions. The brake system works according to specifications and the overall principal works well. However, further development is required and the following actions are recommended:

- The pneumatic system is still susceptible to extreme temperatures and requires full winterization to withstand the harsh climate that it is exposed to in winter maintenance operations.
- Further reliability must be added in future models to prevent failures.

One of the migrations that we made from Phase II to Phases III and IV was to record the friction data in levels and categories of friction, rather than the actual friction level (μ) as measured by the SALTAR. After two seasons of using this method, it has been determined that recording μ along with the friction level category is beneficial as well. The system should be adapted to record μ, so that μ can be integrated into winter maintenance strategies.

The use of friction data, however, is valuable for winter maintenance operations. Should a device be made that could be installed on a supervisor's truck, for example, then data could be collected from an entire district, rather than just one plow route. It is also conceivable that friction data could be included in level of service maintenance. For example, for states where maintenance is contracted out, friction data could be included in performance measures for level of service. Archiving the friction data would also be beneficial for analyzing the effectiveness of the winter maintenance activities following the snowstorms.

Using friction data in winter maintenance operations and decision-making is feasible. However, as has been depicted here with the HMCV, the task of obtaining repeatable, reliable, and cost-effective friction measurements has been difficult to date. But the potential for using winter friction measurements is promising. Scenarios are being developed to incorporate friction data measurements into maintenance decision support systems. Through the use of vehicles, such as the Highway Maintenance Concept Vehicle Mobile Platform, these friction data can be transmitted to the maintenance operations center for analysis. The supervisor then determines the course of action needed to treat the roadways, either applying more or reducing the amount of chemical being applied.

Another possibility is to use winter friction measurements to better inform the public of roadway conditions. Once winter friction levels are calculated they could be graphically displayed and transmitted via Advanced Traveler Information Systems (ATIS) for the traveling public to use to make their traveling decisions. Furthermore, a proper public educational campaign would have to accompany the dissemination of this information to inform the traveling public of the nature and behavior of the friction measurements.

Finally, we can incorporate friction measurements with other weather information such as the RWIS, and predictive forecasting models, such as FORETELL and CARS (Condition Acquisition and Reporting System). By incorporating roadway surface friction measurements into these models the maintenance vehicles can be dispatched to problem areas ahead of time in anticipation of the storm. Thus a potential problem area may be treated prior to a possible loss of friction. The use of roadway surface friction measurements has the potential to improve the level of service while reducing the cost of operations to the taxpayers.

CHAPTER 4: MOBILE FREEZING POINT DETECTION

This chapter documents the bench tests that were done prior to deployment of the Frensor freezing point detection system and the field tests during this past winter season. Testing the Frensor was one of the critical steps in evaluating the overall performance of the Highway Maintenance Concept Vehicle Project. In Phase IV field tests were performed with a mobile monitoring system for freezing point temperature that detects the temperature at which the materials on the road freeze. This process provides a possible method to improve both road maintenance and traffic safety.

The focus of this portion of the project has been to develop the monitoring system technically, to test the techniques in field use, and to see how to use the information.

The Highway Maintenance Concept Vehicle project team tested a Frensor unit manufactured by AeroTech-Telub of Sweden. The tests produced the following observations:

- In order to improve the monitoring process, a more efficient method of cleaning the sensor is required.
- The system requires an interface for automatic monitoring. Presently, we had to connect a personal computer the system and collect data.

Background

In 2001 the project installed a Frensor, donated from Aero Tech Telub, with the purpose of using the Frensor to monitor freezing point temperatures in the splash area from a wet road surface. One of the desires was that, in the future, the freezing point information would enable the operator to adjust the material application rate on the vehicle. During testing the Frensor was placed behind the driver's side front wheel to capture the road sleet and slush.

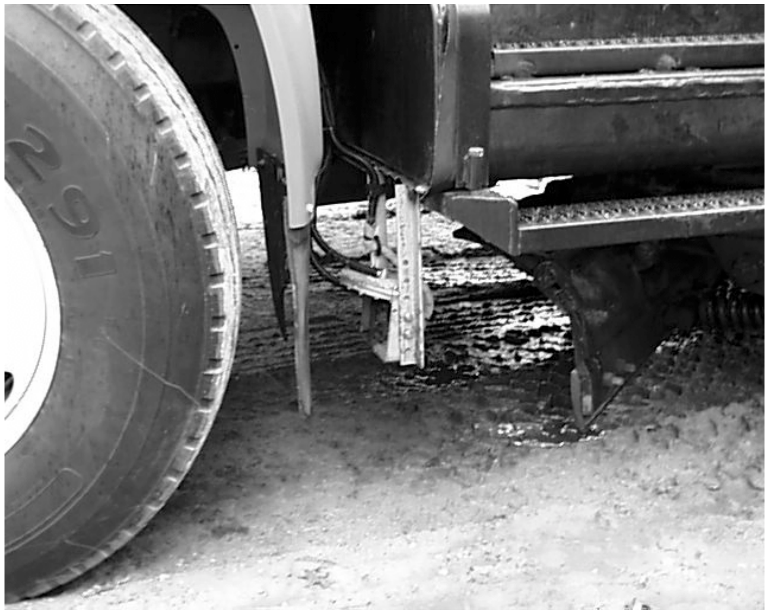

Figure 20: Frensor device mounted on HMCV

Figure 20 shows the Frensor that was installed on the Highway Maintenance Concept Vehicle. Data were collected from the Frensor during actual snow and ice control operations and then those data were compared to the local RWIS station.

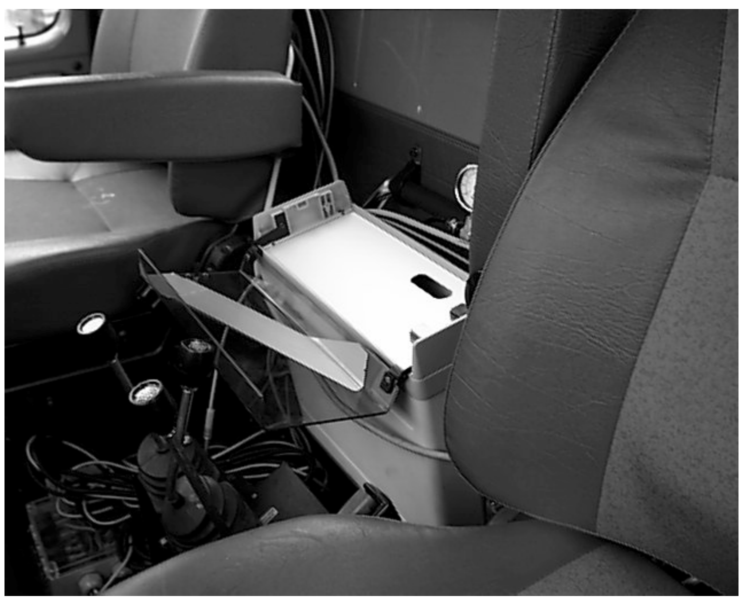

Figure 21: Frensor control computer

Figure 21 shows the unit's control computer that was placed in the HMCV. The computer calculates the freezing point gathered by the sensor outside the vehicle.

Purpose and goal

The purpose of this phase of the project was to field test the Frensor freezing point temperature sensor. An anticipated result was to be able to validate the potential of mobile freezing point temperature detection.

Another important expected result is the increased knowledge of road chemical effects, for example, how long a does a chemical hold when spread with a certain dosage, and how do different situations and local situations affect freezing point temperature detection.

Principal of Freezing Point

When water freezes a crystalline structure is formed. Simultaneously energy is dissipated as what can be called "ice formation heating." Figure 22 displays a temperature vs. time curve for water that is being cooled down. At the freezing point temperature the curve show a temporary increase, a "knee," developed from the dissipated energy.
The water is cooler than the freezing point depending on how clean it is, before it freezes. The freezing point temperature is lowered by 0.7° C / % of NaCl if salt is added to the water and ice.

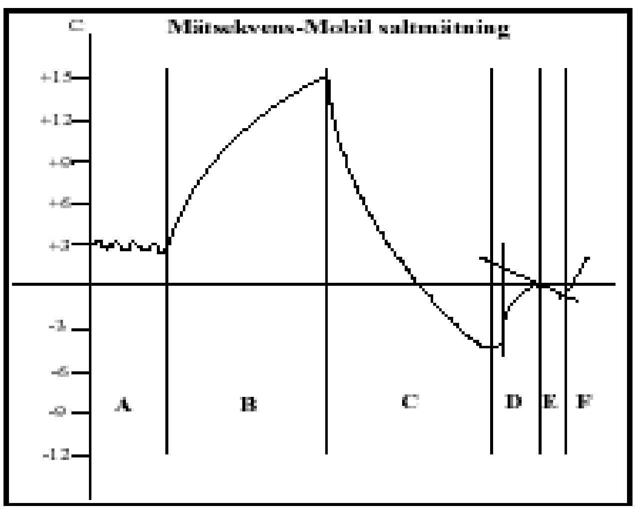

Figure 22: Measuring sequence mobile salt monitoring (obtained from AeroTech-Telub)

A = Start phase
B/F = Heating phase
C = Cooling phase
D = Ice build up
E=Detection

The system measures the eutectic point of the mixture. A simplified way of explaining this process is by example: If you ever made frozen juice bars in the home freezer you have probably observed some simple facts about melting and crystallization. A half-frozen juice bar consists of a mix of ice crystals and concentrated juice. Many mixtures of materials, when they solidify, crystallize into two distinct materials. As they solidify, first one component forms, then the other. A system of this sort is called a *simple eutectic*.

Technical Description of Monitoring System

The monitoring system uses the Frensor to monitor freezing point temperatures. The system is mounted behind each front wheel. When the road is damp or moist, road surface spray is generated on the Frensors.

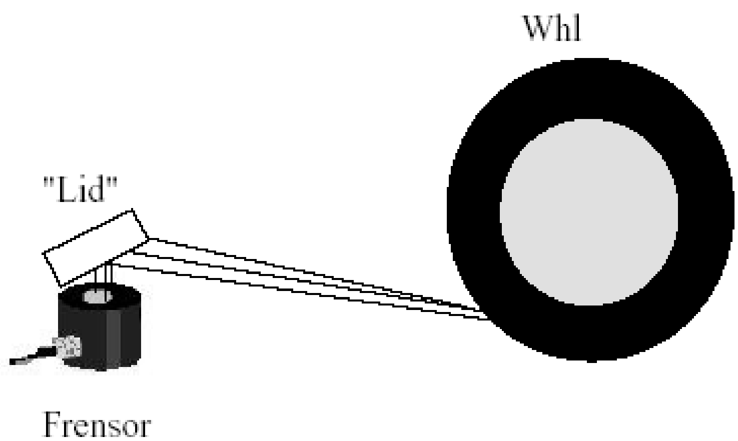

Figure 23: Frensor capturing liquid

When measuring, the “lid” (see Figure 23) is put over the surface of the Frensor so that a “new” liquid will not disturb the cycle. The “lid” is made of rubber and is controlled by the Frensor electronics and by two pneumatic relays.

In order to prepare the Frensor for the next measuring cycle, air is blown over the sensors to get rid of old moisture. This is controlled from the Frensor electronics. The method (Patent pending) to collect the spray behind a front wheel where a Frensor is placed has been tested. (See Figure 24.)

Figure 24 on the next page shows a Frensor, placed behind a front wheel of a test vehicle, collecting the splash and spray from the road surface. From this sample of material from the roadway, the freezing point of the material is calculated.

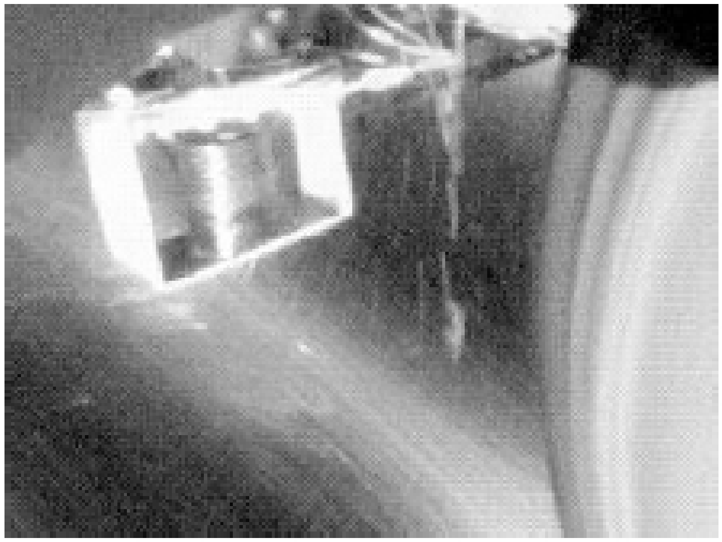

Figure 24: Spray from tire (photograph courtesy of Aero-Tech-Telub)

Air temperature and road surface temperature are detected with a PT-100 temperature sensor and an infrared (IR) sensor, feeding directly to the Frensor computer. These devices are independent of other sensors on the vehicle. The air temperature is used to determine the offset level for the Frensor measuring. For communication, presentation, and logging data, a PC with Windows was used.

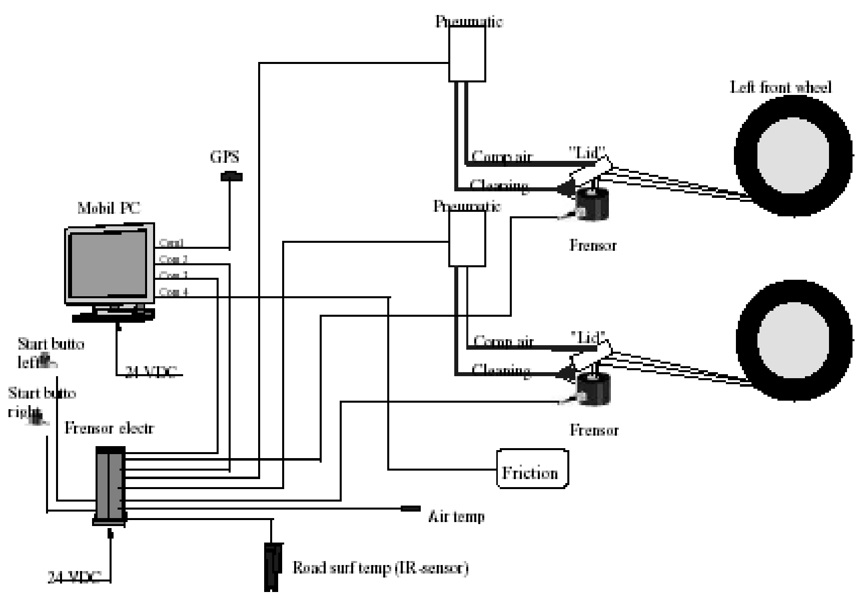

Figure 25: Monitoring System

Figure 25 shows the Frensor monitoring system. The figure above describes a system for two Frensors on one vehicle. The system is capable of monitoring four Frensors at a time. When in the manual monitoring mode, the driver/operator pushes a control button for the respective side (left or right) to begin the measurement cycle. The data are then logged on the PC or an onboard computer.

The time for a monitoring cycle varies from 10–60 seconds and depends on air temperature and the liquid freezing point temperature. The characteristics are shown on the PC display.

Bench Testing

The lab tests were conducted in the Iowa DOT Materials Laboratory in order to have a controlled environment to the extent possible. Output was obtained from the Frensor and collected. Photographic evidence was collected to document the test setup and execution.

Testing concentrated on measurements that ultimately determined the success or failure of a tested technological approach to chemical freezing point calculation. This phase of the concept vehicle project performed field tests on the Frensor and stored and analyzed the data.

AeroTech-Telub suggested the test methods that were used:

- The Frensor unit was placed in a large freezer (see Figure 26).
- Ordinary tap water was used for the bench test as it has a known freezing point temperature (32° F, 0° C).
- Later tests included using water with a known quantity of salt brine added to test the determination of the freezing point of the salt brine solution.
- A PC with a Windows interface was used for recording and storing data (see Figure 27).

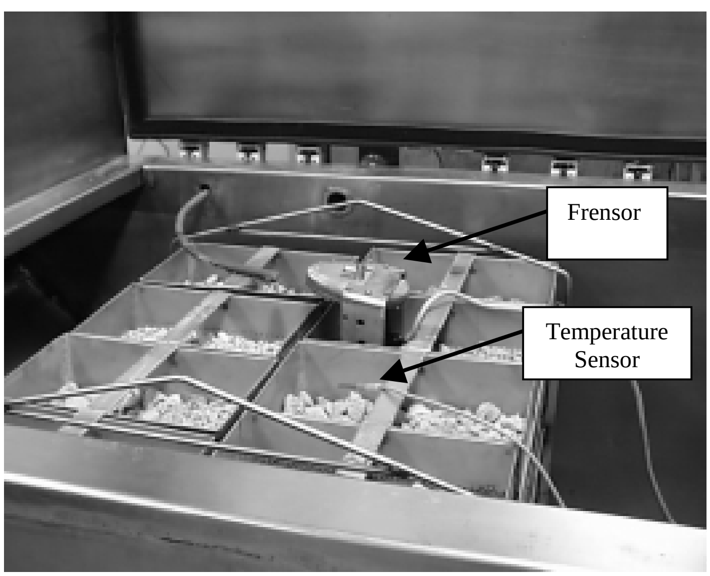

Figure 26: Frensor sensor placed in freezer

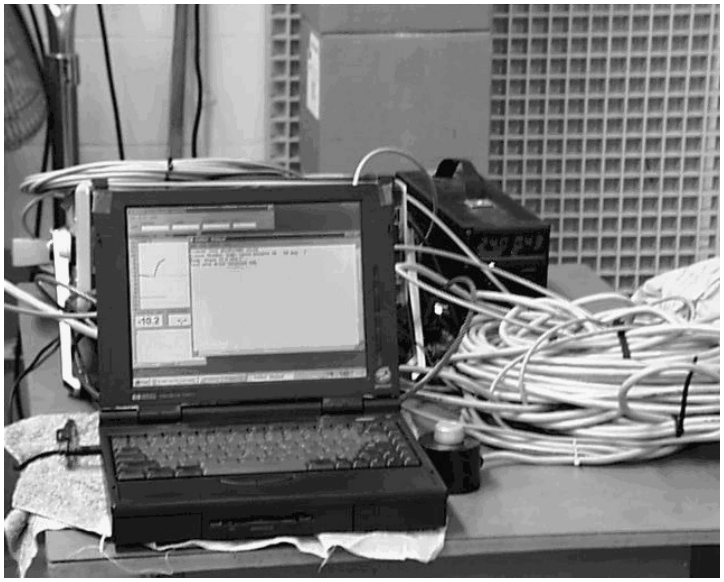

Figure 27: Bench Test Equipment

Approximately 30 bench tests of the Frensor were conducted prior to placing it on the vehicle. These calibration tests were conducted with the aid of Aero Tech-Telub. When the analysis was completed, the data were forwarded to Aero Tech-Telub for their input. They offered recommendations to complete the tests.

Examples of monitoring data

Below are examples of data received from the system. (All data are not shown here). From this it should be possible to create a salt profile to be used for road maintenance. The number of detected freezing points shows a success rate of 85% from the driver's side front wheel. (See Figure 28)

The data are collected in degrees Celsius. The first column is the sensor number, followed by the freezing point temperature, followed by the surface temperature. The data that are received from the Frensor are displayed in a text file. As the sensor calculates the freezing point of the mixture, the program then displays the freezing point on the computer screen (See Figure 31). The text files display numbers only, the decimal points must be added. For example, under the column header "Freeze Point" –38 is actually –3.8 degrees C. Under the column header "Surface Temp." the temperature is actually –2.5 degrees C. The column headers were also added for this report. The text file does not contain any headers.

Sample Data from Calibration Tests

```
status
Sensor 1  Ok
Sensor 2  Ok
Sensor 3  Ok
Sensor 4  Ok
```

Sensor Number	**Freeze Point**	**Surface Temp**	
#M1	34	-25	
#M1	-38	-25	
#M1	-39	-25	
#M1	-42	-25	
#M1	-43	-25	
#M1	-44	-25	
#M1	-45	-25	
#M1	-47	-25	
#M1	-48	-25	
#M1	-49	-25	
#M1	-49	-25	
#M1	-51	-25	
#M1	-51	-25	
#M1	-52	-25	
#M1	-53	-25	
#M1	-53	-25	
#M1	-55	-25	
#M1	-55	-25	
#M1	-56	-25	
#M1	-56	-25	
#M1	-57	-25	
#M1	-58	-25	
#M1	-58	-25	
#M1	-59	-25	
#M1	-30	-25	
#M1	-15	-25	
#M1	-10	-25	
#M1	-6	-25	
#M1	-4	-25	
#M1	-5	-25	
#M1	-4	-25	
#M1	-5	-25	
#M1	-5	-25	
#R1	-5	46	01015 170
#M1	-4	-25	
R1	-5	46	(This is the freezing point at -0.5C)
#M1	12	-25	
#M1	16	-25	
#M1	21	-25	
#M1	23	-25	
#M1	26	-25	
#M1	28	-25	
#M1	29	-25	
#M1	30	-25	
#M1	34	-25	
#M1	34	-25	
#M1	37	-25	
#M1	39	-25	
#M1	41	-25	

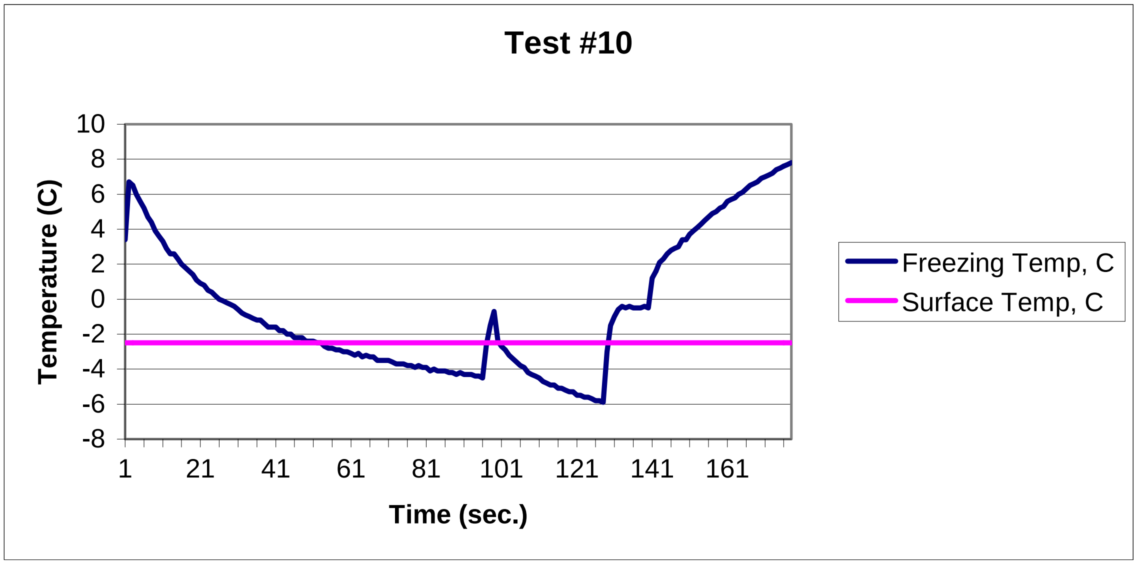

Figure 28: Graph of Calibration Test

The graph above illustrates the calibration test. The light colored line shows the constant surface temperature. The dark line indicates the calculation of the freezing point temperature of the mixture. At the "knee" in the curve, indicated the freezing point temperature.

Comparison with manual road condition monitoring

The mobile Frensor was compared to the temperatures obtained from the RWIS station near Ankeny. Figure 29 shows samples taken on March 2, 2002. The top line is pavement temperature, the middle line shows air temperature, and the bottom line is the freeze point temperature as indicated by the Frensor. On this date, the freeze point is consistently lower than the air or pavement temperature.

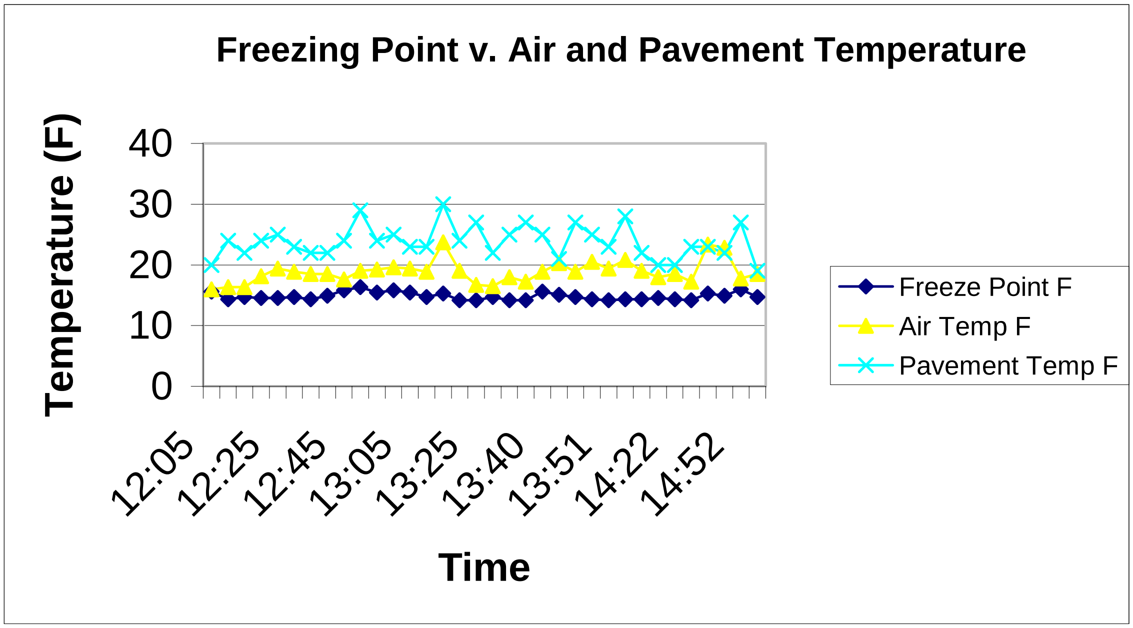

Figure 29: Comparison to RWIS, March 2, 2002

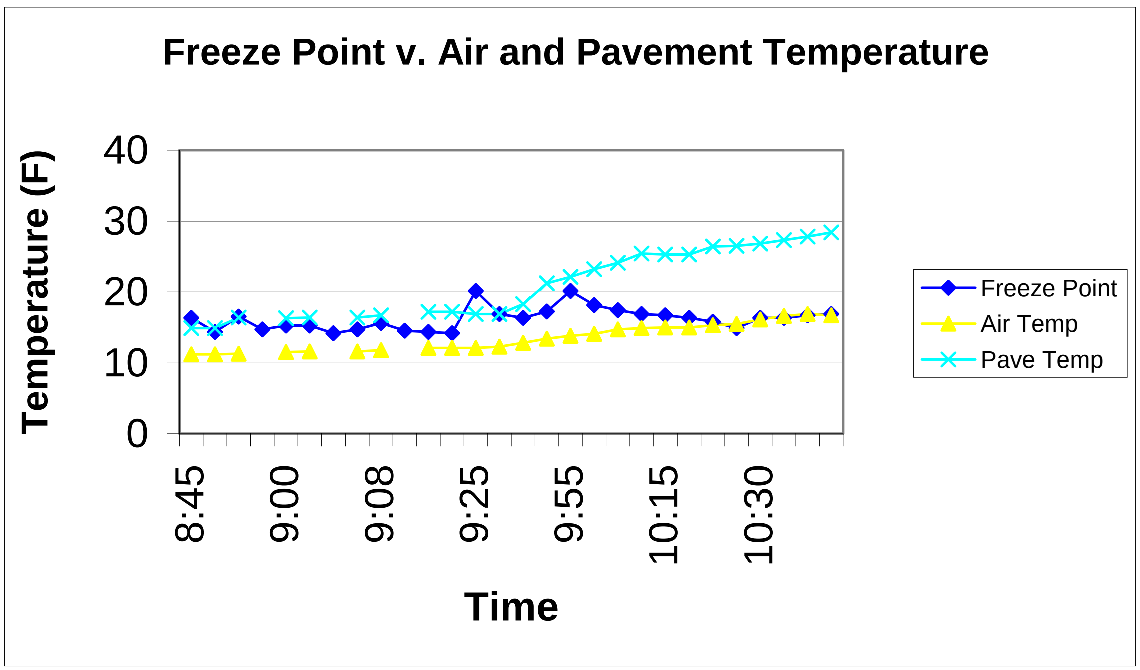

Figure 30: Comparison to RWIS, February 1, 2002

The mobile Frensor was compared to the temperatures obtained from the RWIS station near Ankeny. Figure 30 shows samples taken on February 1, 2002. Again, the top line is pavement temperature, the middle line shows air temperature, and the bottom line is the freezing point temperature as indicated by the Frensor. On this date, the graph shows the pavement temperature rising as daylight progresses. The freeze point is consistently lower than the pavement temperature but is higher than air temperature early in the day. The freeze point and air temperature converge later in the day. During the time that these data were collected, the crews were out treating the pavement with salt brine solution. The conclusions that were made from this comparison is that the freezing point temperature sinks and correlates with the salinity.

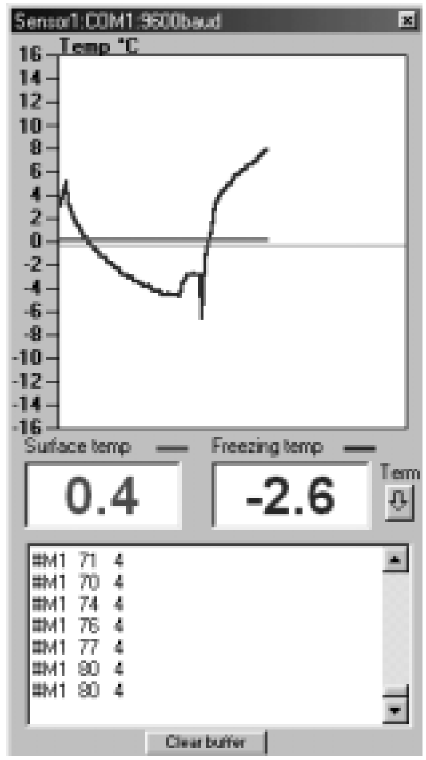

Figure 31: Graph Data from February 1, 2002 as Recorded on Computer. Taken near MM 95 in Ankeny Iowa RWIS Station

Figure 31 is a screen shot of the graph that is displayed on the monitoring computer. The graph indicates a surface temperature of 0.4 degrees C, and the freezing temperature of –2.6 degrees C.

Conclusions

The Frensor has shown to be a reasonable sensor for freezing point measurement and has a potential for continuation on the project. At normal sensor maintenance intervals the system is reliable; however the Frensor sometimes has to be cleaned manually depending on the conditions. When the cycle time to get freezing points goes beyond the typical cycle time of one to two minutes, the operator then knows that there are “dirty” sensors that need to be cleaned. Several times during the data collection periods, the sensor was caked with ice and debris that had to be manually removed. Once the sensor was cleaned, the system worked reliably.

At this point not enough data have been collected to guarantee the repeated accuracy for the system, but the general opinion from all involved is that the system is reliable as can be seen in the graphs. However, if this device is to be used during normal maintenance operations, a plow operator cannot be expected to clean the sensor to collect these data. An automatic cleaning device should be investigated along with an automatic control to alert the operator of a dirty sensor.

CHAPTER 5: COMMUNICATIONS

This chapter documents the evolution in the communications portion of the project, the lab testing of the equipment, and final deployment and use of the system. One of the important aspects of the HMCV project was to develop the Automated Vehicle Location (AVL) system, with commercial–off–the–shelf (COTS) technology. In Phase III of the project, the HMCV had a global positioning system (GPS) but not AVL.

System Description

The need for precise position is critical for precision application of deicing chemicals. The IDA Trakit system was chosen to be included in Phase IV of the project. The IDA Trakit system is fully compatible with the Monroe Truck and Raven system components that are currently on the HMCV. The system consists of the following components:

AMS-200 (Application Management System) Console

The AMS-200 console is manufactured by Raven Industries. This console is a small computer that functions as the central data gathering point, including location. The collected data are stored on a PCMCIA card and are transmitted in real time to a base computer. The PCMCIA card also holds the application software for the AMS-200 console.

Waypoint Switchbox

The waypoint switchbox connects directly to AMS-200 console. Each switch has three positions: "off", "on", and "On Momentary." In the "on momentary" position, the switch will return to the off position when released.

Each switch has a preset definition within the AMS-200 console. Definitions include such items as "bridge," "guardrail repair," and "driveway." When the vehicle operator sees one of these conditions on his route, he moves the related switch to the "on momentary" position and then immediately releases it. The geographical location, or "waypoint" of the condition is recorded on the AMS-200 and PCMCIA card.

The waypoint switches can also be used to create boundaries around selected areas. The driver moves the vehicle to a predetermined location, moves the related switch to the "on" position, and then drives a predetermined route. When the vehicle returns to the starting point, the driver returns the switch to the "off" position. A map of the boundaries will be recorded on the data card.

Currently the waypoints can be mapped only with geographical information system (GIS) software such as ArcView. The waypoints do not appear on the Trakit software or maps.

Device Position Sensors

The waypoint switchbox is equipped with inputs for position sensors. On a plow truck these inputs are used to detect and report the positions of the front plow, underbody blade, and wing plows. The inputs are discrete (on/off) signals from devices such as proximity, mercury, or lever activated snap switches. The switches are activated when the plow, scraper, or wing moves to the operating position. The device positions can be seen in real time with the Trakit software and are stored on the data card.

DCS–710 Console

The DCS–710 spreader console is a ground speed spreader controller with data logging and output capabilities. The DCS–710 console is manufactured by Raven Industries and is compatible with the AMS–200 console.

The DCS–710spreader console contains calibration data for the material spreader system. This includes pre-set material application rates, such as pounds per salt per lane mile. Based on road speed and the selected application rates, the console records the amount of material used and stores it within the console and on the data card. The operating status of the DCS–710 can be seen in real time with the Trakit software and is stored on the data card.

Temperature Sensor

The temperature sensor detects both outside ambient temperature and pavement temperature. The vehicle operator and supervisors use this information to determine when icing may occur. The temperature readings are displayed on the DCS-710 console. The ambient air and pavement temperatures can be seen in real time with the Trakit Software and are stored on the data card.

Trakit 25 Interface Unit

The Trakit 25 is the GPS receiver and data storage buffer. It interfaces with the vehicle data radio to provide a location signal to the base unit. The Trakit 25 box is connected to the data radio using a DB-15 computer cable that is custom wired to the radio inputs and outputs. The Trakit is powered and grounded through the DB-15 cable.

The Trakit 25 box is installed in each vehicle that is using the AVL system. In our case it is the HMCV. This box contains the vehicle identifier with a group number and a vehicle number. This is the identifier that the Trakit base computer looks for when it calls a particular vehicle. The Trakit 25 transfers data to the in-vehicle data radio.

Base Station Computer Specifications (minimum requirements):

- Pentium 200 processor
- 32 meg RAM
- 2-meg video board

- 2-gig hard drive
- CD ROM drive
- 3.5" floppy drive
- PCMCIA card reader
- 19" color monitor
- Windows 95 or NT

Also, allow for 100 meg of hard drive space for Trakit application, plus additional space for storing data and reports. A serial port is required for Trakit communication cable.

Data Radios

The Monroe Truck Equipment (MTE)–IDA Corp. GPS/AVL system requires a dedicated data radio at the base station and a dedicated digital radio in each vehicle. The reason for the dedicated radio is to prevent conflict with normal voice communications. The data radios may operate on the same frequency as normal voice radios or may have their own dedicated frequency.

A data radio is a two-way receiver transmitter that has the ability to convert digital information to an analog signal for transmission. The radio is programmable and has outputs to supply power and ground to other devices. Each Trakit 25 interface device is powered and grounded by its data radio.

The HMCV used a Motorola ASTRO digital radio for this application.

Trakit Software

The Trakit software is stored on the base computer. The software allows real time viewing of the vehicle location and the status of spreader functions. The software can track and view one vehicle or multiple vehicles in a fleet. The Trakit software will record a "trip file" each time the monitoring function is started and stopped. This trip report can be played back to show where the vehicle traveled during that trip.

Although the Trakit software has a data export function, it is primarily a real-time viewer and not a report generation software. The data from the vehicle can be processed further with GIS software. Figure 32, on the next page, shows a "snapshot" of the HMCV on its route. The icon shows the HMCV moving north on I35. The headers indicate date, time, speed, and heading. At the bottom of the picture there are its coordinates in latitude and longitude.

The AVL system was installed in December 2001**.** Once the unit was installed and the (internet protocol) IP addresses were properly identified, the system worked well.

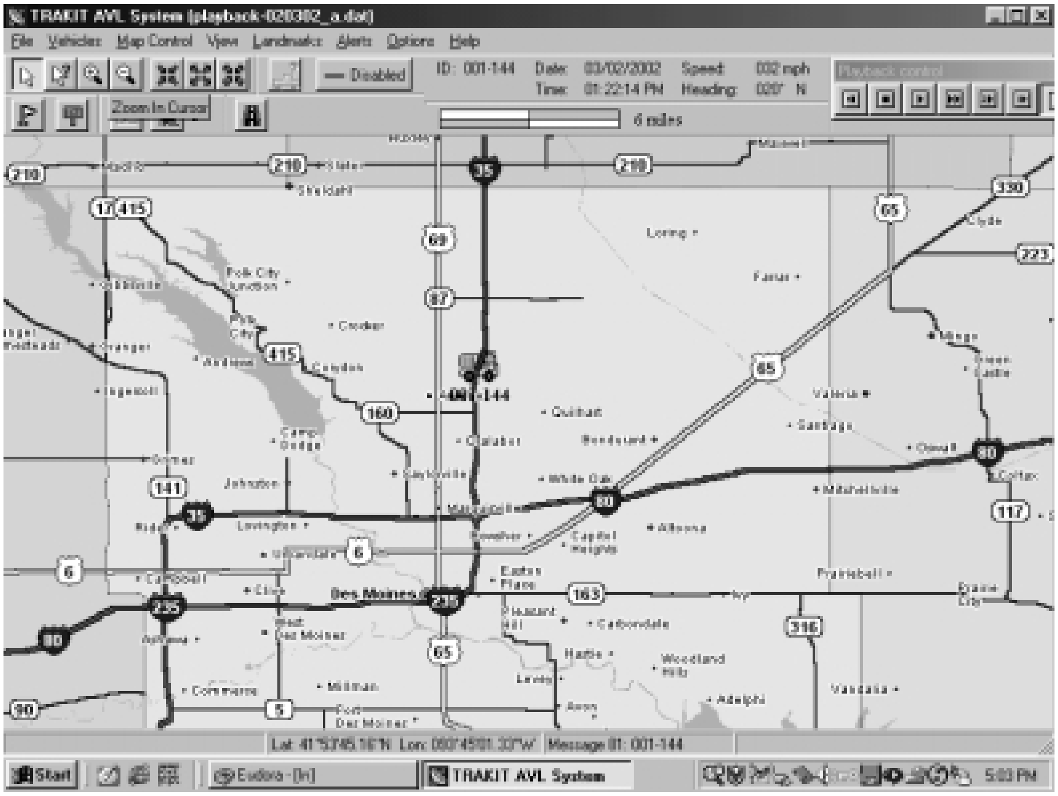

Figure 32: Sample Trakit AVL Map

Laboratory Testing of the System

Prior to the installation of the AVL system on the HMCV, the system was lab tested. Due to the critical nature of the current Iowa DOT radio communications system, it was felt that any system that would be sharing communications with the current radio system be tested in a controlled setting prior to deployment. We tested the system at the Motorola facility in Schaumburg, Illinois on September 24 and 25, 2001.

This document is intended to serve as a certificate of verification for the IDA's ASTRO SLIP client application (firmware) running on the IDA's Trakit-25 interface box. This verification certificate is based on the successful completion of the verified tests that were completed by IDA during their visit to the Motorola Integrated Data Solutions Laboratory (iDSL). Those tests are listed in the "Verified Tests" section of this document. This verification covers only the interaction of the IDA's ASTRO SLIP client application with the Motorola's conventional ASTRO networks. A description of the ASTRO system used during this verification is included in the "System Setup" section of this document. This verification does not focused on the features, functionality, or operation of the Trakit-25 with components that are not part of the ASTRO system. In addition, this verification does not focus on the features, functionality, or operation of the IDA's server and mapping application.

System Setup

- Conventional ASTRO 3.0 system with the following components:
  - WNG:
    - AIX version: 4.3
    - Software Version: R02.03.28
  - RNC3000:
    - Boot ROM Version: R03.01.01
    - Software Version: R04.00.04
  - DIU3000:
    - Application Software Version: DIUSR04.00-5.09
    - Parameter Version #: 98
    - DSP1 Software Version: 03.10
  - UHF ASTRO Quantar Repeater:
    - Control: R020.10.014
    - Wireline: R020.09.809
    - Exciter: B016.07.001
  - UHF XTS3000 Portable Radio:
    - Host: R07.01.01
    - DSP: N08.00.00
- IDA's Trakit-25 interface box including firmware for ASTRO SLIP client application.
- IDA's UDP Server and Mapping Application.

Verified Tests

- Inbound Messaging.
- Outbound Messaging.
- Disconnection of RS-232 cable from the radio while transferring.
- Interrupting data transfer with voice conversation.
- Interrupting data transfer by powering off the radio.

Note: During this verification two issues (not related to how the application interacts with the ASTRO system) arose which required recompiling both the server and the client applications. Fixes for those issues were also tested and were proved to resolve the issues. Those issues are

- Clients returns A2 (unsupported message) to server when the server polls the client for an update.
- Server does not display the correct day and time when it runs a buffer that it has downloaded from the client.

Figure 33 shows the data path from the vehicle to the tower, through the digital interface and the radio network controller, ultimately to the desk side. At the desk side, the data can be processed for analysis. This analysis can aid management to improve winter maintenance operations and assist the agency in implementing service plans to meet the needs of the traveling public.

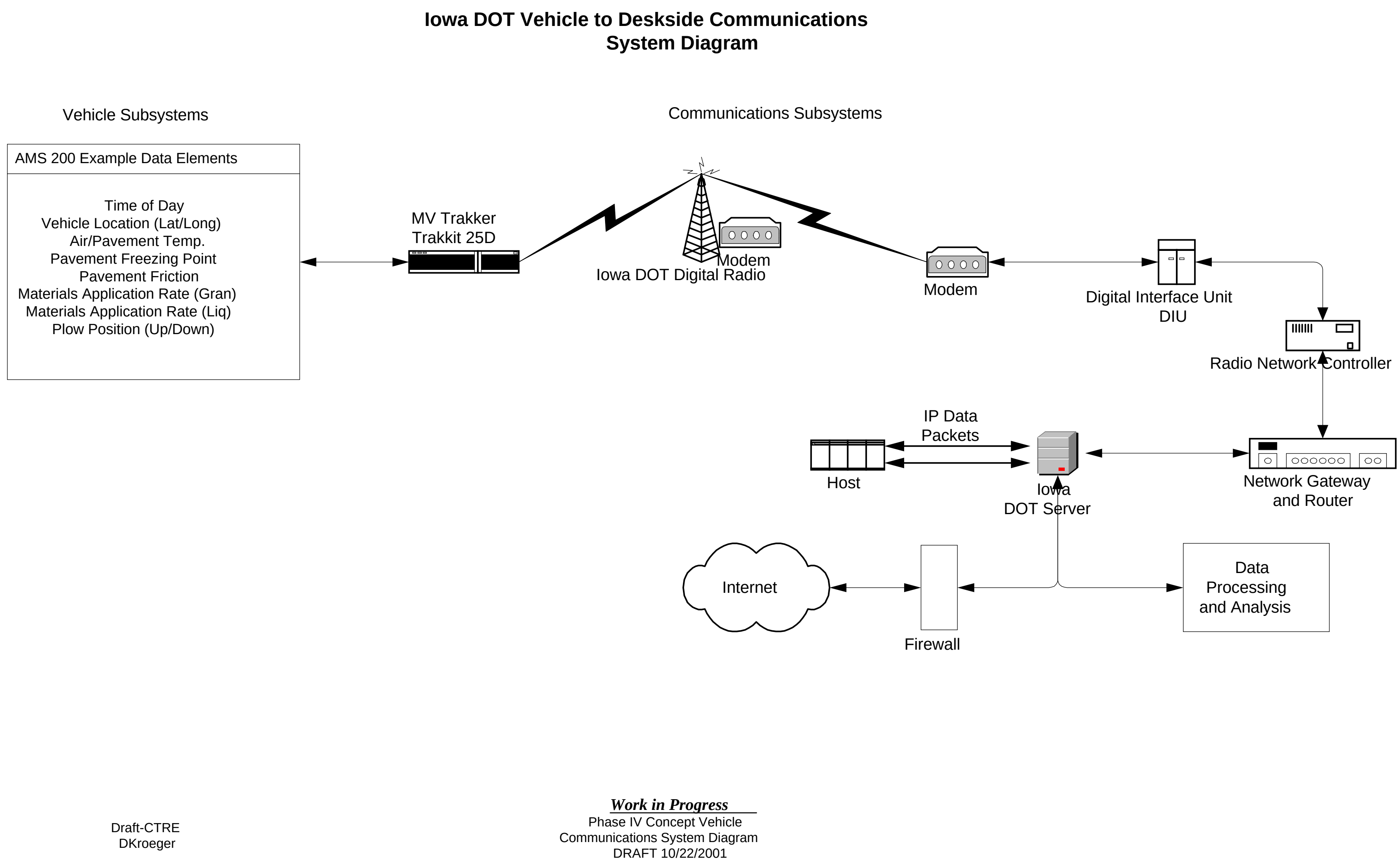

Figure 33: Vehicle to Desk side Communications System Diagram

Cost of AVL

The costs of the AVL system include the development of the software and testing at the Motorola Labs. Now that the development has been completed the costs of expanding the AVL are for additional equipment. See Tables 9 and 10 for cost breakdowns.

Table 9: IDA Trakit Hardware and Software Installation Costs

Components	**Costs**
Trakit 25 Interface Box	$1,584.00
Data Cables, Computer Cables, etc.	$184.00
Trakit USA 5 seat software, can be expanded to 10 seat	$2,895.00
Total	$4,663.00

Table 10: Total Development, Testing, and Hardware Costs

Components	**Costs**
Software Development Share	$4,000.00
Motorola Lab Technicians	$4,500.00
IDA Technicians	$4,100.00
Hardware/Software	$4,663.00
Total	$17,263.00

The software development from IDA Corp. totaled $16,000.00. This investment was shared among IDA, Monroe Truck Equipment, and Iowa DOT. The software development was to match the communications software to the Iowa DOT radio network, specifically, to match the firmware to SLIP protocol-Project 25 ASTRO digital radio.

The development costs include some initial programming and engineering test time. The project partners shared the $16,000 investment:

IDA Corp.	$ 8,000.00
Monroe Truck Equipment	$ 4,000.00
Iowa DOT	$ 4,000.00
Total	$ 16,000.00

Because the Iowa State Patrol and Iowa DOT Motor Vehicle Enforcement division use the radio system, the communications team wanted the AVL communications to be tested at the Motorola Laboratory prior to installing the system on the radio network. The radio carries vital public safety functions, and communications wanted assurance that this new system was compatible with the Iowa DOT radio network.

One week of lab time was obtained from the Motorola iDSL laboratory in Schaumburg, Illinois. The original price was $9,000.00 for the lab facilities and technician time; however, Motorola donated the laboratory facility for the tests.

$4,500.00 for Motorola Technicians
$4,100.00 for IDA technicians, travel, lodging, time

Depending on the system, some areas may not need to test the communications system such as Iowa DOT has done. If the radio network does not have the public safety dimension, then the additional tests that were conducted at Motorola Lab would not have to be done. The Motorola lab tests were viewed as an insurance policy against possibly damaging the Iowa Radio network.

There are numerous commercial off-the-shelf (COTS) AVL systems that don't include the additional tests.

Conclusions

The system was successfully lab tested in September 2001. It was then deployed in December 2001 and used through the rest of the season. The operator and supervisor were interviewed and both stated favorably the use of AVL tracking.

Communications between dispatcher and operator are critical during snow and ice removal operations. Operators call in all types of information, including cars in the ditch, obstacles on the roadway, areas that have been plowed, areas in which they need assistance, etc. Presently, these "status reports" are done by voice communications, somewhat inefficiently. With a fully functional AVL system, the supervisor can determine the areas that have been plowed, where the vehicle is, and whether assistance is needed.

If a maintenance fleet is equipped with AVL, a supervisor can use dynamic dispatching in deploying the fleet. With AVL the supervisor can view several vehicles at a time, then if an area requires additional vehicles to clear the roadway, the supervisor can identify and dispatch those vehicles closest to problem area with a minimum of radio chatter.

While the HMCV was the only vehicle equipped with AVL, the system has shown promise for wide spread application.

CHAPTER 6: DESK SIDE SOFTWARE

An onboard computer integrates the various technologies and collects a multitude of data when the HMCV is in operation. To enable decision-making based on these data, prototype software applications were developed and evaluated as part of Phase IV of the concept vehicle project. This chapter describes the mobile and desk side systems relevant to the development and operation of these software applications.

This chapter begins by describing the conceptual architecture of the system and its high-level components. Each component is described in detail in subsequent sections. Detailed discussion begins by describing the flow of mobile system data into desk side systems. Data are stored in a relational database supplying an object-oriented software model of the concept vehicle with data. The attributes and operations implemented by the object-oriented model are described. Finally, several applications referencing the object-oriented model and currently under development are illustrated.

Conceptual Overview

Conceptually, the desk side software is sub-divided into six logical components (Figure 34). The Concept Vehicle and its mobile systems form the base of the conceptual model. See the Phase III final report for documentation describing mobile systems hardware and software.

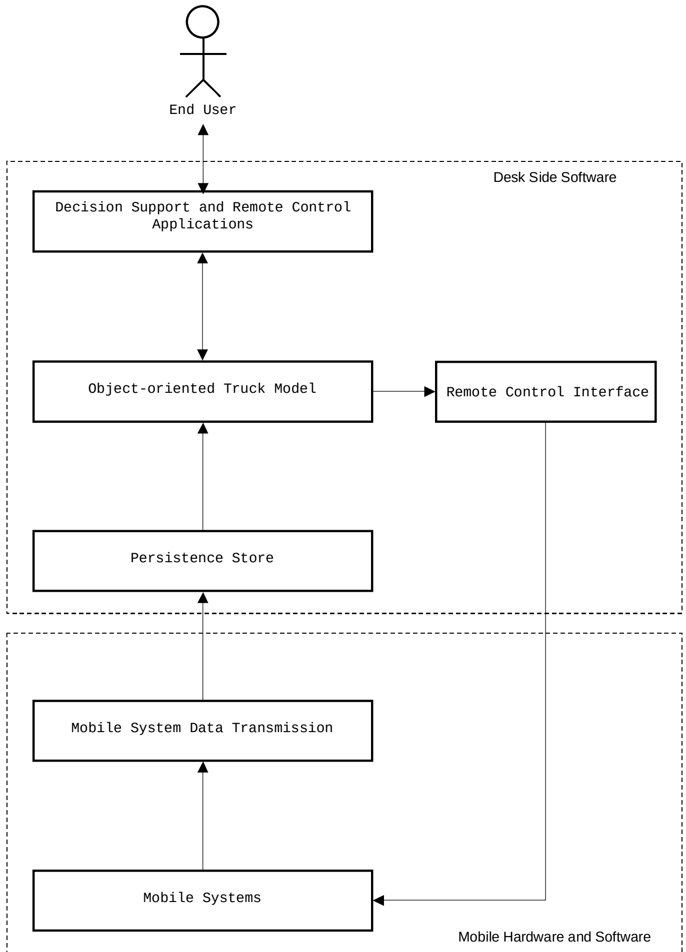

Figure 34: Software Conceptual Architecture

Next in the hierarchy are the Mobile System Data. Section I describes the data elements and the transmission mechanisms supporting the transfer of data into the desk side software systems.

The received Mobile System Data are stored by the components of the Persistence Store. The Persistence Store consists of relational database software and modules controlling the automated storage and retrieval of Mobile System Data. Details of this component are described in Section II.

To facilitate software reusability, scalability, and maintainability, all end-user applications are built around a common object-oriented model of the concept vehicle. This model is described in detail in section IIIa of this chapter.

The Object-Oriented Truck Model supports direct control of the Concept Vehicle Mobile Systems through a software implemented Remote Control Interface. Details of this component are discussed in Section IIIb.

Finally, the end user interacts with all desk-side software through individual Decision Support and Remote Control Applications developed around the Object-Oriented Truck Model. Several analysis and reporting tools are currently under development and are presented in Section IV.

Section I: Mobile System Data

The concept vehicle mobile platform consists of multiple active sensors collecting and recording system data at 2-second intervals. The collected mobile system data follow two paths when flowing into desk side software systems (see Figure 35). The data can be stored on PCMCIA media by the mobile system controller, or transmitted via wireless network directly to desk side systems.

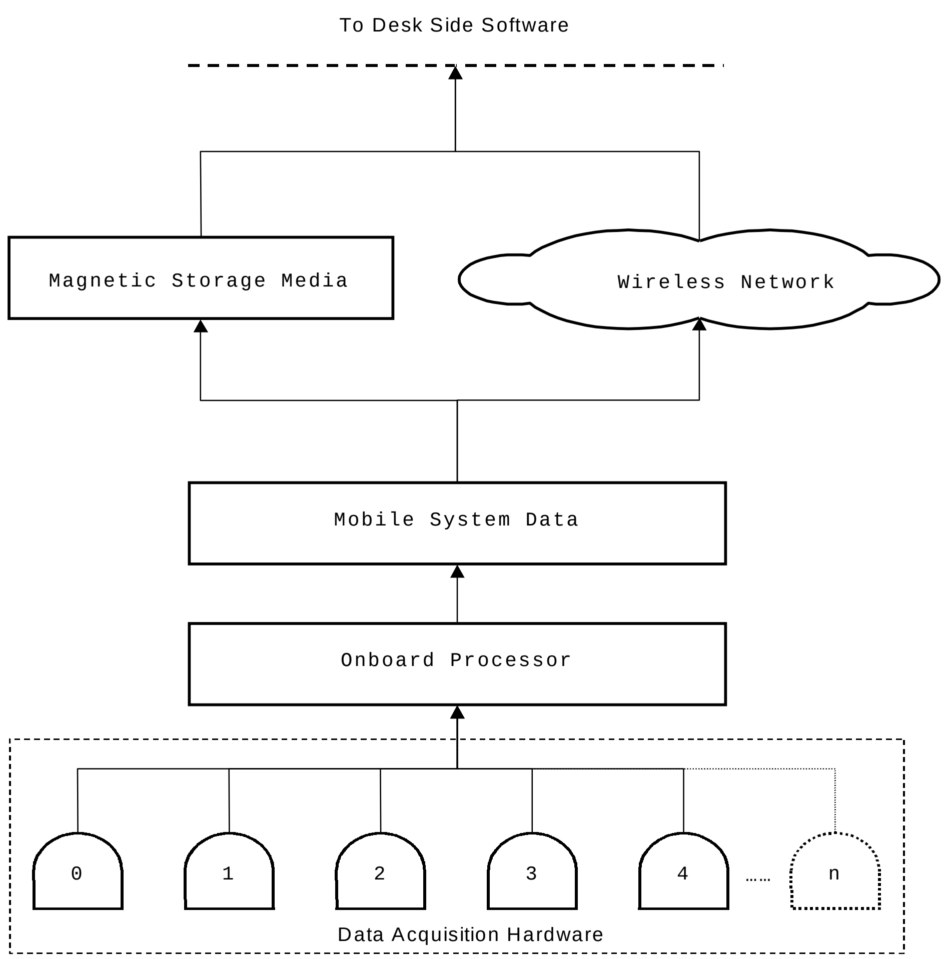

Figure 35: Mobile System Data – Conceptual Architecture

Section II: Persistence Store

The data collected from the concept vehicle mobile systems are staged for persistent storage in a relational database. The relational database serves as the central access point for analysis, reporting, and remote control applications. Architecturally, relational database software provides a layer of indirection separating high-level end user applications from low-level data collection functions. This prevents mobile system upgrades or vendor changes from affecting analysis, reporting, or remote control applications. Any changes would be localized to rewriting only data processing logic mapping mobile system data into relational database tables (Figure 36).

Microsoft Access was selected as the relational database software supporting the first implementation of the desk side software described by this document. Staged data are input into the database software by data processing logic. Currently, disparities exist between data stored on the PCMCIA media and the data transmitted via wireless network. To rectify this, separate data processing logic was developed for PCMCIA and wireless data formats.

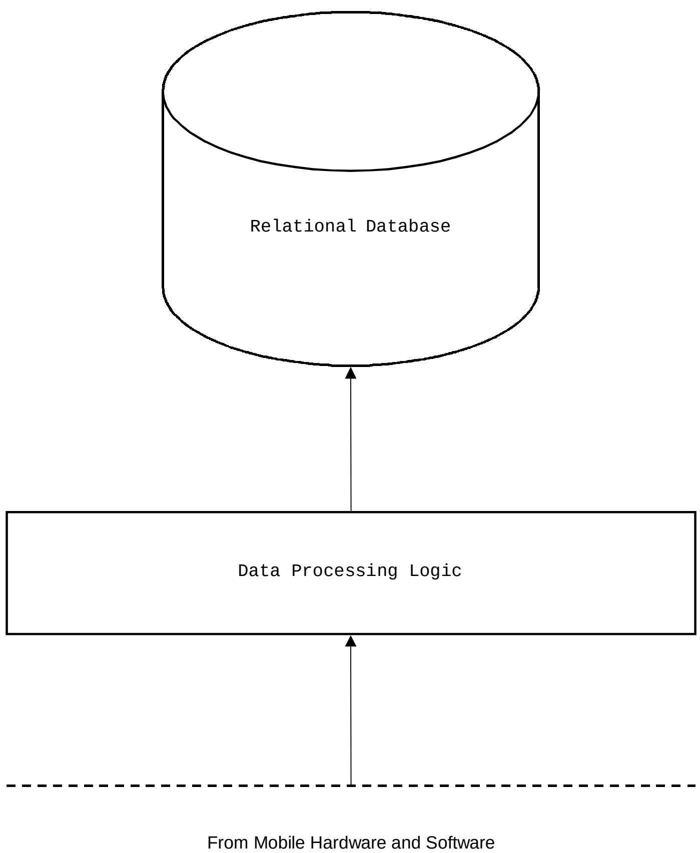

Figure 36: Persistence Store – Conceptual Architecture

Section IIIa: The Object Oriented Model

As part of a software development methodology, desk side software is modeled in an object oriented modeling language, and then implemented in a visual development language. The use of an object–oriented model has the following objectives:

- Support multiple implementation languages
- Provide maximum reusability of system software artifacts
- Support many display and reporting alternatives

The model of system architecture is separate from any implementation language. This model is described and documented using Unified Modeling Language (UML) and provides a blueprint for recreating system objects using any development language able to implement object-oriented structures. In this manner, the system as designed stands separate from it technology implementation, minimizing the cost of re-engineering due to software upgrades or technological change.

Implementations of the model provide for maximum reuse by encapsulating all vehicle functions and data in a format easily referenced by other open-system enabled applications. The model was implemented using Visual Basic 6.0 and therefore is Microsoft Component Object Model (COM) compliant, enabling many Microsoft Windows applications to create and work directly with model objects.

Because of the open system architecture of the software, the system objects support a range of display and reporting applications. Applications are created by referencing and creating instances of model objects and writing behavior performing some action using the object attributes and operations. For example, a map application could display the truck's location by writing behavior against the GPS sensor attributes provided by system objects. The attributes and operations sourced by the system objects are described below. The core system objects are shown in Appendix A.

The top-level (parent) class in the model is the Truck (clsTruck). Attributes and operations of this class provide navigational access to all sub-classes of the model. Individual truck objects are uniquely identified by the ID attribute. The ID attribute supports scalability of the truck model for Fleet Management Applications.

Truck objects are initialized with data from the relational database by calling the Load operation. Instances of the Truck class are initialized with all sensor readings within a selected range of time specified by an end user application. Setting the SQL (Standardized Query Language) attribute of the Truck object, prior to calling the Load operation, specifies the time range of interest. End user applications need only specify the WHERE clause of the SQL query, as the table name is hard-coded into the relational database access functions of the system. An example of SQL code for loading a particular date is: 'TimeStamp > #12/31/01 12:00:00 PM# and TimeStamp < #12/31/01 5:00:00 PM#'

Currently, the model supports six types of sensor information. Individual sensors are group together in collections (colSensors). Truck object behavior maintains temporal concurrency across sensors collections. Sensor concurrency is maintained by individual synchronization objects (clsSynchManager) responsible for each sensor type. The six SynchManager objects are accessed as public attributes of Truck class instances (e.g. GPSSensor, MatlSensor, FrictionSensor, etc).

Setting the TimeStamp attribute of a Truck object (i.e. from an application) initiates behavior causing all child SynchManager objects to locate the sensor with the time nearest to the TimeStamp attribute of the Truck object (Figure 37).

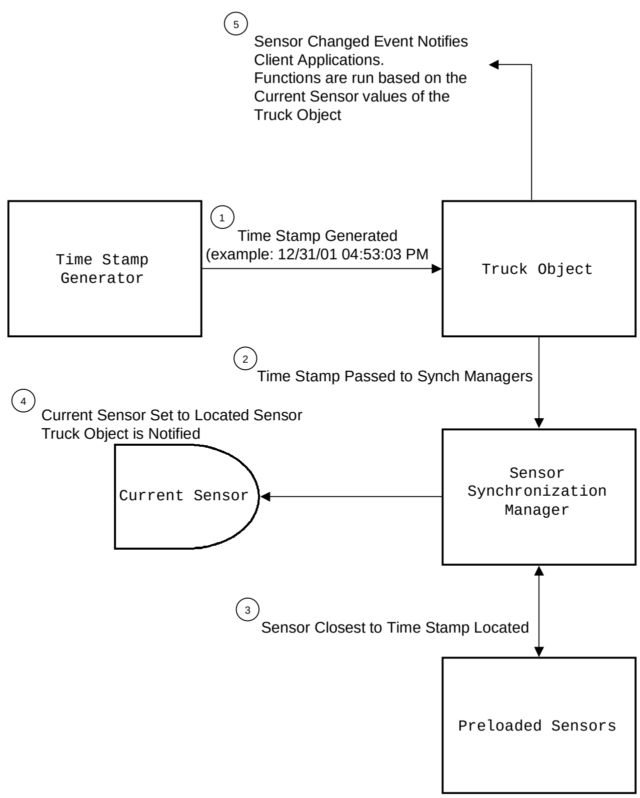

Figure 37: Sensor Synchronization Process

Reading the CurrentSensor attribute of the appropriate SynchManager object provides access to the sensor selected by synchronization behavior. SynchManager objects also message their parent Truck object whenever a new CurrentSensor is referenced. The Truck object in turn notifies client applications of a sensor change through the Changed event. This event driven model is the method by which display and analysis applications are updated by the object model. The section of this document entitled *Decision Support and Remote Control Applications* describes mechanisms for generating timestamp attributes for the truck.

The Window attribute of each SynchManager object can be set to specify a minimum time frame in which the closest time must fall to be set as the current sensor. Client applications can select the chronological units of the Window attribute by setting the WindowUnits attribute. Default chronological units are set to *seconds.*

SynchManager objects have a Load operation, which uses an instance of the clsDatabaseLoader to load all sensor readings it is responsible for from the appropriate table of a relational database. Responsibility is assigned by setting the SensorType attribute of a SynchManager object. Database loading functions are contained in a separate class to provide flexibility in the choice of relational databases. Should a different relational database be selected that is not compatible with the current database loading class, only the DatabaseLoader class would need to be modified and recompiled, with the remainder of the model unaffected.

All six SynchManager Load operations are invoked by calling the single Load operation of the parent Truck class. The sensors loaded by the Load operation are stored internally in a collection. The collection is made accessible through the Sensors attribute of the SynchManager class. The collection is an instance of the class colSensors.

SynchManager objects can manage additional sensor types, provided classes modeling future sensors implement the iSensor interface inherited by all sensor classes (see the interface inset of Appendix C). Objects of the class colSensors are capable of storing any instances of the different sensor classes shown at the bottom of Appendix C. Through the inheritance hierarchy, all sensors share the common attributes SensorType and Timestamp and are permitted to be stored in an instance of the colSensors collection class. In addition, a single class (clsSynchManager) can manage synchronization of all present and future sensor classes. All sensors classes specialize the base iSensor class by adding attributes and operations specific to the type of sensor being modeled.

Freeze point readings collected by the Concept Vehicle are stored in clsFreezePointSensor. Freeze point values are access through the FreezePoint attribute. Global Positioning System (GPS) readings collected by the Concept Vehicle are stored in clsGPSSensor objects. Xcoordinate and Ycoordinate are stored in Longitude and Latitude units. Plow position information collection from the Concept Vehicle are stored in clsPlowPositionSensor objects. Friction readings are stored in clsFrictionSensor objects. Temperature sensor readings are stored in clsTempSensor objects. Units of Celsius or Fahrenheit are selected by setting the Units attribute of the clsTempSensor and clsFreezePointSensor objects. Finally, material application rate data are stored in clsMtrlDataSensor objects.

Section IIIb: Mobile System Remote Control Interface

The parent truck class supports automated control applications (i.e. Materials Distribution Intelligence) through the RavenController class. The behavior of this class encapsulates serial communications routines necessary to poll the mobile systems of the truck for data, as well as control material application rates. The behavior of this class is vendor specific. Should a change in vendors occur, the modular nature of the model would isolate modifications to only the RavenController class.

Attributes of the RavenController provide access to the most recently received granular and liquid rate data, as well as a LastReceived attribute documenting the time of reception. The SetRate operation can pass granular and liquid rate information to the materials application controller on the concept vehicle. The LastSent attribute documents the time of the most recent control transmission.

The software components of the remote control interface were developed and tested in a laboratory environment containing the in-vehicle control electronics hardware. Figure 38 shows the various components of the lab equipment. All components were mounted to an acrylic base facilitating portability of the equipment. The electronics hardware were powered by an external bench power supply.

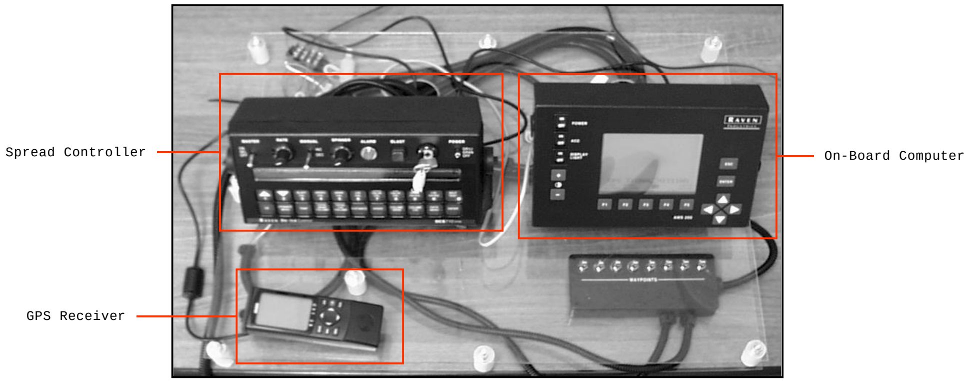

Figure 38: Mobile System Laboratory Configuration

Section IV: Decision Support and Remote Control Applications

Collected data are not very useful without applications designed to analyze data and generate meaningful statistics for decision makers. To this end, several applications are under development that interface directly to instances of the Truck class described previously. All of these applications show different views of the concept vehicle operating during a winter weather event. Because all applications can share the same instance of a Truck object, they provide views of disparate system data at the same instant in time. In addition, selecting a new time in one application causes all other applications sharing the same truck instance to dynamically synchronize to the new time.

The architecture of the end user software consists of a single top-level application providing an interface for users to instantiate a single Truck instance for any given start and end time. This application forms an integrated framework for the addition of a multitude of client Decision Support and Remote Control Applications (Figure 39). Several applications currently under development are described below.

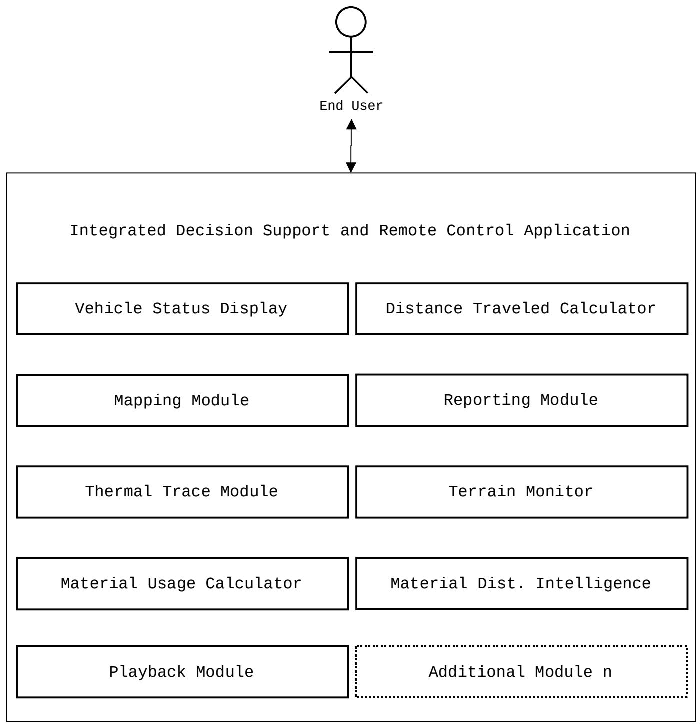

Figure 39: Decision Support and Remote Control Applications

Playback Timer

The functions of the Playback Timer application provide support for dynamic playback of concept vehicle operations. Figure 40 shows the graphic user interface (GUI) developed for this application. The system functions allow end-users to select playback time increment (i.e. steps of 10 seconds) as well as the chronological units (seconds, minutes, hours). The times generated by the Playback Timer are passed directly to the TimeStamp attribute of the Truck instance referenced by the application. Playback direction and speed can be selected by the end user using the Stop, Pause, Play Forward, Fast Forward, Play Reverse, or Fast Reverse buttons. Users may also select a time using the graphical slider located at the top of the GUI.

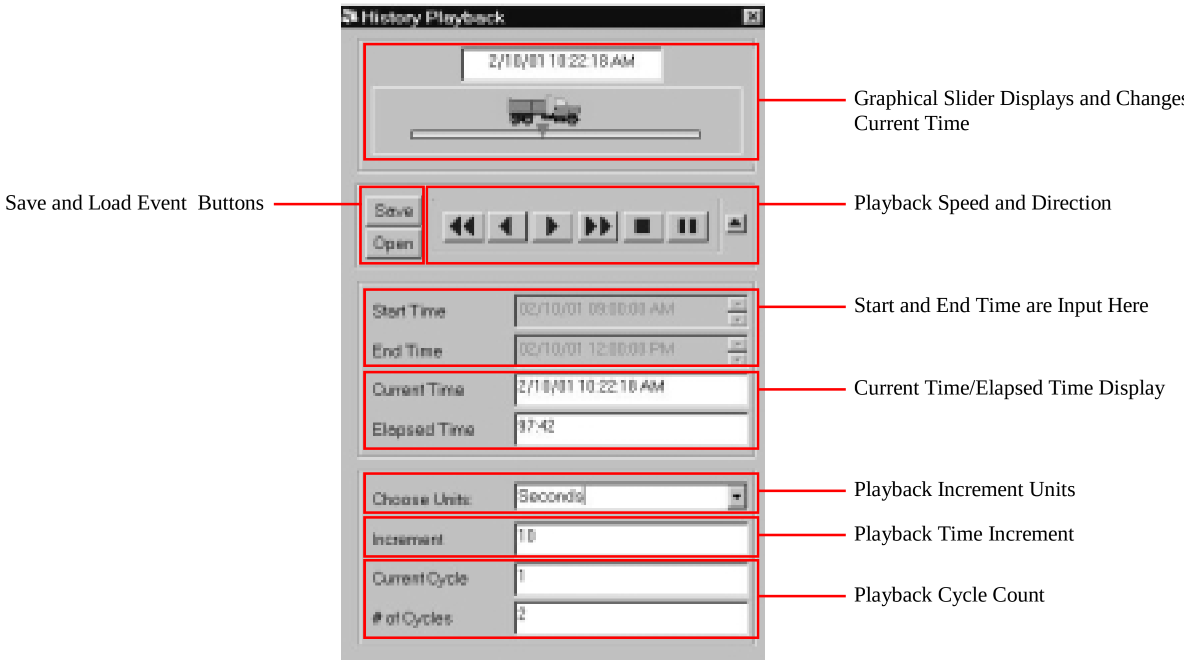

Figure 40: Playback Timer Graphic User Interface

Vehicle Status Display

The Vehicle Status Display application connects to a Truck instance and provides graphical displays detailing active mobile systems on the concept vehicle. Figure 41 shows a screen shot of this application. Display functions provide visual display of the following:

- GPS signal status
- Infra-red thermometer status
- Plow position
- Friction wheel status
- Freeze point sensor status
- Material deployment rates (liquid and granular)
- Remaining material estimate (liquid and granular)

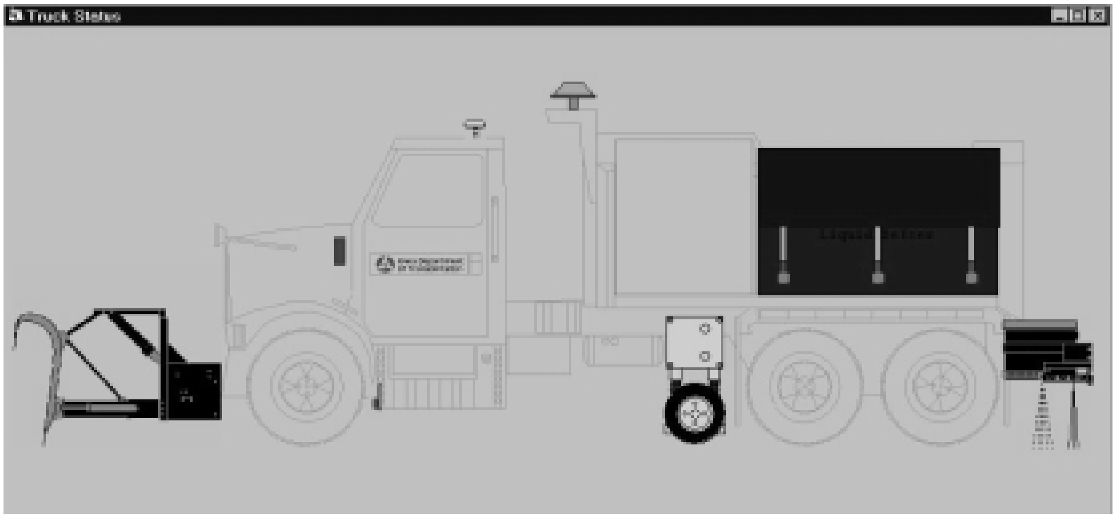

Figure 41: Vehicle Status Display

Mapping Module

A mapping module displays the geographic location of the concept vehicle using GPS data from the vehicle. Geographic Information System (GIS) software forms the core of this application. Map data come from the Iowa DOT and are updated annually. See Figure 42 for a screen shot of this application. The GIS maps provided by DOT offer a range of information from roadway surface type to bridge locations. Research is planned to test the feasibility of automated materials deployment based on map data. One example will test the effectiveness of allowing map bridge locations to automatically trigger concept truck materials deployment during certain pretreatment operations. Material application will be controlled by the remote control interface of the Truck object.

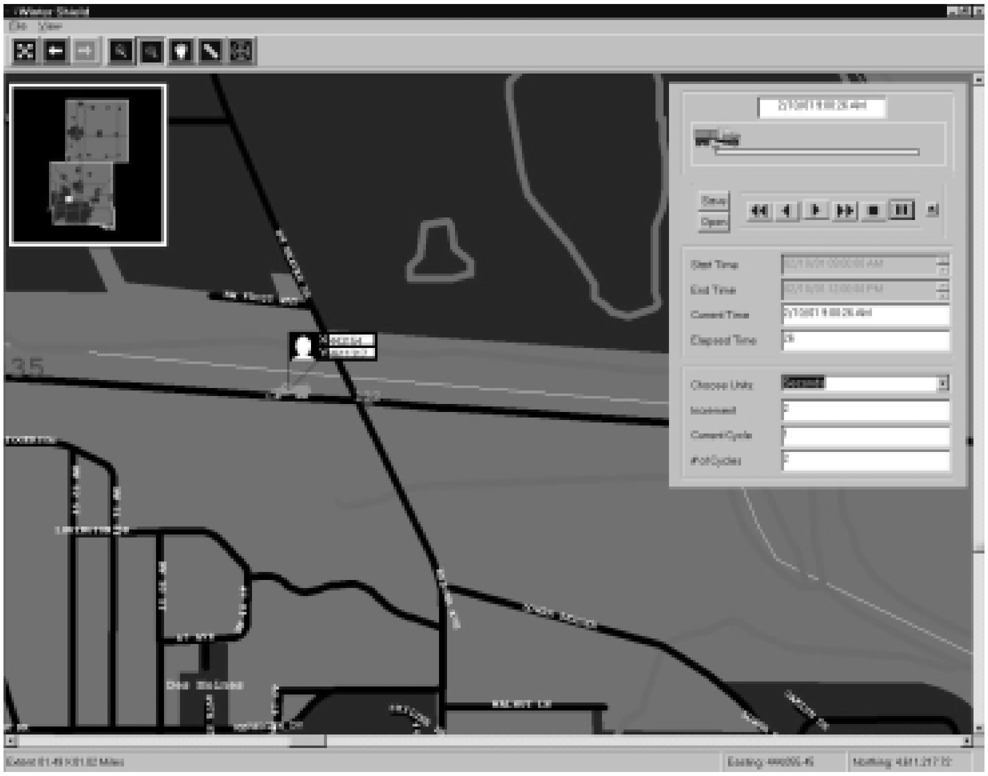

Figure 42 GIS Mapping Module

Materials Distribution Intelligence

Research is planned for the upcoming winter weather season to test the feasibility of computer-controlled materials application based upon concept truck sensor data. Applying rule-based algorithms requires a knowledge base of material application scenarios and their appropriate temperature triggers. To conduct research, the FHWA Manual of Practice for Snow and Ice Control guidelines will be coded into an application capable of controlling materials application behavior based on input parameters provided by the Truck model.

Initial configurations will require user input to select the event scenario (i.e. Light Snow, Heavy Snow, Freezing Rain). Once selected, the choice of material, and application rate will be entirely under machine control. Rates will be adjusted based initially on roadway surface temperature only. The application will always have the capability to be overridden by the concept vehicle operator. Figure 43 shows a screen shot of the Material Distribution Intelligence configuration GUI.

Figure 43: Materials Distribution Intelligence Configuration GUI

Thermal Trace

A thermal trace application is being developed to display roadway and atmospheric temperatures collected by the concept vehicle. The GUI is shown is Figure 44. The functionality provided by this application would display all temperature readings for the analysis period in the chart shown at the top of Figure 44. Separate colored lines display pavement and air temperatures simultaneously.

The box overlaid on the bottom chart represents the area shown in the top inset chart. This chart represents a smaller time sample, allowing more precise viewing of thermal data. The box in the bottom chart will dynamically slide along the x-axis of the chart in response to Truck object TimeStamp attribute changes. In addition, the user can slide the box to areas of interest, thus generating a new timestamp and ultimately causing the Truck object to adjust all other connected applications accordingly (i.e. the Map Display application will display where the truck was when a particular temperature reading was recorded).

The charting functions developed for displaying thermal information will also be adapted to display GPS Altitude, Friction, and Material Application Rates.

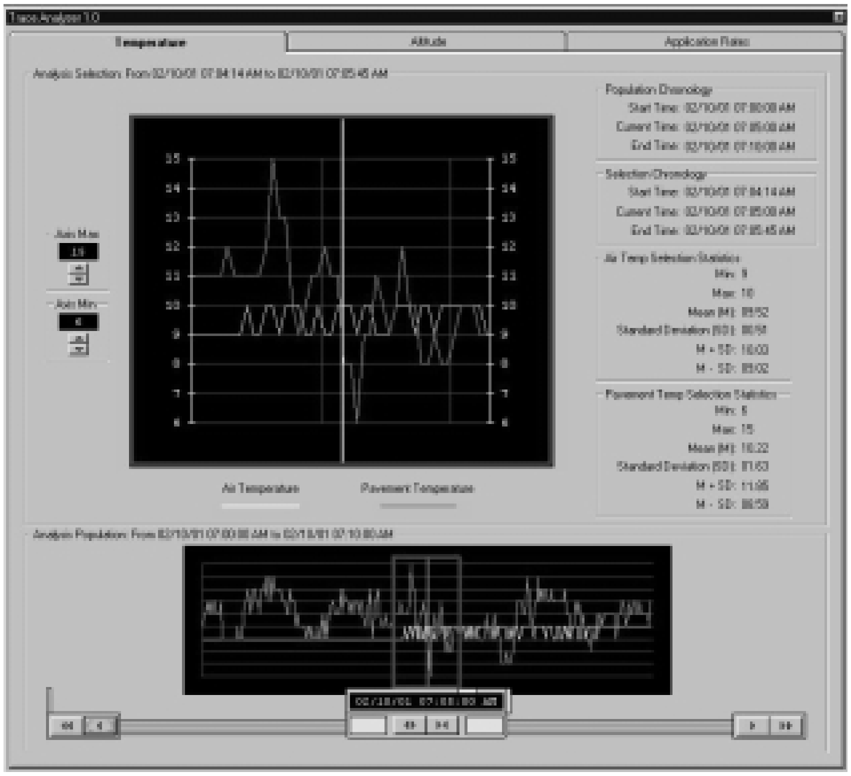

Figure 44: Thermal Trace Chart Analysis Tool

CHAPTER 7: OTHER TECHNOLOGY PERFORMANCE

In order to gain insight into how the technologies on the HMCV performed during operations, the operators of the snowplow were interviewed. The interviews also helped to determine the operators' acceptance of the technologies. The information gathered during these interviews will be used in future technology applications.

Operator Interviews

Interviews were conducted with the operators of the HMCV. A list of questions was prepared but the conversations with the operators and supervisors tended to be a wide–open exchange of comments. This format allowed for anecdotal information to be obtained, and allowed the operators and supervisors to provide detailed assessments of the technology applications.

Generally, the operators were asked to give their impressions of the technology systems that were placed on the vehicle and how these technologies performed. The operators were also asked what recommendations or improvements they would make to the systems. The systems that inquired about were infrared temperature sensors, the automated vehicle location (AVL) system, the friction wheel, the RDS dump body, and the high intensity discharge (HID) lights.

The operators' responses to the individual technology applications are compiled as follows:

- Infrared temperature sensors: The temperature sensors performed well. When they were compared to the RWIS information, the temperature readings on the snowplow were usually within one degree. Knowing the pavement temperature is critical to snow and ice control operations, the more temperature information the better.

- AVL: The AVL system also worked well once it was set-up. It is good to know where the plow is. It will be really nice when more than one truck is equipped with the system.

- Friction Wheel: The results of the friction wheel are mixed. The concept (idea) is okay to know if the applied material is working or not, but if the weather conditions are too severe, one can't treat the road anyway. (For example, if the wind is too strong, you can't deploy material because it will just blow off the road.) Also, the wheel only measures friction in one lane. The conditions may be different in another lane. Also, the friction wheel is used on one snowplow, which is assigned to a specific route. It would be more useful to obtain friction readings in different areas.

- Radius Dump Spreader (RDS) dump body: The operators are very satisfied with the RDS dump body. The RDS is a combination dump body that is designed to spread material more efficiently and make cleaning easier. According to the operators, this design is more versatile allowing them to haul more than one type of material and the truck can be used throughout the year, and not just the winter months.

- High Intensity Discharge (HID) Lights: Again the operators were very satisfied with the HID lights. During whiteout conditions these lights were able to provide additional much needed visibility.

On the whole, the operators were satisfied with the performance of the HMCV. However, they were asked what improvement they would make to snow and ice control practices, and they offered the following recommendations:

- Keep the system simple to ensure that operators have ability to change application rates when needed.
- The supervisors would like to see a display at the desk side that shows what the snowplow is reporting for temperature, and what the RWIS is reporting for temperature for easy comparison.
- Supervisors would like to see more accurate predictive weather information in order to plan for the storms.
- Place the friction wheel on the supervisor’s truck to obtain friction information on different road surfaces, not just on the one assigned route.
- Make the friction wheel more robust.
- The operators would like to see improvements in visibility, particularly at night and in whiteout conditions.

Summary

Safety and efficiency are the paramount concerns for the operators. Regarding safety, they want to be able to see in front of the plow at all times and know what hazards are ahead. They want to be able to determine the road conditions quickly and treat the roadway properly.

Regarding efficiency, operators and supervisors want to be able to treat the roadways with just the right amount material and effort. Tight budgets mean that they don’t want any wasted effort and any efforts to improve productivity are welcome.

Overall the operators gave the HMCV high marks for its potential to increase safety and efficiency.

CHAPTER 8: PHASE IV CONCLUSIONS AND RECOMMENDATIONS

The Phase IV Highway Maintenance Concept Vehicle was deployed in the winter of 2001 by the Iowa DOT. In this pooled fund study, Wisconsin DOT and Pennsylvania DOT also contributed to the research. The HMCV was used in normal operations during the time of study. The vehicle was used primarily along a 14-mile stretch of Interstate 35 between Des Moines, Iowa, to just north of Ankeny, Iowa. The study team analyzed the performance of the system and performed minor maintenance on the system throughout the data collection period. Data were collected both through automated means as well as ride-alongs by the study team.

It is clear that the technologies used on the HMCV have the potential to be beneficial to drivers and the deploying agencies. For example, interviews with the drivers and supervisors indicate that the AVL system and deployment systems are viewed quite favorably. The friction meter and freezing point system have produced mixed results. While the principles of operation are sound, the actual operations of the devices have not performed up to expectations.

The SALTAR friction meter has been field tested in both controlled testing environments and in actual winter conditions operating on a snowplow through two winters. These tests have shown that the SALTAR is still very much a prototype device. However, it can establish friction levels and shows promise in measuring road friction under winter conditions. The brake system works according to specifications and the overall principal works well. However, further development is required and the following actions are recommended:

- The pneumatic system is still susceptible to extreme temperatures and requires full winterization to withstand the harsh climate that it is exposed to in winter maintenance operations.
- Further reliability must be added in future models to prevent failures.

The use of friction data is valuable for winter maintenance operations. Should a device be made that could be installed on a supervisor's truck, for example, then data could be collected from an entire district, rather than just one plow route. It is also conceivable that friction data could be included in level of service maintenance. For example for states where maintenance is contracted out, friction data could be included in performance measures for level of service.

One of the migrations that we made from Phase II to Phases III and IV was to record the friction data in levels and categories of friction, rather than the actual friction level (μ) as measured by the SALTAR. After two seasons of using this method, it has been determined that recording μ along with the friction level category is beneficial as well. The system should be adapted to record μ, so that μ can be integrated into winter maintenance strategies.

The Frensor has shown to be a reasonable sensor for freezing point measurements and has a potential for a continuation of the project. At normal maintenance intervals the system is reliable; however the Frensor sometimes has to be cleaned manually depending on the conditions. When the cycle time to get freezing points gets longer than normal, then the operator knows that there are “dirty” sensors that need to be cleaned. Several times during our data collection, the sensor was caked with ice and debris that had to be manually removed. Once the sensor was cleaned, the system worked reliably well. At this point we have not collected enough data to guarantee the repeated accuracy for the system, but the general opinion from all involved is that the system is reliable as can be seen in the graphs. However, if we are to use this device during normal maintenance operations, we cannot expect a plow operator to clean the sensor to collect these data.

An automatic cleaning device should be investigated along with an automatic control to alert the operator of a dirty sensor.

With regard to the communications system on the HMCV, the system was successfully lab tested prior to deployment. Because of the critical nature of the Iowa DOT communications system, it was deemed necessary to lab test the AVL to ensure that using it would not damage the radio network. Following the deployment of the AVL, the operator and supervisor were interviewed and both viewed the use of AVL tracking favorably. Communications between dispatcher and operator are critical during snow and ice removal operations. Operators call in all types of information, including cars in the ditch, obstacles on the roadway, areas that have been plowed, areas in which they need assistance, etc. Presently, these “status reports” are done by voice communications, somewhat inefficiently. With a fully functional AVL system, the supervisor can determine the areas that have been plowed, where the vehicle is, and if assistance is needed.

If a maintenance fleet is equipped with AVL, a supervisor can use dynamic dispatching in deploying the fleet. With AVL the supervisor can view several vehicles at a time, then if an area requires additional vehicles to clear the roadway, the supervisor can identify and dispatch those vehicles closest to problem area with a minimum of radio chatter. While the HMCV was the only vehicle equipped with AVL, the system has shown promise for wide spread application.

The winter maintenance functions demonstrated by the HMCV project are also compatible with the National ITS Architecture approach. The HMCV can provide critical weather and road condition data to weather forecast models such as Foretell. The architecture presented here provides a “road map” for further deployment of additional vehicles. It is envisioned that more advanced technology maintenance vehicles will be deployed that will serve as mobile data platforms using NTCIP standards to provide real-time data, such as, air and pavement temperatures, wind speed, pavement condition data, etc. to maintenance operations centers to assist in their operational decision making. The information can then be forwarded to a traffic control center for further dissemination, providing for the continued progressive deployment of weather and road condition information throughout the area.

With regard to integrating the technologies, the HMCV serves as a mobile laboratory for the operational testing and evaluation of new winter maintenance technologies. The onboard computer integrates these technologies and collects a multitude of data when the concept vehicle is in operation. To enable decisions to be made from these data, prototype software applications were developed and evaluated as part of Phase IV.

A conceptual architecture of the system and its high-level components was developed, which describes the flow of mobile system data into desk side systems. Data are stored in a relational database supplying an object-oriented software model of the concept vehicle with data. The attributes and operations implemented by the object-oriented model are described. Finally, several applications referencing the object-oriented model currently under development are provided in this report.

Based on the results of the Phase IV HMCV project, it has shown to be a viable system for improving winter maintenance operations. The consortium is exploring methods to move the system forward from one vehicle to more widespread deployment. In addition to hardware and software revisions, the study team recognizes the need for an appropriate management information system in place to receive and analyze all the incoming data. Several management systems currently exist in each of the state DOTs to provide information to maintenance managers at all levels of the organization. These management systems generally include payroll, staffing levels, equipment, purchasing, inventory, equipment maintenance schedules, and weather information. These systems should eventually interface with each other to form a decision support system (DSS). The study team is working toward the development of the DSS and to ensure that the migration from one advanced technology vehicle to wide spread deployment is a smooth transition.

Recommendations

In order to fully implement the technologies deployed on the HMCV, more research and testing are required. If funding were to be made available, here are our recommendations for future testing, based on the results of the tasks completed for Phase IV:

1. Continue using pavement friction readings in winter maintenance operations. The use of friction readings shows promise and should continue to be investigated and incorporated into performance measures for winter maintenance operations. Previously, we changed the friction output readings to be shown in levels of hazard warnings (i.e., from acceptable to hazardous). Having only the friction level categories is incomplete information. The actual μ should also be communicated within the data so that the levels of warnings are more clearly understood.

2. Continue the investigation of using the chemical freezing point on the road surface. The use of chemical freezing point shows promise. The mobile Frensor is a reliable device, and once installed, it performed to expectations. However, during snow and ice removal operations, spray from the road surface built up around the sensor, which required us to stop the vehicle and clean the sensor periodically. The snowplow operator can't be realistically expected to clean the

sensor during critical snow removal operations. An automated cleaning device, more thorough than compressed air, needs to be investigated for measuring the road surface freezing point during snow removal operations.

3. Expand the use of AVL by providing snowplow information to the traveling public. The tracking information obtained from the vehicle can be integrated with the agency's website that will show where the vehicle has plowed and what the current conditions are. This type of information is valuable for the commuter and commercial vehicle operators. In addition, further integration of GIS management solutions and vehicle tracking is needed. Road surface conditions, environmental areas can be stored and cataloged for analysis. Items such as crash locations and problem areas (e.g., continued snow and ice build up on a certain area of roadway) tied to weather information can be integrated in to a comprehensive GIS database that could improve the agency's winter maintenance operations.

4. Develop a business case for deploying the various technologies on a fleet of vehicles. Presently, the concept vehicle employs emerging technologies capable of applying precisely the correct amount of material, accurately tailored to the existing and predicted pavement conditions. If the concept vehicle and the data collected by the vehicle are used to support decision making leading to reduced material usage and average asset usage by just one hour, a reasonable reduction in "out of pocket" cost will result. The "out of pocket" costs do not include safety and environmental impact savings. Using emerging technologies can be expected to have a noticeable impact on the average time taken to reach the expected level of service at least cost to taxpayers.

   A business case will analyze the data and information associated with the technology to DOT maintenance activities and determine their impact on the cost of conducting those activities. Reductions in resource costs, labor, trucks, and materials can be achieved by identifying cost factors and by taking actions to influence those factors. Certainly the severity of the winter affects winter maintenance costs. A "bad" winter is very expensive and requires using a large amount of labor, trucks, and materials to achieve an acceptable level of service.

5. Finally, because winter road conditions are hazardous and change quickly, it is imperative that winter maintenance be equipped with the technology that can meet these demands and provide the taxpayers with the expected level of service. The Iowa Department of Transportation estimates the average cost per hour of fighting a winter storm to be between $60,000 and $70,000. If the technologies tested here can precisely apply the anti-icing materials to existing pavement conditions, and tailor them to the environmental conditions, a reasonable reduction in costs can be expected. Through the use of these technologies and weather forecasting models, such as Foretell, our goal is to model a significant reduction in costs and still reach the expected level of service for the traveling public.

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