PHASE IV
HIGHWAY MAINTENANCE CONCEPT VEHICLE
MOBILE LABORATORY

WORK PLAN

Prepared for the
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a
Center of Iowa State University
reporting to the
Office of the Vice Provost for Research and Advanced Studies

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Approval for the Center for Transportation Research and Education
Approval for Iowa State University

__________________________  ____________________________
Stephen J. Andrle                 Valrey V. Kettner
Director                      Interim Contracts and Grants Officer
RESEARCH PROJECT STATEMENT

The highway maintenance concept vehicle is a mobile laboratory that seeks to examine and test newly emerging technologies that have potential for improving the level of service defined by policy, during the winter season. Further, the goal includes improving the level of service at the least cost to taxpayers and reducing the impact on the environment. This will be accomplished by using data and information regarding actual road conditions to facilitate and adjust snow and ice control activities.

Understanding operational cost is central to the study. The Iowa DOT has estimated the statewide cost of fighting an average winter storm is about $60,000 to $70,000 per hour. The concept vehicle will employ 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 reducing material usage and the average asset usage by one hour, a reasonable benefit/cost will result. Therefore, using emerging technologies can be expected to have a noticeable impact on the average time it takes to reach the expected level of service at the least cost to taxpayers.

This project is designed to fit into the strategic research management process adopted by the Iowa DOT. Figure 1 illustrates this research management process. The concept vehicle study follows the strategic action plan path. The Highway Division maintenance area will participate in the study and benefit from the results.

The method of testing newly emerging technologies and relating the outcome of implementing technologies suggested for this project will likely be used as a model to investigate technologies in the future.
Figure 1. Strategic Research Management Process
BACKGROUND

Highway Maintenance Concept Vehicle Project Phases I, II, and III provided a foundation to identify promising emerging technologies, test the technologies, and conduct benefit/cost analysis. Phase I included inducting focus groups that resulted in identifying problems and public/private sector partnerships to solve the problems. Phase II included conducting proof of concept tests and suggested redesigns of emerging technologies. Phase III included testing newly designed technologies and additional technologies. From Phase III came Figure 2, Iowa Network Diagram that is a comprehensive view of the system infrastructure necessary to implement and achieve the project goal of improving the level of service to travelers at least cost to tax payers. The network diagram includes the “Vehicle Management Subsystems”, communications systems, and “Fleet and Information Management” agency subsystem areas and the relationship among the areas.

WORK IN PROGRESS

Figure 2. Iowa Network Diagram
The “Vehicle Management” subsystem includes air/pavement temperature, pavement friction, pavement freezing point, plow position, vehicle location, materials application control, and materials distribution intelligence. The interface to the communication system is the Iowa DOT mobile digital radio. The current network design provides for delivering the data collected from the subsystems through the Iowa DOT digital radio system. However, other methods of communications such as cellular and satellite can be used. The “Fleet and Information Management” agency systems include both data analysis and decision-making functions that integrate with national weather forecasting elements. The data analysis and decision making element includes providing data for analysis in the “Operations Management Information” system. The national weather forecasting element includes exchanging information with national weather forecasting models and receiving predictions from the national models. The proposed network will result in the concept vehicle applying precisely the correct amount of material, accurately tailored to existing and predicted pavement conditions.

Phase IV builds on work accomplished in previous phases and will support the Highway Division maintenance management system. Phase IV has two major strands, technical and financial. The outcome of Phase IV will be a clear path to technology implementation, operation, and maintenance based on business case analyses.
SCOPe OF WORK

The goal of the highway maintenance concept vehicle, a mobile laboratory, 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 based on figure 3. The scope of work is divided into seven 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
- Develop a business case dealing with implementing technologies
- Determining the usefulness of the advanced technology systems installed on trucks assigned to the Ames maintenance area
- Final report

Figure 3. Technologies and the Iowa Network Diagram
WORK PLAN and TASKS

I. Conduct Project Management

CTRE will be the project manager for the concept vehicle project. Project management will include establishing a project advisory committee (PAC), scheduling and facilitating PAC meetings, recording the actions taking at PAC meetings, facilitating obtaining new partners, working with partners to accomplish project objectives within agreed upon schedules, identifying challenges and facilitating corrective actions, and organizing meetings among partners and recording results. The PAC will include the Highway, Information Technology, and the Research Divisions of the Iowa DOT.

The role of the PAC is:
1. Provide direction to the project that will insure the results meet Iowa DOT expectations and support Iowa DOT operational requirements and strategic plans.
2. Participate in scheduled meetings to review and approve progress.
3. Provide technical support that will insure subsystems meet Iowa DOT requirements.
4. Review and approve products.

II. Develop and Integrate the Materials Distribution Intelligence Function

CTRE will develop a beta version of Iowa Material Distribution Intelligence (IMDI) that will use pavement surface temperature, pavement freezing point and friction data, along with weather forecasting data to control materials mix and application rates. CTRE will develop, in collaboration with the PAC, private and public sector partners, a beta version of the IMDI using the design process illustrated in Figure 4. The beta version will include input and output data strings that will be used in both beta testing IMDI and integration testing in Task 2a-3 and end-to-end network testing. Further, physical design stage of the design process will include simulation testing involving input and output data strings. The simulation program and hardware will be designed to thoroughly test the IMDI and other subsystems. In addition, the simulation program and hardware will be designed to be a diagnostic tool when trouble shooting the systems. CTRE will prepare the beta version of the IMDI, conduct tests, and prepare documentation.
Figure 4. Application Design Process
III. Develop and Integrate the Decision Support System

CTRE will develop the beta version of a Iowa Decision Support System (IDSS) that will assist managers in improving maintenance operations, reducing costs, maintaining level of service, and reducing the environmental impact of winter weather applications. CTRE will follow the design process illustrated in Figure 4. The PAC will participate throughout the design process and approve the final design. The IDSS will include functions such as real-time materials management, vehicle routing optimization, and material inventory control. The IDSS will include operations management information reports in three categories: (1) dynamic, (2) geographic, and (3) financial. Dynamic reports will include operator, vehicle, and materials information according to date, time, and location (mile post). Geographic reports will show pavement surface temperature, freezing point, and friction, and road maintenance status. Financial reports will include operator time, vehicle usage, and materials usage according to date, time, and location (mile post). The IDSS will include functionality that will enable the user to query the database and build special reports. The design process will include identifying input and data strings that will be used in IV, Task 2. Further, CTRE will monitor and participate in the development of the beta version of the Maintenance Decision Support System (MDSS) being lead by the Federal Highway Administration (FHWA). CTRE will prepare the beta version of the IDSS, conduct tests, and prepare documentation.

IV. Test Newly Emerging Technologies

The suggested testing paths are based on Figure 3. Figure 3 highlights in green the technologies to be tested and their relationships. Testing newly emerging technologies mounted on the concept vehicle will follow the activity flow illustrated in Figure 5.

Figure 5. “Vehicle Management” Subsystems Mobile Technology and Integration Testing Path
Testing processing data through the communications system will follow the activity flow illustrated in Figure 6.

![Figure 6. Communications System Testing Path](image)

Testing the “Fleet & Information Management” agency systems will follow the activity flow illustrated in Figure 7a.

![Figure 7a. “Fleet & Information Management” Agency System Testing Path](image)

**Task 1:** Describe the technology and subsystem to be tested and the relationship to highway maintenance activities and standard operating procedures.

CTRE will describe the technologies to be tested and the importance of implementing technologies to highway maintenance operations. The matrix in Appendix A, Iowa concept vehicle status based on the Iowa network diagram dated 8-23-00, provides the current status of the technology, subsystem, and system development process accomplished during Phase III. The steps listed in each of the columns in the matrix will be completed during this phase. Testing will be conducted on subsystems and end-to-end. For example, testing will be conducted on “Vehicle Management” subsystems mobile technology and then conducted on the complete system from the mobile through to the decision support systems.
Further, CTRE will describe the relationship between the data provided by the technology and maintenance activities and standard operating procedures. Figure 3 illustrates data and information flow among functions. The decision support systems functionality will be integrated with maintenance activities and standard operating procedures. As the decision support system is developed, ties to the maintenance management system will be identified and developed as budget permits.

CTRE will report progress using the Iowa concept vehicle status based on Figure 3.

**Task 2: Conduct proof of concept bench tests**

Proof of concept bench tests will be conducted on vehicle management subsystems, communications systems, and fleet and information management agency systems (refer to Figure 3). The following subtasks provide detail on each bench test.

**Task 2a: Mobile technology and integration tests**

Figure 5 illustrates the process testing will follow during Phase IV.

![Diagram of Vehicle Management Subsystems Mobile Technology and Integration Testing Path]

**Task 2a-1: Bench test the pavement freezing point subsystem**

CTRE will bench test the mobile FRENSOR pavement freezing point subsystem according the instructions provided by Enator Tellub AB, Ostersund, Sweden. The bench test will take place at the Iowa DOT materials testing laboratory. Further, CTRE will bench test the FRENSOR mounted on the truck. Both bench tests will include hardware and application software testing. Enator has described the mobile FRENSOR as being in the research and development stage. CTRE will prepare a brief technical memorandum reporting the results of the bench test.
Task 2a-2: Bench test the redesigned pavement friction subsystem
CTRE will bench test the redesigned SALTAR pavement friction measuring subsystem according to the instructions provided by Norsemeter, Rud, Norway. Testing done in Phase III resulted in redesign of the SALTAR. The testing, failure analysis, and redesign is presented in the Phase III report. The bench test of the new SALTAR will include hardware and application software testing. The SALTAR will be mounted on the truck for bench testing. CTRE will program the SALTAR to report the following friction range traction indicators:

- Poor traction (red light)  $< 0.26 \theta_{\text{peak}}$
- Fair traction (yellow light)  $0.26 \leq \theta_{\text{peak}} \leq 0.35$
- Good traction (green light)  $> 0.35 \theta_{\text{peak}}$

CTRE will prepare a brief technical memorandum reporting the results of the bench test.

Task 2a-3: Bench test the technology integration with vehicle systems
CTRE will bench test the integration of the pavement temperature, friction, and freezing point, and the IMDI subsystems with the Raven Industries AMS200 onboard computer. The bench test will include hardware and application software testing. The bench test will include operator displays and controls AVL, and materials distribution intelligence. The subsystems and systems will be mounted on the truck for bench testing. CTRE will prepare a brief technical memorandum reporting the results of the bench test.

Task 2b: Communication system tests
CTRE will manage the communications system testing. The testing will follow the path described in Figure 6. The testing will be based on the network relationships described in Figure 3. Bench tests will take place at the Motorola test laboratory at Schaumburg, Illinois. The test method and expected results will be documented prior to conducting the testing. CTRE will prepare a technical memorandum that will include the results of the test.

Figure 6. Communications System Testing Path
**Task 2c: “Fleet and Information Management” agency system tests**

CTRE will manage and participate in conducting the bench tests on each of the path functions shown in Figure 7b. Figure 7b is an abbreviated version of Figure 3. The relationship between the path functions in Figure 7b and the network elements in Figure 3 will be described in the task descriptions given below. Staff from the PAC, Highway, Information Technology, and Research Management Divisions, will participate in agency system tests. The tests will be based on sending a series of data strings through each testing activity, through activities grouped by task, and finally through all activities. The data string will be representative of the least amount of data to be expected, the greatest amount of data expected, and the least amount of time between transmissions. CTRE, in collaboration with the PAC and private sector partners will develop a matrix describing data strings from the “Vehicle Management” subsystems, DSS, and National Pavement Condition Forecasting Models (external database) to be processed by the “Fleet and Information Management” agency systems. The data strings will be used in the following tasks:

**Figure 7b. “Fleet & Information Management” Agency System Testing Path**

**Task 2c-1: Network interface and data processing testing**

The testing path functions include the following network elements: the TRAKIT-20B, the communications interface, the server array, and the common server. TRAKIT-20B is provided by the Monroe Truck and manufactured by IDA Corporation. The communications interface and server array, owned by the Iowa DOT, are described in more detail on the network draft drawing Maintenance Vehicle, RWIS, and Foretell Mobile Platform Network Architecture dated 10-15-00 prepared by CTRE. This stage of the testing will be accomplished by processing the data strings developed earlier through the network and data processing functions. CTRE will prepare a technical memorandum recording the testing results.
Task 2c-2: Internal database interface and data/information distribution testing
The testing path functions include the following network elements: the common server, the RWIS, the firewall and Internet interface, and national pavement condition forecasting models. All of the network elements are owned by the Iowa DOT. This stage of the testing will be accomplished by processing the data strings developed earlier through the network and data processing functions. CTRE will prepare a technical memorandum recording the results of the testing.

Task 2c-3: Data processing and analysis and decision support testing
The testing path functions include the following network elements included in the Iowa Decision Support System. The primary elements are data processing and analysis and decision processing. The DSS developed in Section III will be tested. All of the network elements are owned by the Iowa DOT. This stage of the testing will be accomplished by processing the data strings developed earlier through the DSS. CTRE will prepare a technical memorandum recording the results of the testing.

Task 2c-4: End-to-end “Fleet & Information Management” agency system testing
The testing path functions include all of the elements tested in Task 2c and is an “end to end” test. This stage of the testing will be accomplished by processing the data strings developed earlier through the network and data processing functions. CTRE will prepare a technical memorandum recording the results of the testing.

Task 2d: End-to-end “Vehicle Management” subsystems, communications, and “Fleet and Information Management” agency system test
The testing path includes all of the network elements previously tested in earlier tasks. This stage of the testing will be accomplished by processing the data strings developed earlier through the total network and data processing functions. CTRE will prepare a technical memorandum recording the results of the testing.

Task 3: Conduct operational field tests
Field operational tests will be conducted based on the Iowa network diagram presented in Figure 3. Field testing will be subdivided into four stages, “Vehicle Management” subsystems, communications systems, “Fleet and Information Management” agency systems and end-to-end tests. Field testing will be conducted based on the availability of system elements and funding. Field tests will begin during the year 2000 winter.
Task 3a: “Vehicle Management” subsystems field test
CTRE in conjunction with the Iowa DOT will conduct field tests on the “Vehicle Management” subsystems installed on the concept vehicle. The field test will be conducted in two stages. The first stage will prove the elements are operating correctly using the simulation program and hardware developed in Task II. This diagnostic tool will be used to provide inputs to the subsystem elements and observe the outputs from the subsystem elements. Following successful completion of the first stage, a road test will be conducted using inputs from the sensor subsystems and will prove the concept vehicle is ready for winter operations. CTRE will prepare a technical memorandum recording the results of the testing.

Task 3b: Communication system tests
CTRE, in conjunction with the Iowa DOT, will conduct field tests on the communications systems. Again the field test will be conducted in two stages. The output generated in Task 3a will be sent through the communications system. The road test data collected in Task 3a will be sent through the communications system proving the communications system is ready for winter operations. CTRE will prepare a technical memorandum recording the results of the testing.

Task 3c: “Fleet and Information Management” agency system tests
CTRE, in conjunction with the Iowa DOT, will conduct field tests on the “Fleet and Information Management” using the data generated during Task 3a and Task 3b. The data will be processed through the Iowa Decision Support System (IDSS). Typical outputs will be generated to prove the system is ready for winter operations. Data from Iowa DOT RWIS and National Pavement Condition Forecasting Models will be processed through the IDSS as they become available. The outcome of this test represents end-to-end testing. CTRE will prepare a technical memorandum documenting the results of the testing.

Task 4: Prepare final report
CTRE will prepare a final report for section IV that will include the outcome of the testing accomplished in Tasks 1 through Task 3.
V. Develop a Business Case Dealing with Implementing Technologies

The goal of the highway maintenance concept vehicle project 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. Iowa DOT has estimated that the average cost of fighting a winter storm to be about $60,000 to $70,000 per hour. The concept vehicle will employ 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 reducing material usage and the average asset usage by just one hour, a reasonable reduction in “out of pocket” cost will result. The “out of pocket” cost 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.

Business cases will be developed that will relate the data and information associated with the technology to Iowa DOT maintenance activities and determine the 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. Figure 8 illustrates the relationships among the areas affecting cost and performance. 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.

![Cost Performance Model](image)

Figure 8. Cost Performance Model
Maintenance managers must be provided data that describes the actual condition of the roadway to support their operational decisions. Figure 9 illustrates the relationship between pavement condition information and decisions made by supervisors during a storm event. Data collected by the concept vehicle, RWIS, and National Pavement Condition Forecasting Models will provide supervisors with road and weather information to support making more informed decisions.

**Task 1: Conduct a Project Advisory Committee Meeting**

CTRE will conduct a PAC meeting to present the cost performance model and to develop performance measures. The data that may be used in the cost performance model will be taken from the Highway Division’s current Maintenance Management System (MMS). Further, CTRE will review the performance measures either currently used plan to be used by the Iowa DOT. CTRE will review the MMS and recommend data to be used in the model and associated performance measures. Further, CTRE will include the appropriate data collected by the concept vehicle and used in the IMDI and IDSS. CTRE will prepare an algorithm that will calculate the performance measures based on data from the IMDI, IDSS and MSS. CTRE prepare a technical memorandum documenting the outcome of Task 1.
Task 2: Evaluate the Impact of Implementing Technologies on Performance Measures

CTRE, in conjunction with the PAC, will conduct scenarios that will compare the difference in operational costs with and without technology. CTRE will prepare a technical memorandum documenting the outcome of Task 2.

Task 3: Develop Business Cases for Technologies

CTRE will develop business cases that will include benefit-cost analysis. Analysis conducted during Phase III found the major problems to be addressed using technology are road surface uniformity among maintenance areas during winter driving conditions and winter maintenance costs. The value of establishing and maintaining uniform surface conditions according to Iowa DOT policy has not been quantified. The impact technology may have on cost can be estimated.

The benefit-cost model used in Phase III is

\[
BC = \frac{OMS + ES}{SC + OC + MC}
\]

where

- BC = benefit-cost ratio
- OMS = operation and maintenance savings
- ES = environmental savings
- SC = start-up costs
- OC = operations costs
- MC = maintenance costs

The operation and maintenance cost savings (OMS) are the savings to the agency on the expenditures for labor, equipment, and materials resulting from the use of the advanced technology and the concept vehicles.

These savings are described as

\[
OMS = LS + EQS + MAT
\]

where

- LS = labor savings
- EQS = equipment savings
- MAT = materials savings
The labor savings are the savings on the expenditures for the agency’s own employees. The equipment savings are the savings on the expenditures for the agency’s own equipment and those hired to assist with snow and ice control (if any) resulting from the use of the concept vehicle. Material savings are the savings on the expenditures for chemicals and abrasives resulting from using the concept vehicle.

The environmental savings are the savings to the traveling public and environment due to the use of technologies. These savings include estimates of less chemical run-off, and reduced travel times.

The start-up costs are the costs directly related to the purchase, installation, and operation of the technologies on the concept vehicles. These include capital costs for the equipment and software, additional equipment (customized frame brackets, wiring, etc.) needed for the systems that were not included and initial training costs. Start-up costs will be amortized over the expected useful life of the technology. The evaluation team will agree on the amortized life for the calculation.

The operations costs are the recurring technology costs, such as communications, and any other related costs incurred after deployment. The maintenance costs are the costs related to the maintenance and replacement of technology.

**Task 5: Prepare Section V Final Report**

CTRE will prepare a final report for section V that will include the outcome of the testing accomplished in Tasks 1 through Task 4.
VI. Determine the Usefulness of the Advanced Technology Systems Installed on Truck Assigned to the Ames Maintenance Area

CTRE will compare operating practice this winter with previous winters. Figure 10, Ames Maintenance Area Network Diagram shows the technology and architecture that has been in use since 1998. Winter 2000 is the third winter of usage.

![Ames Maintenance Area Network Diagram](image)

The comparison will be based on the same factors used to develop business cases in section III, Task 4 and will include both differences in operating policy and costs. CTRE will prepare a technical memorandum documenting the outcome of section VI.

VII. Prepare and Publish the Final Report for the Project

CTRE will prepare a final report that will include an executive summary, technical memorandums, and section reports.
Appendix A
Iowa Concept Vehicle Status Based on Figure 2, Iowa Network Diagram

Table A1 shows the time to implementation for the Iowa vehicle management subsystems. Table A2 shows the time to implementation for the communications systems as established by Iowa. Table A3 indicates Iowa’s time to implementation for fleet and information management agency systems, as best as we can determine. Notes to Tables 1–3 are given below.

1. Integration with mobile communications requires test of the solution presented by IDA Corporation.
2. One month after successful completion of the field test.
3. Six months for each field location and six months for the central location.
4. One month after successful completion of the interface test.
5. The functionality from integration with mobile communications to the common server design and build will be available for all technologies.
### Table A1 Iowa Concept Vehicle Management Subsystems

<table>
<thead>
<tr>
<th>Number</th>
<th>Technology</th>
<th>Partner</th>
<th>Bench Test</th>
<th>Proof of Concept</th>
<th>Redesign</th>
<th>Field Test Initial Design or Redesign</th>
<th>Technology Available or Projected Availability</th>
<th>Integrated with Control and Processor</th>
<th>Field Test Integration with Control and Processor</th>
<th>Integration Available or Projected Availability</th>
<th>Integration with Mobile Communication</th>
<th>Field Test Integration with Mobile Communication</th>
<th>Integrated Mobile Communications Available or Projected Availability</th>
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<td>Air/pavement temperature</td>
<td>Sprague</td>
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<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
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<td>2</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Note 5</td>
<td>Note 3</td>
</tr>
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<td>3</td>
<td>Pavement freezing point</td>
<td>Enator</td>
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<td>No</td>
<td>—</td>
<td>—</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>6 months</td>
<td>Note 5</td>
<td>Note 5</td>
<td>Note 3</td>
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<td>4</td>
<td>Vehicle location</td>
<td>Monroe Truck</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Available</td>
<td>Yes</td>
<td>No</td>
<td>Available</td>
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<td>Note 3</td>
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<td>5</td>
<td>Materials application control and processor</td>
<td>Monroe Truck Raven</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Available</td>
<td>Yes</td>
<td>No</td>
<td>Available</td>
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<td>Note 5</td>
<td>Note 3</td>
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<td>No</td>
<td>No</td>
<td>6 months</td>
<td>Note 5</td>
<td>Note 5</td>
<td>Note 3</td>
</tr>
<tr>
<td>7</td>
<td>Front and underbody plow position</td>
<td>Monroe Truck and Iowa DOT</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Available</td>
<td>Yes</td>
<td>Yes</td>
<td>Available</td>
<td>Note 5</td>
<td>Note 5</td>
<td>Note 3</td>
</tr>
<tr>
<td>8</td>
<td>Mobile transmitter/IDA and Iowa receiver</td>
<td>Iowa DOT</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>6 months</td>
<td>Yes</td>
<td>No</td>
<td>6 months</td>
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<td>Note 5</td>
<td>Note 3</td>
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<td>9</td>
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<td>12 months</td>
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### TABLE A2  Iowa Concept Vehicle Communication System

<table>
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<th>Partner</th>
<th>Communications System Design and Build (14)</th>
<th>Communication System Test (15)</th>
<th>Communications System Available or Projected Availability (16)</th>
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<tr>
<td>1</td>
<td>Air/pavement temperature</td>
<td>Sprague</td>
<td>6 months</td>
<td>1 month</td>
<td>Note 3</td>
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<tr>
<td>2</td>
<td>Pavement friction</td>
<td>Norsemeter</td>
<td>Note 5</td>
<td>Note 5</td>
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<td>3</td>
<td>Pavement freezing point</td>
<td>Enator</td>
<td>Note 5</td>
<td>Note 5</td>
<td>Note 3</td>
</tr>
<tr>
<td>4</td>
<td>Vehicle location</td>
<td>Monroe Truck</td>
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<td>Note 5</td>
<td>Note 3</td>
</tr>
<tr>
<td>5</td>
<td>Materials application control and processor</td>
<td>Monroe Truck and Raven</td>
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<td>Note 5</td>
<td>Note 3</td>
</tr>
<tr>
<td>6</td>
<td>Materials distribution intelligence</td>
<td>Raven</td>
<td>Note 5</td>
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<tr>
<td>7</td>
<td>Front and underbody plow position</td>
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<td>8</td>
<td>Mobile transmitter/ receiver</td>
<td>IDA and Iowa DOT</td>
<td>Note 5</td>
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<td>Note 3</td>
</tr>
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### TABLE A3 Iowa Concept Vehicle Fleet and Information Management Agency Systems

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